Land Use Policy 26S (2009) S30–S42

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Bringing the real world into economic analyses of land use value: Incorporating spatial complexity[☆,☆☆]

Ian J. Bateman[a,b,c,*]

[a] Centre for Social and Economic Research on the Global Environment (CSERGE), School of Environmental Sciences, University of East Anglia, Norwich, NR4 7TJ, UK
[b] Agricultural and Resource Economics, University of Western Australia, Perth, Australia
[c] University of Waikato Management School, Hamilton, New Zealand

ARTICLE INFO

Article history:
Received 10 September 2009
Accepted 13 September 2009

Keywords:
Modelling
Economics
Space
Geographical information systems (GIS)

ABSTRACT

The paper reviews recent developments in the incorporation of real-world spatial issues into the economic appraisal of land use change. The opening discussion introduces non-economists to the concepts underpinning the approach. The remainder of the paper uses a case study approach (concerning potential conversions from agriculture into multi-purpose woodland) to illustrate the quantification and valuation of land use change. The application of geographical information system (GIS) routines allows spatial complexity to be incorporated within the analysis. Key concepts are introduced such as making allowance for subsidies, the marginal value concept, and the valuation of non-market externalities such as carbon storage of open-access recreation. The case study also shows that, if issues such as spatial variation and externalities are ignored, sole reliance upon market prices can lead to perverse outcomes which are actually to the detriment of society.

Basic concepts and terminology

Perhaps the source of most confusion in practical decision-making are two commonplace terms which most people use interchangeably: 'value' and 'price'.[1] But it is easy to demonstrate that they are not in fact equivalent. Consider that most basis of all necessities, water. This is the staff of life without which existence is impossible. Yet the price we pay for water in our household bills is actually very modest. It is clear to see that 'value' and 'price' are definitely not the same thing. In fact price is simply that portion of underlying value which is realised within the market place. As this example shows, that portion can be very much less than 100%.

Why then do prices diverge from values? The most fundamental reason is to do with to property rights. Some goods and services can readily be owned. For example, individuals can purchase woodlands and use private property laws to exclude others from chopping down their trees. The owner can now sell those trees at a price (the determination of which we will consider shortly). However, other resources are much less amenable to private ownership. As the world is beginning to realise, the services of the global climate system are of crucial value to humanity. Yet this is a public good from which no one country can easily be excluded, even if their use of the atmosphere is harmful to other countries.

Even when goods are protected by private property rights, their price may only be a poor indicator of their underlying value. This is reflected in one of the oldest conundrums of economics; Adam Smith's Water and Diamonds Paradox. Writing in the 18th century, Smith puzzled that diamonds, which had no practical purpose other than ostentation, commanded much higher prices than water, which was clearly of infinite value. The reason for this is of course differences in demand and supply for each good. While our demand for water is huge, so is its supply. It literally does fall from the skies. This interaction of demand and supply leads to the prevailing low price of water.[2] Diamonds on the other

☆ While the Government Office for Science commissioned this review, the views are those of the author(s), are independent of Government, and do not constitute Government policy.

☆☆ This paper is abstracted from a report to the UK Foresight—Land Use Futures project. It has benefited greatly from a series of insightful comments from Louise Heathwaite, David Newbery and Nicola O'Connor on the earlier draft. The author is also grateful for the editorial input of Martin Ince. Remaining errors are the responsibility of the author.

* Correspondence address: Environmental Economics, Centre for Social and Economic Research on the Global Environment (CSERGE), School of Environmental Sciences, University of East Anglia, Norwich, NR4 7TJ, UK.
E-mail address: i.bateman@uea.ac.uk.

[1] Another common and related confusion concerns the terms 'accountant' and 'economist'. Accountants are interested in market prices, whereas the *true* economist should be interested in values.

[2] Of course where either demand or supply changes so does price. Consider, for example, the long standing drought in Australia and how this affects water prices.

0264-8377/$ – see front matter © 2009 Queen's Printer and Controller of HMSO. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.landusepol.2009.09.010

hand only occur in a few areas of the world and even there they have to mined from deep underground using costly techniques.[3] The supply of diamonds is consequently small, resulting in high prices.

As we can see from the water example, demand and supply can interact in ways which are highly beneficial to consumers, providing goods at prices which are below the value which consumers attribute to them. This excess between price and value is known as the 'consumer's surplus'.[4] Of course decision makers should be interested in the value which different goods provide rather than their price. Therefore a number of methods have been developed which seek to estimate values. The use of such methods is particularly important when we consider goods for which the consumer surplus is large, and of course there are many high value public goods which do not have market prices (e.g. clean air and walks in woodlands).

The fundamental problem facing any valuation method is one of measurement; how do we measure value? The economist's approach to this is to acknowledge the difficulty of finding units that directly compare the happiness enjoyed by one person with that of another.[5] The economic solution is to use a surrogate measure which is highly compatible with the decision-making process, transparent, and amenable to subsequent adjustment if we wish to allow for different circumstances between individuals. That measure is used to assess the amount that individuals are prepared to pay for changes in the provision of goods. Note immediately that we are relating value to willingness to pay rather than what actually has to be paid. A simple example serves to illustrate the importance of this difference. Consider the value of walking in a woodland. This generates benefits such as exercise, appreciation of nature, perhaps entertainment of one's children, inner calm, etc. Yet if this were a publicly owned woodland the amount paid to enter such a wood is likely to be zero. Clearly here, price paid is a highly misleading indicator of value. However, we can estimate the value of this experience by looking at the amount visitors would be willing to pay in order to fund the creation of a new woodland (a 'stated preference' approach)[6] or infer the value as revealed in the expenses individuals incur and the activities they are willing to forgo in order to visit existing woodlands (a 'revealed preference' approach).[7]

There are no perfect ways in which to estimate the value of any good. However, several decades of research mean that solutions to many valuation problem do exist. For example, the extent to which an individual can express their willingness to pay must be constrained by their ability to pay, i.e. their income. But this can be addressed by reweighting the value estimates to allow for this problem (i.e. giving greater emphasis to the willingness to pay of poorer groups). Nevertheless, there are some limits to economic valuation of which two need to be emphasised: intrinsic values and total values.

Economic valuation methods seek to assess all the diverse values which individuals have for the range of goods and services they enjoy. These can include values related to the use of those goods, as well as to non-use values related to their bequest for others or just the simple pleasure obtained from the continued existence of some entity (for example the value one might hold for the pristine existence of Antarctica, even though the person expressing that value might not expect or even want to visit the place). Note that all of these values relate to human preferences, so the existence value of blue whales is that accorded by humans. Philosophers might argue that many entities also have an 'intrinsic' value quite separate from human appreciation, e.g. the value of the blue whale for itself. Economic theory does not dispute this (instead it is mute on the subject) but it does note that we can never measure such intrinsic values and therefore cannot compare them with those goods which we can value. If humans value the existence of a species then it can and should be included in economic analyses. However, if humans do not value that existence it will not be included in economic analysis.[8]

A second limitation is that, perhaps surprisingly, economics makes no claim to be able to assess the total value of certain goods and services, particularly many of those non-market life-support services provided by the environment. This can be readily proven by reconsideration of the water example. We can assess a wide range of individual willingness to pay for water. However, an infinite loss of value must be associated with the removal of all water. Therefore attempts to value vital life support systems such as the world ecosystem go beyond economics and into the realms of speculation.

Economics then does not attempt to value the whole of any vital service. However, as this is not the normal sphere of decision-making, this is not a problem. Instead economic analysis confines itself to the valuation of changes in provision. A key concept here is the value of an additional unit of provision. This is known as the marginal willingness to pay. This useful concept allows us to assess the value of many typical (i.e. non-extreme) changes in provision.[9] The calculation of the aggregate value of some provision change for a good or service requires three vital pieces of information:

- a clear understanding of the change in provision of the good under consideration (i.e. the number of units being provided);

[3] Here costs are simply reflecting the prices of the factors (e.g. land, labour and capital) used in producing goods.

[4] In addition, efficient producers who face costs which are below the prices they receive also enjoy what is known as a 'producers surplus' being related to the difference between costs and prices. The same good may generate both producer and consumer surplus.

[5] There is a fundamental issue here. The economic definition of value is entirely anthropocentric with value being seen as a uniquely human construct. Economics is posited upon an essentially notion where present-day humans determine value (Pearce and Turner, 1990; Fromm, 2000). Many reject this approach in favour of a rights based approach, some argue for equal treatment between present and future humans (Rawls, 1971) and others that higher animals such as chimpanzees (Watson, 1979) should be accorded equal rights with humans. Some go further by arguing for the rights of extant entities (Leopold, 1949; Rollston, 1988). Side-stepping the theoretical case for such philosophical extensions, a practical problem with these approaches is that they go beyond the scope of conventional, preference-based decision making and valuation. We simply cannot quantify the preferences of non-humans. Furthermore, while the need to impose constraints upon development to conserve and restore the ecological integrity of the environment is clear, the logical consequence of a rights-based approach is to stultify all economic change; an option which is simply unworkable given the need to rise to human-induced global environmental change.

[6] For further discussion of stated preference methods see Bateman et al. (2002).

[7] For further discussion of revealed preference methods see Champ et al. (2003).

[8] To the author's knowledge, there is no way in which intrinsic values can be catered for other than via a rights based approach. This emphasises the rights of different species (indeed different entities) to exist. A problem with such approaches is that they ultimately stifle any move from the status quo, as such rights are inalienable and non-tradable. This is very clearly removed from anything resembling the real world situation facing the policy community where decisions have to be made. Such stances are therefore ultimately of little use in such contexts.

[9] An important issue here concerns the definition of he baseline from which a provision change is quantified and subsequently valued. Typically, the baseline would be the current status quo. However, in a world of rapid environmental change it is often true that the level of provision of a good will change even if there is no policy intervention (e.g. ongoing development may lead to progressively higher levels of pollution). Such changes must be incorporated within any valuation analysis.

- a robust and reliable[10] estimate of the marginal (i.e. per unit) willingness to pay (WTP)[11]; and
- knowledge of how the first of these affects the second.

This approach acknowledges the fact that the value we obtain from an additional unit of a good tends to decline as our stock of those goods increases. Returning to the water example, if we have just spent a day in the sun then our marginal WTP for a first bottle of water is likely to be higher than that for a second bottle. This 'diminishing marginal utility' is reflected in a diminishing marginal WTP. Such changes in marginal WTP have to be allowed for when considering large provision changes. Similarly, marginal WTP for the provision of a good depends on the prior availability of similar substitute goods. One would expect the WTP for a new park in an area with no similar alternatives to be higher than for an identical park in an area well served by existing parks.

This issue of substitutes means that it is vital to consider location when appraising projects to provide environmental goods. As the availability of substitutes increases, so the value of additional similar goods declines. Similarly, the further away that such goods are located from an individual, the lower the value of that good to that person. This 'distance decay' effect[12] mitigates towards the location of environmental goods in more accessible areas.

So far we have only considered the value of a good in terms of the intended services it provides. We can refer to those services as the 'internal benefits' of production to those who consume the good and compare them to the 'internal costs' of production as paid by the manufacturer of that good. However, the production of a good can also have wider impacts than its consumption and production costs. These are the 'externalities' of production. They can include positive benefits which the producer is unable to capture and charge for. For instance, new factories may relieve unemployment in local areas. However, there may also be negative externalities such as air pollution for which the manufacturer does not pay but which impose costs upon others in terms of ill health, building damage, etc. It is one of the central tenets of applied economics techniques such as cost-benefit analysis that the internal and external costs and benefits of any investment should be assessed, including the opportunity costs of forgoing alternative investments of the resources involved.

Changes in provision relative to the status quo, internal and external costs and benefits, and the consequent generation of value gains and losses are relevant to all goods and services. But they apply particularly to land use change. Land use is determined by a wide range of drivers including shifts in national and world markets, policy initiatives, and environmental factors such as climate change. The highly diverse pattern of existing land uses, and variations in its environmental characteristics, mean that these drivers will have highly variable impacts in different areas. Thus planting trees will have very different consequences in terms of timber yield across the country, and the value of the resulting woodlands in terms of recreation benefits will vary substantially according to how accessible forests are and how many substitute woodlands already exist. This again means that we have to bring spatial issues into our analysis. Furthermore, many impacts do not occur immediately (e.g. the slow speed at which carbon balances can shift in response to land use change). Therefore our analysis also has to have a time dimension. This is important because individuals are not indifferent to the timing of when costs and benefits are incurred and tend to progressively reduce (or 'discount') values which occur further and further into the future when assessing their equivalent present-day value.

Bringing all of these factors together means that the challenge for economics is to undertake spatial-temporal cost-benefit analyses of the value of land use change. Following the requirements of the terms of reference, we undertake this via a case-study approach which illustrates the key concepts formulated above. To aid clarity we will refer to a consistent case study for most of our discussions. This features an analysis of the multiple internal and external costs and benefits generated by considering land use change from agriculture into multi-purpose woodland. The case study considers both spatial and temporal effects to identify and estimate net benefits (gains minus losses) in each area of a large case study area; the entirety of Wales. The heterogeneous nature of this area means that such land use change generates very different values in different areas at different times, illustrating the vital importance of considering spatial and temporal issues. We start in the following section, 'Bringing spatial issues into estimates of the change in provision induced by land use change' by addressing the most fundamental question of any policy: what is the change in provision that it will generate?

Bringing spatial issues into estimates of the change in provision induced by land use change

One of the initial challenges for practical cost-benefit analysis is to estimate in quantity terms the changes in provision that are to be valued. It is clearly unreasonable to expect valuation studies to derive robust values for a good when the change in the quantity (or quality) of provision is unknown.

In the case of land use change, the analyst clearly cannot treat all areas as being equal. Thinking of our case study regarding the potential for net benefits arising from land use change from agriculture into woodlands, an obvious provision change which we need to consider is how well trees will grow in different areas. In order to address this we start by examining the available data[13] regarding tree growth. Bateman et al. (2003) examine several thousand records of tree growth collected by the UK Forestry Commission from their forestry 'sub-compartments' located all over the study area, as shown in Fig. 1.

Examination of Fig. 1 shows that, while we have observations scattered across a wide variety of areas, there are many places where we do not know how trees grow. We therefore cannot

[10] One of the problems of stated preference methods is that survey respondents are liable to answer valuation questions even if they have little understanding of the good concerned. This results in the phenomena of 'preference construction' (Ariely et al., 2003; Kahneman et al., 1982; Slovic, 1995) where respondents make up answers to questions they do not understand or rely upon the framing of the valuation questions to infer the 'correct' answer. A number of tests have been developed for identifying such constructed preferences (Arrow et al., 1993; Bateman et al., 2008) and it is important that any stated preference study conduct and satisfy such tests before any reliance is placed upon their findings.

[11] The common usage of the term 'willingness to pay' is the WTP for a gain in provision. This is more properly (but much less frequently) called the 'compensation surplus' (or for market priced goods, the 'compensating variation'), literally the variation (here a reduction) in an individual's income which just offsets an increase in the provision of the good under consideration. While this is the most common measure of the economic value of a provision change, it is actually only one of four such measures (Hicks, 1943). The others are the amount an individual is willing to accept (WTA) in compensation to just offset a loss in the provision of a good (correctly termed the compensating loss); the amount of income an individual is willing to pay to avoid a loss of provision (the equivalent loss); and the amount of extra income compensation which is just equivalent to foregoing a gain of the good (the equivalent gain). Bateman et al. (2000a,b) provide stated preference estimates of all four 'Hicksian' welfare measures within a common public goods case study.

[12] For further discussion of the distance decay effect see Bateman et al. (2006a).

[13] Data availability is generally good in the UK across a number of dimensions. Clearly this is not true of all situations and data limitations will be a constraint upon any analysis.

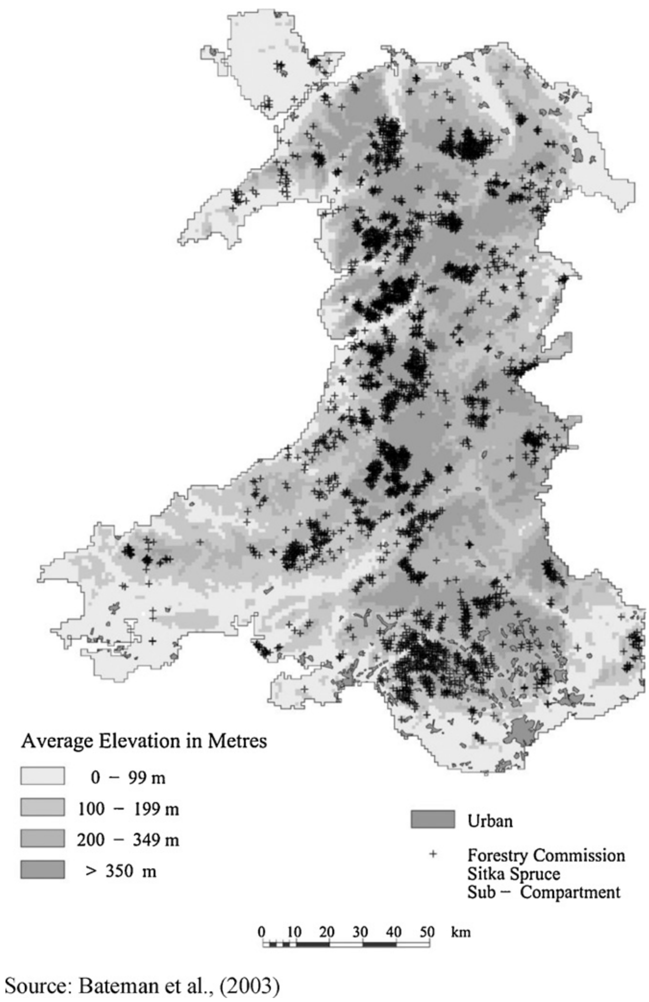


Fig. 1. Location of Forestry Commission sub-compartments for one species (Sitka spruce) in Wales (superimposed upon elevation). *Source*: Bateman et al. (2003).

rely solely upon the raw data to answer our question about the best places for land use change from agriculture to forestry. Such problems are common and the same issue arises with respect to farming; while we know about agricultural output in many areas, by no means do we have records for all.

We therefore need a means of predicting the provision change induced by land use change (here tree growth) in all areas from data which covers just a subset of those areas. Given that we know that tree growth can change abruptly over relatively small areas (due to soil type changes, altitude, etc.) then we cannot simply assume that every area is like every other area. The solution is to build a model of tree growth which incorporates all the factors which influence that growth. Statistical techniques allow us to build such models. Here we relate each sub-compartment tree growth record to the physical environment, management and other characteristics of that sub-compartment. These characteristics include many variables (such as soil type, elevation, rainfall, etc.) for which we have records for all areas of the country. By showing how these factors determine tree growth in the sub-compartments, we can use those relationships to predict tree growth in all areas of the country. Table 1 details a statistical model, estimated using regression techniques, which predicts the growth rate of a particular tree species as a function of the characteristics of each area.

Models such as those given in Table 1 tell us a lot about how the characteristics of each sub-compartment determine the rate at which trees will grow in it. The first column set outs the determinants ('predictors') of timber yield. The last column tells us how significant each of those predictors are in determining yield. These are *t*-ratios. Any value outside the range from +1.96 to −1.96 is considered to be statistically significant, and the further outside that range the more significant a factor is. All of the variables listed here are very highly significant in determining timber yield. The value in the middle column describes the relationship between each variable and the timber yield. The 'Constant' tells us what the timber yield would be if all of the other variables had a value of zero (here it says that yield would be 16.71 m^3/(ha year)). Of course it is implausible that all the other variables would have a value of zero, and their coefficients tells us how yield changes as each one of those variables increases by one unit. So the 'Elevation' variable shows us that if the woodland was one unit (here 1 m above sea level) higher then the timber yield would decline by 0.009 m^3/(ha year). This is of course a tiny change, but this result helps answer more useful questions such as the impact of planting a forest 100 m higher above sea level, which is now a non-trivial loss of 0.9 m^3/(ha year). Similarly the 'Rainfall' variable shows that as the amount of rain in an area increases by one unit (here 1 mm) so timber yield falls[14] by 0.002 m^3/(ha year); a substantial effect when one considers that rainfall across Wales varies from 1000 to 3000 mm annually (Met Office, 2009). That means that rainfall variations alone induce a variation in yield of 4 m^3/(ha year). The remainder of the model is similarly easy to interpret. It identifies those factors that either increase or decrease timber yield and in each case quantifies that relationship.[15]

Notice that the model is composed of two types of variables, those linked to the physical environment and those which describe the effects of management on trees. As an example of the latter, the Mixed Crop variable shows us that this species tends to grow

Table 1
Best fitting regression model predicting Sitka spruce yield (m^3/(ha year))[a].

Predictor	Coefficient	*t*-Ratio
Constant	16.710	47.92
Elevation	−0.009	−22.31
Rainfall	−0.002	−15.65
Shelter	0.024	3.20
Good soil	0.805	10.00
Poor soil	−4.883	−5.05
Area of forest	0.004	10.43
Year planted	0.050	10.31
1st rotation	−1.928	−17.64
Mixed crop	−0.308	−4.02
Parkland	0.948	10.10
Ancient forest	0.927	3.00
Uncleared forest	2.641	11.61
Low inputs	−0.085	−10.49
Lower inputs	−0.434	−4.59
Lowest inputs	−5.142	−6.73

Source: Bateman et al. (2003).

[a] The model reported in Table 1 is based upon tree growth records from 4307 sub-compartments across the study area. The model fitted the data well, yielding a higher degree of fit than recorded in previous tree growth studies (R^2(adj.) = 42.8%).

[14] Readers outside the UK might be surprised that the model shows tree growth decreasing as rainfall rises. However, Wales is one of the wettest areas of a high rainfall country, so that yet higher rainfall is associated with particularly adverse conditions for tree growth. If we were to build a model of tree growth for a much drier country, we would expect the coefficient on rainfall to become positively related to tree growth. This example underlines the need for great caution when extrapolating statistical models to situations for which they were not designed.

[15] Note that the purpose of the model here is primarily illustrative. Some further relationships (e.g. the impact of rain acidity) were not considered at the time of the analysis.

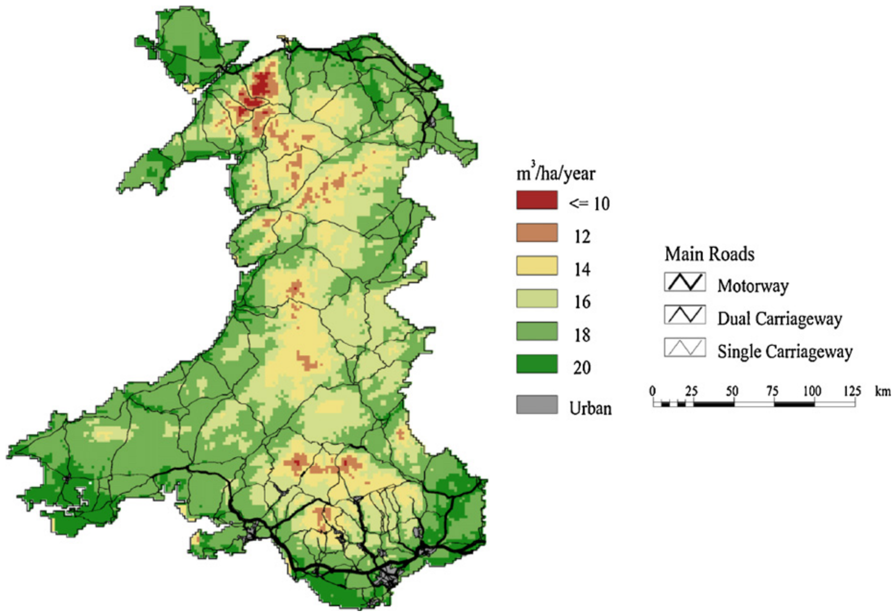


Fig. 2. Estimating a physical change in provision: predicting the timber yield produced by planting trees in different locations across Wales. *Source*: Bateman et al. (2003).

at a slightly lower rate when mixed with other species rather than being grown in a monoculture. This illustrates a familiar dilemma for the forester, landscape diversity versus timber output. We can set these latter management factors in line with any desired policy (e.g. preferring mixed species stands over monocultures).

Turning to the physical environment variables, the UK enjoys a wealth of data, with information on all these factors being held at a very high degree of resolution for the entire country. We can now use this information to predict timber yield for every location across the country and so estimate the physical provision change which would be induced by an afforestation project at any given location. The results of such an analysis are given in Fig. 2, which indicates the physical provision change of an afforestation project and shows where the highest timber response would be achieved.

An important caveat to Fig. 2 (and all subsequent analyses in the present paper) is that it omits any consideration of assumptions and uncertainty. Virtually all analyses which attempt to extrapolate away from those points which have direct measurements rely to some lesser or greater extent on assumptions, and even the most direct measurements involve some degree of uncertainty. The understanding and quantification of uncertainty and error along with the testing of assumptions is a vital part of any modelling research and a major element of the studies underpinning much land use research.[16] However, such issues are not the central thrust of the present paper and we leave these aside with the caveat that such issues are clearly important.

This calculation of the physical provision change effects of a given policy are only the first part of the benefit transfer task. We now need to convert these physical units into monetary amounts. In section 'From the change in provision to its market price, and comparison with other marketed goods: explaining the status quo' we simply use prices rather than values (see section 'Basic concepts and terminology' for the distinction between these terms). In the case of forestry this analysis also allows us to introduce the issue of time. Trees take a long time to grow. We also contrast the market value of growing timber with that of agriculture, which is the alternative land use in this analysis. By conducting all of this analysis using prevailing market prices we provide ourselves with an understanding of the present pattern of land use, which is of course driven by prices rather than by underlying values. However in section 'From prices to values and the incorporation of externalities', we make the transition to values by including alongside market prices the externalities which a move from agriculture to forestry would generate, principally the considerable change in carbon storage which would occur and the value of woodland recreation which would be created.

From the change in provision to its market price, and comparison with other marketed goods: explaining the status quo

The move from provision change to market price is an interesting one in the case of timber, and illustrates the need to consider the temporal dimension. While the current price of timber is readily available from the market,[17] even the fastest-growing trees will take more than 40 years from planting to maturity. This means that in assessing the 'net present value'[18] of a potential investment, the land owner will substantially discount the delayed felling revenues of a woodland. But the costs of establishment, which principally occur at the time of planting, are virtually undiscounted. While there are well-established procedures for assessing present values in such situations, the rate of discount is a key factor. Higher rates result in lower present values for delayed net benefits. Furthermore, the discount rate used by a private investor assessing

[16] For recent examples of the incorporation of uncertainty within land use modelling see Brown and Heuvelink (2007); Burnicki et al. (2007); Crosetto and Tarantola (2001); Deflandre et al. (2006); and Posen et al. (2006, 2008).

[17] An unusual complication is that, unlike most goods, timber does not have a constant unit price. The price of a cubic metre of timber when composed of small trees is less than when that volume is cut from a single tree. This relationship is captured in a 'price-size curve' and is taken into consideration in the results shown here.

[18] The net present value of an investment subtracts the costs from the revenues in each year and then discounts these net benefits back to their present day equivalent. Summing across all years of the investment gives the net present value.

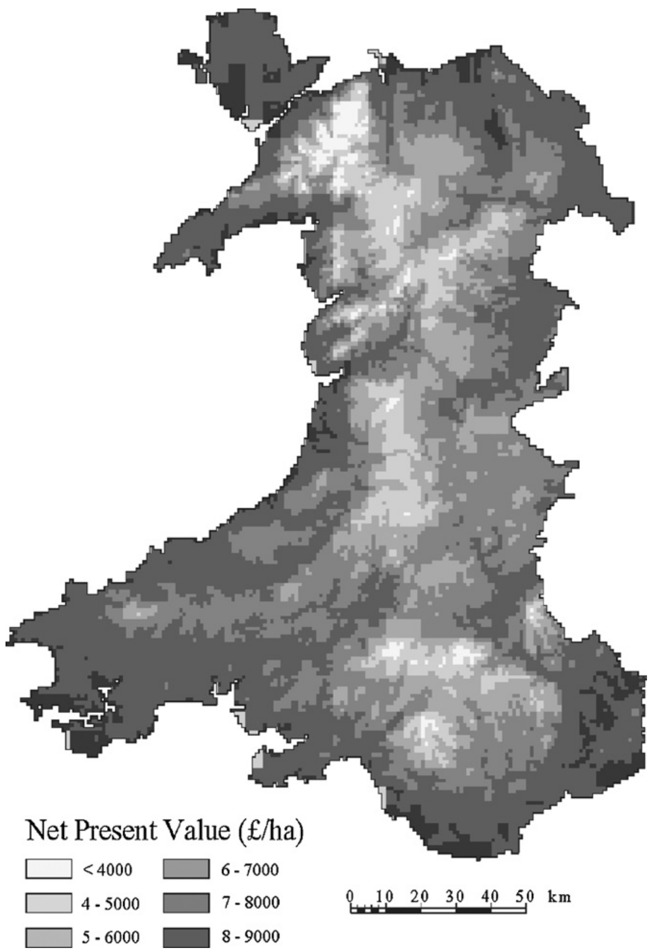


Fig. 3. Net present value of afforesting land across the study area. *Source*: Bateman et al. (2003).

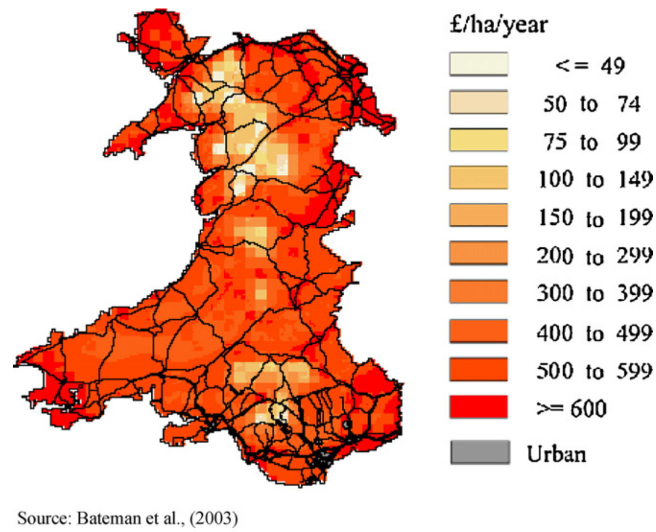


Fig. 4. Predicted farm gate income from present land use. *Source*: Bateman et al. (2003). Farm income varies across sectors with figure illustrating the results for dairy farms. Bateman et al. (2003) also presents results for other sectors.

market returns is likely to be much higher than the 'social discount rate' used by public decision makers, which reflects a longer time horizon. While it is the social discount rate that is relevant to policy makers, in modelling the status quo it is the private discount rate which is relevant to explaining the present pattern of land use. Taking these factors into consideration allows us to move from the quantity provision map of Fig. 2 to the corresponding value map of Fig. 3.

While Fig. 3 shows the net present value of the long term costs and revenues of changing land use to forestry, most farmers prefer to assess options on an annual basis. A simple relationship exists to translate between long term net present value and its annual equivalent (for details see Bateman et al., 2003). This 'annuitizing' procedure translates the long term values of Fig. 3 into annual equivalent values ranging from about £50/(ha year) up to around £175/(ha year), these being distributed in a pattern similar to that of the net present values. In effect this means that any farmer who can generate annual incomes in excess of this from their present farming activities is unlikely to change land use into woodland unless they are given some additional inducement.

To estimate the value of current agriculture we adopt a similar modelling approach to that taken for forestry. Data on farm activities are taken from across the country and modelled using statistical techniques which link them to the physical environment, management and other variables characterising each area. Output prices and costs are then used to estimate the profit which farmers achieve from their present activities. As before, we can then use our model to estimate farm profits for each location in the study area. Fig. 4 illustrates predicted income from the present agricultural land use.

It is important to emphasise that the farm gate income illustrated in Fig. 4 is heavily influenced by prevailing agricultural policies, most notably the EU Common Agricultural Policy (CAP). This policy strongly distorts the price of agricultural outputs (and more indirectly their production costs) away from what they would be under free market conditions. This means that we need to distinguish between the price of a farm product as received by the farmer[19] (which will of course have a major influence upon that individual's land use decisions) and the social value of that produce. The latter adjusts for the various subsidies and price interventions induced by policy, the logic being that such payments are simply transfers from one part of society to another. A problem is that such transfers can very strongly influence behaviour. Policies such as the CAP have radically affected the pattern and intensity of agricultural land use in the UK. Many economists argue that this distortion can result in major differences between the market prices which farmers respond to and consumers pay, and the free market prices which would hold in the absence of such distorting policies.

Although efforts are being made to reform the CAP and move farming back towards being a more market-led enterprise, it is currently far from being a free-market activity. Any cost-benefit analysis of the social value of land use should therefore adjust for such distortions and the analysis above has been subject to such an adjustment by Bateman et al. (2003). This shows that the effect of the CAP is to inflate the value of certain types of agriculture relative to other land uses. For the purposes of the present paper we avoid the detail which such an adjustment process requires. Instead we note simply that land use patterns are influenced by spatial variation but also by market distortions.[20]

[19] Of course farm gate prices are substantially lower than those paid by consumers. For recent analyses see London Economics (2004).

[20] This case is particularly complex. Spatial variation in the natural environment affects land use, and in addition the levels of distortionary subsidies available vary according to location. This variation in subsidy is not guided by non-market benefits such as the carbon consequences of land use (discussed in this paper) but rather by attempts to compensate for the impact of poorer land on farm incomes. This in turn results in further over-exploitation of certain areas, for example over-grazing of

A comparison of Figs. 3 and 4 contrasts the outputs of forestry and agriculture as valued using prevailing prices, those which hold under existing policies and which determine farmers' land use. Recall that the market value of forestry (its timber value) provided an annual equivalent of between £50 and £175/(ha year). We can see that this is lower than agricultural values in all but the central upland areas. It is therefore not surprising that the real world reflects this pattern very well, with forestry generally confined to the central uplands and agriculture dominant elsewhere. We can therefore conclude that:

- land use patterns reflect the profits which farmers and other land users can obtain from the different outputs they can produce from their land;
- those outputs are in part determined by the physical environment characteristics of land, which vary significantly by location; and
- capturing the spatial variation of the physical environment is a vital element of land use assessment, planning and management.

In this particular case the prevailing set of prices and subsidies result in very little land being allocated to woodland rather than agriculture. Indeed further analyses show that farmers require a significant profit premium before undertaking an activity with which they are not particularly familiar (Bateman et al., 2003).[21] However, this may very well not reflect the true social value of these alternative land uses. To estimate this, two important adjustments need to be made. First, assessments of the social value of land use should not solely rely upon market prices. While these are important in understand why the present mosaic of land use is as it is, such prices are liable to be distorted by policies which provide subsidies or change prices of certain outputs. Social value assessments should adjust for such distortions.

In addition, assessments also need to consider the costs and benefits which are 'external' to the producer and so are not reflected in existing costs and prices. These externalities include items such the impact of production on greenhouse gases, and open-access recreation provision. The value of such items is not reflected in farmers' profits. But they do represent genuine value flows to society and therefore have to be considered by the social decision maker.

In subsequent analyses we undertake the adjustments to allow for market distortions. We now move on to consider methods of assessing the externalities identified above.

From prices to values and the incorporation of externalities

From section 'Basic concepts and terminology' we know that a social planning perspective requires that we consider values rather than prices. Therefore we have to take into account any consumer surplus associated with both agriculture and forestry. Bateman et al. (2003) undertake such an analysis, the details of which we will avoid here. However, one of the key issues which that analysis does highlight is that conventional agricultural production is the recipient of substantial government payments in the form of price support (although this is declining rapidly) and direct income subsidies (which have recently increased[22]). While a number of important arguments can be put forward to defend such intervention, it is also true that these transfers from the taxpayer might reasonably be reallocated to any number of alternative uses. Therefore cost-benefit analyses typically remove such transfers as part of the process of moving from private price-based assessments to social value-led decision-making. Thus we find that the social value of agriculture in parts of the case study area is lower than its apparent market value.

The move to values and the removal of subsidies and other transfer payments significantly sways the cost-benefit balance towards forestry rather than agriculture. This move is substantially enhanced when we extend our analysis to consider the external benefits and costs of both agriculture and forestry. While a full cost-benefit analysis would need to consider all externalities, for simplicity we will consider just two of the external benefits of forestry, carbon storage and woodland recreation. Together these illustrate the remaining key concepts which need to be considered here.[23]

Carbon storage generates value by ameliorating climate change and its impacts. There are typically three aspects of carbon storage and loss arising from any land use change, all of which were assessed here[24]:

- Carbon storage in living crops. As plants and trees grow, they store carbon in their biomass. Different plants have different densities and carbon content. But as a simple guide, the greater the biomass of the plant, the more carbon it stores. Obviously this means that trees store far more carbon than typical agricultural crops, while livestock even contribute to greenhouse gas emissions.
- Carbon liberation from finished products and waste. Once a plant stops growing or is harvested, the process of carbon liberation begins. For most agricultural crops all of the carbon sequestered during the growing period is liberated back to the atmosphere relatively quickly following harvest. For trees the situation can be very different. While some tree species are put to end uses where all carbon might be liberated within a few years, others are put to longer lasting uses such as construction, furniture, etc. Such end uses may keep carbon locked up for long period of time (again meaning that we have to consider discounting when we come to value this sequestration).
- Soil carbon gains and losses. Intensive agriculture tends to degrade the carbon content of soils, whereas tree planting tends to enhance it. An exception is when trees are planted on wetlands and peats. Here the process of planting trees can lead to peat soils drying out and releasing the large amounts of carbon they normally store. Tree planting in such areas can result in a net liberation of carbon, with soil losses of carbon exceeding the amount retained by living biomass.

The long time periods of these processes mean that our analysis has to embrace the temporal dimension. Trees last a long time, and some soils take many years to fully adjust to new carbon balance after land use change. Bringing this together with the growth rate models of Fig. 1 allows us to generate models and map results for the change in net carbon balance arising each year as a result of land use change from agriculture to woodland. We then have to convert that change in carbon (the provision change) into values. Fortunately there is a large literature on the value of sequestering a tonne of carbon. These studies estimate the damage which cli-

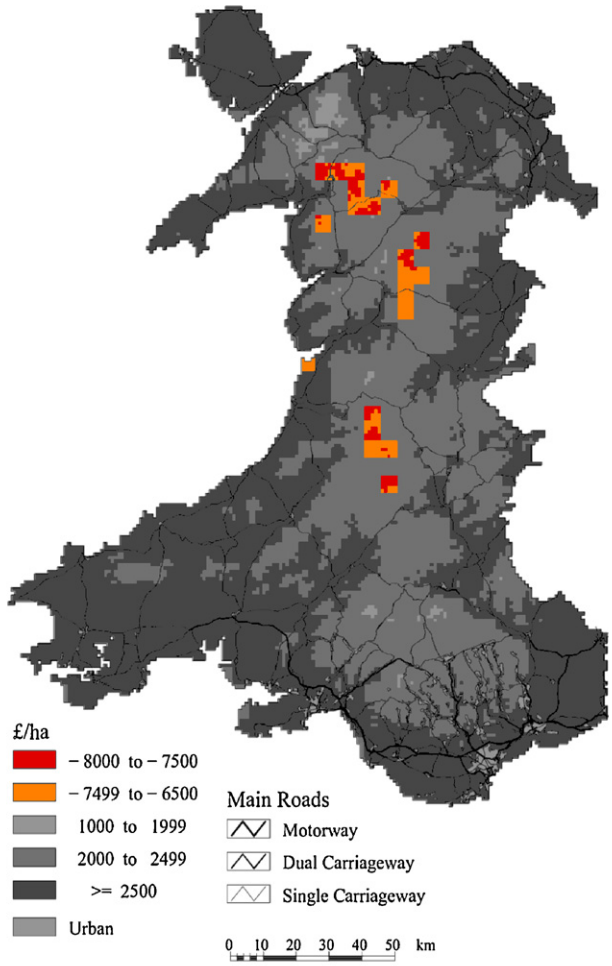
upland areas irrespective of their value as biodiversity habitats (see discussions in Bateman et al., 2003).

[21] This has been made worse by the UK Forestry Authority frequently only issuing felling licences on condition that the land be replanted with trees.

[22] For example the EU Single Farm Payment scheme introduced in 2005–06.

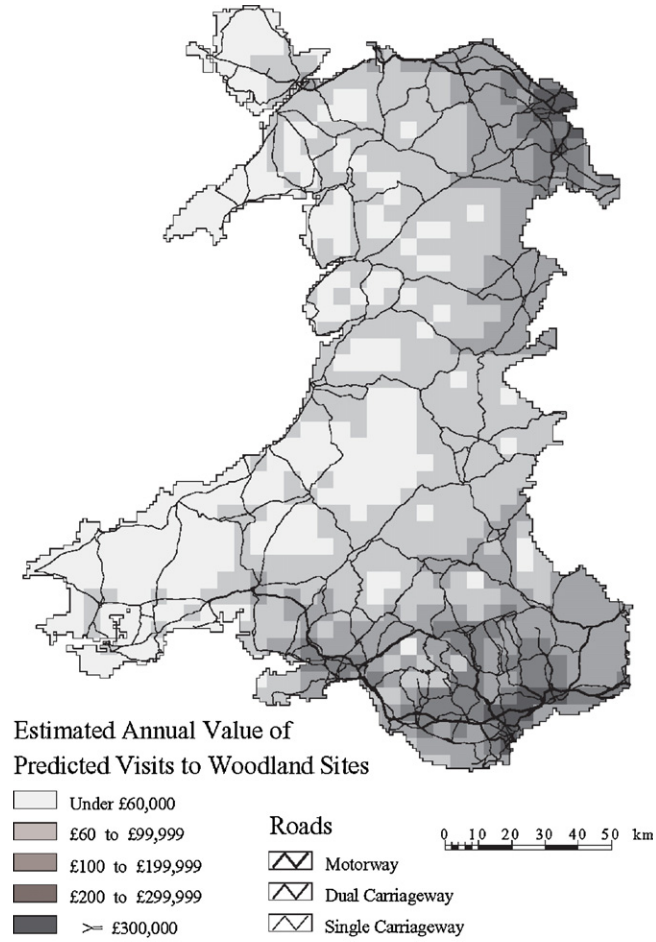
[23] Other key externalities include diffuse water pollution from agriculture (see, for example, Hutchins et al., 2009), social cohesion and impacts upon biodiversity.

[24] This analysis does not embrace non-carbon effects such as the nitrogen cycle. These should be addressed in any full application but their omission does not undermine the methodological illustration given here.



Source: Bateman et al., (2003)

Fig. 5. Net carbon storage values from land use change to forestry. *Source*: Bateman et al. (2003).



Source: Bateman et al., (2003)

Fig. 6. Estimated annual recreational value of land use change into woodland. *Source*: Bateman et al. (2003). A complication is that the marginal recreation value per-hectare is likely to be a complex and ultimately sharply diminishing function of the size of that woodland. There may well be a minimum threshold size for a woodland to deliver recreational benefits such that the initial hectare may actually have lower marginal value than the second hectare. However, once a woodland is of a sufficient size to generate trips, then the marginal value per-hectare is likely to decline rapidly. This intuition flows from the common observation that the majority of recreational visitors do not wander far from the access point or car park of the site (Coombes et al., 2009). This means that simple estimates of per-hectare recreational value, derived by dividing aggregate WTP by the area of a site, are likely to be erroneous. As a partial response to this problem, in subsequent analyses we calculate recreational values on a per site rather than per-hectare basis by assuming that a substantial (say 100 ha) site is created in each 5 km^2 of the Ordnance Survey grid. This avoids the indefensible linear relationship between total and per-hectare values mentioned above. We acknowledge that there is a need for greater research to quantify the relationship between site size and value.

mate change will cause and from that derive the value of removing one tonne of carbon from the atmosphere. Applying these values to our provision change estimates allows us to generate maps such as Fig. 5, which shows the value of net carbon sequestration caused by land use change from agriculture to woodland. As might be expected, areas of high tree growth rates store the most carbon. As we move to higher elevations (near the central mountain spine of the country), so tree growth falls and with it the value of carbon sequestered. In those areas of peat soils (generally near the tops of the mountains), the carbon loss from those soils after tree planting substantially outweighs the amount of carbon which the trees would sequester.

As we discussed in section ‘Basic concepts and terminology’, the marginal utility of a good describes the benefit which individuals obtain from a unit increase in its provision. For goods such as timber and carbon storage, the afforestation of the whole area of Wales would have only a negligible impact upon the marginal utility of further production. Analyses such as those by Sedjo et al. (1997) show that even the afforestation of the entire US would be far from sufficient to generate the sequestration required to address global warming. The amount of carbon which could be fixed by the afforestation of Wales is tiny in comparison to the amount of carbon storage which is required to even begin to offset present and future climate change. Therefore the marginal benefit of further sequestration would stay roughly constant before and after any plausible level of afforestation. The task for the decision maker is to obtain a valid estimate for the sequestration of one tonne of carbon and apply this to the estimated change in physical provision of such services.

From the above discussion we can see that the marginal value of a tonne of carbon stored will remain constant both as the number of tonnes stored increases and irrespective of where that carbon storage occurs. Neither of these characteristics applies to woodland recreation. Recreation benefits, like many goods, exhibit significantly diminishing, spatially confined, marginal utility. The benefit of creating one new recreational forest in an area significantly reduces the benefit of creating a second one nearby. Despite the

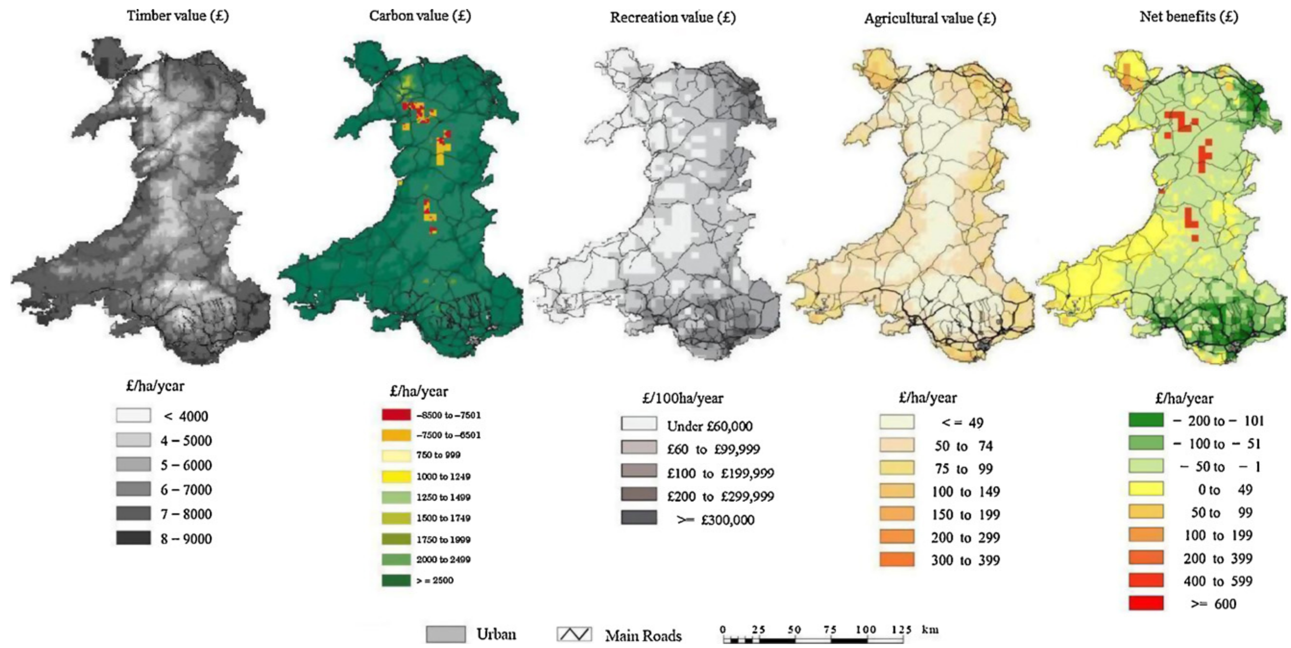


Fig. 7. Spatially explicit cost-benefit analysis of a potential land use change: retaining agriculture as opposed to converting to multi-purpose woodland. *Notes*: From left to right the maps show (i) the annualised equivalent of the social NPV of timber arising from a perpetually replanted woodland; (ii) the annualised equivalent of the social NPV of net carbon flux (live wood, products, waste and soils) under woodland; (iii) estimated annual value of predicted visits to woodland sites (calculated on a per site basis—see notes to Fig. 6); (iv) predicted subsidy adjusted (shadow) value of sheep farming; (v) cost-benefit analysis of retaining sheep farming as opposed to conversion to woodland (defined as timber, carbon storage and recreation). Here negative values (shown in dark to light greens) indicate areas where woodland values exceed agricultural values, while positive values (shaded from yellow to red) indicate the opposite result highlighting areas which should stay in agriculture. Further details given in Bateman et al. (2003) from which the above figures are adapted.

significance of this effect, there is a paucity of good valuation evidence regarding diminishing marginal utility (and hence diminishing marginal WTP) for most non-market environmental goods. The few studies that have examined this issue find it to be highly significant (e.g. Egan et al., 2009; Lanz et al., 2009). In effect, the greater the provision of a good, the more satiated we become with it and the lower the marginal utility (and hence marginal WTP) of that good.

Marginal utility can decline because of the presence of substitute goods as well as direct replacements. For example, while the provision of woodlands can generate benefits by providing recreational walks, these will be at least partially substituted for in areas where there are riverside walks. As Jones et al. (2002) show, this substitution effect can arise from quite diverse resources including man-made recreation sites and urban attractions.[25]

Even in the absence of substitutes, location matters with regard to spatially confined goods such as recreation. The further away a new recreational resource is from an individual, the greater will be the travel and time costs of accessing that good and so the lower their WTP. This effect will be heightened by poor transport provision. This phenomenon is termed distance decay (Bateman et al., 2006) and can be observed if we examine the pattern of recreation values which would be generated by land use change from agriculture to woodland. By undertaking a revealed preference study of visitor behaviour we can observe how increasing travel time and cost reduce the willingness of individuals to visit a site. Furthermore, given that travel costs can be expressed in money terms, we can observe the trade-off between money and visits and so infer the value of those visits. We can then use this model of behaviour and, taking into account the distribution of population and the road network and its quality, predict the number of visits which would be generated by placing a recreational woodland at any given location and their value. Fig. 6 illustrates the results of this analysis.[26] As would be expected, the pattern of recreation values shown strongly reflects the distribution of population. The highest values are in the south east (around Cardiff, the largest Welsh city) and the north east (reflecting the proximity of Liverpool and Manchester) while values along the central upland spine and the remote west coast are relatively small.

Given the importance of distance decay, substitution effects and consequent diminishing marginal utility and WTP, we discuss these issues further in the Appendix A to this report.

We conclude by bringing together the internal and external values (rather than prices) generated by a land use change from agriculture into woodland, using our spatial approach to emphasise those areas that yield the highest net benefits from such a policy.

Bringing it together: a spatial cost-benefit analysis of land use change

We have now moved our analysis from simple consideration of market prices to a value-based analysis. Furthermore, we have employed a spatially sensitive methodology which incorporates

[25] Note that complementary relations can also arise. For example forests with lakes may attract additional visitors.

[26] The interpretation of the recreation map is not as straightforward as for, say, the carbon map. Whereas we can simply sum the values shown on the latter map to get the carbon value of afforesting any given area or indeed the whole country, this is not the case for the recreation map. As we have seen, once a recreational woodland is located in any given area, it serves as a substitute for any further nearby new woods and would depress the marginal WTP for the later addition. The estimation of values for the creation of multiple recreation sites has to take into account this substitution effect. This caveat needs to be kept in mind when considering our spatial cost-benefit analysis in section 'Bringing it together: a spatial cost-benefit analysis of land use change'. While the results shown here are valid, recreation values would alter if partial implementation of the land use change were to be undertaken.

the vital issue of location throughout our analysis. Because all values are expressed in common monetary units and each value stream is spatially referenced, we can now sum our values.

Fig. 7 provides a visual representation of this analysis. In maps (i)–(iii) we detail the timber, carbon and recreation values which would be generated by multi-purpose woodland. Map (iv) shows the social value of an existing agricultural land use (sheep) once we have subtracted the various price distortions, subsidies and other transfer payments arising from policies such as the CAP. To ensure a fair comparison we have also removed any transfer payments associated with woodland. Map (v) provides a cost-benefit analysis which is obtained by summing all of the woodland values and subtracting them from the agricultural value. Here negative values indicate areas where the agricultural value is lower than the sum of woodland values. These cases are coloured with various shades of green, the darker areas indicating locations where woodland values most substantially outweigh agricultural values. As can be seen, our analysis shows that substantial areas of the country would indeed yield a higher social value under woodland than they do under agriculture. This result arises because we have now removed subsidy payments (which favour agriculture) and included two of the major externalities of this land use change; carbon storage and recreation benefits. There are further externalities that should be considered, but if anything they seem likely to reinforce and strengthen this result. For example, we have omitted the external costs of diffuse water pollution[27] from agriculture and the external benefits of some (but not all) types of woodland in terms of biodiversity habitat creation.

The net benefits result of Fig. 7 is in marked contrast to the market price outcome of the current status quo discussed previously, where agriculture dominates the rural landscape. Because land owners do not receive payment for the carbon storage and recreation values which would be created by land use change, and because agriculture is currently much more heavily subsidised than forestry, the market price solution is heavily skewed towards agriculture in most lowland areas. If we contrast this map with Fig. 1 we can see that the failure to consider externalities has resulted in a situation where forestry is confined to the upland central spine, away from the populated areas where recreation values are highest and, perversely, concentrated in just those areas where woodland can result in net carbon emissions due to planting on peat soils.

Conclusions

This report focuses upon the key issues which have to be addressed in considering the complex issue of land use change. In particularly we have highlighted the vital importance of bring spatial issues into analyses of land use change. The inherent heterogeneity of the physical environment and human influences upon it means that it is only through an understanding of the complexity of the real world that we can hope to make efficient land use decisions. Location plays a major role in determining the physical changes in provision which arise as a result of land use change. However, it can also affect the value of those provision changes, for example by the interaction of such values with the spatial location of substitutes or proximity to populations.

The paper also highlights the vital distinction between prices and values and the need to move from simple consideration of the direct, internal costs and benefits of land use change to embrace its wider external impacts, both positive and negative. Through case study examples, we have shown that a failure to consider all of these factors can result in highly inefficient and even perverse outcomes where social values are ignored or even become negative. It is to be hoped that future decision-making embraces these challenges so as to move towards outcomes than are guided by values rather than imperfect market signals.

Appendix A. Distance decay and substitution effects

The benefits generated by any environmental improvement associated with land use change can be described through a spatially explicit valuation function. This measures the value of the improvement as individuals' willingness to pay (WTP) for that change. The function relates that WTP to the factors which determine it. These include:

(i) the quantity or quality change being considered (reflecting the higher utility of large provision changes);
(ii) the distance between the site of the improvement and the individuals' home (reflecting the higher costs of use associated with more distant goods—this may be exacerbated if as distance to the improvement increases so distance to alternative substitute decreases);
(iii) the individuals' income (reflecting the individuals' ability to express their WTP);
(iv) other relevant variables

Fig. A.1 illustrates maps of WTP derived from such a value function, estimated for improvements to the quality of the River Tame in the Midlands of England. Data for this analysis was obtained from a public survey employing a stated preference valuation method which directly elicited WTP for the improvement in question.[28]

The analysis considered three levels of improvement which for simplicity we will refer to as the 'Small', 'Medium' and 'Large.' Consideration of the first of these maps for the Small improvement shows that the values generated are highest nearer to the river and decrease as distance from the river rises. This is the 'distance decay' effect (Bateman et al., 2006a) which reflects the increasing travel costs of accessing the river from more distant locations. Again this result shows the clear necessity of considering spatial issues in the assessment of any change in the physical environment. Distance decay is also clearly visible in the maps of the Medium and Large improvement. An examination of all three shows the increased values generated as the scheme size grows.[29]

The map for the Large improvement also most clearly shows the impact of income upon WTP. Examining areas of similar distance either side of the river (i.e. controlling for the distance decay effect) one can see substantial variation in WTP. This reflects the diverse range of incomes across the study area. People in higher-income areas are more readily able to express their WTP values for the

[27] See, for example, Harris and Heathwaite (2005), Lane et al. (2006).

[28] The study used the contingent valuation method. For details of the study see Bateman et al. (2006a). The study also illustrates the vital necessity of including spatial issues when aggregating upon from individual WTP to the social value of a project, showing the gross errors that can occur if such issues are ignored.

[29] To date relatively few valuation studies have considered the issue of distance decay although exceptions include Bateman et al. (2000a,b, 2005, 2006a); Hanley et al. (2003); Imber et al. (1991); Loomis (2000); Mouranaka (2004); Pate and Loomis (1997); and Sutherland and Walsh (1985). These findings suggest that distance decay can be approximated by a nonlinear function in which the slope indicates that values decay relatively quickly with increasing distance but that the rate of decay itself falls such that statistically significant if low values can arise some distance from the improvement site. The distance at which values fall to zero (defining the 'economic jurisdiction' of an improvement project; Loomis, 2000) is reflected in the intercept of the distance decay function which increases with the scale of the improvement. Ongoing work by Carlo Fezzi and Silvia Ferrini at the RELU ChREAM project investigates non-parametric distance decay functions although these still fit conform to the general pattern described above.

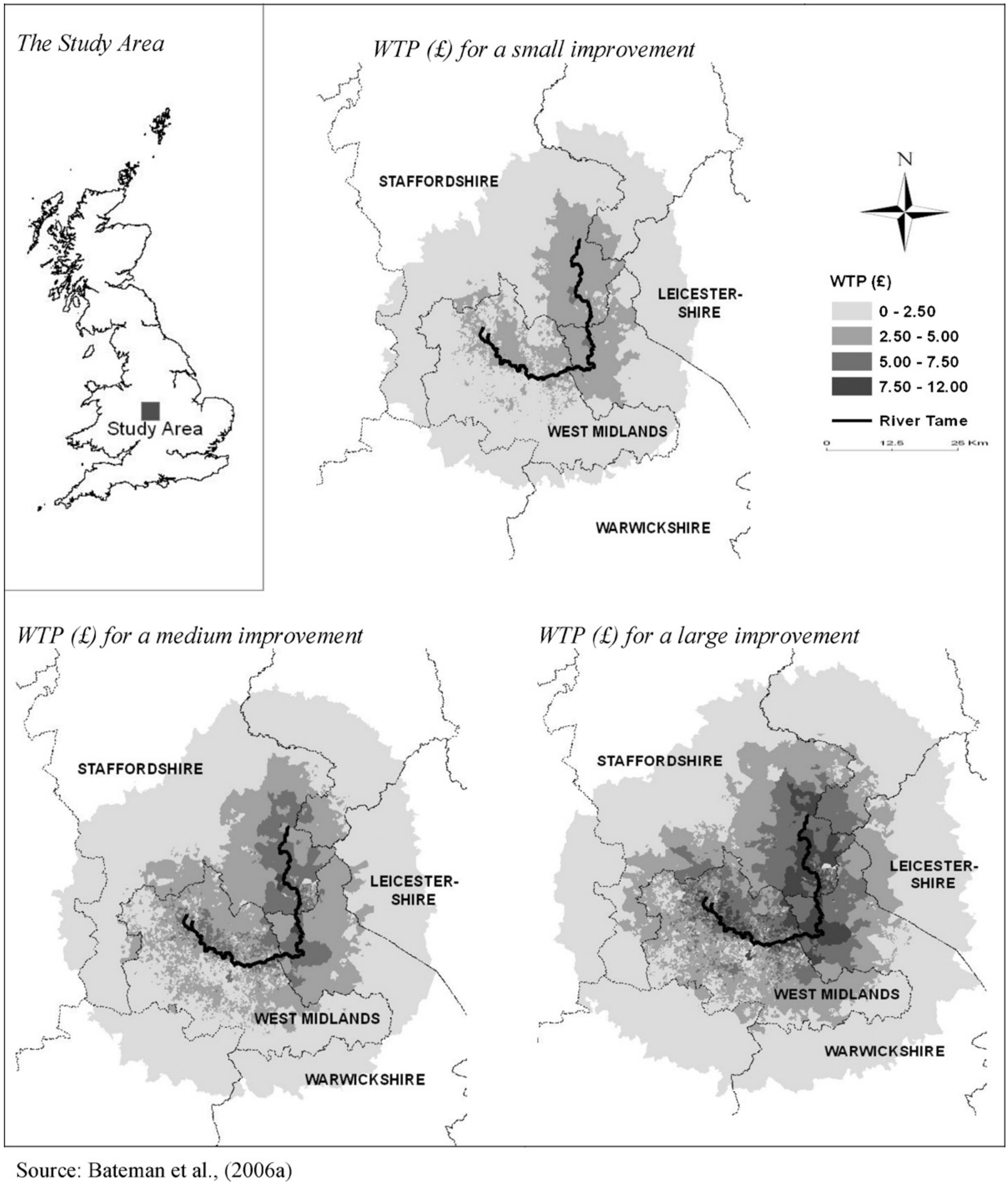


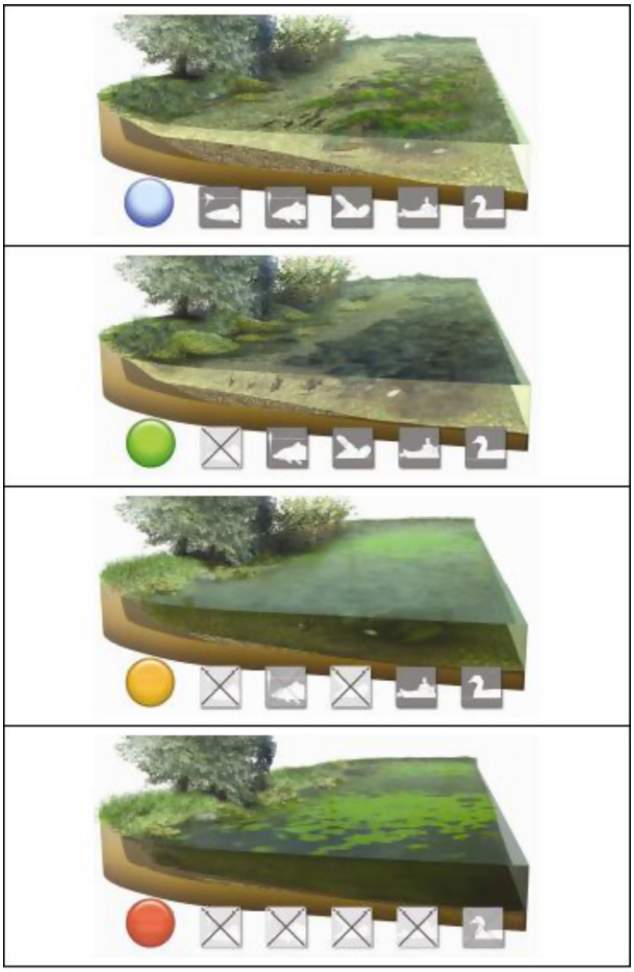
Fig. A.1. Maps of estimated mean WTP (per household, per annum) of Census output areas for various water quality improvements. *Source*: Bateman et al. (2006a).

improvements in river quality. This variation reflects the realities of life; richer groups can afford to access more goods, be they market priced or environmental. Policy makers can, if they wish, decide to adjust for this factor if they feel that access to environmental goods should not be determined by ability to pay. This is done by reweighting the WTP responses so that poorer groups receive a higher weight that cancels out the effect of income distribution. This is a social decision which is entirely in line with economic analyses if it does indeed reflect society's preferences.[30]

[30] Such income related utility weights are explicitly allowed for in the HM Treasury (2003) 'Green Book' guidance on cost-benefit analysis.

The above analysis clearly demonstrates distance decay, but the maps do not show the impact which substitutes can have upon values. In effect, the presence of a substitute can be thought of as heightening the distance decay effect. The closer an individual is to a substitute, the less their WTP for some new alternative. When that alternative is some distance from the individual, and particularly if it is further away than the existing substitute, then WTP is likely to decline substantially and may become zero.

This impact of substitutes across space is more clearly demonstrated in results from the RELU-funded ChREAM project (Bateman et al., 2006b; Ferrini et al., 2008; Hime et al., 2009). This study again concerned river water quality, employing the quality ladder illustrated in Fig. A.2 to convey river water quality levels. Here the



Source: adapted from Hime and Bateman (2009); copyright protected.

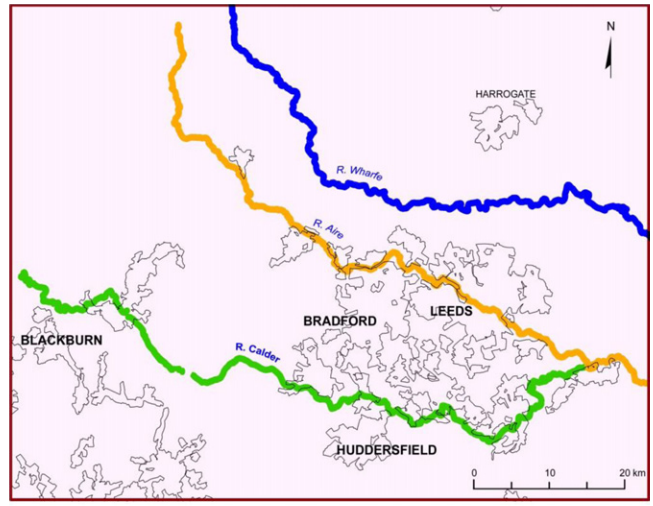
Fig. A.2. The water quality ladder. *Source*: Adapted from Hime et al. (2009); copyright protected.

highest quality water is represented by the picture with the blue-coloured disc. A somewhat lower quality level is denoted by the green disc, then the yellow state and finally the worst quality is denoted by the red disc.

The water quality ladder was used to convey both the status quo and potential alternative river qualities in and around the area of Bradford and Leeds in Yorkshire. A large sample survey of the study area shown in Fig. A.3 was used to examine the WTP for improvements in the quality of the River Aire, the middle of the three rivers shown. The survey used a stated preference approach to examine a number of permutations of provision change. At the time of writing, results from the survey are still being analysed and so the following is purely illustrative.

In Fig. A.3 the current status is that the River Aire is described as being at the yellow level of the water quality ladder, while the River Calder (to the south of the Aire) is designated as green quality and the River Wharfe (to the north) is described as the best (blue) quality.

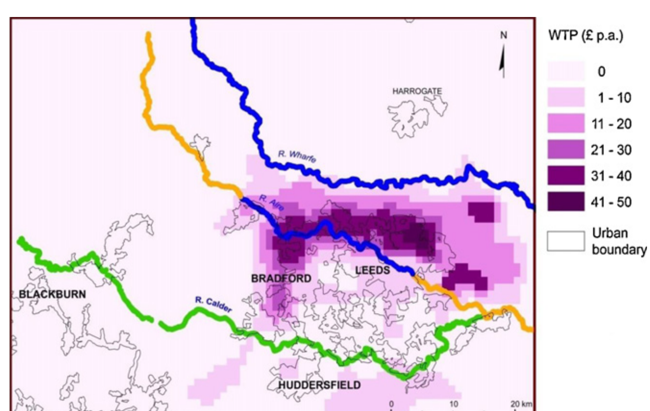
Fig. A.4 illustrates expected WTP per household per annum for a single-stretch improvement in water quality as shown by the blue section of the River Aire. The pattern of values reflects all the factors mentioned at the start of this Appendix (provision change, distance decay and substitute availability, and ability to pay). The provision change has generated significant positive WTP but there is a clear distance decay effect, with values falling as distance from the improvement increases. There is also a clear substitution effect. Values near to the existing high-quality river Wharfe fall rapidly and are zero for virtually all areas north of that river. In contrast, the substitution effect of the lower quality River Calder is much weaker and positive values are recorded even some way south of this river. Finally there is the clear effect of socioeconomic drivers such as income. WTP is substantially higher in the wealthier areas to the north of Leeds and Bradford than in the poorer inner city areas of both cities. As mentioned previously, we could add distributional weights to these results to compensate for the income inequality which drives this pattern.



Source: Bateman et al., (2009)

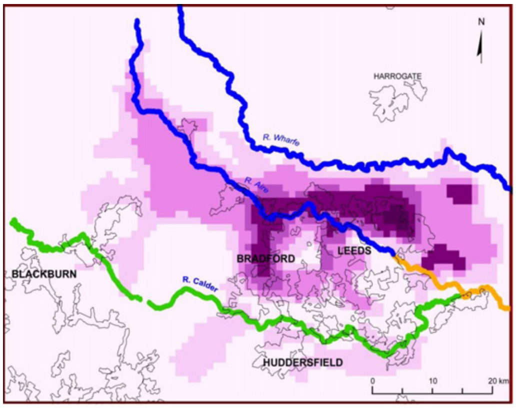
Fig. A.3. Baseline water quality. *Source*: Bateman et al. (2009).

Fig. A.5 illustrates predicted WTP per household per annum for a larger double stretch improvement in water quality as shown as the longer blue section of the River Aire. Again patterns reflect the factors captured in our value function, the main difference from Fig. 6 being the longer area of non-zero values now generated along the upper reaches of the Aire, although the relatively lower incomes of this area mean that WTP in this additional area is not as high as some of the high values near to the initial stretch.



Source: Bateman et al., (2009)

Fig. A.4. Map of estimated mean willingness to pay (per household, per annum), for a single-stretch improvement in water quality on the River Aire. *Source*: Bateman et al. (2009).



Source: Bateman et al., (2009)

Fig. A.5. Map of estimated mean willingness to pay (per household, per annum), for a larger (two stretch) improvement in water quality on the River Aire. *Source*: Bateman et al. (2009).

References

Ariely, D., Loewenstein, G., Prelec, D., 2003. "Coherent arbitrariness": stable demand curves without stable preferences. Quarterly Journal of Economics 118 (1), 73–105.

Arrow, K., Solow, R., Portney, P.R., Leamer, E.E., Radner, R., Schuman, H., 1993. Report of the NOAA panel on contingent valuation. Federal Register 58, 4601–4614.

Bateman, I.J., Brouwer, R., Davies, H., Day, B.H., Deflandre, A., Di Falco, S., Georgiou, S., Hadley, D., Hutchins, M., Jones, A.P., Kay, D., Leeks, G., Lewis, M., Lovett, A.A., Neal, C., Posen, P., Rigby, D., Turner, R.K., 2006b. Analysing the agricultural costs and non-market benefits of implementing the Water Framework Directive: The Catchment Hydrology, Resources, Economics And Management (ChREAM) project. Journal of Agricultural Economics 57 (2), 221–237.

Bateman, I.J., Brouwer, R., Hime, S., Provins, A., 2009. Development of Guidelines for Use of Benefits Transfer in Policy and Project Appraisal, Interim Report to the Department for Environment, Food and Rural Affairs, 17th February 2009, Economics for the Environment Consultancy (eftec), London.

Bateman, I.J., Burgess, D., Hutchinson, W.G., Matthews, D.I., 2008. Contrasting NOAA guidelines with Learning Design Contingent Valuation (LDCV): preference learning versus coherent arbitrariness. Journal of Environmental Economics and Management 55, 127–141, http://dx.doi.org/10.1016/j.jeem.2007.08.003.

Bateman, I.J., Carson, R.T., Day, B., Hanemann, W.M., Hanley, N., Hett, T., Jones-Lee, M., Loomes, G., Mourato, S., Özdemiroglu, E., Pearce, D.W., Sugden, R., Swanson, J., 2002. Economic Valuation with Stated Preference Techniques: A Manual. Edward Elgar Publishing, Cheltenham.

Bateman, I.J., Cooper, P., Georgiou, S., Navrud, S., Poe, G.L., Ready, R.C., Reira, P., Ryan, M., Vossler, C.A., 2005. Economic valuation of policies for managing acidity in remote mountain lakes: examining validity through scope sensitivity testing. Aquatic Sciences 67 (3), 274–291.

Bateman, I.J., Day, B.H., Georgiou, S., Lake, I., 2006a. The aggregation of environmental benefit values: welfare measures, distance decay and total WTP. Ecological Economics 60 (2), 450–460, doi:10.1016/j.ecolecon.2006.04.003.

Bateman, I.J., Langford, I.H., Munro, A., Starmer, C., Sugden, R., 2000a. Estimating the four Hicksian measures for a public good: a contingent valuation investigation. Land Economics 76 (3), 355–373.

Bateman, I.J., Langford, I.H., Nishikawa, N., Lake, I., 2000b. The Axford debate revisited: a case study illustrating different approaches to the aggregation of benefits data. Journal of Environmental Planning and Management 43 (2), 291–302.

Bateman, I.J., Lovett, A.A., Brainard, J.S., 2003. Applied Environmental Economics: A GIS Approach to Cost-Benefit Analysis. Cambridge University Press, Cambridge.

Brown, J.D., Heuvelink, G.B.M., 2007. The data uncertainty engine (DUE): a software tool for assessing and simulating uncertain environmental variables. Computers & Geosciences 33, 172–190.

Burnicki, A.C., Brown, D.G., Goovaerts, P., 2007. Simulating error propagation in land-cover change analysis: the implications of temporal dependence. Computers, Environment and Urban Systems 31, 282–302.

Champ, P.A., Boyle, K., Brown, T.C. (Eds.), 2003. A Primer on Non-market Valuation, The Economics of Non-Market Goods and Services, vol. 3. Kluwer Academic Press, Dordrecht.

Coombes, E.G., Jones, A.P., Bateman, I.J., Tratalos, J.A., Gill, J.A., Showler, D.A., Watkinson, A.R., Sutherland, W.J., 2009. Spatial and temporal modelling of beach use: a case study of East Anglia, UK. Coastal Management 37 (1), 94–115, http://dx.doi.org/10.1080/08920750802527127.

Crosetto, M., Tarantola, S., 2001. Uncertainty and sensitivity analysis: tools for GIS-based model implementation. International Journal of Geographical Information Science 15, 415–437.

Deflandre, A., Williams, R.J., Elorza, F.J., Mira, J., Boorman, D.B., 2006. Analysis of the QUESTOR water quality model using a Fourier amplitude sensitivity test (FAST) for two UK rivers. Science of the Total Environment 360, 290–304.

Egan, K.J., Herriges, J.A., Kling, C.L., Downing, J.A., 2009. Recreation demand using physical measures of water quality. American Journal of Agricultural Economics 91 (1), 106–123.

Ferrini, S., Fezzi, C., Day, B.H., Bateman, I.J., 2008. Valuing Spatially Dispersed Environmental Goods: A joint revealed and stated preference model to consistently separate use and non-use values *CSERGE Working Paper EDM 08-03*, Centre for Social and Economic Research on the Global Environment, University of East Anglia.

Fromm, O., 2000. Ecological structure and functions of biodiversity as elements of its total economic value. Environmental and Resource Economics 16 (3), 303–328.

Hanley, N., Schläpfer, F., Spurgeon, J., 2003. Aggregating the benefits of environmental improvements: distance-decay functions for use and non-use values. Journal of Environmental Management 68, 297–304.

Harris, G., Heathwaite, A.L., 2005. Inadmissible evidence: knowledge and prediction in land and riverscapes. Journal of Hydrology 304, 3–19.

Hicks, J.R., 1943. The four consumer surpluses. Review of Economic Studies 8, 108–116.

Hime, S., Bateman, I.J., Posen, P., Hutchins, M., 2009. A transferable water quality ladder for conveying use and ecological information within public surveys, *CSERGE Working Paper EDM 09-01*, Centre for Social and Economic Research on the Global Environment, University of East Anglia.

H.M. Treasury, 2003. The Green Book: Appraisal and Evaluation in Central Government, available at http://greenbook.treasury.gov.uk/.

Hutchins, M., Fezzi, C., Bateman, I.J., Posen, P., Deflandre-Vlandas, A., 2009. Cost-effective mitigation of diffuse pollution: Setting criteria for river basin management at multiple locations. Environmental Management 44 (2), 256–267, doi:10.1007/s00267-009-9306-8.

Imber, D., Stevenson, G., Wilks, L., 1991. A contingent valuation survey of the Kakadu Conservation Zone, Research Paper No. 3, Resource Assessment Commission, Canberra.

Jones, A.P., Bateman, I.J., Wright, J., 2002. Estimating arrival numbers and values for informal recreational use of British woodlands, report to the Forestry Commission, Edinburgh, published at http://www.forestry.gov.uk.

Kahneman, D., Slovic, P., Tversky, A., 1982. Judgement Under Uncertainty: Heuristics and Biases. Cambridge University Press, New York.

Lane, S.N., Brookes, C.J., Heathwaite, A.L., Reaney, S., 2006. Surveillant science: challenges for the management of rural environments emerging from the new generation diffuse pollution models. Journal of Agricultural Economics 57 (2), 239–257, 07.

Lanz, B., Provins, A., Bateman, I.J., Scarpa, R., Willis, K.G., Ozdemiroglu, E., 2009. Investigating willingness to pay—willingness to accept asymmetry in choice experiments. In: Presented at the Inaugural International Choice Modelling Conference, Institute for Transport Studies, University of Leeds, 30th March to 1st April.

Leopold, A., 1949. A Sand County Almanac and Sketches Here and There. Oxford University Press, New York.

London Economics, 2004. Investigation of the determinants of farm-retail price spreads, Report to Defra, February 2004, London.

Loomis, J.B., 2000. Vertically summing public good demand curves: an empirical comparison of economic versus political jurisdictions. Land Economics 76 (2), 312–321.

Met Office, 2009. Regional mapped climate averages, available at http://www.metoffice.gov.uk/climate/uk/averages.

Mouranaka, A., 2004. Spatial economic evaluation of artificial Japanese cedar forest management as a countermeasure for Japanese cedar pollinosis: an analysis using a model of multizonal contingent markets with data from cities, towns and villages in Yamaguchi Prefecture, Japan. Geographical Review of Japan 77 (13), 903–923.

Pate, J., Loomis, J.B., 1997. The effect of distance on willingness to pay values: a case study of wetlands and salmon in California. Ecological Economics 20, 199–207.

Pearce, D.W., Turner, R.K., 1990. The Economics of Natural Resources and the Environment. Harvester Wheatsheaf, Hemel Hempstead.

Posen, P., Hutchins, M., Lovett, A., Davies, H., 2008. Robust interpolation of agricultural census data to hydrological units and implications for diffuse pollution modelling. In: Zhang, J.X., Goodchild, M.F. (Eds.), Proceedings of the 8th International Symposium on Spatial Accuracy Assessment, vol. 1. Spatial Uncertainty: Shanghai, China, pp. 46–53.

Posen, P., Lovett, A., Hiscock, K., Reid, B., Evers, S., Ward, R., 2006. Error propagation in groundwater pesticide vulnerability modelling. In: Caetano, M., Painho, M. (Eds.), Proceedings of Accuracy 2006: 7th International Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Sciences. Lisbon, Portugal, pp. 349–358.

Rawls, J., 1971. A Theory of Justice. Belknap Press of Harvard University Press, Cambridge, Massachusetts.

Rollston, H., 1988. Environmental Ethics. Temple University Press, Philadelphia.

Sedjo, R.A., Sampson, R.N., Wisniewski, J. (Eds.), 1997. Economics of Carbon Sequestration in Forestry. CRC Press, New York.

Slovic, P., 1995. The construction of preferences. American Psychologist 50, 364–371.

Sutherland, R.J., Walsh, R.G., 1985. Effects of distance on the preservation value of water quality. Land Economics 61 (3), 281–291.

Watson, R.A., 1979. Self-consciousness and the rights of non-human animals. Environmental Ethics 1 (2), 99.