Measuring the Impact of Climate Change on Britain

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Abstract

Adaptation to past changes in the climate of Britain may be indicative of the way in which society will respond to future climate change. The long run costs associated with climate change are, once full adaptation has occurred, not obviously detrimental. Furthermore even if the frequency of 'extreme events' such as floods and storms increases it is not apparent that these will necessarily be as detrimental to society as they currently might seem since society in effect chooses its exposure to extreme events. Some extreme events such as hard frosts are likely to decrease in frequency.

The thesis uses the theory of hedonic prices to examine the role of climate variables in explaining differences in average residential land prices and wage rates relating to 127 English and Welsh counties, Scottish regions, metropolitan areas and London boroughs. Substantial evidence is found in favour of the hypothesis that compensating land price differentials exist for climate variables. An alternative approach to estimating amenity values is to argue that households respond in part to differing levels of environmental amenities by altering their patterns of consumption. This phenomenon can be given a 'Household Production Function' interpretation. Given the assumption of 'demand dependency' between climate variables and marketed commodities it is possible to determine the amenity value of climate change from market data. Using cross country data for 60 countries the analysis points unambiguously to the existence of a 'climatic optimum'.

The hedonic technique can also be used as a means of determining the value to British agriculture of a marginal change in climate. In the hedonic approach sale price differentials between land characterised by different climates is given an interpretation in terms of underlying productivity differences. Data characterising over 400 separate transactions in farmland is analysed and the value of marginal changes in climatic variables computed. The analysis suggests that the financial value of climate variables to farmers could in some cases be quite high and also that changes in seasonal patterns and the frequency of 'extreme events' are quite important.

The impact of climate change on the chosen destinations of British tourists is also investigated. Destinations are characterised in terms of various 'attractors' including climate variables, travel costs and accommodation costs. Together these variables are used to explain the observed pattern of overseas travel in terms of a model based on the precept of utility maximisation. This approach permits the changes in consumer surplus following climate change to be predicted and effectively identifies the 'optimal' climate for generating tourism. It is argued that British tourists are likely to experience a large gain in welfare in the sense that the attributes of nearby (low cost) locations improve following climate change.

Finally, information on marginal willingness to pay for climatic amenities is combined with predictions concerning the scale and direction of possible climate change over Britain in order to provide a money measure of the welfare impact of such changes. Because households appear to prefer a climate characterised by much higher temperatures than currently prevail over Britain households reap large gains from climate change.

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This thesis is dedicated to GAKM, TMM and especially to LM.

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1. The impact of climate change on Britain

Even since the time that this research began several climate records have been broken in the UK. October 1995 for example was the warmest ever in more than 330 years and the summer that preceded it the third hottest on record. The period from December 1994 to November 1995 was also the hottest 12 months since instrumental records began in the late 17th century[1].

Nevertheless, climate records might be broken anyway even in the absence of any anthropogenic interference with the climate and in any case the enhanced greenhouse effect is not the only hypothesis that has been put forward to explain climate change. Even so, analysing the temperature record for Central England pieced together by Manley (op cit) Maddison (1996) shows that whilst changes in the earth's orbital parameters and a major volcanic eruption both have a discernible influence on the climate of Central England, the principal driving force behind climatic change is the elevated concentration of GHGs in the atmosphere. Indeed the analysis succeeds in rejecting the hypothesis of no change against the hypothesis of warming with a high degree of statistical confidence. In other words, the enhanced greenhouse effect has already significantly altered the climate of Central England. By contrast there is no evidence that changes in solar output have had any effect on the climate.

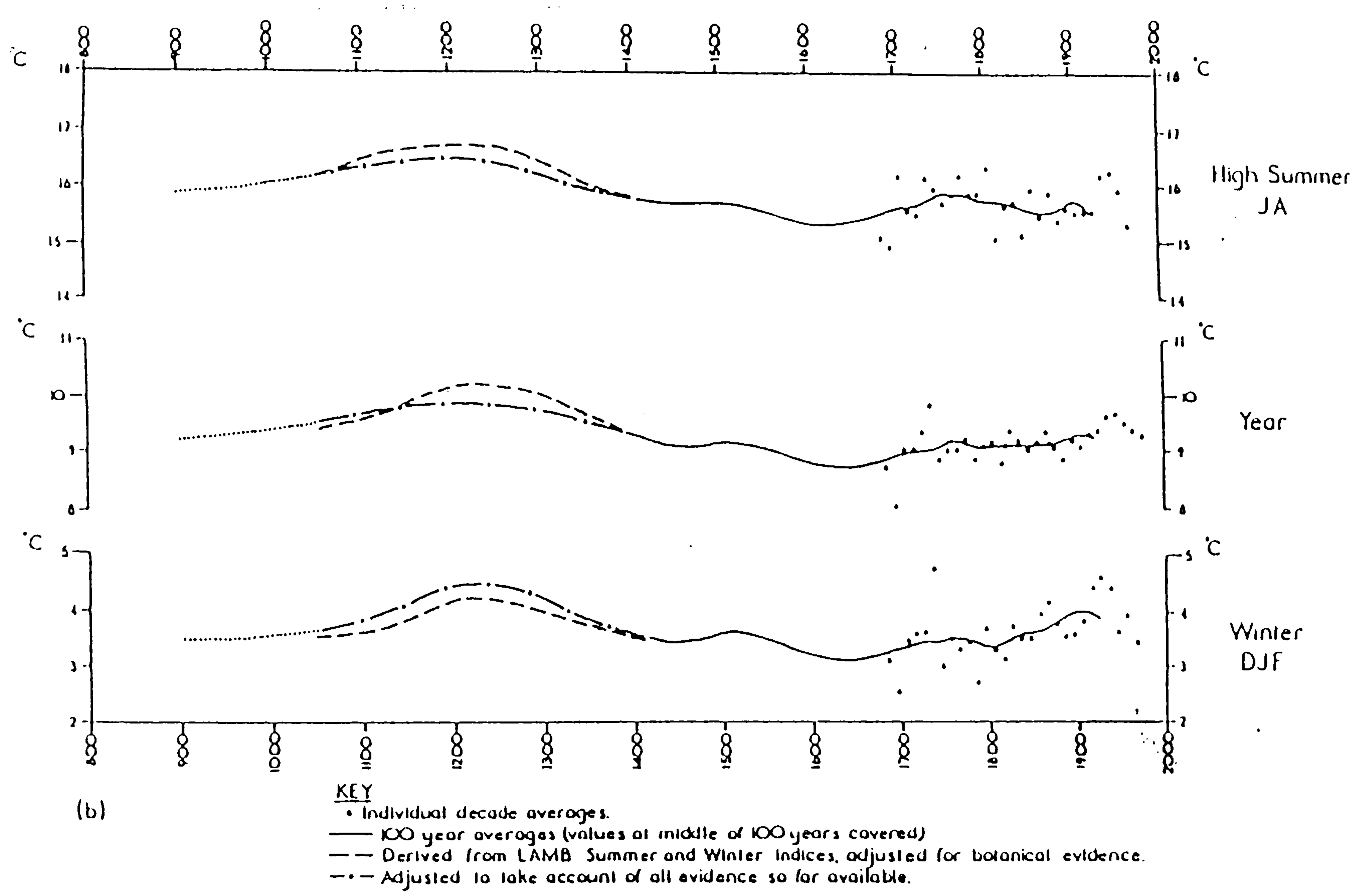
These findings are not necessarily a cause for concern. It bears well to remember that the climate of Britain has actually been very variable even over historical times. Evidence of climate variation prior to the use of recording instruments comes from a variety of sources. A massive amount of information regarding past climates is for instance contained within individual diaries, records of military campaigns and chronicles of various descriptions. Every season which has been in some respect dramatic in character is apt to have been recorded by someone. Though they are qualitative descriptions they can nevertheless be turned into numerical values quite readily if they overlap with the instrumentation records. There is also proxy data

[1] Temperature records for Central England began in 1659 (Manley, 1974) following the invention of the thermometer in Italy. Continuous rainfall records for England are available as far back as 1727 (Cradock, 1976).

such as grain prices, tree rings or other fossil data. Piecing together all the available evidence has enabled climatologists (eg Lamb, 1977) to describe the climate of Britain since as far back as AD 800 (see figure 1.1).

What stands out from figure 1.1 is the existence of a very warm spell lasting several centuries reaching its zenith at around the end of the 13th century: a period referred to as the 'medieval optimum' followed by a gradual decline, a temporary reversal, but eventually culminating in the so called 'little ice age' of the 16th and 17th centuries. During the little ice age 'frost fairs' were held on the river Thames which froze to a depth of several metres on a number of occasions and remained so for several months. A good description of these frost fairs is contained within the book by Andrews (1887) or in the contemporaneous diaries of John Evelyn who describes the scene one January 24th thus: "The frost continuing more and more severe, the Thames before London, was still planted with boothes in informal streets, all sorts of trades and shops furnish'd and full of commodities, even to a printing press, where the people and ladyes tooke a fancy to have their names printed, and the day and the yeare set down when printed on the Thames". Since then temperatures have recovered and the current climate now appears almost as warm as it was during the medieval optimum. The same pattern can be seen in the reconstructed climate records of other European countries. The changes in climate experienced by our ancestors were thus not necessarily much smaller and certainly not less abrupt than the changes which are currently predicted to occur as a result of anthropogenic interference with the climate.

Figure 1.1: The climate of Central England since 800 AD



Source: *Lamb (1977).*

The ghost of climates past

The testimony of climates past is perhaps most conspicuous in agriculture. As the climate deteriorated, new crops were grown and areas of cultivation moved into the valleys. Furrows can be seen on ground which would now be regarded as too marginal for cultivation. Parry's (1978) analysis for the Lammermuir hills south of Edinburgh indicates movements up and down the slopes which is consistent with the agro-climatic requirements of the crops grown. A large quantity of land was opened up and farmed on the Lammermuir hills between 1150 and 1250 AD according to documents from the Scottish Border abbeys. Aerial photographs confirm that its upper limit was 400m above sea level. Analysis of summer warmth and wetness suggests that the failure of the crop would occur on average one year in every 20. By 1350 however the crop would have failed one year in every five, by 1450 one year in 3 and by 1700 every other year the crop would have failed.

Following changes in climate products which could no longer be grown satisfactorily have been imported instead. There exists evidence of numerous vineyards operating even north of the Humber; some of them operating for more than 100 years and sometimes of considerable size. Their existence was little to do with high transportation costs since this wine was exported to Bordeaux in France. It is clear that the wine they produced was of fair quality since there is evidence that French producers attempted to have their exports curtailed shortly after the Norman conquest. Moreover, contemporaneous descriptions of how English wine compared to French are favourable (Lamb 1977). Eventually however these vineyards fell into abandonment at a time coinciding with the downturn of the climate at around 1300. Although some continued to operate after that time and a number of new vineyards were started there is no evidence that they thrived.

Changes in fashion have also been attributed to changes in climate. The decade from 1810 to 1819 was one of the coldest recorded since the 1690s and the return of the cold weather led to the design of certain articles of warm underwear notably the 'Spencer' and the 'Bosom Friend' and put an end to the daring fashions imported from post revolutionary France which 'exposed the person' a good deal. It was remarked at the time that it was 'the chill north wind which enforced a return to modesty in womens' dress (Woodforde, 1949, as cited by Lamb, 1977).

Comparison of the record of human history with the climate record can offer some significant insights and there is much to be gained from studying it. If one wants a catalogue of the probable impacts of climate change, how populations responded to gradual or abrupt changes in climate is a pointer to how people might respond in the future. Otherwise, in order to evaluate the changes that climate change might bring us it is necessary to imagine all possible adaptations that might eventually be made. This is a very hard thing to do: to see the opportunities that an altered climate would bring, one has to escape the narrow geographical and temporal frame within which we live our own lives. Once full adaptation has occurred it is far from obvious to the author that any change in the climate will necessarily prove detrimental, although others speak as if damaging effects would inescapably follow. In other words, whilst some effects of climate change might be detrimental yet more might be beneficial.

Capital goods, durable goods and housing frequently embody within them a certain 'suitability' for a particular design-climate. In such circumstances, even if the permanent change in climate is properly perceived, there may be significant costs in the short run depending upon their inoperability and possibly significant changes in the cost of living. Society would in effect be mal-adapted to living in that climate (see Nordhaus, 1994 for a diagrammatic interpretation of this argument). Transitional costs depend upon the useful lifetime of these durable goods relative to the pace of climate change. Given sufficient time many things can be changed in response to the climate. Purchases of durable goods can clearly respond in a matter of years. An entire wardrobe of clothes might be replaced within a couple of years. Household 'white goods' have a lifetime of perhaps ten years. Other goods like the housing stock, office buildings and infrastructure might take longer. Brooks (1950) describes a vast number of ways in which houses can be adapted to the climate in terms of the materials used, the styles adopted and the positioning of the dwelling. He advises that: "The type of building favoured by local residents should be studied, as this has been developed as a result of long experience" and goes on to give examples of how differences in climate result in different allowances made during the construction of the house. But they are still replaced quite quickly in relation to the pace of climate change. Table 1.1 prepared by Skea and taken from Parry and Duncan (1995) illustrates the point.

So whilst there have been numerous empirical studies on the impact of adverse weather conditions on for example agricultural yield (see Bolin et al, 1986 for a survey), road accidents and the construction industry (Taylor, 1974), mortality (Langford and Bentham, 1995) and numerous analyses of the links between weather and retail sales of various commodities, indices of industrial production, stock market values and other macroeconomic variables (Palutikof, 1996) these empirical studies are, from the perspective of determining the impact of climate change on society, at best uninteresting and at worst downright misleading. The reason is that these activities all involve capital goods (including human capital), and institutional practices and procedures which are suited to a particular type of climate and installed on the assumption that past climatic conditions will continue to prevail. Crops for example are sown on the assumption that a certain climate will prevail. If climate were expected to be different then a different type of crop would be grown. So there is no point in trying to infer from how agricultural yields vary with annual variability in weather what the impact of climate change on agriculture will be: these are two completely different things. Analogously, whilst there has been considerable interest in the health effects of climate change using dose-response functions as it is typically presented, the dose-response function technique is mechanistic incorporating no model of how individuals really behave. A behaviourally more appealing model would take into account that an individual's health is not exogenously determined but is rather determined by biological and economic constraints. In response to permanent changes in the climate the individual will adjust their personal investments in health care, their homes and their lifestyles. In other words, the individual acclimatises.

Table 1.1: Asset lifetimes in the UK energy sector

Asset	Lifetime
Conventional light bulb	Up to 3 years
Electric white goods	5 - 10 years
Central heating	10 - 15 years
Motor vehicles	10 - 15 years
North sea oil field	10 - 30 years
Renewable energy project	20 years
Conventional power plant	40 - 45 years
Housing stock	50 years or more
Infrastructure	50 - 100 years
Tidal barrage	120 years

Source: *Parry And Duncan (1995).*

Whilst the weather which occurred during the extraordinary summer of 1995 was widely heralded as a harbinger of climate change, the changes in behaviour which it induced reflected only the existence of the short run constraints. Because that kind of weather was so unexpected, it was difficult for people to take full advantage of the opportunities that it afforded to them (eg taking their holidays in Britain) or to offset the disbenefits associated with that kind of weather. The London Evening Standard reported that an astonishing 97% of offices in London were not equipped with air conditioning. Severe water shortages afflicted Yorkshire and the residents of that region were forced to draw their water from stand-pipes in the street. But once again, there is not much sense in saying that the water shortages experienced by that region are a foretaste of the consequences of climate change. For those water shortages which afflicted the Yorkshire region are as much a result of the inadequacy of water storage facilities, the failure to price water properly and high leakage rates from the distribution network. These capital and institutional problems are arguably much more important than small changes in run-off and could be changed in the future (see Parry and Duncan, 1995 for a more detailed discussion). In the following year's heatwave, that of August 1996, the London Evening Standard on Tuesday 20th August cited a report by the Heating and Ventilating Contractors' Association stating that, although home air conditioning units cost only 5 pence per hour to run just half of one percent of homes - less than 10,000 in the entire country - had any form of air conditioning. Similarly less than 6 percent of motorists who bought a vehicle manufactured by Ford ordered air conditioning. These examples make it clear why one cannot infer anything about the economic impacts of climate change from two consecutive hot summers. We just weren't ready.

Perhaps a more compelling problem than adjusting to a slowly changing climate comes through failing to perceive the change in climate thereby unwittingly exposing oneself to greater risks than one would otherwise choose to do. Probably the first sector of the economy to feel the brunt of climate change will be the insurance business (see Parry and Duncan, 1995, and also Dlugolecki, 1991). Lamb (1977) states that during the 1950s the insurance industry lost many millions of pounds because the insurance rates had not been adjusted to the increased frequency of hurricanes in the North Atlantic compared to the beginning of the century. Depending on the impact of climate change on the profitability of the insurance sector, these adjustments might involve the withdrawal of cover, or more likely an increase in premiums or greater discrimination on the part of the insurers. Similarly, farmland was abandoned presumably only after years of dismal failure and the dawning realisation that the climate had 'permanently' changed. Failure to recognise this from the start no doubt contributed to the severity of the famines which struck England during the end of the warm period, and Scotland at the end of the 17th century (Trevelyan, 1942).

In contrast, today the risk of climate change is widely acknowledged and much discussed. Significantly, economic agents are building climate change assumptions into their capital projects. For example the Shell oil rigs in the North Sea are already built to accommodate sea level rise as are the most recently built Caledonian MacBrayne ferry terminal facilities in the Western Isles and sea defences around the country. Even if agents do not know the exact magnitude of climate changes they can decide to invest in designs which allow for post-installation flexibility of operation. Even the retro-fitting of certain structures may be possible. See for example the paper by Ingham and Ulph, 1992, which refers *inter alia* to the desirability of purchasing ex post flexibility in production technology with regard to energy requirements.

Because climate change is very slow in comparison to the lifetime of durable assets and agents sense the change in climate (or at least accept the possibility of climate change) purely transitional costs are arguably going to be small. This thesis is therefore concerned with any remaining costs (or benefits) once *long run adaptation* to climate change has occurred by seeking latter-day analogues for future climates. Before doing so however we consider the question of changes in the frequency of 'extreme events'.

Extreme weather events are probably the only occasions when people are made aware of the impact that the climate has on their lives. There is currently some fear of an increase in the severity of storms due to climate change leading to these events becoming more frequent. History produces a catalogue of these events. Daniel Defoe (1704) wrote a detailed description of the great storm which swept across Southern England on 7-8th December 1703. Eight thousand lives are said to have been lost (most of them at sea), innumerable trees blown down, sailing vessels wrecked and houses damaged. In London alone the losses amounted to an estimated £2 million pounds. The October 1987 storm which swept across the South East of England cost rather more: £1 billion in 1987 prices (Association Of British Insurers, 1988 as cited in the report by the Department of the Environment, 1988). There have been several major floods over the north sea coast line involving the loss of many towns and villages on the East coast of England with significant loss of life (see Lamb 1977 for a list of these). These incursions owe much more to storminess than an increase in sea level. The 12th century in particular recorded many severe floods of North Sea coastlines and in 1364 the former great port of Ravenspur in Humberside was destroyed. The town of Dunwich in Suffolk was also lost to the sea. Most recently the storm on the 31st of January 1953 killed several hundred people in Lincolnshire, East Anglia and the Thames estuary, and several thousand people in Holland.

Apart from the obvious difficulty that there will be in attributing any named extreme event to climate change rather than general weather variability, the basic point being overlooked is that, in a sense, we choose our exposure to extreme events. Structures are built with a mind to withstanding weather anomalies of certain strength. These are calculated by 'return periods' which summarise knowledge based on historical records of the frequency that an event exceeding the critical design dimensions of a structure will occur. If these events become more frequent then society will adapt to them by building higher sea walls or retreating from low lying areas or constructing stronger buildings in more sheltered locations; and it may even decide to accept a higher degree of risk than before. All this is not to say that changes in the frequency of extreme events do not have a cost attached to them, but rather that it is likely to be a cost which is significantly lower than the option of *not responding*. Whereas many damage cost assessments of climate change appear to be based on the assumption of no response, in fact the problem is likely to be, as outlined earlier, in recognising that such changes have occurred rather than in responding to them, since, by their very nature, extreme events occur only infrequently and it is possible to gather information on changes in their frequency only slowly. Moreover; it is possible that some extreme events will diminish in frequency, for example very hard frosts, leading to a reduction in insurance claims for water damage caused by water pipes split by ice.

Research into climate future

The purpose of the preceding discussion is to cultivate in the mind of the reader the importance of allowing for long run adaptation in any investigation into the value of a permanent change in climate and to avoid the type of approach which has so far characterised the research into the impact of climate change: the approach which values climate change by considering the short term response to unpredicted fluctuations in the weather occurring on a daily basis. A far more meaningful approach is to look for current day analogues to future climates such that one measures differences in welfare levels once long run cost-minimising adaptation has occurred.

In chapter two a theoretical model is developed to illustrate how amenity values can become collateralised into both land prices and wage rates. This model is based on the 'hedonic' approach which assumes that migration eliminates the net advantages of different locations through adjustments in land prices and wage rates. Using a data set relating to 127 English Counties, Scottish and Welsh Regions, Metropolitan Areas and London Boroughs the chapter tests the ability of a suite of amenity variables (including climate variables) to explain regional variations in property prices and wage rates.

A basic assumption of the hedonic technique is that there are no barriers to mobility which prevent prices changing to reflect the net benefits of a given location. But climate variables are undeviating over relatively large distances and the absence of a common language and/or cultural ties may prevent the net advantages associated with a particular region from being eliminated. Methods alternative to the hedonic approach may be required to estimate the amenity value of climate. Accordingly, chapter three seeks to undertake a systematic examination of the role played by climate in determining consumption patterns using cross sectional data from 60 different countries and then proceeds to calculate the implicit price of a range of climate variables for each of the 60 countries.

The fourth chapter considers the impact of climate change on agricultural productivity in Britain once more using the hedonic approach. In the hedonic approach sale price differentials between land characterised by different climates are given an interpretation in terms of underlying productivity differences. Such an approach differs radically from the more conventional 'land allocation' approach to determining the impact of climate change on agriculture. Data characterising over 400 separate transactions in farmland is analysed and the value of marginal changes in climate variables computed. The study suggests that the financial value of climate variables to farmers could, in some cases, be quite high and also that seasonal patterns are very important. Thus the impact of climate change on British agriculture is likely to depend acutely on differential changes across the seasons. Adjusting these implicit prices to account for the price support given to agricultural commodities would presumably reduce the perceived impact of climate change on agriculture. The opportunity also arises to test a number of auxiliary hypotheses not connected with climate change. These concern the ability of landowners to costlessly 're-package' their land, the impact of regulated tenancies on farm prices and the accuracy of the valuations performed by land agents.

Hedonic models only capture the amenity value of climate as experienced at the place of home and work. But what about the amenity value of climate when individuals are travelling, possibly abroad? Chapter five investigates the impact of climate change on the chosen destinations of British tourists. Destinations are characterised in terms of various 'attractors' including climate variables, travel costs and accommodation costs. These and other variables are used to explain the observed pattern of overseas travel in terms of a model based on the precepts of utility maximisation. This approach permits the tradeoffs between climate and expenditure to be analysed and effectively identifies the 'optimal' climate for generating tourism. The impact of particular climate change scenarios on typical tourist destinations is predicted.

The sixth chapter summarises the intellectual contribution of the thesis and combines information on marginal willingness to pay for climate variables with predictions concerning the scale and direction of possible climate change over Britain. These predictions are drawn from General Circulation Models of the climate. This procedure provides a money measure of the welfare impact of such changes. Finally, suggestions are made for the direction of future research efforts and the applicability of the various methodologies to different conditions. Certain methods are highlighted as having special strengths and weaknesses and an applicability to data which can reasonably be expected soon to become available.

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2. The amenity value of the climate of Britain

Hedonic theory suggests that if individuals are freely able to select from differentiated localities then the tendency will be for the benefits associated with particular amenities to become collateralised into land prices and wages. Households are attracted to cities offering preferred combinations of environmental amenities and this inward migration both increases land prices within those cities as well as depressing the wage rates in local labour markets (but see below for an important qualification). Thus, across different cities there must generally exist both compensating wage and house price differentials. In such cases both the consumption of amenities and disposable income become choice variables and the value of marginal changes in the level of amenities can be discerned from the hedonic house and wage price regressions. Hedonic theory has a natural application to the determination of the amenity value of climate variables. Combined with predictions concerning the scale and direction of possible climate change, implicit prices of climate variables from regional markets for labour and land might form the basis for a money metric measure of the resultant change in amenity values to households.

This chapter reports on a study which attempts to determine the extent to which differing climates and the services they provide are collateralised into land prices and wage rates in Britain. The chapter commences with a resume of the existing hedonic literature insofar as it extends to dealing with the amenity value of climate variables followed by a discussion of the theory underlying the hedonic technique. The chapter then discusses the plausibility of some of the assumptions underlying the hedonic technique in the context of uncovering the amenity value of climate variables before describing the data used to estimate the model. Following sections deal with the estimation of the hedonic house and wage price models. The full implicit price of amenities obtained from the analysis are then discussed. The final section concludes.

Existing literature

Although there are many early papers describing regressions of land prices on the levels of local amenities (see for example Ridker and Henning, 1967) the theoretical underpinnings of the hedonic approach were developed only later by Rosen (1974).

An important theoretical contribution by Roback (1982) was to demonstrate that values for environmental amenities could be incorporated into both land prices and wage rates. At around the same time others were beginning to consider how to use the hedonic technique to uncover the uncompensated demand curves (rather than just implicit prices) for environmental amenities (eg Brown and Rosen, 1982). Comprehensive reviews of the hedonic approach can be found in Palmquist (1991) and Freeman (1993).

Since Rosen's contribution a large number of hedonic studies have been published in the US although rather less in Britain. Early studies used either census tract data (ie average house prices in an area) or the self reported values of those who owned the houses. Later analyses have used actual sale price data of individual properties instead. These studies considered both inter-urban and intra-urban regions. Other analyses looked at regional differences in wage rates. The main subject of enquiry in these empirical analyses is the impact of noise from transport on house prices (see Nelson, 1978, for a survey of these) and the impact of air pollution on house prices. Smith and Huang (1991) perform a meta-analysis of 37 different hedonic studies of the impact of air pollution of house prices and conclude that the technique succeeds in providing a consistent set of results; a finding which is generally supportive to the continued use of the hedonic technique.

A considerable number of hedonic studies have included climate variables as environmental amenities. Unfortunately, early studies generally utilised the hedonic technique primarily to measure the value of amenities such as air quality, crime rates and climate variables using wage data only. They did not consider the possibility of both wages and house prices being affected by the differing availabilities of the environmental amenities (see below). In addition, only one or two climate variables are typically included.

In a seminal paper Hoch and Drake (1974) analysed US wage rates using Bureau of Labour Statistics micro data for 86 Standard Metropolitan Statistical Areas (SMSAs). Climate was specified in terms of precipitation and summer and winter temperature, the squares of the two latter terms, an interaction term for summer temperature and precipitation, wind speed, degree days, snowfall, the number of very hot (>90°F) and the number of very cold (<32°F) days. The analysis was performed separately for three job category subsamples. In the first one, the coefficients on climate variables were significant and had the expected sign only as long as regional dummies were excluded, whereas in the other two they performed better. It must be noted however, that the only other explanatory variables were racial composition and urban size. No account was given of important site specific characteristics like crime rates, pollution and other quality of life indicators.

The first attempt to estimate climate effects on both wages and house prices is to be found in Roback (1982) as an empirical illustration of her theoretical model. She used microdata for the 98 largest urban areas in the US. Roback performed a different pair of regressions (on wages and residential site prices) for each climate variable (snowfall, degree days, cloudy days and clear days). These variables are highly significant and their coefficients have the expected sign in the wages regression, but performed poorly in the residential site prices regressions, where only population growth, population density and unemployment rates are significant. Also for the US Smith (1983), used only real wages as dependent variables, and employed a cost of living index as a deflator. The focus of the analysis was mainly on the different effects of job-specific and site-specific characteristics on wages for different industries, job categories and ethnic composition of the workers. Climate, expressed by five variables (mean annual sunshine hours, higher and lower temperatures, annual average wind speed and precipitation) was one of the site-specific characteristics considered. Only sunshine proved to have significant (negative) effect on wages indicating that it is regarded as an amenity.

Hoehn et al. (1987) and Blomquist et al. (1988) utilise the same empirical analysis as empirical illustration of two slightly different theoretical models. Micro data drawn from 285 SMSAs in the US was used. They estimated two hedonic regressions one for wages and one for housing expenditures. They controlled for structural characteristics of houses and individual characteristics of workers. The same amenity variables were used in both equations and included coast proximity, crime rates, teacher-pupil ratios, total suspended particulates, visibility and six climate variables (sunshine, precipitation, humidity, wind speed, heating and cooling degree days). Amenity variables were found highly significant in both equations. Among the climate variables, only sunshine was found unambiguously to be an amenity, i.e. its coefficient displayed the same sign in both equations, whereas the other climate variables net effect depended on the relative magnitude of their coefficients. In Blomquist et al. the same set of result was used to derive quality of life rankings for the metropolitan areas considered.

Most recently, Maddison and Bigano (1996) analyse property prices per square metre of floor space over 95 provinces of Italy. This analysis is notable in three respects; firstly it was undertaken specifically to investigate the amenity value of climate variables, secondly the authors experiment with two alternative specifications of the climate variables and thirdly the authors analyse property prices for five consecutive years and find that the amenity values are stable over the period in question. This suggests that the hedonic methodology might be capable of producing figures that are sufficiently reliable for policy purposes (and also that the income elasticity of demand for climate variables is rather low). The authors include three climate variables (temperature, precipitation and cloud cover) and experiment with using annual averages and January and July averages. The climate variables are all highly significant (partly one may suppose because Italy possesses a very diverse climate). The results based upon January and July averages are the best and suggest that the amenity value of additional units of particular climate variables depends upon which season they fall into. In particular, whereas precipitation is viewed as a disamenity in summer or winter, temperature is viewed as an amenity in winter but as something of a disamenity in summer.

Measuring the value of amenities

Roback (1982) provides a formal model in which individuals make decisions in both the market for labour and the market for housing. In her paper the household faces a constraint on disposable income linking income to the quantity of land occupied for housing (L), non-wage income (I), wages (w) and time spent working (T). Both wages and land prices (r) are a function of the level of the amenities (z) associated with each location. The price of the composite marketed commodity (X) is normalised at unity. The Lagrangian is:

$$\max \quad U = U(X, T, L, z) + \lambda[I + Tw(z) - Lr(z) - X] \tag{1}$$

where U is utility. Associated with this problem of constrained maximisation is the indirect utility function V containing non-labour income, wage rates, land prices and the level of the environmental amenity as its arguments:

$$V(I, w, r, z) = k \tag{2}$$

Because z is presumed to be an amenity dV/dz > 0. In equilibrium the utility associated with each location must be equalised at level k otherwise some individuals would have an incentive to move. Turning to the production side of the economy, assume that a numeraire good is produced by a constant returns to scale technology in which land (L), man-hours of labour (N) and the amenity are arguments:

$$\min TC = wN + rL + \lambda[X(N, L, z) \geq \bar{X}] \tag{3}$$

Associated with this technology is a unit cost function C. The equilibrium condition is that the unit cost function must equal a constant. If it did not then some firms would have an incentive to move to a different location.

$$C(w, r, z) = 1 \tag{4}$$

Totally differentiating the two equilibrium conditions gives:

$$\frac{\partial V}{\partial w}\frac{dw}{dz} + \frac{\partial V}{\partial r}\frac{dr}{dz} + \frac{\partial V}{\partial z} = 0 \tag{5}$$

$$\frac{\partial C}{\partial w}\frac{dw}{dz} + \frac{\partial C}{\partial r}\frac{dr}{dz} + \frac{\partial C}{\partial z} = 0 \tag{6}$$

Solving for the expressions dw/dz and dr/dz gives:

$$\frac{dw}{dz} = \frac{-V_z C_r + C_z V_r}{V_w C_r - V_r C_w} \tag{7}$$

and:

$$\frac{dr}{dz} = \frac{-V_w C_z + C_w V_z}{V_w C_r - V_r C_w} \tag{8}$$

Given the signs of the various derivatives it can be seen that the following conditions hold: if the amenity is unproductive (ie $C_z > 0$) or is neutral with respect to production costs then the wage gradient is negative and the rent gradient is positive. But if the amenity is productive then the sign of the wage gradient is ambiguous since workers may not be forced to accept lower wages by the ability of the firm to relocate. If the amenity is neutral or productive to firms then the rent gradient is positive. But if the amenity is unproductive then the rent gradient is ambiguous since land prices might need to fall in order to encourage firms to locate in areas with high levels of z.

Using Roy's Identity and solving for the implicit price of the amenity it can be shown that the implicit price of the amenity to the household is the sum of the amount of land occupied by the household multiplied by the marginal cost of obtaining land with an additional unit of the amenity minus the marginal change in labour income associated with working in an area with an additional unit of the amenity. In general both the change in land prices and in wage rates have to be considered in order to determine the implicit price of the amenity to the household.

$$p_z = L\frac{dr}{dz} - T\frac{dw}{dz} \tag{9}$$

The amount of land consumed by each household, the hours of work, dw/dz and dr/dz are in principle observable entities as are the amount of land occupied by each producer and the share of land and labour in overall production costs.

Additional tradeable goods sectors and additional amenities add essentially nothing new to the story. More interesting extensions of the model by Roback include the addition of a non-traded goods sector and a second set of workers. The introduction of a non tradeable goods sector modifies the conclusions of the model slightly. Roback (op cit) assumes that there is a single non tradeable goods sector producing services. This sector also enjoys constant returns to scale and has a unit cost function which can be written:

$$G(w, r, z) = p(z) \tag{10}$$

Totally differentiating this expression gives:

$$\frac{\partial G}{\partial w}\frac{dw}{dz} + \frac{\partial G}{\partial r}\frac{dr}{dz} + \frac{\partial G}{\partial z} = \frac{dp}{dz} \tag{11}$$

The household's indirect utility function must also be amended to include the price of non tradeables and is written:

$$V(I, w, r, p, z) = k \tag{12}$$

Totally differentiating this expression then gives:

$$\frac{\partial V}{\partial w}\frac{dw}{dz} + \frac{\partial V}{\partial r}\frac{dr}{dz} + \frac{\partial V}{\partial p}\frac{dp}{dz} + \frac{\partial V}{\partial z} = 0 \tag{13}$$

The three equations (6), (11) and (13) can be solved to yield expressions for dw/dz, dr/dz and dp/dz:

$$\frac{dw}{dz} = \frac{C_z(V_r+V_pG_r) - C_r(V_z+V_pG_z)}{C_r(V_w+V_pG_w) - C_w(V_r+V_pG_r)} \tag{14}$$

$$\frac{dr}{dz} = \frac{C_z(V_w+V_pG_w) - C_w(V_z+V_pG_z)}{C_w(V_r+V_pG_r) - C_r(V_w+V_pG_w)} \tag{15}$$

$$\begin{aligned}\frac{dp}{dz} = G_w \frac{C_z(V_r+V_pG_r) - C_r(V_z+V_pG_z)}{C_r(V_w+V_pG_w) - C_w(V_r+V_pG_r)} &+ \\ G_r \frac{C_z(V_w+V_pG_w) - C_w(V_z+V_pG_z)}{C_w(V_r+V_pG_r) - C_r(V_w+V_pG_w)} &+ G_z\end{aligned} \tag{16}$$

The implicit price of the amenity is once again derived by the use of Roy's theorem to obtain:

$$p_z = L\frac{dr}{dz} - T\frac{dw}{dz} + G\frac{dp}{dz} \tag{17}$$

where G is the quantity of non-tradeable goods purchased (again G could be a function of z). This makes it clear that when non-tradeable goods are brought into the picture, hedonic price schedules need to be calculated for those goods too. The sign of dp/dz is generally ambiguous (even in the case where the amenity is unproductive to both the traded and the non-traded good). But whilst theory suggests that hedonic regressions are required for local service price indices (excluding housing) such detailed data do not exist at the county level in Britain. The empirical implementation of the model described below therefore abstracts from reality in that it assumes that all goods are tradeable[2].

A critique of the hedonic approach

There are several acknowledged problems with the hedonic method and the assumptions which underpin it. These relate to problems of individual perception,

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[2] There are no published examples of hedonic analyses involving the price of non-traded goods in the literature. The extent to which the assumption of the 'law of one price' affects the ensuing analysis is an open question.

subjectivity, continuity, averting behaviour, market segmentation and the assumption of equilibrium and need to be addressed prior to confronting the model just outlined with real-world data.

Individual perceptions are important because amenity values will only be reflected in house and wage price differentials to the extent that individuals are aware of differences in amenity levels and the effect that these might have on say health (Freeman, 1993). Lack of information is a criticism which is often levelled against the use of hedonic studies to determine the amenity value of air quality where individuals are subjected to some pollutant whose health effects they are incognizant of.

It is important in hedonic analyses to include all relevant variables, as variable omission can lead to biased estimates. But there is no accepted list of which environmental variables need to be controlled for. Furthermore climate in particular can be described in a large number of ways. One possible response might be to include all possible variables from the outset. But apart from the fact that one seldom has all the variables one thinks are important inclusion of irrelevant variables leads to increased variance in the estimates. It is necessary to use judgement as to which variables are likely to be the important ones. Furthermore with environmental variables problems of multicollinearity frequently arise (Freeman, 1993). The implication is that it is difficult to measure the individual contribution of particular variables to overall amenity levels.

To the extent that 'averting' behaviour is possible, this should be accounted for in the hedonic equation. Averting behaviour refers to the purchase of goods partly or wholly for reasons connected with reducing the direct effect of environmental disamenities on utility. To understand why averting behaviour might be an issue in the context of hedonic studies into the amenity value of climate note first that in theory what is required is a measure of variations in land prices with levels of environmental variables. But seldom are the financial details of transactions in land made public and most studies resort to using house prices instead. This is satisfactory insofar as building land is not generally sold separately from the house which stands upon it. However, certain characteristics of houses (double glazing, loft insulation, central heating etc) are likely to be correlated with climate variables whilst simultaneously contributing to the value of the property thus imparting bias to the coefficients on the variables of interest. If the extent of these averting expenditures were known they could be included as a separate regressor in the hedonic house price function. Partly for this reason there is a general presumption in favour of using data detailing actual market transactions concerning individual properties with known characteristics rather than census tract data (ie data dealing in average prices rather than the price of particular properties). On the other hand individual observations contain a large amount of noise which can be overcome only by including a large number of observations and/or by controlling for a range of variables which are not the main focus of the study (Palmquist, 1991).

The theory underlying the model relies on the existence of smoothly continuous trade-off possibilities among all characteristics. In other words, all possible combinations of housing characteristics should be available on the market. This is necessary for households to be able to locate at a position of simultaneous equilibrium with respect to all characteristics. Without this assumption the observed implicit price of the amenity cannot be taken as an estimate of marginal willingness to pay for it since the household may be located at a 'corner solution'. This assumption seems to be a reasonable one in the context of climate variables which vary smoothly over adjacent areas (Maler, 1977).

If there is restricted mobility among different sections of an area, then different markets will exist and pooling of data might lead to bias since only a single regression line is effectively fitted to two or more spline functions (Straszheim, 1974). Restricted mobility might well present a problem to hedonic studies into the amenity value of climate since climate variables only vary significantly over relatively large distances at which points the assumption of unrestricted mobility becomes harder to defend because of cultural and even language differences. Fortunately, the stability of the hedonic price functions across different regions is a testable hypothesis. Finding that the hedonic price function is not stable across different regions means that the separate hedonic price functions must be fitted to each but it does not render the hedonic technique invalid.

Finally, there is the heroic assumption of perfect equilibrium in the housing market and the labour market. For this assumption to hold there must be perfect information, zero transaction costs, zero moving costs and perfectly flexible prices. Evans (1990) argues that the assumption of equilibrium is likely to mean that the environmental quality values derived from hedonic analyses are likely to be systematically incorrect and should not without qualification be used as measures of attractiveness of an area. However, if climate amenities are valued then in the process of equilibration following supply or demand side shocks then other things being equal migration ought to be observed flowing in the direction of more pleasant climates and away from regions where the climate is less pleasant[3]. In the approach favoured by 'disequilibrium' theorists net or gross migration rates are regressed on a set of regional variables to establish the trade-off between financial variables and environmental amenities (eg Greenwood and Hunt, 1986).

But the conclusion that amenity values for environmental variables derived from hedonic analyses are likely to be systematically incorrect is wrong. There is no reason to suppose that the implicit prices derived from hedonic analyses are biased because there is no a priori reason to suppose that the extent of disequilibrium in any area is correlated with the levels of particular amenities. The consequence of disequilibrium is likely to be an increased variance in results rather than systematic bias (Freeman, 1993). In fact the debate between the proponents of the 'equilibrium' and 'disequilibrium' approaches actually involves a matter of emphasis on different aspects of the location decision (Hunt, 1993). The different positions are characterised by beliefs concerning the speed of adjustment, the motivation for migration etc. The disequilibrium approach reviewed in Greenwood (1985) sees

[3] The theory underlying migration studies involves the potential migrant comparing the present value costs and benefits of each location giving due consideration of costs of relocation (Sjaastad, 1962).

adjustment to equilibrium as being extremely slow and equilibrium concepts of little relevance. The equilibrium approach typified by the work of Blomquist et al (1988) sees local labour markets and housing markets as operating relatively efficiently. Disequilibrium theorists see migration primarily as a response to real utility differences between locations whereas equilibrium theorists tend to emphasise changes in the level of consumption amenities and life-cycle events in migration. Were it the case that both of these approaches could be based explicitly on utility maximisation which of them constitutes the superior approach for the purposes of obtaining monetary estimates of the amenity value of climate variables would be a purely empirical matter. However, unlike the hedonic technique the migration based approach is not typically based on utility maximisation.

Do house prices reflect differences in the level of climate amenities?

The chapter now turns to consider the estimation of the first component of the implicit price of climate: the hedonic land price schedule. This study uses census tract property prices relating to 127 English and Welsh counties, Scottish regions, metropolitan areas and London boroughs as the dependent variable in lieu of difficult-to-obtain data on land prices[4]. The census tract data are taken from Focas et al (1995) and refer to the year 1994. The prices correspond to a straight average across five different property types (terraced house, semi-detached house, detached house, bungalow, flat/maisonette). Since outright purchase prices are used rather than annual rental values the implicit prices which emerge reflect the discounted stream of benefits over the remaining lifetime of the house.

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[4] It was earlier argued that this is not really a problem since land is seldom sold separately from the structures which stand upon it, but that it would be a serious problem if there were some characteristics of housing which, apart from contributing to the value of a property, systematically varied with amenity levels. Chief among the characteristics of housing is the quantity of land consumed. Plausibly the quantity of land is a function of the unit price of land which is in turn a function of the level of environmental amenities. This implies that a failure to control for average floor-space could bias the coefficients on the amenity variables towards zero. Of course this problem can be assumed away by positing that households cannot adjust their consumption of land but the true relevance of this point can only be assessed through empirical analysis. For an example of a study which uses property prices per unit land area see Maddison and Bigano (1996).

Turning to the explanatory variables, an oft-encountered problem involved in the use of the hedonic technique is how best to represent a fluctuating amenity such as the climate in the regression. Normal practice is to enter the annual mean as a summary statistic. But there is evidence that using information on the distribution of the level of the amenity can significantly increase the statistical performance of the hedonic price regression. One possibility therefore might be to include a variable representing the expected number of days per year when temperatures exceed 90°F or remain below freezing. The number of days on which a gale blows might also be a far more useful measure of amenity rather than average windspeed if indeed households are primarily concerned about extremes of weather rather than averages. It might also be useful to experiment with the concept of heating and cooling degree days (the annual average cumulative deviation on either side of 65°F). Heating and cooling degree days have regularly been used with some success in American studies as indices of climate (see for example Blomquist et al, 1988).

The only published attempt to discriminate between different specifications of climate variables of any sort is Cushing (1987). Cushing's analysis deals only with temperature variables. He uses non-nested tests to examine the power of alternative specifications of temperature variables in the context of an inter-state study of migration in the USA. He examines the concept of average temperatures, heating and cooling degree days and average temperatures during the hottest and coldest months. His findings suggest that the latter concept is the single most appropriate one whilst annual average temperatures are rather poor. Cushing rationalises this by stating that the annual averages cannot distinguish between a climate is mild all the year round and onee which is extremely cold in winter and extremely hot in summer. Similarly the concept of heating and cooling degree days do not distinguish between deviations above or below an arbitrary point (typically 65°F). Cushing's findings should be seen as referring primarily to the case of the United States for which the concept of heating and cooling degree days may be particularly apt. This is because the USA can be described as having a 'continental' climate (ie one of seasonal extremes). Britain however enjoys what could be described as a 'maritime' climate and this study restricts itself to examining the impact of average climates.

Annual average values of climate variables (1961-1990) were available on a 10km grid square basis measured at the average altitude within each grid square[5]. A gazetteer (Ordnance Survey, 1992) of Great Britain was used to determine the grid reference location of the major conurbation (or conurbations) within each county. From this procedure average values were obtained for precipitation, temperature and sunshine for each county, region or borough whilst avoiding uninhabited regions (like mountain-tops). Values for humidity levels and average windspeed were not included in the analysis: humidity is only important in either very hot or very cold conditions neither of which apply to Britain and average windspeed (unlike the number of gale-days) is too unfamiliar a concept. Apart from climate variables a range of other amenity variables are also controlled for. These include the local crime rate, local taxes, school quality variables, the quality of health care services, transport links, population density and unemployment. These are now discussed in turn.

GB crime statistics are recorded at an individual police force level by the Home Office and the Scottish Office (see Focas et al, 1995 for precise details). One could make a case for using several alternative measures of criminal behaviour rather than just using the rate for all reported crime. But given the degrees of freedom problem affecting this study it was decided to select one from a list of three possible measures of criminal activity. These were all crime, violent crime and burglaries per thousand of population. Of these alternatives the number of burglaries appeared to provide the best explanation of variations in house prices and wage rates. The frequency of burglaries presumably increases the cost of residing in a given area insofar as it raises the cost of home insurance.

The importance of including variables describing local services and fiscal conditions are discussed in Gyourko and Tracy (1989) and Charney (1993). Both sets of authors argue that what is required are separate measures of local taxes and the quality of

[5] These were provided by the Climate Research Unit of the University of East Anglia under the auspices of the TIGER initiative.

local services rather than measures of expenditures on local services. The problem with employing expenditures on local services is that expenditures on its own cannot distinguish between the existence of a high quality service and a service which is expensive because it is managed ineptly. Furthermore Charney argues that higher local taxes are a disamenity only insofar as they do not reflect higher quality or more extensive provision of public services. If these factors are not adequately controlled for then it is possible that the implicit price of additional taxation could be zero or even positive. Local 'council' taxes are set on a sub-county level and 'band D' tax levels are averaged to yield a single figure for each county.

It is of course very difficult to find suitable indices to measure the quality of local services and the best that can be done is to use what (often very crude) proxies are available at the correct level of regional aggregation. In the case of education services the most widely cited measure of quality relates to the percentage of students obtaining five GCSE passes at grade C or better (alternative measures used in other studies include the number of students per teacher or the rate of truancy). In the case of health services the proxy used for the quality of the service is the number of patients per GP (an alternative might be the length of waiting lists for key surgical procedures although such a variable is available at the level of Regional Health Authorities rather than counties). These statistics are available from the Department of Education and the Department of Health respectively (again see Focas et al, 1995 for details). The abundance of transport links is crudely approximated by the number of railway stations per unit area multiplied by 100.

There are many other factors besides climate which determine the level of environmental quality to be enjoyed in a particular area. These include the ambient concentration of air pollution in a particular locality (see for example Smith and Huang, 1991), the level of noise nuisance (Nelson, 1978) and the extent of local traffic congestion (Maddison and Bigano, 1996). There might even be benefits in the form of economies of agglomeration. All these phenomenon are arguably a reflection of physical proximity to one's neighbours and, in the absence of more reliable measures, are proxied by population density.

Note carefully that the definition of 'population density' employed in the empirical model is quite different from the definition of 'population density' in the theoretical model. The latter is simply the inverse of land for habitation per individual. The former concept is the more commonly employed one: population per unit of all-land area. Whilst these measures are probably not entirely unrelated the majority of hedonic studies treat all-land population density as an exogenous regressors[6]. Population density is taken from the Central Statistical Office (1995).

Unemployment has been frequently included as a disamenity in hedonic house price and wage rate analyses. One can interpret unemployment as a disamenity in the sense that households require compensation to live in areas characterised by scant opportunities for employment (Todaro, 1969 and Harris and Todaro, 1970). In the context of this latter explanation one would expect the full implicit price of an additional percentage point on the local unemployment rate to be negative. But instead of treating unemployment as a disamenity a more realistic formulation of the locational problem is one in which the expected utility of all locations is equalised given that there are two possible states: employed and unemployed. However, reformulating the problem would not change the analysis except in a trivial way. In particular, one would still expect to find differences in unemployment rates reflected in local land prices and wage rates[7].

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[6] In other models population density is explicitly endogenous; see for example Steinnes and Fisher (1974). Using the technique of Two Stage Least Squares Nordhaus (1996) treats population density as endogenous regressor in his hedonic wage rate analysis of the amenity value of climate variables. He selects amongst other things the number of military personnel as an instrument for population density on the grounds that these individuals are not drawn to a given location by virtue of the going wage rate. Whilst the assumption of exogeneity is in principle a testable hypothesis to do so requires instrumental variables which are not normally available. In any case the use of instrumental variables would probably frustrate the purposes of using population density as a proxy for other environmental disamenities.

[7] To see this note that maximising the expected utility function across the two possible states (employed and unemployed) results in an indirect expected utility function in which the probability of unemployment enters as an exogenous variable. Invoking the equilibrium assumption and totally differentiating the indirect expected utility function with respect to the probability of unemployment demonstrates that the probability of unemployment must be reflected in regional wage and/or land prices. Dividing this expression throughout by the expected utility of money shows that the marginal willingness to pay for a reduction in the

Outside the hedonic literature here have been numerous empirical analyses of the influence of unemployment on regional labour markets. Savouri (1989) for example considers ten regional labour markets of Britain over time and finds that local unemployment exerts strong downward pressure on regional wage rates. Unemployment rates are from the Department of Employment's New Earnings Survey (DOE, 1995).

Finally, three dummy variables are used to test for (and at the same time hopefully correct for) the existence of a segmented market for housing. A separate dummy variable is used if the observation is drawn from a London borough, Scotland or Wales. This allows the intercept of the hedonic price regression to vary across the different regions (common slopes across the different regions is a maintained hypothesis because of the degrees of freedom constraint). The inclusion of dummy variables for Scotland and Wales has the unfortunate effect of identifying respectively the coldest and wettest parts of Britain and in this sense clearly compete with the climate variables.

The variables included in the hedonic house price regression are shown in table 2.1 and the range of values that these variables take is shown along with their mean values and standard deviations in table 2.2. From inspecting the mean to standard error ratio it is apparent that whereas precipitation varies markedly across Britain the other climate variables do not. It is therefore likely that among the climate variables only the coefficient on rainfall will be determined with any real degree of precision.

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probability of unemployment can be inferred from the hedonic land and wage rate regressions in the usual way.

Table 2.1: Definition of variables included in the hedonic land price regression

HOUSE	Current purchase price of property in 1994 (£s).
BURGLARY	Number of reported burglaries per 1000 of population (1993).
TAX	Council tax at band D (£s).
RAIL	Railway accessibility (number of railway stations divided by area multiplied by 100).
GP	Average number of patients per doctor (1994).
EXAM	Percentage of students obtaining 5 GCSE exam passes (grade C or better) or Scottish equivalent.
POPDEN	Population density (persons per square kilometre).
UNEMP	Percentage of economically active workforce unemployed.
PRECIP	1960-1991 average precipitation (mm).
TEMP	1960-1991 average temperature (°C).
SUN	1960-1991 average hours of sunshine.
LONDON	Dummy variable which takes the value unity for Greater London, zero otherwise.
SCOTLAND	Dummy variable which takes the value unity for Scotland, zero otherwise.

WALES Dummy variable which takes the value unity for Wales, zero otherwise.

Source: *See text*

Table 2.2: The characteristics of the data set

Variable	Mean	Std. Dev.	Minimum	Maximum
HOUSE	65640.	22462.	0.4199E+05	0.1852E+06
BURGLARY	26.063	11.325	1.000	55.00
RAIL	14.113	25.270	0.0000	139.2
TAX	450.05	71.323	256.8	657.8
GP	1885.8	220.28	1131.	2219.
EXAM	38.205	7.9330	18.00	53.00
POPDEN	2168.6	2714.6	8.000	0.1247E+05
UNEMP	8.7449	3.2675	2.900	22.40
PRECIP	789.98	210.33	568.0	1640.
TEMP	9.2472	0.84310	7.000	10.60
SUN	1404.2	118.32	1044.	1770.
LONDON	0.25197	0.43457	0.0000	1.000
SCOTLAND	0.94488E-01	0.29280	0.0000	1.000
WALES	0.62992E-01	0.24319	0.0000	1.000

Source: *See text.*

Estimation

Once the dependent variables have been selected one is left with the task of determining the appropriate functional form. It is typically found that fitting an inappropriate functional form to hedonic price equations has serious implications for the implicit prices which emerge (Palmquist, 1991). The most desirable procedure is to employ transformations which are flexible enough to accommodate a variety of functional forms. Perhaps the most rigorous procedure is to apply the Box-Cox (1962) transformation to all of the dependent and independent variables as suggested by Halvorsen and Pollakowski (1981). For the purposes of this study such a procedure is computationally infeasible because of a degrees of freedom constraint. The one concession made to the functional form of the hedonic house price regression was to attempt the transformation of the dependent and independent variables considering four frequently discussed cases:

$$\frac{HOUSE_i^{\lambda}-1}{\lambda} = \alpha + \beta_1\frac{BURGLARY_i^{\theta}-1}{\theta} + \beta_2\frac{RAIL_i^{\theta}-1}{\theta} + \beta_3\frac{TAX_i^{\theta}-1}{\theta} + \beta_4\frac{GI}{}$$

$$\beta_5\frac{EXAM_i^{\theta}-1}{\theta} + \beta_6\frac{POPDEN_i^{\theta}-1}{\theta} + \beta_7\frac{UNEMP_i^{\theta}-1}{\theta} + \beta_8\frac{PRECIP_i^{\theta}-1}{\theta} +$$

$$\beta_9\frac{TEMP_i^{\theta}-1}{\theta} + \beta_{10}\frac{SUN_i^{\theta}-1}{\theta} + \beta_{11}LONDON + \beta_{12}SCOTLAND + \beta_{13}WALE \tag{18}$$

The four cases are: $\lambda = 0,1$ and $\theta = 0,1$. In the log-log, semi-log and lin-log model the marginal value of any one characteristic depends upon the value of all other characteristics. Only in the linear model is the marginal value of a change in any one of the characteristics independent of the level of any other characteristic. Note that the dummy variables LONDON, SCOTLAND and WALES are not transformed.

Results

Using the method described by Maddala (1977) it was found that a semi-logarithmic model (corresponding to the case where $\lambda = 0$ and $\theta = 1$) was the model more likely to have generated the observed data and this specification was adopted for the remainder of the study. The estimated coefficients of the semi-logarithmic model are shown in table 2.3. The regression analysis manages to explain in excess of 80% of the variation in house prices; a fact which reflects the use of census tract data and the fact that the characteristics of individual properties are averaged out of the data. That amenity variables are able to explain differences in regional house prices to the extent that they do suggests that the 'equilibrium' (hedonic) approach to amenity values is the appropriate one. Property prices evidently contain a great deal of information on the value of amenities and cannot therefore be 'too far' away from equilibrium.

Dealing first with the non-climate variables it is apparent that whilst some of these play a highly significant role in determining residential property prices other variables may be failing to capture the quality of local services. To begin with the variable describing the rate of burglaries appears to significantly affect property prices in the anticipated direction. The number of transport terminuses is also a statistically significant determinant of property prices. But on the other hand, the tax variable is highly significant and unexpectedly signed. Possibly this is because, as indicated earlier, this variable plays a dual role in acting as a proxy for higher levels of public services as well as indicating a higher charge to pay. The unexpectedly signed coefficient on this variable can thus be interpreted as a failure to control adequately for the differences in the levels of public services paid for through local taxes. This interpretation is borne out by the fact that the variables describing the quality of health care services and education services are statistically insignificant. Population density is highly significant and positively signed. Whereas one might have expected it to play a role as a proxy for various forms of pollution such as noise pollution, air pollution and congestion these factors seem to be outweighed by benefits from agglomeration. Local unemployment on the other hand reduces house prices markedly.

Turning now to the climate variables, it is evident that a house in a warm and sunny location is significantly more expensive than a house in a wet location. An F test of the joint significance of the climate variables was performed and confirmed that the hypothesis that the coefficients on these three variables were all simultaneously zero could be rejected even at the 99% level of confidence[8]. Thus this study provides very strong support in favour of the hypothesis that amenity values for climate variables are embedded within British property prices. It is also interesting to note that one of the dummy variables, that for Scotland, is significant suggesting that the housing market is segmented in Britain along a North-South axis.

[8] $F_{5,113} = 5.57$; CV at the 99% level of confidence = 3.20.

Table 2.3: The estimated hedonic house price regression (semi-logarithmic model)

Ordinary least squares regression.		Dep. Variable	= Log HOUSE
Observations	= 127	Weights	= ONE
Mean of LHS	= 0.1104822E+02	Std.Dev of LHS	= 0.2796593E+00
StdDev of residuals	= 0.1305315E+00	Sum of squares	= 0.1925348E+01
R-squared	= 0.8046199E+00	Adjusted R-squared	= 0.7821426E+00
F[13, 113]	= 0.3579692E+02	Prob value	0.0000000E+00
Log-likelihood	= 0.8580140E+02	Restr.(ß=0) Log-l	= -0.1788195E+02
Amemiya Pr. Criter.	= -0.1130731E+01	Akaike Info.Crit.	= 0.1891674E-01

ANOVA Source	Variation	Degrees of Freedom	Mean Square
Regression	0.7929026E+01	13.	0.6099251E+00
Residual	0.1925348E+01	113.	0.1703848E-01
Total	0.9854374E+01	126.	0.7820932E-01

Variable	Coefficient	Std. Error	t-ratio	Prob|t|≥x
Constant	9.8870	0.4555	21.706	0.00000
BURGLARY	-0.29835E-02	0.1512E-02	-1.973	0.05098
RAIL	0.43612E-02	0.1005E-02	4.340	0.00003
TAX	0.95164E-03	0.2391E-03	3.980	0.00012
GP	-0.36255E-04	0.1074E-03	-0.338	0.73630
EXAM	0.16801E-02	0.3268E-02	0.514	0.60813
POPDEN	0.55751E-04	0.1275E-04	4.374	0.00003
UNEMP	-0.49220E-01	0.7714E-02	-6.381	0.00000
PRECIP	-0.15642E-03	0.7761E-04	-2.016	0.04622
TEMP	0.90885E-01	0.4230E-01	2.148	0.03381
SUN	0.24155E-03	0.1937E-03	1.247	0.21492
LONDON	-0.80640E-01	0.5847E-01	-1.379	0.17059
SCOTLAND	0.23892	0.8475E-01	2.819	0.00569
WALES	0.71696E-01	0.6426E-01	1.116	0.26691

Source: *See text.*

Do wages compensate for an unpleasant climate?

Having shown that amenity values for climate variables are to a significant extent embedded in property prices the following sections seek to determine whether differing levels of environmental amenities and in particular climate amenities are similarly reflected in regional wage differences across Britain. It was earlier shown that the only circumstances under which the land price gradient would capture the entirety of the implicit price of environmental amenities would be in a situation where firms do not use land in production and production is unaffected by the level of the amenity. In these circumstances wages cannot differ from location to location because this would necessarily imply different production costs which competition would eventually eliminate. It is not even certain that the hedonic wage gradient need be negative with respect to the level of an environmental amenity.

Regional wage data

Pooled average hourly wage rates for full time workers relating to 127 English and Welsh counties, Scottish regions, metropolitan areas and London boroughs are analysed. These are taken from the New Earnings Survey (DOE, 1995) and refer to the year 1994. The characteristics of the regional wage data are described in table 2.4. The hourly wage rates exclude overtime payments and consider only full time workers. The study is hampered somewhat by an inability to standardise for very many of the characteristics of different workers or the characteristics of employment insofar as they may happen to vary across the country. In fact, only two characteristics of the workers can be controlled for: differences between manual and non manual labour and differences between male and female workers. Remaining differences between workers (eg educational attainment, racial composition etc) and characteristics of the industry or the job (eg the extent of unionisation) are consigned to the error term. Neither industry based wage rates nor micro-level data detailing the characteristics of individual workers and their employ are available at the required level of disaggregation for Britain (ie by county).

Besides worker characteristics, the same set of amenities as was used in the hedonic house price regression are entered into the hedonic wage regressions: measures of criminal activity, the level of local taxes, transport linkages, the quality of health care, the quality of local schools, population density, unemployment, climate variables and dummy variables for different regions to test for possible segmentation of the labour market.

Table 2.4: The characteristics of the regional wage data for 1994 (pence per hour)

Category	Mean	Std. Dev.	Minimum	Maximum
MAN. MALE	627.02	56.470	513.0	841.0
MAN. FEMALE	448.34	29.156	395.0	521.0
NON MAN. MALE	1079.2	163.11	880.0	1620.0
NON-MAN. FEMALE	736.83	107.06	551.0	1115.0

Source: Department of Employment (1995).

Estimation and results of the hedonic wage regression

The first model estimated was a 'pooled' model which combines the four different categories of labour and uses dummy variables to control for differences in the intercept of the hedonic wage regression between male, female, manual and non manual workers. The one concession made to functional form is to attempt the transformation of the dependent and independent variables by the means suggested by Box and Cox (1962). The following model was considered (note that the dummy variables are not transformed):

$$\frac{WAGE_i^{\lambda}-1}{\lambda} = \alpha + \beta_1\frac{BURGLARY_i^{\theta}-1}{\theta} + \beta_2\frac{RAIL_i^{\theta}-1}{\theta} + \beta_3\frac{TAX_i^{\theta}-1}{\theta} + \beta_4\frac{GP_i}{\theta}$$

$$\beta_5\frac{EXAM_i^{\theta}-1}{\theta} + \beta_6\frac{POPDEN_i^{\theta}-1}{\theta} + \beta_7\frac{UNEMP_i^{\theta}-1}{\theta} + \beta_8\frac{PRECIP_i^{\theta}-1}{\theta} +$$

$$\beta_9\frac{TEMP_i^{\theta}-1}{\theta} + \beta_{10}\frac{SUN_i^{\theta}-1}{\theta} + \beta_{11}LONDON + \beta_{12}SCOTLAND + \beta_{13}WALE$$

$$\beta_{14}MALE_i + \beta_{15}MANUAL_i + e_i \tag{19}$$

Once again four special cases are entertained: $\lambda = 0,1$ and $\theta = 0,1$ and once more it was found that the combination $\lambda = 0$ and $\theta = 1$ was most likely to have generated the observed data. The pooled model however constrains the slopes of the regression equation to be identical across the different worker categories. Previous researchers have run separate regressions for different occupations and skill groups arguing that since different groups of workers compete in different markets there is no reason why the slopes (and hence the implicit prices paid by workers of each type) should be the same (Roback, 1988)[9]. Alternatively, it may be believed that the underlying assumptions of the hedonic technique are more likely to be met for one group of workers rather than the other. More specifically it might be that greater mobility of skilled workers means that only they are able to respond to real utility

[9] Interestingly Roback finds that when she extends the framework referred to earlier by considering two different types of workers that the hedonic wage gradient of one group of workers depends not only on the productivity effects of climate but also on the preferences of the other group.

differentials existing between locations. If this were so then climate variables might be significant in the hedonic wage regressions for skilled workers but not in those for unskilled workers.

In order to test the hypothesis of common slopes a separate regression is run for each category of worker (male/female/manual/non-manual) and the sum of squared residuals compared with the sum obtained from the pooled model. The results of this F test suggest that the slopes of the model do indeed differ substantially across the four groups[10]. The estimated regression equations for each category of worker are presented in tables 2.5 to 2.8. Next, a test of the joint significance of the coefficients of the climate variables is performed in each of the worker-specific hedonic wage equations. In three out of the four categories the hypothesis of zero slopes on the climate variables cannot be rejected at the 95% level of confidence. But in the case of non-manual female workers the hypothesis of zero slopes on the climate variables can be rejected at the 95% level of confidence (although not at the 99% level of confidence)[11]. The evidence therefore appears to be rather against the compensation for the amenity value of climate variables through regional differences in wage rates at least in Britain.

Turning to the unrestricted regressions, their ability to explain variations in regional wage rates varies between 64% and 82% of the total variation around the mean. The significance of the dummy variable LONDON points to the existence of a segmented labour market. As expected the coefficient on unemployment is either negative and significant (or in one case positive and insignificant). There are no other consistent patterns regarding the significance of the remaining amenity variables between the respective regressions. In particular *none* of the climate variables are individually significant at 95% level of confidence in *any* of the regressions.

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[10] $F_{40,452} = 5.71$; CV at the 95% level of confidence = 1.39.

[11] The exact results are as follows: for non-manual males $F_{3,113} = 1.39$; for non-manual females $F_{3,113} = 3.81$; for manual males $F_{3,113} = 0.40$; and for manual females $F_{3,113} = 2.15$. CV = 2.68 at the 95% level of confidence and CV = 3.81 at the 99% level of confidence.

Table 2.5: **The estimated hedonic wage regression (male manual workers)**

Ordinary least squares regression.		Dep. Variable	= Log WAGE
Observations	= 127	Weights	= ONE
Mean of LHS	= 0.6437117E+01	Std.Dev of LHS	= 0.8752555E-01
StdDev of residuals	= 0.5489917E-01	Sum of squares	= 0.3405728E+00
R-squared	= 0.6471666E+00	Adjusted R-squared	= 0.6065751E+00
F[13, 113]	= 0.1594342E+02	Prob value	0.0000000E+00
Log-likelihood	= 0.1957982E+03	Restr.(ß=0) Log-l	= 0.1296465E+03
Amemiya Pr. Criter.	= -0.2862964E+01	Akaike Info.Crit.	= 0.3346162E-02

ANOVA Source	Variation	Degrees of Freedom	Mean Square
Regression	0.6246782E+00	13.	0.4805217E-01
Residual	0.3405728E+00	113.	0.3013919E-02
Total	0.9652510E+00	126.	0.7660722E-02

Variable	Coefficient	Std. Error	t-ratio	Prob|t|≥x
Constant	6.1834	0.1916	32.277	0.00000
BURGLARY	-0.11104E-02	0.6361E-03	-1.746	0.08361
RAIL	0.13870E-03	0.4226E-03	0.328	0.74336
TAX	0.16348E-03	0.1006E-03	1.626	0.10682
GP	0.10094E-03	0.4517E-04	2.235	0.02740
EXAM	0.12010E-03	0.1374E-02	0.087	0.93052
POPDEN	-0.30802E-06	0.5360E-05	-0.057	0.95428
UNEMP	0.58772E-02	0.3244E-02	1.812	0.07271
PRECIP	-0.35353E-04	0.3264E-04	-1.083	0.28106
TEMP	-0.45679E-02	0.1779E-01	-0.257	0.79784
SUN	0.26666E-05	0.8146E-04	0.033	0.97394
LONDON	0.10128	0.2459E-01	4.118	0.00007
WALES	0.10438E-01	0.2703E-01	0.386	0.70006
SCOT	0.18238E-01	0.3564E-01	0.512	0.60988

Source: *See text.*

Table 2.6: The estimated hedonic wage regression (male non-manual workers)

Ordinary least squares regression.		Dep. Variable	= Log WAGE
Observations	= 127	Weights	= ONE
Mean of LHS	= 0.6973714E+01	Std.Dev of LHS	= 0.1407272E+00
StdDev of residuals	= 0.7461864E-01	Sum of squares	= 0.6291774E+00
R-squared	= 0.7478573E+00	Adjusted R-squared	= 0.7188498E+00
F[13, 113]	= 0.2578146E+02	Prob value	0.0000000E+00
Log-likelihood	= 0.1568229E+03	Restr.(ß=0) Log-l	= 0.6933513E+02
Amemiya Pr. Criter.	= -0.2249180E+01	Akaike Info.Crit.	= 0.6181730E-02

ANOVA Source	Variation	Degrees of Freedom	Mean Square
Regression	0.1866146E+01	13.	0.1435497E+00
Residual	0.6291774E+00	113.	0.5567942E-02
Total	0.2495323E+01	126.	0.1980415E-01

Variable	Coefficient	Std. Error	t-ratio	Prob|t|≥x
Constant	7.1019	0.2604	27.274	0.00000
BURGLARY	-0.40924E-03	0.8646E-03	-0.473	0.63690
RAIL	0.11721E-02	0.5744E-03	2.041	0.04363
TAX	0.17125E-03	0.1367E-03	1.253	0.21286
GP	-0.87145E-04	0.6139E-04	-1.419	0.15852
EXAM	-0.19039E-02	0.1868E-02	-1.019	0.31026
POPDEN	0.20513E-04	0.7286E-05	2.815	0.00575
UNEMP	-0.13088E-01	0.4410E-02	-2.968	0.00366
PRECIP	-0.40571E-04	0.4436E-04	-0.914	0.36240
TEMP	-0.16719E-01	0.2418E-01	-0.691	0.49074
SUN	0.17622E-03	0.1107E-03	1.592	0.11426
LONDON	0.14351	0.3343E-01	4.293	0.00004
WALES	-0.26813E-01	0.3673E-01	-0.730	0.46696
SCOT	0.68384E-02	0.4845E-01	0.141	0.88800

Source: *See text.*

Table 2.7: The estimated hedonic wage regression (female manual workers)

Ordinary least squares regression.		Dep. Variable	= Log WAGE
Observations	= 127	Weights	= ONE
Mean of LHS	= 0.6103480E+01	Std.Dev of LHS	= 0.6436843E-01
StdDev of residuals	= 0.4078658E-01	Sum of squares	= 0.1879806E+00
R-squared	= 0.6399219E+00	Adjusted R-squared	= 0.5984970E+00
F[13, 113]	= 0.1544776E+02	Prob value	0.0000000E+00
Log-likelihood	= 0.2335356E+03	Restr.(ß=0) Log-l	= 0.1686745E+03
Amemiya Pr. Criter.	= -0.3457254E+01	Akaike Info.Crit.	= 0.1846928E-02

ANOVA Source	Variation	Degrees of Freedom	Mean Square
Regression	0.3340746E+00	13.	0.2569804E-01
Residual	0.1879806E+00	113.	0.1663545E-02
Total	0.5220552E+00	126.	0.4143295E-02

Variable	Coefficient	Std. Error	t-ratio	Prob|t|≥x
Constant	5.9612	0.1423	41.883	0.00000
BURGLARY	-0.76784E-03	0.4726E-03	-1.625	0.10700
RAIL	0.41973E-03	0.3140E-03	1.337	0.18396
TAX	0.11853E-03	0.7471E-04	1.586	0.11543
GP	-0.74304E-05	0.3356E-04	-0.221	0.82516
EXAM	-0.10213E-02	0.1021E-02	-1.000	0.31929
POPDEN	0.18625E-05	0.3982E-05	0.468	0.64092
UNEMP	-0.52905E-02	0.2410E-02	-2.195	0.03021
PRECIP	-0.34346E-05	0.2425E-04	-0.142	0.88762
TEMP	0.80578E-02	0.1322E-01	0.610	0.54334
SUN	0.74048E-04	0.6052E-04	1.224	0.22366
LONDON	0.73291E-01	0.1827E-01	4.011	0.00011
WALES	0.86439E-02	0.2008E-01	0.430	0.66766
SCOT	0.37457E-01	0.2648E-01	1.414	0.15998

Source: *See text.*

Table 2.8: The estimated hedonic wage regression (female non-manual workers)

Ordinary least squares regression.		Dep. Variable	= Log WAGE
Observations	= 127	Weights	= ONE
Mean of LHS	= 0.6593009E+01	Std.Dev of LHS	= 0.1336734E+00
StdDev of residuals	= 0.5952513E-01	Sum of squares	= 0.4003862E+00
R-squared	= 0.8221644E+00	Adjusted R-squared	= 0.8017055E+00
F[13, 113]	= 0.4018603E+02	Prob value	0.0000000E+00
Log-likelihood	= 0.1855239E+03	Restr.(ß=0) Log-l	= 0.7586597E+02
Amemiya Pr. Criter.	= -0.2701163E+01	Akaike Info.Crit.	= 0.3933834E-02

ANOVA Source	Variation	Degrees of Freedom	Mean Square
Regression	0.1851054E+01	13.	0.1423888E+00
Residual	0.4003862E+00	113.	0.3543241E-02
Total	0.2251440E+01	126.	0.1786858E-01

Variable	Coefficient	Std. Error	t-ratio	Prob|t|≥x
Constant	6.4494	0.2077	31.049	0.00000
BURGLARY	-0.44956E-03	0.6897E-03	-0.652	0.51585
RAIL	0.18671E-02	0.4582E-03	4.075	0.00009
TAX	0.20026E-03	0.1090E-03	1.837	0.06891
GP	-0.65332E-04	0.4898E-04	-1.334	0.18489
EXAM	-0.47934E-02	0.1490E-02	-3.217	0.00169
POPDEN	0.12046E-04	0.5812E-05	2.073	0.04049
UNEMP	-0.14870E-01	0.3518E-02	-4.227	0.00005
PRECIP	0.23674E-04	0.3539E-04	0.669	0.50490
TEMP	0.26442E-01	0.1929E-01	1.371	0.17317
SUN	0.11038E-03	0.8832E-04	1.250	0.21397
LONDON	0.10349	0.2667E-01	3.881	0.00018
WALES	0.25895E-01	0.2930E-01	0.884	0.37876
SCOT	0.33449E-01	0.3865E-01	0.865	0.38861

Source: *See text.*

The full implicit price of amenities

Having investigated the evidence for the collateralisation of amenity values for climate in the hedonic house price and hedonic wage rate regressions it is now possible to make some pronouncement on the full implicit price for climate amenities. Although it is the implicit price of climate rather than non-climate amenities which is the main focus of this chapter it is nevertheless of interest to present the implicit prices of non-climate variables too since the plausibility or implausibility of those results also has some bearing on the overall credibility of the technique being used.

Using the estimated parameters of the hedonic house price equation and the model in which wage rates for manual and non-manual workers are pooled the implicit prices of amenities are calculated for the typical household receiving £11,830 annually after tax in wages and salaries in 1994 (CSO, 1995) and a typical property costing £65,640 whose benefits are annuitised using a conventional 5% rate of discount.

The full implicit prices are obtained by subtracting column two from column one in table 2.9. This reflects the fact that an amenity with a negative coefficient in the hedonic wage equation implies that a positive price is being paid in order to obtain incremental units of it. Note also that the coefficients on the climate variables in the hedonic wage regression have been set equal to zero in light of the finding that none of the coefficients on climate variables are significantly different from zero in any of the hedonic wage-rate regressions. In principle it would of course be possible to derive the full implicit prices pertaining to different skill groups by estimating hedonic wage regressions for skilled and manual workers separately. But to do so properly would require information on average house prices for each group as well.

To begin with, the full implicit price of burglaries is, as expected, negative at -£1.70 per each additional burglary per thousand people. The coefficient on the level of the council tax is however unexpectedly signed at +£1.21 and this is almost certainly due to it acting as a proxy for higher spending on local services. The variables indicating the quality of local public goods and services however are mixed. Longer GP patient lists have a positive amenity value of +£0.05 per person whereas a negative implicit price would have been more plausible. However, schools with higher exam pass rates are associated with much higher amenity values (+£27.98 per additional 1 percent of pupils achieving 5 or more GCSEs at grade C or above). The density of railway stations is also regarded as an amenity worth +£3.67 per station per square kilometre times 100. Similarly, population density is viewed as an amenity worth £0.08 per additional person per square kilometre (presumably there are net benefits from agglomeration which outweigh the disamenities from lower environmental quality).

The negative coefficient on unemployment in the pooled hedonic wage regression is consistent with the literature suggesting that unemployment exerts a downward pressure on wages through competition between workers. But overall, the full implicit price on unemployment is negative indicating that unemployment is viewed as a disamenity which is consistent with the Harris-Todaro thesis. Each percentage point increase in the unemployment rate costing £80.59 per household on average.

Turning finally to the climate variables, as anticipated households in Britain display an aversion to greater precipitation (51 pence per millimetre) and a strong preference for warmer temperatures (£298 per °C) and more sunshine (79 pence per hour). Unfortunately it is difficult to make comparisons between the findings of this study and others with regards to the impact of climate variables on house prices and wage rates. First, the measurement of climate differs between studies and second the effect of a marginal increase in the level of a climate variable may differ between countries. All that can be said is that this study, like its predecessors (eg Blomquist et al, 1988 and Maddison and Bigano, 1996) finds a significant role for climate variables in explaining variations in house prices. However, unlike previous studies (eg Hoch and Drake, 1974) there is no role for climate variables in explaining variations in wage rates. In the final chapter of this thesis these implicit prices are compared to those obtained from the alternative methodology described in chapter three and then used to determine the impact of various climate change scenarios on amenity values in Britain.

Table 2.9: The full implicit price of amenities to households calculated using an 5% discount rate and evaluated at sample means (1994 prices)

Variable	House price	Wage rate	Full price
Burglary Rate	-£9.79	-£8.09	-£1.70 / burglary / 1000 persons
Tax Rate	+£3.14	+£1.93	+£1.21 / £1 of council tax
GP Lists	-£0.12	-£0.17	+£0.05 / additional patient / GP
Exam Passes	+£5.51	-£22.47	+£27.98 / % passing 5 or more GCSEs
Railway Stations	+£14.31	+£10.64	+£3.67 / station / sq. km. x 100
Population Density	+£0.18	+£0.10	+£0.08 / person / sq. km.
Unemployment	-£161.54	-£80.95	-£80.59 / % point
Precipitation	-£0.51	-	-£0.51 / mm
Temperature	+£298.28	-	+£298.28 / °C
Sunshine	+£0.79	-	+£0.79 / hour

Source: *See text.*

Conclusions

This chapter has demonstrated how households' preferences for climate variables can in theory be deduced from hedonic price regressions for land and labour. Moreover the analysis offered illustrates that in order to determine the full implicit price of climate amenities it is necessary to consider both markets jointly and that it is even possible that the amenity price gradient may be unexpectedly signed in one of the markets.

The analysis has also discussed the desirability of using data describing residential land prices rather than the price of individual properties with which to uncover the implicit prices of climate variables. The advantage of using data relating to individual properties is that the characteristics of properties (such as physical dimensions, insulation and heating and cooling equipment) themselves change with climate and are otherwise difficult to control for. On the other hand the existence of building standards may prevent certain characteristics from changing across different sites and census tract data may be more appropriate given that the impact of climate variables on property prices may be small compared to the effect of other non-modelled factors.

In the empirical section of the chapter the model is estimated on data for Britain and it is shown that the market for housing is segmented along geographic lines. This was presaged by the concerns of theoretical practitioners. The study confirms that when segmentation of the housing market is not dealt with several important coefficients become statistically insignificant and/or implausibly signed. Similarly, the analysis has also shown that the inclusion of unemployment into the hedonic wage and house price regressions produces results which are consistent both with the view that unemployment leads to wage competition and also that unemployment is viewed as a disamenity by households. There is also evidence that the hedonic price schedule is unstable over different skill groups and that the reason for this is that the taste for amenities differs between manual and non manual workers rather than the underlying assumptions of the hedonic technique being more applicable to one group than the other.

The main deficiency of the study providing this evidence however is that relatively few characteristics of workers have been controlled for in the hedonic wage regression. Controlling for more characteristics of the work force and also for differences in the occupational structure is clearly desirable since these are likely to vary considerably across the country. There is also clearly work outstanding in terms of further specifying the levels of other environmental amenities and the quality of local services. This is shown by the unexpected sign of the variable describing the level of local taxes (which was attributed to a failure to control for the levels of all local services). Nevertheless, empirical analysis of census tract data has shown that as a group some climate variables appear to exercise a highly significant and moreover plausible influence over residential property prices in Britain.

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3. The amenity value of climate: the Household Production Function approach

Economic activity is directed at the satisfaction of human wants arguably the most basic of which is protection from the privations of the climate. But the idea of climate as a direct input to human welfare has received relatively little attention in the climate change literature. When such issues have been addressed (as in chapter 2 or in Maddison and Bigano, 1996) it is typically within the context of the hedonic approach. The hedonic approach argues that, if individuals are able to freely select from differentiated localities then the tendency will be for the benefits associated with them to become collateralised into property prices and wages. In such cases the value of marginal changes can be discerned from the hedonic house and wage price regressions.

But a basic assumption of the hedonic technique is that there are no barriers to mobility which prevent prices changing to reflect the net benefits of a given location. Yet climate variables are undeviating over relatively large distances and the absence of a common language and cultural ties may prevent the net advantages associated with a particular region from being eliminated. These considerations suggest that, except for countries like the United States and Italy, alternative methods may in the end be more suitable for estimating the amenity value of climate. Accordingly, this chapter seeks to undertake a systematic examination of the role played by climate in determining consumption patterns using cross sectional data from 60 different countries and asks under what circumstances is it possible to derive a measure of the amenity value of climate simply from observed patterns of consumption. The chapter further assumes that these conditions are met and then proceeds to calculate the implicit price of a range of climate variables for each of the 60 countries.

The Household Production Function approach

The role of climatic variables in determining patterns of observed expenditures can best be motivated by reference to the Household Production Function (HPF) theory of Becker (1965). In the HPF approach households combine marketed commodities using a given production technology. These result in a variety of service flows which are of direct value to the individual concerned. The overall level of utility is maximized by choice of service flows subject to the budget constraint. The price of a service flow is determined by the cost-minimising combination of marketed commodities necessary to produce a unit service flow.

The majority of work however has been on the concept of 'weak complementarity' or 'weak substitutability' as a restriction on preferences rather than on the production technologies themselves (Maler, 1974, and Feenberg and Mills, 1980). Both weak complementarity and weak substitutability imply that there must exist either a commodity bundle or a price vector at which the marginal utility afforded by additional amounts of the environmental amenity is zero (Bradford and Hildebrandt, 1977, refer to this restriction as 'demand interdependency'). Given the assumption of demand interdependency the economic value of non-marketed environmental amenities can be determined from observing the consumption of marketed commodities.

The intuition underlying weak complementarity and weak substitutability is best understood by realising that integrating the restricted Hicksian demand functions generally results in unknown constants of integration which are a function of the level of the environmental amenity and can only be eliminated if it is known that there is some price vector for which marginal changes in the level of the amenity have no effect upon the expenditure function (see for example Smith, 1991). Whether or not demand interdependency holds is itself, of course, not a testable hypothesis.

It is as well to be aware that there are a class of commonly used utility functions which do not permit the full impact of changes in the levels of environmental amenities to be recovered. These are utility function in which the environmental amenities form a strongly-separable subset. With strong separability of the utility function changes in the levels of environmental amenities would leave the marginal rates of substitution between all other marketed goods unchanged and in that case environmental amenity variables could legitimately be excluded from the demand functions altogether. In this case nothing can be learned about preferences for environmental amenities from studying consumer behaviour since parameters of interest are omitted from the Marshallian demand equations.

Previous literature

A bare handful of analyses have attempted to implement the HPF approach to valuing environmental amenities, either by using a restricted indirect utility function from which demand functions can be derived or, alternatively, by telling the HPF story and specifying the production technologies and preferences for the various service flows available. The advantage of the latter approach is that it enables the analyst to examine the credibility of the technological relationships being proposed. That so few researchers should have attempted to implement the HPF methodology is perhaps surprising particularly since others have seen considerable potential in the technique (eg Smith, 1991). Perhaps this is because whereas researchers have been willing to accept the assumptions underlying techniques such as the hedonic approach they have been unwilling to make the assumptions associated with the HPF approach (eg the assumptions relating to preferences and the absence of choice concerning the level of the amenities to be valued). Alternatively it may be that the data required to implement the HPF approach is expensive to obtain.

Shapiro and Smith (1981) begin with an indirect utility function in which four environmental amenities are included. Expressions for the expenditure shares are derived and the system of equations econometrically estimated using maximum-likelihood methods imposing the cross equation restrictions suggested by theory. The indirect utility function chosen parodies the transcendental utility function although the variables are not taken in logarithmic form. Using Roy's identity the Marshallian demand equations are derived and then the parameters econometrically estimated and inserted into an expression which yields the implicit price of each of the environmental amenities. The results of the exercise are moderately encouraging especially since only three different commodity bundles are separately identified. This would severely limit the opportunities to identify any relationships between environmental amenities and commodity purchases.

Studies by Math-Tec (1982) and Gilbert (1985) by contrast both explicitly adopted the HPF approach. Both studies used the Stone-Geary utility function to describe both the aggregated expenditure system as well as the cost sub-functions for each activity. Environmental amenities are brought into the analysis by specifying that the 'subsistence' parameters should be a function of environmental variables. In the context of consumer preferences the subsistence parameters are often interpreted as a subsistence level of a commodity which must be purchased before any increment to utility is possible. In the context of a production technology the interpretation is that a change in the provision of one or more of the environmental amenities changes the amount of marketed commodities which must be purchased before any addition to the flow of services is achieved. The Math-Tec study considers average expenditure patterns for a variety of American cities and seven aggregated commodities and includes both temperature and rainfall as potential influences on expenditure shares. Neither variable appears to play a significant role.

Apart from the literature on attempting to derive implicit prices for environmental amenities using the HPF approach there is also something of a literature on attempts to explain variations in cross-country patterns of consumption which is briefly surveyed in Selvanathan and Selvanathan (1993). The attraction lies in the fact that there is a large variation in both incomes and prices relative to time series studies or cross sectional studies undertaken within a single country. This literature was in part stimulated by the controversial hypothesis of Stigler and Becker (1977) that tastes are the same across different countries - a maintained assumption in this analysis. Pollak and Wales (1987) and Selvanathan and Selvanathan (op cit) test the hypothesis that tastes are identical across countries by pooling international data and testing the acceptability of restricting the equations of different countries to share common parameters. In both cases the hypothesis of common tastes is rejected. Of course the results of such tests do not determine whether tastes differ between countries or whether consumption patterns differ as a consequence of differences in household production technologies or the endowment of environmental amenities used in household production processes. To the best of the author's knowledge no study has ever before attempted to use climate variables as an explanation of why consumption patterns vary between countries.

Extending systems of demand equations to reflect the role of environmental amenities

The procedure used to incorporate environmental variables into systems of demand equations is borrowed directly from the literature on the incorporation of demographic variables into systems of demand equations. More specifically, the analysis utilises 'demographic translating', 'demographic scaling' and the 'Gorman procedure' (see Pollak and Wales, 1981, and Gorman, 1976). The advantages of this approach are that the nature of the role played by environmental amenities in determining consumption patterns is very clear and the use of established utility functions whose limitations can constrain the results in important ways is already well understood. The assumption of demand interdependency and common tastes is maintained throughout.

In 'translating' fixed costs are added to or deducted from the operations of the household according to the levels of the environmental amenities. For example, hot weather may be involve a reduction in the demand for heating. Translating replaces the original demand system by:

$$q_i = d_i + q^i(p, y - \Sigma d_k p_k) \quad (20)$$

where the d's are the translation parameters given by:

$$d_i = d_i(z) = \Sigma \eta_i z_i$$

and z is a vector of environmental amenities. This corresponds to the direct utility function:

$$u = u(x_1 - d_1, x_2 - d_2, ...) \quad (22)$$

In demographic scaling the effective prices of the commodities are increased. This has an obvious interpretation in the context of household composition where the scaling factors can be interpreted in terms of 'adult equivalents'. In the context of environmental amenities these can be thought of as representing changes in the marginal utilities of commodities. For example, in cold weather the marginal utility of soft drink presumably falls so that one would expect the scaling parameter to be a decreasing function of temperature. Scaling replaces the original demand system by:

$$q_i = m_i q^i(p_1 m_1, p_2 m_2,.., y) \tag{23}$$

where the m's are the scaling parameters given by:

$$m_i = m_i(z) = \Sigma\eta_i z_i \tag{24}$$

This corresponds to the direct utility function:

$$u = u(x_1/m_1, x_2/m_2, ...) \tag{25}$$

In the Gorman procedure there is a change in the perceived costs of particular commodities whilst at the same time there is a change in fixed costs to the household. The Gorman procedure replaces the original demand system by:

$$q_i = d_i + m_i q^i(p_1 m_1, p_2 m_2,..., y-\Sigma d_k p_k) \tag{26}$$

This corresponds to the direct utility function:

$$u = u((x_1-d_1)/m_1, (x_2-d_2)/m_2, ...) \tag{27}$$

The specification for the translating and scaling parameters in the Gorman procedure is:

$$d_i = v\Sigma\eta_i z_i \tag{28}$$

and:

$$m_i = 1 + (1 - v)(\Sigma\eta_i z_i) \tag{29}$$

This requires only one more parameter than either scaling or translating separately and both the translating and the scaling procedures are nested as special cases[12].

It is not necessary that the translating and scaling parameters be a linear function of environmental amenities and this is certainly undesirable in the context of climate variables. For example, it is plausible to assume that the marginal utility of a unit of electricity with which to modify the interior climate of the home first falls with outdoor temperature and then rises as energy becomes increasingly used to cool the home. The inclusion of quadratic terms effectively enable one to test for an 'optimal' level of the environmental amenity, any departure from which requires compensation to maintain utility levels.

Prior to analysing the data set it is necessary to lend particular functional form to the proposed relationships to provide a basis for estimation. Given the paucity of observations the Linear Expenditure System (LES) of Stone (1954) is adopted. The LES is parsimonious in terms of parameters such that a quite disaggregate group of commodities can be dealt with. This parsimony however means that the underlying demand system is not an appealing description of preferences[13]. The Almost Ideal Demand System (AIDS) model of Deaton and Muelbauer (1980a) is by contrast a much more appealing description of preferences but because it contains many more parameters than the LES it would be necessary to use a much more highly aggregated set of commodities which may very well prevent the identification of the exact role that environmental amenities play in shaping consumption.

The expenditure share equations associated with the LES are:
with the adding-up restriction that:

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[12] Translating corresponds to $\nu = 1$ and scaling to $\nu = 0$. Replacing ν by ν_i yields a more general specification which allows the balance between translating and scaling to differ between goods.

[13] Brenton (nd) for example finds the fit afforded by the LES to international consumption data to be especially poor and is compelled to split his data set into 'rich' and 'poor' countries prior to progressing suggesting that different regimes are appropriate to these two groups.

$$\frac{p_i q_i}{m} = \frac{p_i \gamma_i}{m} + \beta_i (1 - \frac{\Sigma p_i \gamma_i}{m}) \tag{30}$$

$$\Sigma \beta_i = 1 \tag{31}$$

The LES implies additivity (commonly referred to as 'wants' independence) and rules out complementarity, although the latter is unlikely to be important provided that the commodity groupings are sufficiently broad. The LES also implies an approximate proportionality between price and expenditure elasticities: a proposition without any theoretical backing. Crucially however the LES does not impose homotheticity (although the system approaches homotheticity as incomes grow). Note that whilst the γs are commonly referred to as the 'subsistence' levels of each commodity there is no requirement that they should be positive. Unless total expenditure exceeds 'subsistence expenditure' however the cost function is not concave and cannot therefore be derived from utility maximisation (see Deaton and Muelbauer, 1980b).

The evaluation of welfare change is in terms of the Compensating Surplus (CS). The CS is defined as the minimum change in expenditure necessary to leave the individual as well-off prior to the change in the level of environmental amenities as after:

$$\begin{aligned} CS = {} & \Sigma d_i(z^0) p_i + u^0 \Pi (p_i / m_i(z^0))^{\beta_i} \\ & - \Sigma d_i(z^1) p_i - u^0 \Pi (p_i / m_i(z^1))^{\beta_i} \end{aligned} \tag{32}$$

where u^0 refers to the base level of utility and z^0 and z^1 refer to the pre and post-change level of the environmental amenities respectively. Note that in the case of translating that the costs associated with a change in the level of amenities are independent of the base level of utility. In the case of scaling the costs associated with a change in the level of environmental amenities tend towards proportionality with the level of income.

Data sources

The price and expenditure data is taken from the 1980 International Comparisons Project (ICP) involving 60 different countries (Kravis et al 1982). This project provides quinquennial information on per capita consumption patterns in national currencies and PPPs in terms of national currencies per US dollar for 108 consistently defined final consumption commodities[14]. For the purposes of this study a 5 commodity disaggregation is adopted: food, alcohol and tobacco, clothing and footwear, housing, fuel and other goods and services. The components of these commodity aggregates are given in table 3.1 along with their group classification numbers. Prices are aggregated using quantity weights (national expenditures divided by purchasing power parities).

The ICP consumption data for 1980 has already been analysed by among others Brenton (nd). Brenton finds that the degree of fit afforded by a LES system to be extremely disappointing. He estimates the LES model again dividing the sample into rich and poor countries. The hypothesis of parameter homogeneity between the two sets of countries is overwhelmingly rejected. Brenton conducts a similar exercise using the Almost Ideal Demand System (AIDS) of Deaton and Muellbauer (1980). Brenton finds the AIDS model also provides a poor fit to the data and that the hypothesis of parameter homogeneity between rich and poor nations can again be rejected. An overriding degrees of freedom constraint prevents this study from sub-dividing the sample into rich and poor countries.

Climate records for each country's major cities are taken from Landsberg (1969-84). To arrive at a single index for each country the records for individual cities are

[14] Countries measure quantities in value units based on their own national currency. Pooling consumption data from different countries requires transforming them to common units using different transformations for each good. The required transformation factors are called Purchasing Power Parities (PPPs). Except under the assumption of perfect goods arbitrage these cannot be inferred from market exchange rates.

population-weighted[15]. The records used to determine the indices for each country are shown in table 3.2. Two climatic variables are included in the analysis: the annually averaged temperature and its square expressed in terms of degrees centigrade. This means that the translation parameters are given by:

$$d_i = \nu(\eta_{1i}z_i + \eta_{2i}z_i^2) \tag{33}$$

and the scaling parameters are given by:

$$m_i = 1 + (1 - \nu)(\eta_{1i}z_i + \eta_{2i}z_i^2) \tag{34}$$

where z stands for annual average temperature.

The characteristics of the data set are described by table 3.3. Substantial variation in annual average temperature (z) is observed over the dataset.

[15] Even this procedure would not work well in a country like India where the vast majority of the population live in rural areas. More generally, the validity of this approach depends upon the proportion of the population living in the cities covered by the data and the representativeness of cities to the general climate of the country as a whole.

Table 3.1: Definition of commodity aggregates for the LES model

1. Food, drink and tobacco: (11011-14022)	Bread, rice and cereals Meat, fish, dairy products and fats Fruit and vegetables Coffee, tea, cocoa and sugar Soft drinks Alcoholic drinks Tobacco
2. Clothing: (21011-22021)	Clothing Footwear
3. Housing: (31011-31013)	Rents and imputed rents Repair and maintenance of housing
4. Fuel and power: (32011-32041)	Electricity Gas, oil, and other fuels
5. Other: (41011-86011)	Household goods and appliances Furniture, fixtures and household textiles Glassware and cutlery Cleaning and domestic services Personal transport equipment Gasoline, motor oils, grease and other running costs Fares Telephone and postal services Radio and television Sports equipment Books, newspapers and magazines Education

Pharmaceutical products, medical goods etc

Toiletry articles, beauty and hairdressing

Jewellery etc

Restaurants and hotels

Financial services

Table 3.2: Records used to compute climate averages for different countries

Country	City / Record	Pop. ('000s)
USA	New York	18,120
	Los Angeles	13,770
	Chicago	8,181
	San Francisco	6,042
	Philadelphia	5,963
	Detroit	4,620
	Dallas	3,766
	Boston	3,736
	Washington DC	3,734
	Houston	3,642
	Miami	3,001
	Cleveland	2,769
	Atlanta	2,737
	Saint Louis	2,467
	Seattle	2,421
	Minneapolis	2,388
	San Diego	2,370
	Baltimore	2,343
	Pittsburgh	2,284
	Phoenix	2,030
Belgium	Brussels	
Denmark	Copenhagen	
France	Paris	8,510
	Lyon	1,170
	Marseille	1,080

W. Germany	Berlin	3,301
	Hamburg	1,594
	Munich	1,189
Greece	Athens	
Ireland	Dublin	
Italy	Rome	2,817
	Milan	1,464
	Naples	1,203
Luxembourg	Luxembourg	
Netherlands	De Bilt	
UK	London	
Austria	Vienna	
Finland	Helsinki	
Hungary	Budapest	
Norway	Oslo	
Poland	Warsaw	
Portugal	Lisbon	1,612
	Oporto	1,315

Spain	Madrid	3,123
	Barcelona	1,694
Yugoslavia	Belgrade	
Botswana	Francis Town	
Cameroon	Douala	
Ethiopia	Addis Ababa	
Ivory Coast	Abidjan	
Kenya	Nairobi	
Madagascar	Antananarivo	
Malawi	Lilongue	
Mali	Bamako	
Morocco	Rabat	
Nigeria	Lagos	1,097
	Ibadan	1,060
Senegal	Dakar	
Tanzania	Dar es Salaam	
Tunisia	Tunis	

Zambia	Lusaka	
Zimbabwe	Harare	
Israel	Haifa	
Hong Kong	Hong Kong	
India	Calcutta	9,194
	Bombay	8,243
	Delhi	5,729
	Madras	4,289
	Bangalore	2,922
	Ahmadabad	2,548
	Hyderabad	2,546
Indonesia	Jakarta	7,348
	Surabaya	2,224
	Medan	1,806
Japan	Tokyo	11,829
	Yokohama	2,993
	Osaka	2,636
	Nagoya	2,116
P R Korea	Pyongyang	
Pakistan	Karachi	5,208
	Lahore	2,953
	Hyderabad	1,104
Philippines	Manila	

Sri Lanka	Colombo	
Argentina	Buenos Aires	10,728
	Cordoba	1,055
	Rosario	1,016
Bolivia	La Paz	
Brazil	Rio de Janeiro	11,141
	Belo Horizonte	3,446
	Recife	2,945
	Porto Alegre	2,924
	Salvador	2,362
Chile	Santiago	
Colombia	Bogota	4,185
	Medellin	1,506
Costa Rica	San Jose	
Dominica	Rouseau	
Ecuador	Guayaquil	1,301
	Quito	1,110
El Savlador	San Salvador	
Guatemala	Guatemala City	
Honduras	Tegucicgalpa	

Panama	Balboa Heights	
Paraguay	Asuncion	
Peru	Lima-Callao	
Uruguay	Montivideo	
Venezuela	Caracas	3,247
	Maracaibo	1,295
Canada	Toronto	3,427
	Montreal	2,921
	Vancouver	1,381

Source: *The Phillips Atlas and Landsberg (1969-84).*

Table 3.3: Characteristics of the HPF data set

	Mean	Std Dev	Minimum	Maximum
Y	258743.51618	1003605.54382	119.82353	6602200.00000
P1	100.89354	322.09376	0.22575	2322.19995
P2	100.37725	349.03959	0.34507	2574.12598
P3	128.46822	501.78962	0.26282	3741.69019
P4	77.05016	254.38490	0.10582	1627.63635
P5	70.91960	266.22871	0.16718	1952.55164
S1	0.38758	0.13774	0.15290	0.66055
S2	0.078966	0.022543	0.030187	0.14621
S3	0.092583	0.035292	0.0078395	0.18137
S4	0.034387	0.015411	0.0053442	0.069694
S5	0.40648	0.12617	0.14326	0.60783
Z	17.76667	6.56487	4.80000	27.80000

Source: *Kravis et al (1982) and Landsberg (1969-84). Note that 'Y' is income in national currency 'P' is purchasing power parity price and 'S' is expenditure share.*

Estimation and results

The demand system is estimated in share form in order to overcome likely problems associated with heteroscedasticity and the system of n-1 equations is estimated by the maximum-likelihood technique[16].

For the sake of comparison each of the three alternative ways of introducing environmental variables into the LES model was estimated alongside the untransformed LES model. The results in the form of the log-likelihoods are presented in table 3.4. It is evident that the scaling procedure cannot be rejected against the more general Gorman procedure. The translating procedure however can be readily rejected against the Gorman procedure[17]. This should come as no surprise given what the translating procedure implies about the independency of marginal willingness to pay for climate of the level of income. The main point of interest however is to establish whether the exclusion of all climate from the model represents a statistically significant restriction. Using a Likelihood Ratio test the null hypothesis of no role for the climatic variables (ie the simple LES model) may be rejected against the model involving the scaling procedure at the 95% level of confidence[18]. The parameter estimates of the scaled model are given in table 3.5.

The main source of cost savings arise from a reduction in the demand for fuel. This makes perfect sense in the case of the United Kingdom whose cold climate means that houses require to be heated for the majority of the year and seldom if ever cooled. The marginal utility of a given quantity of energy is minimised at around 25°C. It is interesting to see that the marginal utility of a given quantity of food and

[16] As is well known, the adding up property implies singularity of the variance-covariance matrix. This can be treated by dropping one of the budget share equations. The estimation technique is such that the parameter estimates which emerge are not affected by the choice of which equation to drop. The value of the last β parameter is determined from the adding-up constraint.

[17] The chi-squared statistics are 3.18 and 26.29 respectively against a CV of 3.84 at the 95% level of confidence with 1 degree of freedom.

[18] The chi-squared statistic is 39.39 against a critical value of 18.31 at the 95% level of confidence with 10 degrees of freedom.

drink falls initially but eventually increases quite sharply with temperature. This might be as a consequence of that commodity aggregate containing soft beverages, alcohol and ice creams whose consumption is dramatically affected by climate. The marginal utility of all other commodities is not affected by climate. This is somewhat surprising in the context of both clothing and housing.

Turning now to the individual equations themselves, it appears to be difficult to explain much if anything of the cross country variation in the purchase of some commodities unless account is taken of differences in climates (see table 3.6). This is particularly true of expenditures on clothing and fuel where the greatest proportionate increases in fit are observed. Still, the ability of the scaled LES model to explain variations in patterns of consumer demand for most goods is very poor which mirrors the finding made by Brenton (nd). It would obviously be interesting to examine whether, in a more extensive data set, fitting a more flexible functional form and/or adopting a more disaggregate commodity grouping affects estimates of the implicit prices of climate variables or more generally the significance of the climate variables.

Table 3.4: Summary statistics for four alternative models of demand

Model	Log likelihood	Number of parameters
LES	485.661	9
LES with translating procedure	493.803	19
LES with scaling procedure	505.358	19
LES with Gorman procedure	506.946	20

Source: *See text.*

Table 3.5: Parameter estimates of the LES model of consumer demand employing the scaling procedure

Log of likelihood function = 505.358
Number of observations = 60

Commodity	Parameter	Estimate	Standard Error	t-statistic
Food	γ	10.5983	9.35005	1.13350
	β	.255339	.054560	4.67999
	η_1	-.035394	.026405	-1.34041
	η_2	.171429E-02	.525524E-03	3.26206
Clothing	γ	-1.08639	3.18955	-.340609
	β	.066495	.014635	4.54348
	η_1	.012624	.036548	.345399
	η_2	-.180403E-03	.807399E-03	-.223437
Housing	γ	-.442026	3.97723	-.111139
	β	.101467	.021641	4.68866
	η_1	.739926E-04	.032868	.225120E-02
	η_2	-.276625E-03	.791693E-03	-.349409
Fuel	γ	-3.64780	7.49326	-.486811
	β	.055953	.010425	5.36698
	η_1	-.060940	.019306	-3.15661
	η_2	.120960E-02	.493934E-03	2.44892
Other	γ	-103.477	250.079	-.413775
	β	.520746	-	-
	η_1	.459983	1.30525	.352410
	η_2	-.012386	.032578	-.380201

Source: *See text.*

Table 3.6: The relative explanatory power of the constrained and unconstrained (scaling procedure) LES model of consumer demand

	R^2 statistic	
Commodity group	Constrained	Scaling procedure
Food	0.48	0.64
Clothing	0.00	0.12
Housing	0.07	0.06
Fuel	0.00	0.04
Other	0.48	0.49

Source: *See text.*

Table 3.7 reports the marginal willingness to pay for temperature increases in terms of national currency and in US dollars converted by means of PPP exchange rates for mean temperature for each of 60 different countries. Most of the countries in Europe and North America appear to benefit substantially from an increase in temperatures at least in terms of the direct amenity value. Canada and the Scandanavian countries in particular appear willing to pay as much as $200 in order to secure the first 1°C of warming. Along with these very high income countries, the United Kingdom appears to be among the chief beneficiaries of climate change. Her residents appear willing to pay up to $74 per capita in 1980 prices for the amenity value provided by first 1°C of warming and furthermore these gains extend over a considerable range of possible temperature increases. The same appears to be true of the United States where willingness to pay for the first 1°C rise in mean temperature is $65 per capita. Italy and Spain on the other hand appear close to the climatically optimal conditions right now and are largely indifferent to a marginal increase in average annual maximum daytime temperatures (marginal willingness to pay for a 1°C change in mean temperature is less than $2 in Italy). Only Portugal and Greece lose out among the EC countries but their losses are small in comparison with the gains enjoyed elsewhere in Europe and North America.

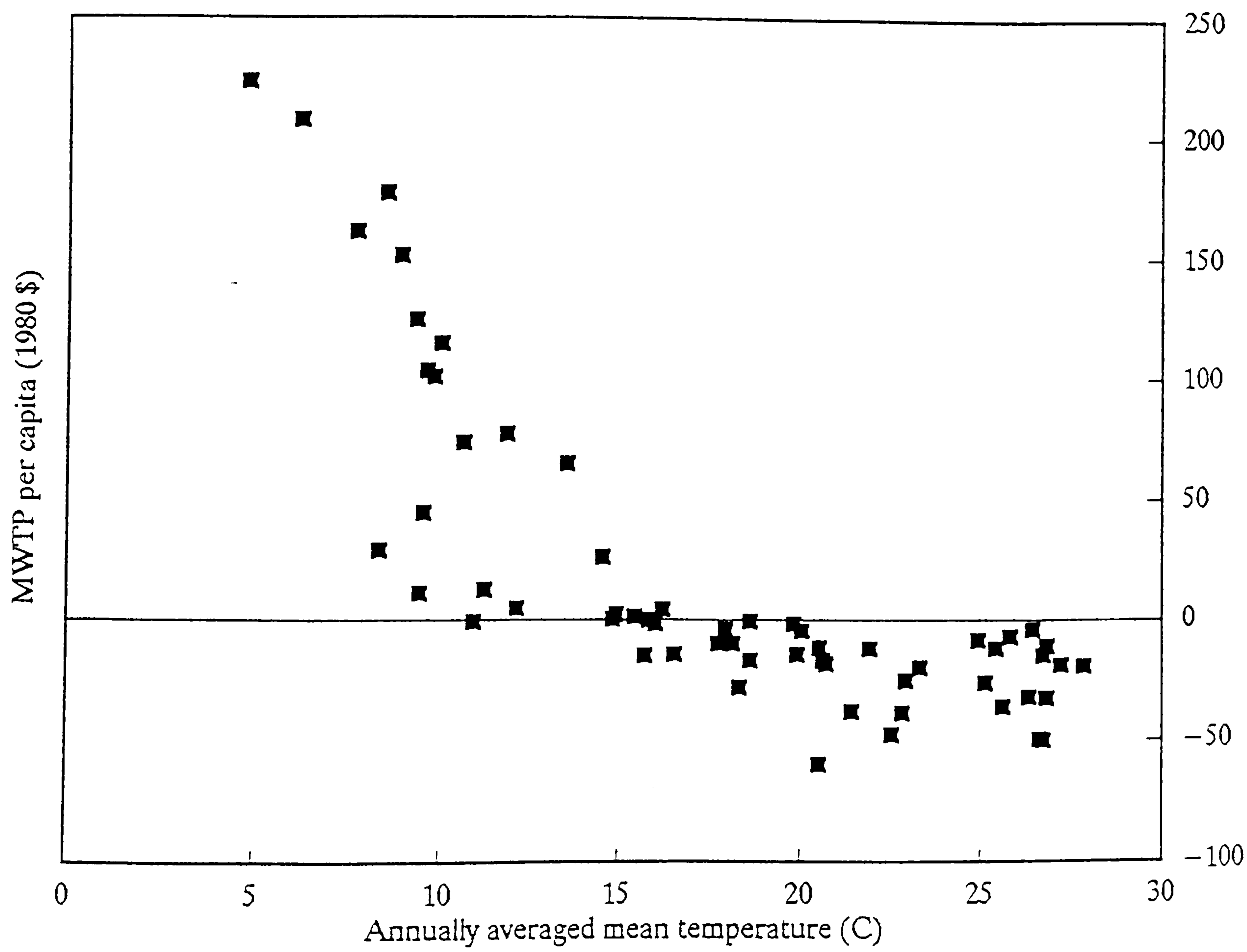
Turning to the Indian subcontinent Pakistan, India and Sri Lanka all lose from a 1°C rise in temperature although the amounts involved are small in absolute terms they are significant insofar as these countries are themselves so very populous and the current levels of income so low. The remainder of Asia exhibits mixed effects with the Philippines and Hong Kong losing out whilst Japan gains. Alarmingly, the whole of the African countries in the data set lose out with the sole example of Ethiopia (due to the relatively cooler climate of that country due to its height above sea level). Nigeria, Mali and Zambia in particular appear to have most to be concerned about: increases in mean temperatures of 1°C would carry an implicit price of $32, $19 and $59 per capita respectively. These represent very significant changes in the cost of living in those countries. The precise reasons for Zambia's predicament appear to be its already high temperature and the relatively high price of fuel in that country. Turning to Central and South America, Argentina, Chile, Colombia, Peru and

Uruguay are not much affected by a 1°C rise in temperature due in part to their relatively lower temperatures in part due to the elevation of those countries above sea level and their higher latitudes. Closer to the equator however countries such as Panama are very adversely affected.

The ability of climate change to redistribute welfare between rich and poor nations is brought out in table 3.8 which provides the change in the cost of living for nations ranked by current income levels. The 16 richest countries in the dataset all benefit from a 1°C rise in temperature. And with one exception (Ethiopia) the 26 poorest countries in the data set all lose from a 1°C rise in temperature. On the other hand, anthropogenically induced increases in temperature are expected to be greatest in the higher latitudes and it appears that this will increase the benefits to the Northern European countries whilst reducing the losses to poor countries located in the tropics. It is thus conceivable that the Hicks-Kaldor welfare criterion would suggest that overall welfare would be improved following limited climate change and that the real challenge posed by climate change is a political one in the sense of responding to undesirable redistributions of welfare.

As regards the question of whether there exists some average temperature which can be considered generally 'optimal', it is important to understand that what is perceived to be the 'optimal' climate is in reality dependent upon both income and prices. For example, if higher temperatures are desired solely because fuel for heating is expensive then a change in the price of fuel might result in a change in what is perceived to be the optimal climate as attention turns more to for example what constitutes the best climate for recreation and sports. Similarly the tastes for particular activities which are dependent upon the climate may change with income. It is for this reason not possible to present an overall optimum climate for all nations as a whole. Nonetheless when willingness to pay for a 1°C rise in temperature is plotted against current average climate (see figure 1) it appears that there are no examples of countries with a current mean temperature of lower than 15°C being inconvenienced by a marginal increase in temperatures and no examples of countries with a climate warmer than 20°C benefitting. The results therefore strongly suggest the existence of an optimal mean temperature of between 15°C and 20°C which is a plausible result. The dispersion of the plot in figure 3.1 reflects of course the differences in price and income levels between countries in the data set.

Figure 3.1: The implicit price of annually averaged mean temperature



Source: *See text.*

Table 3.7: The estimated per capita value of a 1°C rise in mean temperature

Country	Domestic currency	PPP exchange rate	US dollars
USA	65.27	1.00	65.27
Belgium	3378.28	29.24	115.52
Denmark	1002.45	5.64	177.87
France	327.23	4.23	77.43
W Germany	276.29	1.82	152.00
Greece	-1186.62	42.62	-27.84
Ireland	21.72	0.49	44.71
Italy	1611.62	856.50	1.88
Luxembourg	3661.62	29.24	125.21
Netherlands	206.83	1.99	104.03
UK	31.92	0.43	74.17
Austria	1310.55	12.94	101.29
Finland	834.92	3.73	223.83
Hungary	426.47	32.73	13.03
Norway	1027.65	4.94	208.06
Poland	915.99	31.05	29.50
Portugal	-738.27	50.03	-14.76
Spain	208.67	71.77	2.91
Yugoslavia	134.31	24.91	5.39
Botswana	-14.18	0.78	-18.25
Cameroon	-7623.24	211.30	-36.08
Ethiopia	0.39	2.07	0.19
Ivory Coast	-10507.58	211.30	-49.73
Kenya	-27.33	7.42	-3.68
Madagascar	-88.19	211.30	-0.42
Malawi	-11.62	0.81	-14.31
Mali	-8011.07	422.60	-18.96
Morocco	-37.48	3.94	-9.52
Nigeria	-17.73	0.55	-32.45

Senegal	-5522.47	211.30	-26.14
Tanzania	-54.45	8.20	-6.64
Tunisia	-3.96	0.41	-9.77
Zambia	-47.13	0.79	-59.77
Zimbabwe	-10.78	0.64	-16.78
Israel	-194.00	5.12	-37.86
Hong Kong	-237.99	5.00	-47.60
India	-29.94	7.86	-3.81
Indonesia	-9163.43	626.99	-14.61
Japan	5995.95	226.74	26.44
PR Korea	6931.64	607.43	11.41
Pakistan	-114.57	9.90	-11.57
Philippines	-140.92	7.51	-18.76
Sri Lanka	-180.57	16.53	-10.92
Argentina	-25664.35	1837.20	-13.97
Bolivia	-5.75	24.51	-0.23
Brazil	-2023.01	52.71	-38.38
Chile	29.32	39.00	0.75
Colombia	230.97	47.28	4.89
Costa Rica	-94.41	8.57	-11.02
Dominica	-31.90	1.00	-31.90
Ecuador	-415.77	25.00	-16.63
El Salvador	-20.97	2.50	-8.39
Guatemala	-4.32	1.00	-4.32
Honduras	-23.78	2.00	-11.89
Panama	-49.51	1.00	-49.51
Paraguay	-2482.35	126.00	-19.70
Peru	-376.01	288.65	-1.30
Uruguay	-10.38	9.16	-1.13
Venezuela	-106.85	4.29	-24.89
Canada	188.08	1.16	162.14

Source: *See text.*

Table 3.8: The estimated change in the cost of living following a 1°C rise in mean temperature (ranked by current per capita income)

Country	PPP Income (US$)	% change in cost of living
W Germany	8919	-1.70
Denmark	8873	-2.00
Belgium	8284	-1.39
France	8249	-0.94
USA	7910	-0.83
Luxembourg	7863	-1.59
Netherlands	7727	-1.35
Canada	7195	-2.25
Norway	7151	-2.91
Austria	7039	-1.44
UK	6365	-1.17
Finland	5927	-3.78
Japan	5524	-0.48
Italy	4875	-0.04
Spain	4163	-0.07
Ireland	3801	-1.18
Argentina	3594	0.39
Israel	3465	1.09
Hong Kong	3449	1.38
Greece	3048	0.91
Uruguay	2724	0.04
Venezuela	2347	1.06
Portugal	2030	0.73
Yugoslavia	1876	-0.29
Chile	1861	-0.04
Poland	1546	-1.91
Brazil	1531	-2.51

Costa Rica	1526	0.72
Hungary	1177	-1.11
Panama	1175	4.21
Paraguay	1066	1.85
PR Korea	1064	-1.07
Dominica	978	3.26
Colombia	950	-0.51
Ecuador	946	1.76
Tunisia	909	1.07
Guatemala	884	0.49
Ivory Coast	801	6.21
Peru	784	0.17
Bolivia	695	0.03
Nigeria	639	5.08
Botswana	632	2.89
Morocco	630	1.51
Cameroon	598	6.03
El Salvador	582	1.44
Philippines	523	3.59
Honduras	494	2.41
Zimbabwe	475	3.53
Senegal	440	5.94
Zambia	378	15.80
Indonesia	310	4.72
Madagascar	298	0.14
Pakistan	295	3.92
Kenya	293	1.26
Sri Lanka	228	4.80
Tanzania	215	3.10
India	172	2.22
Mali	170	11.14
Malalwi	148	9.70

Ethiopia	113	-0.17

Source: *See text.*

Conclusions

Given the lack of data available for this exercise and its limitations it is perhaps all the more surprising then, that using cross country data one is able to produce a set of results which are so much in line with expectations. These results imply that, given the enormity of the climate change question, it would surely be worthwhile engaging in a major effort to collect the large amount of data from narrowly defined climatic regions such that more detailed commodity groups could be analysed and a more complete range of climatic variables be introduced. It is of interest to observe the extent to which differing specifications of the underlying demand system and different commodity aggregations effect the implicit prices for the environmental amenities since there is no discussion of these issues in the literature. Similarly, it would be interesting to examine the use of other variables such as heating degree days or climate variables relating to for example precipitation. At the same time more data would permit less restrictive functional forms to be estimated and there is the possibility that results such as those offered above may be seen to have been driven by the restrictions of the functional forms adopted. It would be much more difficult to argue that the significance of environmental variables is merely compensating for the inadequacies of the functional form within the context of the AIDS model since such a model provides a degree of generality comparable to the translog functions. Because the kind of climate change problems which are discussed are not expected until mid-way through the next century some knowledge of the role of income in determining amenity values seems a prerequisite. In short, one needs to know whether climate is an inferior good, a normal good or a luxury good and using a more flexible functional form might be capable of shedding some light on this important question.

In the meantime, these preliminary results suggest that climate change is likely to confer, at least in some respects, considerable benefits on cold northern countries (of which the United Kingdom is a good example) whilst in hot tropical countries any increase in temperatures is likely to reduce welfare and result in a large change in the cost of living in those countries. In this sense anyway the main problems posed by climate change are those involved in compensating such countries.

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4. The impact of climate change on agriculture in Britain

It is widely believed that climate change could have a significant impact upon agricultural productivity, both positive and negative, and much research effort has been spent in constructing models of the agricultural sector to investigate various climate change scenarios (Parry, 1990). The most rudimentary approach is an empirical representation of the climate-yield relationship. This technique uses multiple regression analysis to explain some aspect of production (normally yield) by reference to fertiliser applications, a time trend for technology and a set of weather variables. Using the estimated model it is possible to simulate the effect of changed weather patterns on yield. Explicitly however (and as was argued in chapter 1) these analyses provide little information on the cost to agriculture of climate change. In particular; to regard them as indicative of the likely impact of climate change on agricultural productivity would be to adhere to the 'dumb farmer hypothesis' in which farmers fail entirely to respond to or even apparently notice the change in climate. One must at least have regard for the likely alterations to agro-practices that could be expected in response to a permanent change in climate. Permanent changes in climate will also cause agriculture to migrate to more suitable areas and a more sophisticated model of land allocation is required to address such considerations.

In land allocation models producers respond to changed climates by a changed overall pattern of production as well as regional changes in production. An example of such a model for England and Wales is found in Hossell et al (1993). The basic land allocation model is a linear programme which allocates land between a choice set of activities in an attempt to maximise economic surplus. The constraints relate to the contents of the choice set, the availability of suitable land and the price of factor inputs. Using such models investigators have attempted to predict the efficient response of farmers in particular regions frequently taking equilibrium 2xCO_2 as a reference scenario. The technique is to interpret climate change as an alteration in the availability of land suitable for particular activities and then measure the difference in realisable economic surplus in the face of climate change.

This modelling strategy has recently been challenged by Mendelsohn et al (1993, 1994). Mendelsohn et al argue that such models typically fail to find the highest value use for land by considering only a limited number of alternative uses and that they inevitably neglect a whole range of adaptations and changes in the practices of farmers. Mendelsohn et al suggest that given the number of changes which might occur the land allocation approach *cannot as a practical matter* account for them all. Instead, the authors propose a 'Ricardian' (or Hedonic) approach to measuring the potential impact of climate change on United States agriculture which seeks current day analogues for climate change. They argue that the value of land derives from the sum of discounted profits which may be derived from its use. Anything which affects the productivity of land will be reflected in the purchase price. In principle therefore land prices contain information concerning the value of climate as a characteristic of the land. Rather than studying the yield changes of specific crops the Ricardian approach examines how the climate in different locations is consolidated into different rents for land. The approach also accounts for the impact of climate on pests and diseases as well as changes in practice and technique. The analysis of Mendelsohn et al confirms that climate variables exert a significant influence on land prices along with other characteristics of the land such as the quality of the soil, its elevation and drainage. On the basis of their results the authors argue that the adaptations possible are such that the impact of climate change on the agricultural sector of the United States would be negligible or even mildly beneficial. However, the approach cannot value changes due to elevated CO_2 concentrations[19] and does not allow for price effects arising from changed levels of inputs and output (and neither, unfortunately, will the analysis which follows). The hedonic technique has also been employed by Palmquist and Danielson (1989) to measure the value of erosion control and drainage and by Miranowski and Hammes (1984) to determine the implicit prices for soil characteristics in Iowa.

[19] Elevated concentrations of CO_2 have been shown to have a beneficial effect on plant growth in laboratory experiments. It is argued by some researchers that this fertilisation effect may provide an offset against the potentially deleterious impacts of climate change on agriculture (eg Bolin et al, 1986). To the extent that hedonic analyses ignore the fertilisation effect they either exaggerate the negative impacts of climate change or understate the benefits.

The remainder of the chapter is organised as follows: the economic basis of the hedonic technique is explored in more depth in the following section and then applied to data on farm sales drawn from Britain. Next, various auxiliary hypotheses are tested. These include tests of the ability of landowners to costlessly 're-package' their land, the effect of regulated tenancies on market prices and the accuracy of professional valuations as a guide to the eventual sale price. The amenity values of key climate variables are computed and the final section concludes.

The hedonic technique

In the model developed below agricultural production is assumed to be a constant returns to scale activity and agricultural production a perfectly tradeable commodity such that a unit cost function can be defined for agricultural production. This price must equal the world price in all locations for if it did not the price of agricultural land would adjust under pressure from farmers vacating high-cost production sites in favour of low-cost ones.

The unit cost function (A) is:

$$A(w,\ r^{a},\ z)\ =\ 1 \qquad (35)$$

where w is the wage rate, r^a is the price of agricultural land and z is a characteristic of the land (such as the climate). The unit price of agricultural output is normalised to unity. Totally differentiating the unit cost function gives:

$$\frac{\partial A}{\partial w}\frac{dw}{dz} + \frac{\partial A}{\partial r^{a}}\frac{dr^{a}}{dz} + \frac{\partial A}{\partial z} = 0 \qquad (36)$$

Re-arranging the equation and substituting in expressions obtained from differentiating the unit cost identity gives:

$$-A_{z} = N^{a}\frac{dw}{dz} + L^{a}\frac{dr^{a}}{dz} \qquad (37)$$

where N^a is the number of agricultural workers and L^a is the amount of agricultural land available.

Hence the marginal change in production costs with respect to the climate amenity is, with a change in sign, equal to the marginal change in labour costs multiplied by the current labour force plus the marginal change in the cost of the land multiplied by the current area of land.

Clearly it does not suffice to estimate only the hedonic land price schedule and differentiate it with respect to the characteristics to obtain the implicit price of the amenities. This captures only a subset of the value of the climate variables to agriculture. One has also to account for the fact that the price of labour in general depends upon climate amenities too. However, despite the potential importance of accounting for climate induced compensating wage differentials for agricultural workers the subsequent section deals exclusively with the estimation of the hedonic agricultural land price schedule, and then goes on to derive the implicit prices of climate variables from this schedule. The reason for the focus on agricultural land prices is that detailed information concerning geographical differences in the wages of workers in the agricultural sector are not available for Britain. For this reason alone the exercise cannot (yet) be regarded as producing definitive estimates of the implicit prices of climate variables[20].

The Data Set

This exercise draws on data on land transactions in Britain taken from *Farmland Market* (1994). This journal contains a county by county record of almost 500 transactions in farmland during the first six months of 1994. The journal records the location, acreage, whether the property sold has vacant possession along with other important details concerning dwellings and other buildings included in the sale. The prices shown are in some cases the results of sales auctions although many are sales by private treaty. In the latter case the guide (brochure) price is quoted along with

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[20] Whilst it has been suggested to the author that wages paid to farm labourers do not vary much across the country (National Farmers Union, private correspondence) and the results of chapter 2 suggest that workers do not on the whole require compensation for working in different environments surely a special case must be made for farm workers. Since they spend their lives outdoors they simply cannot be indifferent to the climates which they work in.

some indication of whether the actual sale price was above, below or close to the guide price. The Ordnance Survey (1992) Gazetteer of Great Britain is used to determine the grid reference location of the individual properties from the given address either to a named farm or the nearest named settlement.

A set of land quality variables are included in the data set by indirectly utilising the 5km grid square Agricultural Land Classification Of England and Wales (MAFF, 1988). This classifies land into one of seven grades according the extent to which its physical characteristics impose long term limitations on agricultural use. This grading system does not, it is claimed, necessarily reflect the current economic value of the land although it is almost invariably taken that grade 1 land is the best since there are few limitations to its use. Grade 7 is urban land, non agricultural land or land which was not surveyed. The principal physical factors included in the grading system are those relating to the site (gradient, microrelief and flood risk), soil (texture, structure, depth and stoniness) and climate. That climate variables should have been incorporated in this classification is a nuisance since it tends to leave the land classification correlated with the individual climate variables discussed below, although it need not bias the results. Although the soil quality data has the form of a single variable taking the integer values 1-7, the information is incorporated into the ensuing statistical analysis by means of 6 dummy variables. The reason is that the increase in value of the dependent variable to a change in the grading of soil quality need not be a constant.

Climate variables are calculated on a 10km grid square basis[21]. Observations can thus be fitted into one of several thousand different climatic regions. Various annual, summertime and wintertime 30 year climate averages (1961-1990) are matched to the location of the farmland along with the land classification. The information currently contained in the data set is described in table 4.1.

[21] These were provided by the Climate Research Unit of the University of East Anglia under the auspices of the TIGER initiative.

The relevance and expected impact on land values of some of the recorded variables may need further explanation. First, many of the farms or land were sold together with other assets of worth. Virtually all farmsteads have large farm houses attached to them and often labourers' cottages or holiday homes too. By contrast farm buildings are not consistently recorded in the source and are consequently excluded from the data set which represents an unfortunate closure on the information available. Milk quotas permit a farmer to sell up to a given volume of milk and any excess production must be discarded. These milk quotas are thus of considerable value to dairy farmers and are sometimes sold along with the farm. Farm equipment and livestock is, by contrast, usually sold separately. Nowadays in Britain only a very few farms are sold as tenanted property. Tenanted property is highly regulated in Britain and it seems likely that the many regulations reduce the value of tenanted property in the eyes of an institutional investor. The data set thus records whether a property is sold as a regulated tenancy or not.

Table 4.1: Definition of variables contained in the data set

Variable	Definition
PRICE	Sale price (£s).
ACRES	Acreage.
BEDROOMS	Number of bedrooms in dwellings of a specified size.
COTTAGES	Number of dwellings of unspecified size.
POSSESS	Dummy variable which takes the value unity if the property is vacant possession, zero otherwise.
PRIVATE	Dummy variable which takes the value unity if the property was sold by private treaty, zero otherwise.
MILK	Number of milk production quotas offered with the property (x 1000 litres).
SOIL1	Dummy variable which takes the value unity if land is officially classified as grade 1; zero otherwise.
SOIL2	Dummy variable which takes the value unity if land is officially classified as grade 2; zero otherwise.
SOIL3	Dummy variable which takes the value unity if land is officially classified as grade 3; zero otherwise.
SOIL4	Dummy variable which takes the value unity if land is officially classified as grade 4; zero otherwise.

SOIL5	Dummy variable which takes the value unity if land is officially classified as grade 5; zero otherwise.
SOIL6	Dummy variable which takes the value unity if land is officially classified as grade 6; zero otherwise.
FD	30 year average number of frost days.
TEMP	30 year average temperature (°C).
WIND	30 year average wind speed (m/s).
PRECIP	30 year average precipitation (mm).
SUN	30 year average hours of sunshine.
REH	30 year average relative humidity (percentage).

Table 4.2: **Characteristics Of The Data Set**

	Mean	Std Dev	Minimum	Maximum
PRICE/ACRE	2584.81563	2338.27779	25.47771	32545.45508
ACRES	173.01516	527.74914	7.00000	9000.00000
POSSESS	0.97602	0.14511	0.00000	1.00000
PRIVATE	0.63789	0.47994	0.00000	1.00000
BEDS/ACRE	0.020357	0.037621	0.00000	0.27273
MILK/ACRE	0.16651	1.43838	0.00000	27.27273
COTTS/ACRE	0.0010344	0.0083522	0.00000	0.15556
SOIL1	0.021583	0.14549	0.00000	1.00000
SOIL2	0.12950	0.33615	0.00000	1.00000
SOIL3	0.45803	0.49883	0.00000	1.00000
SOIL4	0.17506	0.38047	0.00000	1.00000
SOIL5	0.031175	0.17400	0.00000	1.00000
SOIL6	0.095923	0.29484	0.00000	1.00000
FD	103.02947	18.02178	50.10000	151.70399
TEMP	9.16209	0.70113	6.60000	10.63300
WIND	4.82396	0.45941	4.06700	7.25000
PRECIP	889.27040	270.71954	547.29602	1929.40198
SUN	1456.62747	116.46908	939.90002	1725.19800
REH	85.96114	1.72231	81.97500	90.47500

Source: *See text.*

The 're-packaging' of farmland

Although the question of what constitutes the appropriate functional form of the hedonic price schedule is typically viewed as being solely an empirical question there are in fact theoretical reasons for supposing that the price of locational characteristics such as climate increases proportionately with plot size unless there are problems involved in 're-packaging' land; and also that the hedonic price function should be additively separable in terms of the structural attributes of the land (eg the buildings it has on it). If however transactions and bargaining costs form a significant cost then land cannot be costlessly re-packaged and otherwise identical plots of different sizes may well be sold for different unit costs. There appears to be only one formal test of the re-packaging hypothesis in the hedonic literature even this is in the context of housing rather than agricultural land[22]. The assumptions underpinning these theoretical restrictions are nothing more than the assumption of perfect competition in the market for land and attributes as well as zero transactions costs (so that the number of sales does not itself enter as an argument in the seller's profit function). These reasons behind these theoretical restrictions can be best appreciated in the following manner (attributable to Parsons, 1990).

Let p represent the sale price of a 'non-standard' plot of land, p(.) the hedonic price function, c(.) the cost of providing structural attributes, and x_1^*, x_2^* and x_3^* represent the 'standard' level of structural attributes, locational characteristics and plot size respectively. Let 't' and 'a' represent an integer greater than one. The land owner will be prepared to sell a plot of non-standard size and non-standard structural attributes provided that:

$$p - c(ax_1^*) \geq tp(x_1^*, x_2^*, x_3^*) - tc(x_1^*) \tag{38}$$

The logic of this condition is obvious. Each owner knows that they can sell a standard plot with standard attributes for a profit equal to $tp(x_1^*, x_2^*, x_3^*) - tc(x_1^*)$ so

[22] Coulson (1989) tests the linearity-as-repackaging hypothesis in the context of a sample of single-family house sales in Harrisburg, PA. Using the Box Cox transformation he finds that the repackaging hypothesis has a great deal of empirical content and that the hedonic price schedule is most nearly linear in plot-size.

that the buyer of a non standard plot must be prepared to pay the owner at least that much plus the cost of providing the non standard structural attributes. Note also that perfect competition in the supply of land and structural attributes means firstly that the inequality must hold *exactly* and also that the derivative of the hedonic price function with respect to the structural attributes must be equal to the marginal cost of supplying them. This implies that:

$$p = tp(x_1^*, x_2^*, x_3^*) - tc(x_1^*) + c(ax_1^*) \tag{39}$$

and:

$$\frac{\partial p(x_1^*, x_2^*, x_3^*)}{\partial x_1^*} = \frac{\partial c(x_1^*)}{\partial x_1^*} \tag{40}$$

respectively. Differentiating the equation for the price of a non-standard plot with respect to the locational characteristics yields:

$$\frac{\partial p}{\partial x_2^*} = t\,\frac{\partial p(.)}{\partial x_2^*} \tag{41}$$

In other words, whatever the functional form of the hedonic price function the price of locational attributes must be proportional to the size of the plot. Differentiating the price function with respect to the structural attributes yields:

$$\frac{\partial p}{\partial x_1^*} = t\,\frac{\partial p(.)}{\partial x_1^*} - t\,\frac{\partial c(.)}{\partial x_1^*} + \frac{\partial c(ax_1^*)}{\partial x_1^*} \tag{42}$$

but by virtue of the competitive supply of attributes then the derivative of the hedonic price function is a function only of the level of structural attributes:

$$\frac{\partial p}{\partial x_1^*} = \frac{\partial c(ax_1^*)}{\partial x_1^*} \tag{43}$$

This necessarily implies additive separability of the hedonic price function in terms of structural characteristics[23]. Finally, differentiating the price function with respect to the size of the non-standard plot size gives:

$$\frac{\partial p}{\partial t} = p(x_1^*, x_2^*, x_3^*) - c(x_1^*) \tag{44}$$

which is not a function of t. Of course t was arbitrarily chosen so that these restrictions must hold for all non-standard plot sizes. It is possible to show however that not all of the restrictions implied by repackaging actually hold (presumably because the underlying assumptions of the theory with regards to transactions costs are not met). Consider the case of the simple linear model below. The theory outlined above suggests that the coefficient on the term relating to the size of the plot could be set equal to zero without significant loss of fit:

$$\begin{gathered} PRICE_i\,/ACRE_i = \alpha + \beta_1 ACRE_i + \beta_2 POSSESS_i + \beta_3 PRIVATE_i + \\ \beta_4 BEDROOMS_i\,/ACRE_i + \beta_5 MILK_i\,/ACRE_i + \beta_6 COTTAGES_i\,/ACRE_i + \\ \beta_7 SOIL1 + \beta_8 SOIL2 + \beta_9 SOIL3 + \beta_{10} SOIL4 + \beta_{11} SOIL5 + \\ \beta_{12} SOIL6 + \beta_{13} FD_i + \beta_{14} TEMP_i + \beta_{15} WIND_i + \beta_{16} PRECIP_i + \\ \beta_{17} SUN_i + \beta_{18} REH_i + e_i \end{gathered} \tag{45}$$

In fact β_1 is negative and significant (see table 4.3) suggesting that the price per acre falls with plot size. This is consistent with the existence of fixed costs per transaction and it is presumably what prevents landowners from repackaging their plots into smaller sizes thereby increasing their overall profit[24].

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[23] It is of course possible to imagine some case in which additive separability would not be expected (for example it probably costs more to build a house on marshy ground).

[24] It may alternatively be argued that the failure of the hypothesis is a reflection of the functional form used. For example, one of the implications of the purely linear model is that the marginal value of any one of the characteristics is independent of the level of any other characteristic implying for example that the value of climate amenities are independent of the underlying quality of the land; something that seems a little counter-intuitive. But introducing all possible cross-products into the equation results in rather too many terms.

Table 4.3: The simple repackaging model

Method of estimation = Ordinary Least Squares

Dependent variable: PRICE/ACRE

Current sample: 1 to 417

Number of observations: 417

Mean of dependent variable = 2584.82

Std. dev. of dependent var. = 2338.28

Sum of squared residuals = .515288E+09

Variance of residuals = .129469E+07

Std. error of regression = 1137.85

R-squared = .773450

Adjusted R-squared = .763204

Durbin-Watson statistic = 1.83390

F-statistic (zero slopes) = 75.4880

Schwarz Bayes. Info. Crit. = 14.3020

Log of likelihood function = -3516.36

Variable	Estimated Coefficient	Standard Error	t-statistic
C	7271.94	4912.89	1.48018
ACRES	-.231996	.079043	-2.93505
POSSESS	1185.73	239.483	4.95120
PRIVATE	-181.786	125.630	-1.44699
BEDS/ACRE	33475.6	2286.11	14.6431
MILK/ACRE	725.156	72.3960	10.0165
COTTS/ACRE	65460.9	17666.5	3.70537
SOIL1	276.703	255.640	1.08239
SOIL2	402.422	195.685	2.05648
SOIL3	276.665	178.112	1.55332
SOIL4	-149.552	187.069	-.799448
SOIL5	-305.526	342.844	-.891151

SOIL6	710.470	267.050	2.66044
FD	5.16057	5.94238	.868434
TEMP	-70.8851	187.906	-.377237
WIND	-446.291	186.746	-2.38983
PRECIP	.072206	.351121	.205643
SUN	.066098	1.25884	.052507
REH	-54.2725	64.4734	-.841782

Source: *See text. S.E.s and variance shown are heteroskedastic-consistent estimates.*

Measuring amenity values for climate variables

The findings of the previous section suggests that substantial transactions costs make it difficult to put too much weight on arguments based on arbitrage. In this section the remaining hypotheses are tested and amenity values are inferred in the context of a model whose functional form is based solely on goodness of fit criterion rather than theoretical considerations.

The only concession made to functional form was to attempt the transformation of the dependent and independent variables by the means suggested by Box and Cox (1962):

$$\frac{PRICE/ACRE_i^{\lambda}-1}{\lambda} = \alpha + \beta_1\frac{ACRES_i^{\theta}-1}{\theta} + \beta_2 POSSESS_i + \beta_3 PRIVATE_i +$$

$$\beta_4\frac{BEDROOMS/ACRE_i^{\theta}-1}{\theta} + \beta_5\frac{MILK/ACRE_i^{\theta}-1}{\theta} + \beta_6\frac{COTTAGES/ACRE_i^{\theta}-1}{\theta}$$

$$\beta_7 SOIL1 + \beta_8 SOIL2 + \beta_9 SOIL3 + \beta_{10} SOIL4 + \beta_{11} SOIL5 + \beta_{12} SOIL6 +$$

$$\beta_{13}\frac{FD_i^{\theta}-1}{\theta} + \beta_{14}\frac{TEMP_i^{\theta}-1}{\theta} + \beta_{15}\frac{WIND_i^{\theta}-1}{\theta} + \beta_{16}\frac{PRECIP_i^{\theta}-1}{\theta} +$$

$$\beta_{17}\frac{SUN_i^{\theta}-1}{\theta} + \beta_{18}\frac{REH_i^{\theta}-1}{\theta} + e_i \qquad (46)$$

Four special cases were considered: $\lambda = 1$ and $\theta = 1$, $\lambda \to 0$ and $\theta = 1$, $\lambda = 1$ and $\theta \to 0$, and $\lambda \to 0$ and $\theta \to 0$. These refer to the linear, semi-log, log-lin and log-log models respectively. Note that the dummy variables are not transformed. In the log-log and semi-log models the marginal value of any one characteristic depends upon the levels of all other characteristics.

Using the method described by Maddala (1977) it was found that the semi-log model (corresponding to the case $\lambda \to 0$ and $\theta = 1$) was most likely to have generated the observed data (rather than the linear model) and the semi-log model was adopted for the remainder of the study in which the aim is to measure amenity values for climate variables. The equation succeeds in explaining 58% of the variation in the data with an adjusted R^2 of 56% (see table 4.4).

It is disappointing to see however that only one of the climate variables (windspeed) is statistically significant in this equation. One possible explanation is that annual averages are on the whole unimportant to agriculture and that seasonal averages are more meaningful. To investigate this possibility the equation is re-estimated using seasonal averages corresponding to 'summer' (April to September) and 'winter' (October to March). Accordingly the equation is re-estimated replacing each of the climate variables in turn with seasonal averages for summer and winter. In the case of frost days and precipitation quite dramatic improvements in fit are registered. For the remaining variables however including summer and winter averages does not cause the fit to improve significantly. In some cases this is because including both summer and winter averages introduces no new information to the model (for example the correlation between windspeed in summer and winter for a given location is 0.94). In these circumstances it is difficult to say whether or not such variables are valued differently at different stages of the growing cycle. In other cases the climate variables show significant variation across the seasons but do not appear to be valued in either summer or winter. The equation is re-estimated with frost days and precipitation included as both summer and winter averages and the remaining climate variables still as annual averages. The fit of the regression increases to 60% and the adjusted R^2 increases to 58% (see table 4.5).

Table 4.4: The hedonic land price regression with annual averages of climate variables

Method of estimation = Ordinary Least Squares

Dependent variable: PRICE/ACRE

Current sample: 1 to 417

Number of observations: 417

Mean of dependent variable = 7.62153

Std. dev. of dependent var. = .708015

Sum of squared residuals = 87.3581

Variance of residuals = .219493

Std. error of regression = .468501

R-squared = .581086

Adjusted R-squared = .562140

Durbin-Watson statistic = 1.80015

F-statistic (zero slopes) = 30.6708

Schwarz Bayes. Info. Crit. = -1.28818

Log of likelihood function = -265.797

Variable	Estimated Coefficient	Standard Error	t-statistic
C	10.7845	2.48963	4.33175
ACRES	-.399696E-03	.904873E-04	-4.41715
POSSESS	.529067	.159707	3.31273
PRIVATE	-.138266	.050250	-2.75158
BEDS/ACRE	10.0701	.748648	13.4511
MILK/ACRE	.027326	.013974	1.95548
COTTS/ACRE	9.65419	4.62359	2.08803
SOIL1	.072023	.119722	.601590
SOIL2	.191626	.087232	2.19673
SOIL3	.089096	.078038	1.14169
SOIL4	-.847167E-02	.085992	-.098517

SOIL5	-.260540	.169611	-1.53610
SOIL6	.171883	.103879	1.65465
FD	.111181E-02	.306664E-02	.362551
TEMP	.030075	.109237	.275319
WIND	-.346594	.105941	-3.27159
PRECIP	.117028E-03	.162622E-03	.719632
SUN	.271068E-04	.669301E-03	.040500
REH	-.031145	.031100	-1.00145

Source: *See text. S.E.s and variance shown are heteroskedastic-consistent estimates.*

Table 4.5: The hedonic land price regression with seasonal averages of climate variables

Method of estimation = Ordinary Least Squares
Dependent variable: PRICE/ACRE
Current sample: 1 to 417
Number of observations: 417
Mean of dependent variable = 7.62153
Std. dev. of dependent var. = .708015
Sum of squared residuals = 83.7221
Variance of residuals = .211419
Std. error of regression = .459804
R-squared = .598522
Adjusted R-squared = .578245
Durbin-Watson statistic = 1.81249
F-statistic (zero slopes) = 29.5177
Schwarz Bayes. Info. Crit. = -1.30176
Log of likelihood function = -256.933

Variable	Estimated Coefficient	Standard Error	t-statistic
C	7.22792	3.07122	2.35344
ACRES	-.382880E-03	.841929E-04	-4.54765
POSSESS	.521473	.157574	3.30939
PRIVATE	-.141975	.050511	-2.81075
BEDS/ACRE	10.2829	.755772	13.6058
MILK/ACRE	.030082	.014126	2.12958
COTTS/ACRE	9.98021	4.87923	2.04545
SOIL1	.030643	.107632	.284703
SOIL2	.163191	.085563	1.90726
SOIL3	.098827	.076228	1.29646
SOIL4	.731187E-02	.083322	.087754

SOIL5	-.253309	.166173	-1.52436
SOIL6	.162568	.102619	1.58420
FD(S)	-.094336	.031725	-2.97356
FD(W)	.025179	.756290E-02	3.32934
TEMP	.148091	.120092	1.23315
WIND	-.407503	.105581	-3.85961
PRECIP(S)	.194229E-02	.103003E-02	1.88565
PRECIP(W)	-.450625E-03	.479391E-03	-.939994
SUN	-.136086E-02	.832132E-03	-1.63539
REH	.018315	.036636	.499913

Source: *See text. S.E.s and variance shown are heteroskedastic-consistent estimates.*

Discussion

The first issue of interest relates to the combining of data from auctions and private treaty sales. Originally many hedonic studies were conducted using private or professional valuations rather than sale price data (see Freeman 1993 for a discussion). Here the presence of both actual market data and valuations make it possible to test whether the intercept of the model is different for the two price measures (for simplicity, common slopes is a maintained hypothesis). Clearly, if the guide price is an unbiased predictor of sale price then $\beta_3 = 0$. In reality however the guide price appears on average to overestimate the eventual sale price by about 15%. Furthermore there is evidence that the error variances differ between observations which are based on the guide price rather than the true sale price. The error variance of the former group are larger than those for the latter[25]. This might be interpreted as evidence of informational asymmetries between the land agents who set the guide price and those bidding for it.

The coefficient on the variable indicating vacant possession is both positive and significant illustrating that regulations governing tenancies hold rents beneath market values and reduce the value of the property to institutional investors. More specifically, the same property sold with vacant possession fetches 50% more on the open market.

The coefficients on the variables describing the number of bedrooms, the number of cottages and the number of milk quotas per unit of land are significant and have the anticipated signs. However, the land quality grading system appears to play an uncertain role. Given the way that they are commonly presented in a sales prospectus one might have anticipated that the signs on these variables would all be positive and the coefficients would decline as land quality moves from grade 1 quality to grade 7. In fact however whilst grades 1 to 3 are more valuable than grade 7, grades 4 and

[25] This is easily confirmed using the Goldfeld Quandt test for homoscedasticity (Goldfeld Quandt, 1965). $F_{247, 132} = 1.28$; CV at the 95 % level of confidence also = 1.28. As a consequence of the (near) failure of the assumption of homoscedasticity all the reported standard errors and variances are heteroscedastic-consistent (White, 1980).

5 are less valuable. Moreover, grade 6 land is the most valuable of all. This underlines the fact that the grading system classifies land according to physical rather than economic criterion (see above).

Turning now to the climate variables, when looked at individually many of these are seen to have a highly significant impact on the price of land. Moreover the impact of these variables on land values is often differently signed according to the season, so continuing to work with seasonal statistics rather than annual averages appears to be important. The hedonic price schedule is differentiated with respect to these variables to obtain the implicit price schedule. The implicit prices are evaluated at sample means and presented in table 4.6. These implicit prices have been annuitised at 5% per annum so that they refer to the annual stream of benefits associated with an additional unit of each climate variable.

It appears that the an increase in the number of frost days during summer reduces the value of land quite markedly. What is more surprising is that an increase in the number of frost days during winter increases land values. This could be explained by stating that a cold snap during winter time kills pests and vermin to the benefit of agricultural production[26]. Annual average temperature however appears to be an insignificant determinant of land prices. It is interesting to see that the use of a measure of extremes is much more significant than a measure of averages and this appears to be a confirmation of what many others have suggested would be the case for agriculture (see for example Mearns et al, 1984). Wind speeds might have been expected to have had a significant influence on land values and do so. First one could say that wind speeds cause physical damage crops such as corn. Secondly one could argue that strong winds during the summer are likely to cause erosion of the topsoil. Greater precipitation in the summertime is viewed as an amenity but during the wintertime appears neither advantageous or detrimental. Marginal changes in the hours of sunshine or relative humidity appear not to be important.

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[26] There is a lugubrious old saying that "a warm winter makes for a fat graveyard."

Not withstanding the problems caused by the absence of a hedonic wage rate regression for farm workers it would be tempting to present these values as a measure of the *value* of climate change's impact on Britain so far as agriculture is concerned. But it must be acknowledged that whereas the implicit prices genuinely reflect the marginal bid of the farmer to pay for climate amenities, that the values viewed from the perspective of society are different. The value of agricultural output and therefore land values are inflated due to the operation of the Common Agricultural Policy (CAP). One could be content with just calculating the implicit prices from the perspective of farmer or alternatively one could attempt some kind of ad hoc adjustment to the land prices. One possibility (not attempted here) is to determine the impact of CAP interventions on the level of land prices generally using a time series econometric model. The model might then be used to simulate the removal of the CAP and the results used to adjust land prices in order to bring the values expressed by the farmer more into line with the values of society. The only published attempt to ascertain the impact of the CAP on UK land prices is the work of Traill (1979).

Table 4.6: The impact of climate variables on farmland prices (evaluated at sample means and annuitised at 5% per annum)

Climate variable	Implicit price per acre
Frost (Summer) ***	-£12.19 / frosty day
Frost (Winter) ***	+£3.25 / frosty day
Temperature	+£19.14 / °C
Windspeed ***	-£52.67 / m/s
Precipitation (Summer) *	+£0.25 / mm
Precipitation (Winter)	-£0.06 / mm
Sunshine	-£0.18 / hr
Relative Humidity	+£2.37 / percentage point

Source: *See text. Note that *** means significant at 99%, ** means significant at 95% and * means significant at 90%.*

Conclusions

This chapter has presented a new and alternative means of calculating the impact of marginal changes in climate to the UK agricultural sector. The results appear to suggest that the effect of climate change on UK agriculture would be very sensitive to the precise nature of any change. There are however many caveats attached to the results: in the first place the value of climate to the farmer is not necessarily the value of climate to society by virtue of the CAP. Nor can the technique identify the impact of the CO_2 fertilisation effect on productivity. The most important caveat however is that this analysis investigates the implicit price of climate amenities only insofar as they are embedded in the hedonic land price schedule (and not in the wages of agricultural workers).

As a group climatic variables are shown to exert an important influence on land prices. Although the signs of the coefficients can often be given sensible interpretations the individual coefficients are not always well determined. This is because there is insufficient variation in climate across the data set. In this respect anyway the analysis would work best on data drawn from a country not subject to such large scale interventions in agricultural markets as well as being broad enough to include quite different climatic regimes. There is also evidence that the use of seasonal values rather than annual averages is important to land prices and also that the use of measures of climatic extremes can improve the fit of the hedonic land price regression.

The chapter also produces a set of other interesting findings unrelated to amenity values. It demonstrates that the guide price used by land surveyors is a biased (as well as a rather noisy) guide to the eventual sale price. It demonstrates that tenanted farms significantly reduce the value of similar farmsteads but with vacant possession. Finally, it demonstrates that farmland cannot be costlessly re-packaged in the sense that the size of a plot exerts a significant effect on the eventual sale price per acre.

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5. In search of warmer climates: the impact of climate change on flows of British tourists

The preceding chapters have dealt with the amenity value of the *British* climate. But insofar as British people are now, largely for the purposes of recreation, spending more time away from home than ever before the climate of other countries may also be important to the welfare of the British, if only for purely selfish reasons[27]. Organised trips are now available taking people from Britain to destinations in North America, Asia, Africa and Oceania whilst package tours to the Mediterranean are now almost a quintessential part of British life. The rapid growth in international tourism whether as a part of an organised tour or independently is a reflection of greater leisure time (due in part to an ageing population) and a growth in real incomes. There is also evidence linking the growth of package holidays in the Mediterranean with reductions in cost caused by more fuel efficient planes and with a decrease in the cost of accommodation (Perry and Ashton, 1994). In addition to the relative price of different locations choice of destination is presumably influenced by a desire to visit particular landscapes or sandy beaches for recreational purposes, motivated by a desire to explore or renew cultural ties between countries or to partake of the alleged health benefits of particular locations. Poor health has often been cited as a reason for making a journey (eg the remedial properties of hot spas, mountain air and coastal climates). Even until quite recently a tan was considered rather a 'healthy' thing to possess. Choice of destination is also heavily influenced by the image that a country has with regards to its political stability and crime rate (eg the recent poor publicity surrounding Florida following the murder of several British tourists).

But a major factor in choice of both destination and time of departure is climate. Indeed, when British tourists go abroad they are often described as being 'in search of warmer climates'. Tourists might be construed as making a decision to go abroad in order to gain some short-term climatic advantage. Certainly, with regard to domestic tourism retired people in particular can be observed migrating south for the

[27] In 1994 UK residents made almost 40 million trips abroad (CSO, 1995).

winter in America to Mexico whilst in Australia they head north to the 'Gold Coast' resorts of Queensland. Both 'push' and 'pull' factors are clearly at work. Whilst the importance of climate to both domestic and international tourism is hardly disputed there are not very many studies which have explored the implications of various climate change scenarios for international tourism even in a qualitative fashion (see Wall, 1992 for an exception).

The potential impact of climate change on tourism *within* Britain is dealt with by Smith (1991) and published in the Government's own review of the potential impacts of climate change on the United Kingdom. According to Smith, the tourist season may lengthen and tourist satisfaction may increase. But here too there is no attempt to determine the changes in the overseas destinations of UK tourists, changes in the number of holidays taken (although these changes are argued to be small when compared to likely changes arising from greater leisure time and higher incomes) nor to value the costs or benefits from changes in the climate insofar as international tourism is concerned. The purpose of this chapter then is to assess in a quantitative fashion, probably for the first time, the importance of climate as a determinant of choice of travel destination for British residents among a number of other possible factors including travel cost[28].

From a purely strategic perspective it is of obvious interest to examine how the numbers visiting different sites change as the climate changes. Many island economies in particular are heavily dependent on tourism and if climate is what tourists are seeking then climate change may have significant consequences for these island economies. Furthermore, following the methodology outlined in this chapter it is possible to compute a money-metric measure of how welfare changes as the attributes of a set of sites change (the welfare of tourists changes in the sense that more desirable climates may be brought closer to home). There is also a possibility that several low-lying island states may well become 'unavailable' in the sense that

[28] Somewhat surprisingly perhaps, a survey of the economics and geographic literature failed to uncover any empirical analyses of climate as a determinant of holiday destination.

they risk being inundated by rising sea levels. The methodology employed enables monetary values to be placed on this eventuality at least in so far as 'use' values are concerned. The methodology rests on the fact that different sites are characterised by different travel costs and accommodation costs. By observing differences in visitation rates it is possible to examine the rate at which individuals are willing to trade off higher money costs against desirable 'site attributes' such as climate. The economic values of changes in both site quality and availability may be of interest to those seeking to compile an overall damage cost assessment to the effects of climate change.

The remainder of this chapter is organised as follows. The next section examines the plausibility of one of the key assumptions underlying revealed preference techniques: the existence of perfect information. The third section describes the model used to explain the pattern of observed visitation rates, the extraction of money metric measures regarding changes in site quality and availability and discusses some alternative specifications. The fourth section looks at the data sources available for the purposes of estimating the proposed model. The fifth section considers the results of the statistical exercise. The penultimate section uses the results of the exercise to illustrate the impact of climate change on particular tourist destinations and the final section concludes.

Climate and tourism: the assumption of perfect information

The first information that potential holidaymakers encounter regarding the climate of a particular destination is through the travel company's brochure. The image of an attractive climate is cultivated in the mind of the consumer (usually) bounded by the requirement to remain within certain standards. There is obvious scope to be selective in the presentation of particular climate variables. The existence of warm temperatures in the Mediterranean during wintertime is pushed but the relatively higher rainfall (compared to London) occurring at that time is downplayed. Holiday tour operators frequently use the same 'blue sky' photographs in their summer and winter brochures. Even when climatic tables are given there is a concern that these raw data are not readily understood by the potential tourist and that some 'expert interpretation' is required.

The view that tourists were largely ignorant of or were purposefully deceived about the climate of their intended destinations (and therefore suffered disappointment as a result) and were moreover incapable of assessing for themselves raw climate data led to the construction of indices which purported to objectively evaluate tourist potential of the climates of different countries. In the view of the contributors to this literature (eg Mieczkowski, 1985) the climatic resources of the world were not being fully utilised or, to put it another way, the inadequate provision of information resulted in market failure. In these indices different components of climate were subjectively weighted and placed on a labelled scale.

Perhaps as a result of the view that tourists do not have access to perfect information there are no examples of taking a revealed preference approach to tourist flows in the literature. But are tourists really so lacking in information? Do they allow themselves to be persuaded by blue-sky photographs? Tourists presumably have come to expect blue-sky photographs and discount such tricks. Furthermore the traveller has ready access to sources of high quality low cost information which is independent of the travel company he goes with in the form of countless travel guides, television programmes such as *The Travel Show*, daily weather reports for world capitals published in the newspaper as well as television and radio weather forecasts which now cater for the overseas traveller and even quite specialised weather guides such as Pearce and Smith (1993). The main source of information however is surely from people who have already visited a particular destination. They know how the climate actually felt and can describe it in terms familiar to their family and friends. Tourists are also able to take legal redress against tour operators whose holidays were for one reason or another sub-standard. Since the cost of obtaining this information is low relative to the cost of a typical package holiday the tourist has every incentive to take advantage of it (Perry, 1993). It is frankly hard then to conceive of how travel companies could consistently mislead the majority of tourists with respect to what type of climate to expect and the concerns of earlier researchers appear misplaced. As such the revealed preference approach, which rests on the assumption of perfect knowledge concerning the attributes of different destinations, can be expected to work well whereas much of the earlier literature looks like an anachronism. Furthermore, the revealed preference approach is capable of expressing in monetary terms the extent to which changes in the climate of different holiday destinations changes welfare which is a fundamental objective of this chapter.

The Pooled Travel Cost Model

The travel cost method is most often used to estimate the value of individual recreation sites. The basic idea behind the travel cost method is that individuals base decisions on whether or not to visit particular sites on the various costs associated with travel to the site, and on the benefit they derive from using it. Comparing different levels of visitation to a site from populations with different travel costs to reach that site, then allows the value of the site to be estimated.

The most straightforward form of the technique is the zonal travel cost method. The method is as follows: the area surrounding the site is divided into concentric circular zones, for which travel cost is estimated for a return trip; visitation rates are calculated for each zone (number of visits divided by population); visitation rates are regressed on travel cost and selected socio-economic variables; observed total visitation represents one point on the demand curve for each zone; other points on the curve are estimated by assuming that visitors respond to an increase in admission price in the same way that they would respond to an increase in travel cost.

There are several potential sources of bias in the travel cost method, and the following list is not exhaustive. For one, the model relies on the assumptions that the demand structures are identical, and that preferences are the same, in every respect other than is controlled for in the regression equation. In order for the full travel cost to be the correct variable for determining benefits, a visit to the site must be the sole purpose of the trip. Often, however, visits to one site may be combined with visits to other sites (whether for recreational or other purposes, e.g. shopping). Perhaps the single most intractable difficulty with the travel cost method lies in the valuation of the time spent on the visit. The method requires the valuation of the total time spent on travel, and the valuation of time spent on site. Thus, the value of several hours (at least) of each individual's time is sought. The zonal travel cost technique is reviewed in Freeman (1993).

The travel cost technique may also be used to estimate the value of a quality change at a site. The procedure invokes the assumption that the characteristic of interest is weakly complementary with a private good; in other words, the assumption is that the environmental quality variable is valued only if a trip is made. The paper now presents a theoretical model of the allocation of time and money spent visiting different destinations (or 'sites' as they are called in the travel cost literature) and the consumption of other goods. The model is based largely on McConnell (1992) and Johansson (1987). Note that unlike in the majority of the travel cost literature the time spent at particular sites is modelled as being a variable of choice and places particular emphasis on the valuation of site characteristics.

Assume that the individual derives utility from the number of visits to different destinations, the time spent on each visit, as well as from the consumption of a vector of other goods. The individual's utility function can be written as:

$$u = u(q, x, t, z) \tag{47}$$

where u is utility, q is a vector of consumption goods, x is a vector containing the number of visits made to each site, t is a vector detailing the time spent on each visit to site j and z is a vector of site quality. The constraint attached to the choices made is as follows:

$$qp_q + xp = m + lp_w - tp_w - axp_w \tag{48}$$

where p_q is a vector of prices, p is the (ticket) price of travel, m is unearned income, l is the amount of time available for work, p_w is the wage rate and 'a' is the time required to visit a site. Thus the final term of the right-hand side of the equation represents the economic cost of time spent travelling. Associated with the solution to this problem of constrained maximisation is the indirect utility function V (in which some constants are suppressed in order to simplify the notation):

$$V = V(p, z) \tag{49}$$

Employing Roy's theorem yields a set of demand equations for among other things the number of visits to each site:

$$\frac{V_p}{\lambda} = -x(p, z) \tag{50}$$

where λ is the marginal utility of money (which is treated as a constant). Let p^0 represent the current price of travel and p^c a price so high that no trips are taken at all (p^c may be infinity and is often referred to as the 'choke' price). Integrating both sides with respect to p between the limits of p^c and p^0 gives the Consumer Surplus (CS) obtained from the site:

$$CS = \frac{V(p^c, z^0)}{\lambda} - \frac{V(p^0, z^0)}{\lambda} = -\int_{p^o}^{p^c} x(p, z^0)dp \tag{51}$$

Next, differentiating both sides with respect to z gives:

$$\frac{V_z(p^c, z^0)}{\lambda} - \frac{V_z(p^0, z^0)}{\lambda} = -\int_{p^o}^{p^c} x_z(p, z^0)dp \tag{52}$$

But given the assumption of weak complementarity between x and z (see Freeman, 1993):

$$\frac{V_z(p^c, z^0)}{\lambda} = 0 \tag{53}$$

In other words, if it can be assumed that there exists a price so high at which the number of trips taken to the site falls to zero, then changes in the level of the site attribute z do not affect utility. Integration of this equation with respect to z gives the change in CS following a change in the level of site attribute z:

$$\Delta CS = -\int_{p_0}^{p_c} [x(p, z^0) - x(p, z^1)]\ dp \tag{54}$$

where z_0 and z_1 are the pre and post change level of site attribute. Note that even though several commodities may exhibit weak complementarity with environmental quality (eg flight costs, accommodation costs etc) all that is required in order to measure the value of changes in environmental quality is the demand curve for one of those commodities.

When many alternative sites are being studied there may be substantial variation in qualities across sites. But whilst travel costs to the same site may or may not differ between individuals (in the empirical application of the model described below they do not) the site quality is the same for everyone. Therefore all empirical models which attempt to incorporate site quality have involved some kind of simplification and as a consequence suffer limitations in their ability to characterise recreation demand accurately (Freeman, 1993). One approach (see for example Smith et al, 1986 or Caulkins et al, 1986) has been to pool all of the observed visitation rates for the different sites and to estimate a single demand function in which the observed visitation rates are solely a function of the own price and quality variables:

$$x_j = x(p_j, z_j) \; \forall j \tag{55}$$

This model is referred to as the Pooled Travel Cost Model (PTCM) and is the model employed in this paper. The fundamental weakness of the PTCM is that it predicts changes in the overall number of visits to a group of sites but does not allow for a reallocation of visits between different sites following a change in the price or quality attributes of alternatives. Moreover it assumes that the coefficients on the own price and quality variables are the same across all sites. By contrast, reallocation effects are dealt with explicitly by the Random Utility Model (RUM) of choice approach to valuing site attributes.

With the RUM an individual chooses from a set of alternatives according to the utility which they provide. The indirect utility function (V) associated with a particular site j and choice-occasion is:

$$V_j(z_j, y-p_j) \tag{56}$$

where z_j is a vector of site attributes, y is income and p_j is the price of visiting the site. The indirect utility function contains a random error term which means that the choices made cannot be predicted with certainty but only with a given probability. The random error term reflects the existence of unobserved site characteristics and/or variations in taste between individuals. An individual visits a particular site k provided that:

$$V_k(z_k, y-p_k) + e_k > V_j(z_j, y-p_j) + e_j \quad \forall \; sites \; j \neq k \tag{57}$$

If the random error terms are distributed as type I extreme value variates then the probability of an individual i making choice j is given by:

$$Prob\ (Y_i = j) = \frac{e^{V_{ij}}}{\sum_{j=1}^{j=n} e^{V_{ij}}} \tag{58}$$

This is referred to as the Conditional Logit model. This model however has well known shortcomings of its own, one of which is the implicit assumption of the Independence of Irrelevant Alternatives (IIA). A further defect of the RUM is that it is incapable of predicting any possible change in the total number of tourist trips made following a change in site attributes: all that is predicted is how an exogenously determined number of trips are allocated between different destinations (eg see Bockstael et al, 1986). The only reason why the PTCM is preferred to the RUM in this instance is because the RUM is computationally difficult when the number of choices exceeds more than just a few.

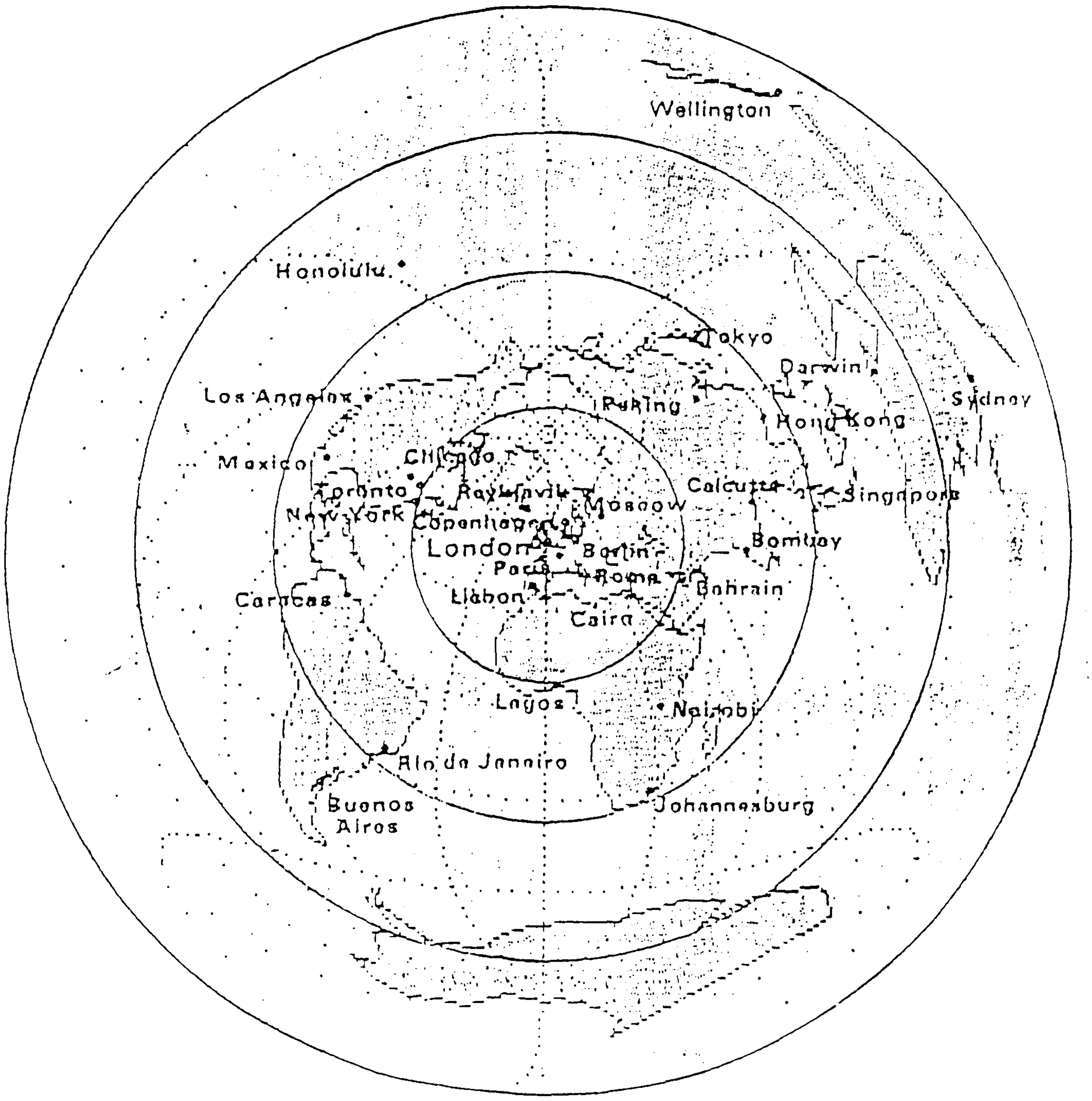
Data and specification

Having outlined its theoretical underpinnings, this section describes the data sources for the variables used to estimate the PTCM as described by equation (55). There is little in the way of existing literature to act as a guide to the appropriate specification of the model (at least in terms of what quality attributes are the important ones). Accordingly the analysis should be looked upon as a probationary one.

For the dependent variable quarterly data on international travel by British residents is taken from the International Passenger Survey (IPS) for 1994. Visits abroad for reasons other than holidaymaking (eg business trips) are excluded since they are not as responsive to climatic factors. The data set also contains the average return fare paid per person to each destination, average spending on items other than fares and the average duration of the stay. From the latter two variables it is possible to determine daily expenditure. Whilst this is not the same thing as having a sterling price index for the cost of living relevant to tourists it is quite clear that things such as accommodation costs are an important consideration to the potential tourist and also that some countries are considerably more expensive to stay in than others. It was argued in the theoretical model that the amount of time required to travel to the country of interest had an opportunity cost attached to it such that other things being equal nearby resorts are preferred. The average time spent in transit is not available so as a proxy the 'great circles' distance from London is used instead. The great circles distance is the shortest distance which an aircraft could fly to reach a particular destination. Ordinary rectangular (mercator projection) maps found in most atlases obviously cannot be used to measure the great circles distance and instead an azimuthal equidistant projection map is required (see fig. 5.1)[29].

[29] A computer programme made available through the University of Michigan to measure the great circles distance between the world's capital cities can be found on the following internet site: http://www.indo.com/distance/.

Figure 5.1: An azimuthal equidistant projection map based on London



Source: *The Times Atlas.*

GDP per capita in US dollars converted using purchasing power parity exchange rates is taken from the UNDP (1995). Its inclusion in the data set reflects the belief that countries with higher GDP possess better tourist infrastructure (hotels, restaurants, visitor centres etc). Furthermore some tourists might be upset by visions of poverty and squalor which would greet them in many low income countries. Population and population density are taken from the Times Atlas (1992). Population proxies for the quantity of what might be called the 'cultural capital' that a particular country possesses (eg notable museums, sites of historical significance, buildings of architectural interest). Population density proxies for what might be referred to as 'natural capital' (eg unspoilt areas, environmental quality). These are unashamedly broad terms. It is anticipated that whereas the former will be positively related to tourism flows, the latter will negatively affect them.

The attraction of some countries clearly lies in the fact that they possess unspoilt sandy beaches fit for recreation. The total length of beaches found in different countries is available from a report by Delft Hydraulics (1990) and is added to the data set. Climate variables are taken from Pearce and Smith (1994). The climate of the country's capital city is taken since this is arguably the most relevant for tourists (although there are arguments for producing a weighted average of several records to represent the climate of the larger climatically more diverse countries). Two variables are included as a description of the climate: averaged maximum daytime temperature and precipitation on a quarterly basis. The former is included in both a linear and quadratic fashion. Including both linear and quadratic terms allows temperature to exert both a positive and negative influence on visitation rates depending upon the current temperature. Finally, three dummy variables are included to represent the different quarters. The role of these variables is to demonstrate that differences in visitation rates can ascribed to climate rather than any other seasonal factors such as statutory holidays. Many other variables might be expected to have an important influence on holiday destinations even though they are not included in the data set. Foremost among these are surely variables describing the level of personal security. This might in some future study be satisfactorily proxied by the inclusion of countries' respective murder rates. Sunshine too is omitted since it is not collected on a consistent basis for very many capitals. This is unfortunate in that many tourist destinations (such as Cyprus) are renowned for their sunny climate.

In total 305 complete observations are available from 88 different countries. The variables contained in the data set are listed in table 5.1, and the characteristics of the data set are examined in table 5.2. The different countries represented in the data set are listed in table 5.3.

Turning now to the functional specification of the model, the demand equation for the PTCM is modelled as:

$$\frac{VISITS_j^{\lambda}-1}{\lambda} = \alpha_0 + \beta_1 FARE_j + \beta_2 GDP_j + \beta_3 POP_j + \beta_4 POPDEN_j + \beta_5 BEACH_j + \beta_6 PDAY_j + \beta_7 DIST_j + \beta_8 TEMP_j + \beta_9 TEMP_j^2 + \beta_{10} PRECIP_j + \beta_{11} Q1_j + \beta_{12} Q2_j + \beta_{13} Q3_j + e_j \qquad (59)$$

where the subscript j refers to each different observation in the data set. Two special cases were considered: $\lambda = 1$ and $\lambda \rightarrow 0$. These refer to the linear and semi-log models respectively[30]. In the linear model the impact on visitation rates of a change in the level of any variable is independent of the level of any other variable whereas in the somewhat more plausible semi-log model this is not the case. β_1, being the coefficient on the own-price variable is expected to be negative, as are the coefficients β_4, β_6, β_7, β_9 and β_{10}. In contrast the coefficients β_2, β_3, β_5 and β_8 are expected to be positive. There are no prior expectations regarding the sign of the coefficients β_{11}, β_{12} and β_{13}.

[30] In contrast to the previous chapters the left-hand side variables are not transformed into logarithms since some of them take negative values.

Table 5.1: Definition of variables contained in the travel cost data set

Variable	Definition
VISITS	Number of visits from the UK
FARE	Average cost of a return fare (£s)
GDP	GDP per capita (1992 USD)
POP	Population
POPDEN	Population density (persons per km^2)
BEACH	Beach length (km)
PDAY	Cost of an extra day's stay (£s)
DIST	Great circles distance from London to the capital (miles)
TEMP	Quarterly averaged maximum daytime temperature of the capital city (°C)
PRECIP	Quarterly precipitation in the capital city (mm)
Q1	Takes the value unity for the first quarter, zero otherwise
Q2	Takes the value unity for the second quarter, zero otherwise
Q3	Takes the value unity for the third quarter, zero otherwise

Source: *See text.*

Table 5.2: Characteristics of the travel cost data set

Number of observations = 305

Variable	Mean	Std. Dev.	Minimum	Maximum
VISITS	85134.	0.26600E+06	235.0	0.2332E+07
FARE	225.58	148.47	17.00	818.0
GDP	10015.	6950.7	620.0	0.2376E+05
POP	0.4948E+08	0.1570E+09	6700.	0.1100E+10
POPDEN	395.83	1378.5	0.2455E-01	0.1350E+05
BEACH	131.03	368.09	0.0000	2970.
PDAY	37.397	15.774	9.287	181.0
DIST	3565.9	2523.3	199.0	0.1168E+05
TEMP	22.496	8.5632	-3.667	38.67
PRECIP	83.404	69.773	0.0000	403.3
Q1	0.23279	0.42330	0.0000	1.000
Q2	0.25902	0.43881	0.0000	1.000
Q3	0.26557	0.44236	0.0000	1.000

Source: *See text.*

Table 5.3 Countries included in the travel cost data set

Anguilla
Antigua
Argentina
Australia
Austria
Azores/Madeira
Bahamas
Barbados
Belgium
Bermuda
Bolivia
Brazil
Brunei
Canada
Canaries
Cayman Islands
Chile
China
Colombia
Cuba
Cyprus
Denmark
Djibouti
Dominican Republic
Ecuador
Egypt
Fiji
Finland
France
French Polynesia

Gabon

Gambia

Germany

Gibraltar

Greece

Greenland

Grenada

Hong Kong

Hungary

Iceland

India

Indonesia

Iran

Israel

Italy

Jamaica

Japan

Jordan

Kenya

Lebanon

Luxembourg

Malaysia

Malta

Mauritius

Mexico

Monaco

Morocco

Nepal

Netherlands

New Caledonia

New Zealand

Norway

Pakistan

Philippines

Poland

Portugal

Puerto Rico

Romania

South Korea

Seychelles

Singapore

Slovenia

South Africa

Spain

Sri Lanka

St Lucia

Sweden

Switzerland

Syria

Tanzania

Thailand

Trinidad

Tunisia

Turkey

UAE

Uganda

USA

Venezuela

Results

Using the method described by Maddala (1977) it was found that the semi-log model (corresponding to the case $\lambda \rightarrow 0$) was indeed most likely to have generated the observed data. The results of the semi-log regression analysis are displayed in table 5.4. Note that the coefficients can be interpreted as the proportionate change in the number of visits per unit change in the level of the dependent variable.

Overall the regression is highly significant and manages to explain almost 50% of the variation in the log of observed visitation rates. Furthermore the hypotheses put forward in the preceding section are all upheld. Nonetheless not all visitation rates are well predicted which is unsurprising given the importance of country-specific factors in determining choice of destination. As expected, the coefficient on the own-price variable 'FARE' is negative and highly significant indicating that, other things being equal, more expensive destinations generate fewer trips. It is also observed that countries with a higher GDP per capita are likely to generate more trips as are more populous countries but that countries with a lower population density are preferred. Countries with greater numbers of beaches are well-liked. The variable indicating the cost per day of visiting the different sites is negative and highly significant indicating that the more expensive a country is to stay in, the more infrequently it is visited. The variable describing the great circles distance from London has the correct sign but has only marginal significance. In part this may be because of the relatively high correlation between distance travelled and fare price[31].

Turning to the climate variables, the coefficients on the linear and quadratic terms describing quarterly averaged maximum daytime temperature are positive and negative respectively pointing to the existence of an 'optimal' maximum daytime temperature for tourism of around 29°C[32]. Precipitation on the other hand has a

[31] The correlation coefficient is 0.81.

[32] No attempt should be made to compare the optimal temperatures for tourism with the optimal temperatures for the provision of human amenity described in chapter three. The ideal temperature for leisure and recreational pursuits and the ideal temperature for everyday

negative coefficient indicating that greater rainfall deters tourists although not significantly so. This suggests that perhaps a different measurement concept other than precipitation such as rain-days might have been more appropriate or else that other omitted climate variables like hours of sunshine have biased the coefficient on rainfall. None of the dummy variables describing the time of departure are significant implying that it is climate rather than other seasonal factors which explain observed visitation rates.

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living and working are likely to be profoundly different.

Table 5.4: The estimated pooled travel cost model

Ordinary least squares regression.			Dep. Variable = Log VISITS	
Observations = 305			Weights = ONE	
Mean of LHS = 0.9244884E+01			Std.Dev of LHS = 0.1987143E+01	
StdDev of residuals = 0.1438978E+01			Sum of squares = 0.6025611E+03	
R-squared = 0.4980400E+00			Adjusted R-squared = 0.4756157E+00	
F[13, 291] = 0.2220981E+02			Prob value 0.0000000E+00	
Log-likelihood = -0.5366101E+03			Restr.(ß=0) Log-l = -0.6417184E+03	
Amemiya Pr. Criter. = 0.3610558E+01			Akaike Info.Crit. = 0.2165703E+01	
ANOVA	Source	Variation	Degrees of Freedom	Mean Square
	Regression	0.5978556E+03	13.	0.4598889E+02
	Residual	0.6025611E+03	291.	0.2070657E+01
	Total	0.1200417E+04	304.	0.3948739E+01

Variable	Coefficient	Std. Error	t-ratio	Prob|t|≥x
Constant	8.3472	0.5370	15.545	0.00000
FARE	-0.56164E-02	0.1003E-02	-5.602	0.00000
GDP	0.73447E-04	0.1539E-04	4.772	0.00000
POP	0.13699E-08	0.5751E-09	2.382	0.01785
POPDEN	-0.20062E-03	0.6318E-04	-3.175	0.00166
BEACH	0.14725E-02	0.2569E-03	5.732	0.00000
PDAY	-0.12633E-01	0.5436E-02	-2.324	0.02082
DIST	-0.76482E-04	0.5964E-04	-1.282	0.20069
TEMP	0.17252	0.4205E-01	4.103	0.00005
TEMPSQ	-0.29564E-02	0.1022E-02	-2.893	0.00410
PRECIP	-0.11087E-02	0.1342E-02	-0.826	0.40954
Q1	0.10804	0.2466	0.438	0.66162
Q2	-0.28269	0.2390	-1.183	0.23792
Q3	-0.13340	0.2448	-0.545	0.58617

Source: *See text.*

Discussion

Using these results it is possible to examine the change in consumer surplus following a change in site attributes. The PTCM is also capable of answering the question "do British tourists have measurable use values for the low lying islands". The future facing these particular tourist destinations may not be a change in 'site quality' but instead elimination through inundation under some climate change scenarios. These benefits are of course estimated only for British residents and many caveats apply, not least the assumptions made about the unimportance of the price and quality of substitute sites. The effect of this particular assumption is to make it appear that changes in the price and quality of alternative sites have no effect anywhere else whilst in reality of course, significant substitution between sites can be expected. Nevertheless, in the absence of anything better it is possible to use the model to predict the percentage change in the number of tourists visiting each country following a change in the attributes of the choice set as well as the ensuing change in consumer surplus and the overall worth of the site itself in terms of use values. These uses are illustrated for three different countries: Greece, Spain and the Seychelles. The first two are of particular interest since they are among the most popular tourist destinations for British people whilst the latter consists of a group of islands *some* of whose very existence is threatened by rising sea levels[33]. The impact of climate change on Greece and Spain is investigated inputting assumptions for the change in climate taken from the United Kingdom Meteorological Office's (UKMO) General Circulation Model as reported in Houghton et al (1990). This model predicts a uniform increase of around 2°C for Southern Europe (30°N -50°N) by the year 2030 complete with changes in seasonal precipitation patterns following 'business as usual' emission assumptions.

Table 5.5 illustrating the situation for Greece indicates that there is a lengthening and a flattening of the tourist season with tourist numbers almost unchanged. The first,

[33] In fact the Seychelles consists of over 90 small islands situated in the Indian Ocean. They have a tropical climate and have recently become well known as a tourist resort. Most of the islands are low-lying but the largest island, Mahé, has hills rising to 3000 ft. Hence the complete disappearance of the Seychelles is unlikely.

second and fourth quarters show an increase in consumer surplus whereas the third quarter marks a sharp decline as maximum daytime temperatures pass well beyond their optimum level of 29°C. Overall however there is a small increase in consumer surplus of just over £2.5 million. Table 5.6 illustrates the situation for Spain; a country whose attraction lies in its climate, low population density and many miles of beaches. The results of climate change for Spain are qualitatively similar to those for Greece, but given Spain's lower prices and slightly cooler climate the beneficial effects of climate change on tourism are more pronounced. There are large gains for both tourist numbers and consumer surplus in the first, second and fourth quarters. In the third quarter there is a small decline in tourist numbers but overall consumer surplus for trips to Spain increases by almost £55.5 million and the number of tourists visiting Spain goes up by more than 6%.

Finally, in table 5.7 the total consumer surplus arising from trips to the Seychelles is estimated as being slightly more than £2 million pounds for quarters 1-3. This is the 'use' value for this group of islands and the amount which would be lost if the whole group were inundated (as explained earlier this is a rather exaggerated proposition). In comparison with the gains from Spanish tourism this sum seems very small, as it would be for most of the islands in the Indian and Pacific Oceans. The reason is that these islands are very small and quite distant (therefore expensive) and not visited much as a consequence. As a result they generate little consumer surplus. What this means is not that these low-lying islands are without value, but rather that their main value is likely to be in the form of existence rather than use values. The benefits to outsiders from preserving these islands lie in the vicarious consumption of their services through films, literature and the appreciation of their cultural heritage. The value of these services cannot be estimated through the travel cost technique but might be assessed through the use of contingent valuation methods.

Table 5.5: The impact of global climate change on the British tourism: the effects of the UKMO's 2030 scenario for Greece

Quarter	Temp.	Precip.	Tourism	Change in CS
1	+2°C	+5%	+16.0%	+£189,429
2	+2°C	-5%	+3.9%	+£3,992,970
3	+2°C	-15%	-2.8%	-£6,325,774
4	+2°C	-5%	+11.1%	+£4,691,700
Total			+0.7%	+£2,548,325

Source: *See text.*

Table 5.6: The impact of global climate change on the British tourism: the effects of the UKMO's 2030 scenario for Spain

Quarter	Temp.	Precip.	Tourism	Change in CS
1	+2°C	+5%	+19.4%	+£13,610,068
2	+2°C	-5%	+6.3%	+£16,541,888
3	+2°C	-15%	-0.5%	-£1,972,685
4	+2°C	-5%	+16.7%	+£27,258,392
Total			+6.3%	+£55,437,663

Source: *See text.*

Table 5.7: The impact of climate change on British tourism: the effects of the inundation of the Seychelles

Quarter	Change in British tourists	Change in CS
1	-100%	-£623,887
2	-100%	-£1,204,152
3	-100%	-£191,938
4	-100%	n/a
Total	-100%	> -£2,019,977

Source: *See text. The change in consumer surplus is evaluated with unchanged temperatures.*

Conclusions

It has been demonstrated that quarterly climate variables are able to explain differences in flows of tourists. In particular, it is shown that British tourists are attracted to climates which deviate little from an averaged daytime maximum of 29°C. Furthermore, as the attributes of low cost (ie nearby) destinations are likely to improve following climate change this is likely to result in a sizeable welfare gain to British tourists, even in the case of Southern European countries like Spain and Greece. Both these countries however, experience a lengthening and a flattening of the tourist season. In contrast, the losses experienced by the possible inundation of low-lying islands in the Indian and Pacific Oceans are likely to be small because these destinations are, at least to British residents, very expensive and consequently not much visited. But it is important to stress that the values which this chapter seeks to estimate are use values and not total economic values which may be much greater.

At an empirical level there is also further work to be done in terms of specifying the demand equation: including alternative measures for precipitation (such as rain days), including variables representing hours of sunshine and variables representing the degree of personal security. It would be interesting to examine the role of socio-economic factors such as age and income in explaining travel patterns. At a theoretical level reallocation effects are not dealt with well in the PTCM in the sense that the effect of changes in the quality (and price) of substitute sites are set to zero. This is most unlikely to be a fair representation of what would in fact happen. In the RUM set-up by contrast, the number of holidays remains unchanged irrespective of the quality of the experience provided by different destinations so neither approach is entirely satisfactory.

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6. Conclusions and recommendations for future research

This thesis comprises the following research topics: the use of the hedonic house price approach to explain variations in property prices as a function of climate variables; an econometric analysis of differences in wage rates also as a function of climate variables; an attempt to determine differences in the cost of living attributable to differences in climate using international data on per capita consumption patterns; a hedonic analysis of agricultural land prices in Britain to determine the amenity value of climate to agriculture; and an attempt to determine the role of climate in explaining flows of British tourists. The objective of this final chapter is to identify more precisely the contribution made by the thesis, to provide welfare estimates of the impact of climate change on Britain and to draw together some suggestions for future research.

A summary of the contribution of the thesis

The main contribution of this thesis does not primarily lie in the empirical estimates which it provides but rather in providing a framework for thinking about the impact of climate change on amenity values, cataloguing the alternative methodologies for unearthing them complete with a discussion of the advantages and disadvantages of the methodologies. True, all of these methodologies have been tested on empirical data and found to produce plausible results. But the reliability of these results as a basis for making statements concerning the impact of climate change on Britain has not been demonstrated because the data sets were for one reason or another never wholly suited to the purpose.

The framework adopted by the thesis can be summarised as follows: climate is an important input to many household activities. Climatic factors alter the cost of engaging in various pastimes and this suggests that households ought to be interested in climate as well as explaining why households living in climatically different regions are likely to consume different patterns of marketed commodities: it is to compensate for, or alternatively take advantage of particular sorts of climate. This observation in itself provides a route into benefits estimation via the HPF approach. Never before has there been an attempt to determine climate-equivalence scales from analysis of consumption patterns or an attempt to explicitly utilise the theory underlying household equivalence scales.

At the same time the framework for analysis adopted by the thesis has shown that valuation methodologies based on an analysis of human response to short run changes in climate are quite inadequate for the purposes of valuing the impact of a permanent change in climate. Durable goods and investments of all sorts are made on the presumption that a typical climate will prevail. But these investments would change in nature in response to a permanent change in climate, certainly over the period in question. It is thus wrong to attempt to infer anything about long run adaptation to climate change from the short-run effects of variations in the weather about its mean level.

But if at the same time as being free to adjust patterns of demand individuals are also freely able to select from differentiated localities then climate itself becomes a choice variable. The tendency will be for the benefits associated with particular climates (in terms of the differing costs of providing particular service flows of value to the household) to become collateralised into property prices and wages suggesting that the hedonic technique may be applicable. Households are attracted to regions offering preferred combinations of environmental amenities and this inward migration both increases house prices within those cities as well as depressing the wage rates in local labour markets. To the best of the author's knowledge this is the first hedonic study specifically on the amenity value of climate which considered both the labour market and the market for land. Explicit consideration is given to the role of unemployment in hedonic land and wage price regressions.

Similar reasoning can be employed to show why the price of agricultural land ought to reflect underlying productivity differences due to the existence of particular climates. This is the first hedonic study into the amenity value of agricultural land characteristics outside the United States. The hedonic land price study was also interesting in that it formally tested some of the restrictions imposed by arbitrage on the functional form of the hedonic land price regression and found them not to hold.

It also combined price data from auctions and professional valuations of land agents in the same regression.

In the final chapter the basic idea behind the travel cost method is that individuals base decisions on whether or not to visit particular sites on the various costs associated with travel to the site, and on the benefit they derive from using it. Comparing different levels of visitation to a site from populations with different travel costs to reach that site then allows the value of the site to be estimated. There is a similarity with the HPF approach in that the travel cost method implicitly invokes the assumption that the characteristic of interest is weakly complementary with a private good (the cost of travel); in other words, the assumption is that the environmental quality variable is valued only if a trip is made. This is the first attempt to determine the value of climate as a characteristic of various holiday destinations. The welfare impact of climate change through foreign travel had apparently not even been identified as an issue.

The impact of climate change on amenity values in Britain

This section uses the results obtained in chapter two to estimate the potential impact of climate change on household amenity values in Britain. The procedure adopted is to multiply the predicted changes in climate by the full implicit price of the climate variables (evaluated at GB sample means). These are then summed across all climate variables whilst holding the levels of all non-climate amenities constant. The resulting total is then multiplied by the number of households to obtain the aggregate change in welfare.

As estimates of the overall impact of climate change on Britain these estimates are of course incomplete in the sense that there are many other impacts of climate change which are not considered, for example the impact on agriculture, water supply, international tourism, the fauna and the flora of Britain and the impact of sea level rise. However, amenity values may constitute a substantial component of the overall damages incorporating as they do the impact on heating or air conditioning requirements, clothing needs, nutritional requirements, recreational expenditures and the impact of climate on health etc. However they suffice to show what could be achieved with a good knowledge of amenity values. The following section describes the changes in climate to be evaluated.

The climate change scenarios

Four alternative climate change scenarios are entertained drawn from two different General Circulation Models (GCMs) in order to examine the sensitivity of the estimated change in amenity values to the descriptions of climate change offered by different GCMs. The first set of estimates are taken from the Hadley Centre's UK high resolution (UKHI) GCM equilibrium experiment. Details of the experiment and the results obtained were first reported in Mitchell et al (1989) and Mitchell et al (1990). The climate changes in this data set are expressed in terms of changes per °C of global warming and can accordingly be scaled to any specified global warming projection. Using global warming projections generated by a simple model it is thus possible to generate climate change scenarios based on any desired emissions scenario and any assumed climate sensitivity. Assuming the standard IPCC emissions scenario IS92A (Houghton et al, 1992) and a central climate sensitivity of 2.5°C for $2xCO_2$ a temperature change of 0.62°C and 1.38°C are predicted for 2020 and 2050 respectively. The standardised climate changes are multiplied by these quantities and the resultant changes applied to the baseline climate. The climate change scenario per °C of global warming is described in table 6.1.

A second set of results are taken from UK transient model experiment (UKTR). The results drawn from this experiment are deemed to be the more accurate since they are obtained using a coupled ocean-atmosphere GCM. Further details of the experiment and the results obtained can be found in Murphy (1994) and Mitchell and Murphy (1994). The results extracted and used in this study refer to the years 2033 and 2065 using the emissions scenario IS92a and excluding the sulphate aerosol effect (Hume et al 1994). The climate changes are detailed in tables 6.2 and 6.3. Further details regarding both the UKTR and the UKHI experiments can be found in Hulme et al (1994).

Table 6.1: Climate change scenario for Britain per 1°C global warming (UKHI model)

Variable	Change
Precipitation (annual av.)	+8.5 %
Temperature (annual av.)	+1.1 °C
Sunshine (annual av.)	-1.9 hours

Source: Hulme et al, 1994.

Table 6.2: Climate change scenario for Britain for 2033 (UKTR model)

Variable	Change
Precipitation (annual av.)	+4.0 %
Temperature (annual av.)	+0.9 °C
Sunshine (annual av.)	-46.0 hours

Source: Hulme et al, 1994.

Table 6.3: Climate change scenario for Britain for 2065 (UKTR model)

Variable	Change
Precipitation (annual av.)	+6.0 %
Temperature (annual av.)	+1.6 °C
Sunshine (annual av.)	+5.0 hours

Source: Hulme et al, 1994.

Methods and results

Multiplying the anticipated changes in climate variables predicted by the UKHI experiment by the implicit prices of climate variables described in chapter 2 and cumulating these changes over the 22.9 m households present in Britain (Central Statistical Office, 1995a) suggests that the climate forecast for 2020 would typically confer an aggregate annual benefit of £4.2 bn (see table 6.4). For the climate anticipated by 2050 these benefits would increase to £9.2 bn. For the UKTR experiment aggregate benefits are £4.9 bn for 2033 and £10.5 bn for the climate of 2065. These increases in amenity values are due primarily to the increase in annual mean temperatures. Changes in amenity values due to changes in the values of other climate variables are less important by an order of magnitude.

Note also the similarity of the results provided by the hedonic approach and the HPF approach in terms of what they suggest the marginal willingness to pay for a 1°C rise in annual mean temperature might be. In 1980 prices the HPF approach predicts a willingness to pay of £31.92 per British person to enjoy a 1°C rise in mean annual temperature. Converting from 1980 prices to 1994 prices using the RPI of 227.0 (Central Statistical Office, 1995b) the HPF approach suggests a MWTP of £72.46/person/°C in 1994 prices whereas the hedonic approach suggests a MWTP of £94.49/person/°C in 1994 prices (assuming 2.41 persons to each household). Allowing for income effects these findings are quite consistent with each other. Thus the thesis provides empirical support in favour of what others have ventured to suggest: that climate change could actually improve the climate of *some* countries like Britain (eg Mortimer, 1996).

Table 6.4: The welfare impacts of climate change on British households as inferred from the hedonic approach (1994 prices)

Model	Year	Welfare change
UKHI	2020	+£4.2 bn
UKHI	2050	+£9.2 bn
UKTR	2033	+£4.9 bn
UKTR	2065	+£10.5 bn

Source: *See text.*

Recommendations for future research

The results of table 6.4 indicate that changes in amenity values may prove to be a considerable proportion of the overall impact of climate change on society and deserve rather more attention in the climate change literature than they have hitherto enjoyed. Indeed, economic studies of the amenity value of climate are still at a nascent stage. There is still no consensus on the usefulness of the different methodologies given their different underlying assumptions, not much indication as to how climate should be specified in the estimating equations and whether the results from different methodologies coincide or whether the results obtained from particular data sets can be replicated in such a manner as would convince one of the general worth of the approach. There is nonetheless a demonstration in this thesis that a number of alternative techniques are capable of providing plausible (and convergent) results and deserve further investigation with more extensive data sets.

Considering the hedonic house and wage price approach two important questions are: can amenity values ever be measured with sufficient precision and are they stable across consecutive years? The results from Maddison and Bigano (1996) suggest an affirmative answer to both of these questions, at least in the context of Italy. Is the same true for other countries? Future work on hedonics might concentrate on the task of identifying the demand curve for climate amenities. This is likely to involve combining studies undertaken in different countries with different climates and different levels of income and could shed light on the income elasticity of demand for climate amenities and the existence of an 'optimal' climate both of which are of relevance to the debate on the economic impacts of climate change (the former because the impacts of climate change are not expected to be felt until the mid part of the next century). The ability to undertake such an analysis in which the results from many different studies are combined however depends upon researchers employing similar specifications and measurement concepts for the climate variables.

Much more work needs to be done on the appropriate specification of the climate variables. This might consider whether monthly or annual averages or synthetic indices like heating and cooling degree-days and temperature-humidity and wind-chill indices are appropriate. It is also interesting to analyse the expected occurrence of extreme values (eg gale-days) as a determinant of house prices and wage rates. Controlling for characteristics of houses (such as their size and the presence or absence of central heating systems) is clearly desirable when using census-tract data. Alternatively, one could attempt to investigate the price of building land directly. Similarly, much greater attention needs to be paid to the specification of the level of locally provided services. These were very crudely modelled and did not have the expected effects on wage rates and property prices. A final question is the extent to which differences in the regional prices of consumer commodities can be explained by climate and whether these would make a significant difference to the implicit prices derived from the markets for land and labour (Roback, 1982).

Although the equilibrium approach to modelling the amenity value of climate was found to be satisfactory (in the sense that a considerable proportion of the variance in property prices and wage rates can be explained by differences in the levels of amenity variables) this does not mean that the migration approach is devoid of interest. On the contrary, an important question is whether analyses based upon migration flows suggest trade-offs between economic variables like wages and rents and climate variables which are similar to those derived from hedonic analyses. Yet another interesting question which could be determined from migration based analyses is whether life-cycle events explain migration behaviour. It is plausible that individuals' preferences for climate amenities change with age in part because of declining health. If so then it would be possible to observe the coefficient on the temperature variable for example increasing around the age following retirement. This may be one way of determining how the implicit price of climate amenities changes between different social groups.

Presumably neither hedonic methods nor migration based approaches would work in the context of Less Developed Countries or Ex-Communist countries where the twin assumptions of information and freedom to choose location are not met. In such countries the household production function approach is arguably more appropriate. With regard to the HPF approach it may be that the results are either very sensitive to the commodity groupings, the flexibility of the functional form, the specification of the climate variables or the (untestable) implicit assumption that climate variables do not form a separable subset in the direct utility function. Most of these issues could be addressed through access to a large detailed data set drawn from a climatically diverse region. Some of these concerns, including functional form and the more extensive specification of climate variables are addressed in the HPF study of the value of climate amenities in India (Maddison and Tol, 1997). Apart from further helping to redress the developed country bias in the impacts literature a similar study for China would be of obvious interest; then almost half of the world's population would be covered!

Turning now to the question of determining the amenity value of climate to agriculture, there are also more issues waiting to be dealt with. First of all, whereas theory states that the implicit price of climate to farmers can be deduced from considering the hedonic price schedule for land *and* for hiring the requisite labour, only the former was considered in this thesis. The extent to which the measurement of the implicit price of climate to agriculture is affected by differences in wage costs between climatically different regions is therefore an open question. The specification of climate in the hedonic price schedule may be even more crucial in agriculture than in human amenity values and there is a view that changes in the extremes of climate may be far more important than changes in mean climate. Is it correct therefore to assume that variables which better reflect the extremes of weather (eg concepts such as the number of frost-days) are more relevant to hedonic studies than concepts such as annual average temperature? Experimentation with alternative specifications of climate variables is clearly warranted. Similarly, soil quality deserves more attention. There are for example, commercially available data sets which catalogue different soil types on a relatively low level of spatial resolution and it might be worthwhile incorporating these into future analyses. The functional form of the hedonic price regression is also likely to be crucial given the interdependencies between the different characteristics of land and the 'law of limiting factors' approach to crop growth. The question of to what extent the system of price supports means that these implicit prices diverge from values to society is of course an important issue but one which is unlikely to be answered by any model which does not model the intervention system in detail.

Finally, to tourism. At an empirical level there is also further work to be done in terms of specifying the demand equation: including alternative measures for precipitation (such as rain days), including variables representing hours of sunshine and variables representing the degree of personal security (proxied perhaps by the respective murder rates). In addition it will be important to model the influence of income on visitation rates such that the impact of climate change on future (rather than current) generations of tourists can be predicted. Since international tourism is highly income elastic it is probable that this category of impacts will grow in significance over time. These results would then be combined with regional predictions of climate change and the resultant changes in consumer surplus summed across sites.

At a theoretical level reallocation effects are not dealt with well in the PTCM in the sense that the effect of changes in the quality (and price) of substitute sites are set to zero. These effects are dealt with much better by the RUM model which models the relative probabilities of an individual visiting different sites based upon the characteristics of the site (and possibly the characteristics of the individual as well). Just as in the PTCM the value of predicted changes in the attributes of sites, and even the elimination of various sites from the choice set can be investigated, this time using methods based on expected utility as described by Bockstael et al (1991). What prevented the RUM approach from being used in the current study is that the Conditional Logit model which underlies it is computationally infeasible if the number of choices exceeds more than just a few. Nevertheless, it may be possible to consistently (if inefficiently) estimate the RUM model on a subset of the possible choices thereby taking advantage of the IIA assumption (see for example Train, 1986). But in the RUM set-up by contrast, the number of holidays remains unchanged irrespective of the quality of the experience provided by different destinations so neither the RUM nor the PTCM approach is entirely satisfactory.

Conclusion

These studies into amenity values and any descendants from them are not (primarily) of interest in their own right. They must be carried forward to a point where they are combined with regional predictions concerning the scale and direction of climate change such that damage assessments can be conducted for various climate change scenarios. The results might then, for the purposes of exposition, be linked to Integrated Assessment models such the welfare impact of various scenarios can be more readily assessed. Determining whether the resources currently being committed to slow climate change are adequate (or alternatively whether they would have higher social value elsewhere) is the ultimate goal of this line of research. Attaching a money metric measure to the various impacts of climate change is a necessary step towards an economically founded evaluation.

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