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# The amenity value of the climate: the household production function approach

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**Abstract**

A basic assumption of the hedonic technique is that there are no barriers to mobility that 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 coupled with the existence of political boundaries may prevent the net advantages associated with a particular region from being eliminated. Apart from in a handful of countries, methods alternative to the hedonic approach may therefore be required to estimate the amenity value of climate. Adopting the household production function approach this paper undertakes a systematic examination of the role played by climate in determining consumption patters using data from 88 different countries. Given certain assumptions the paper then proceeds to calculate the constant utility change in the cost of living for a 2.5 °C increase in globally averaged mean temperature. It is determined that high latitude countries benefit from limited climate change whereas low latitude countries suffer significant losses.


*JEL classification:* Q0

*Keywords:* Climate change; Household production function; Amenity values; Valuation

## 1. Introduction

Economic activity is directed at the satisfaction of human wants. Arguably the most basic of these 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. This omission is not attributable to any consensus that amenity values are of negligible value to households. Such issues have however been addressed typically in

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the context of the hedonic approach. The hedonic approach argues that, if individuals are able to select freely from differentiated localities then the tendency will be for the benefits associated with them to become capitalised into property prices and wage rates. In such cases, the value of marginal changes can be discerned from the hedonic house price and wage rate regressions.

A basic assumption of the hedonic approach (and other related methodologies) to valuing climate amenities is that there are no barriers to mobility. But climate variables are often undeviating over relatively large distances. Over such distances the absence of a common language and the existence of cultural ties and political boundaries may prevent the net advantages associated with a particular climates from being eliminated. These considerations suggest that, except for highly developed and climatically diverse countries like the United States alternative methods may be required for estimating the amenity value of climate. The purpose of this paper is to present such a method. More specifically, using the household production function (HPF) approach this paper seeks to undertake a systematic examination of the role played by climate in determining consumption patterns using cross-country data from 88 different countries. Given certain assumptions the paper then proceeds to calculate the per capita compensating surplus for a 2.5 °C increase in globally averaged mean temperature.

The remainder of the paper is organised as follows. Section 2 looks at existing attempts to include climate variables in consumption analyses and also attempts to combine consumption data from different countries. In Section 3, the paper motivates the inclusion of environmental variables into demand analyses and asks under what circumstances is it possible to derive a measure of the value of environmental goods from observed patterns of consumption. Section 4 describes a number of ways in which environmental variables may conveniently be introduced into systems of demand equations. Section 5 describes the data used to estimate a model of consumer demand incorporating climate variables. Section 6 estimates a system of demand equations and discusses the alternative ways in which climate variables might be incorporated into the analysis. Section 7 describes the results of the econometric analysis. Section 8 uses the parameter estimates provided by the econometric analysis to calculate the welfare impact of a 2.5 °C increase in globally averaged mean temperature and Section 9 concludes with some reflections on the limitations of the technique.

## 2. Existing empirical literature

Numerous researchers have analysed the amenity value of climate to United States households using the hedonic technique although most appear to have included climate variables for reasons incidental to the main purpose of the analysis.[1] In what follows only those studies that have deliberately set out to explore the amenity value of climate are discussed in detail.[2]

The seminal contribution of Hoch and Drake (1974) considered the wages paid to different types of worker and sought evidence of compensation for climate amenities. Climate was

[1] Palmquist (1991) gives a general overview of the hedonic technique.

[2] In this respect, see also Cropper and Arriaga-Salinas (1980); Roback (1982); Smith (1983); Hoehn et al. (1987); Clark and Cosgrove (1990); and Clark and Cosgrove (1991). All of these authors present hedonic studies that include numerous climate variables in their hedonic price regressions.

specified in terms of precipitation, January and July temperatures, wind speed, degree–days, snowfall and the number of very hot and very cold days. Of all the climate variables, July temperatures, precipitation and wind velocity appear to have the greatest explanatory power. Englin (1996) investigated the amenity value of rainfall using annual average rainfall and the variation of rainfall. Within the context of a hedonic house price study he finds that households prefer less rainfall to more but other things being equal they also prefer a greater seasonal variation in rainfall. In the most detailed hedonic study to date, Nordhaus (1996) attempts to explain variations in wage rates corrected for differences in the cost of living in the United States by reference to January, April, July and October averages for temperature and precipitation. Climate variables are shown to be highly significant determinants of variations in wage rates.

What emerges from the hedonic literature (including those studies in which climate variables have been entered merely as additional controls) is that climate is a highly important amenity but differences in the specification of climate variables frustrates any attempt to draw more detailed conclusions.

Recently Cragg and Kahn (1997, 1999) offer an alternative approach to earlier hedonic analyses. Using a random utility modelling framework they estimate the demand for climate in the United States based on the locational choice of migrants. Hours of sunshine, annual rainfall, humidity and February and July temperatures are included in their analysis.[3] This work provides estimates of the willingness of migrants to trade off climate amenities against the financial costs and benefits of different locations. It also reveals that willingness to pay for warmer winter temperatures has risen over time.

Frijters and Van Praag (1998) adopt a radically different methodology. Their approach uses 'hypothetical equivalence scales'. This study is unique not only because of the methodology employed but also because it is empirically implemented using Russian data. Because this approach may be unfamiliar, it might be worth explaining it in slightly more detail. Respondents to an 'income evaluation question' were asked how much income would be required in order for them to describe their household's standard of living as 'very good' 'good' 'neither good nor bad', etc. Their responses were analysed using an ordered probit model to determine what factors influenced an individual's assessment of the minimum income required for their household to reach particular welfare levels. January and July temperatures, temperature range, average temperature, average wind speed, January wind speed, the number of rain days, precipitation, humidity and hours of sunshine were all included as possible determinants of individual assessments. The results indicate that individuals implicitly regard climate as an important determinant of their household's standard of living.[4]

Only two papers have attempted to implement the HPF approach to valuing climate amenities. Using per capita consumption data from different counties in California, Shapiro and Smith (1981) begin with an indirect utility function in which four environmental amenities (temperature, precipitation and two air-pollution variables) are included. Expressions for

[3] There are also several studies of migration which, although lacking an explicit welfare-theoretic foundation, show that migrants are alternately attracted and repelled by particular sorts of climate e.g. Graves (1979, 1980); Graves and Linneman (1979); Greenwood and Hunt (1989); and Cushing (1987).

[4] Frijters and Van Praag (1998) find that the differences in climate between Moscow and Dudinka (just inside the Arctic Circle) are sufficient to generate a 400% difference in the cost of living.

the expenditure shares are derived and the system of equations econometrically estimated using maximum-likelihood methods imposing the cross equation restrictions suggested by theory. 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 and because the environmental variables do not vary much across the sample. Either would severely limit the opportunities to identify any relationships between environmental amenities and commodity purchases.

Kravis et al. (1982) analysed per capita consumption patterns from 34 different countries using the linear expenditure system. The annually averaged temperature and precipitation of the capital city of each country were used to explain variations in 'subsistence' expenditures. Although they do not attempt to infer differences in the cost of living attributable to climatic conditions this is what their analysis actually amounts to. Whilst precise details of the study are unavailable the results were in any case reported as not very encouraging. This may be because of the inadequacies of the linear expenditure system or the description of each country's climate solely in terms of the annual average of the capital city.

Apart from the single attempt to derive implicit prices for climate amenities using the HPF approach on cross-country, there is of course a much more extensive literature exploring and exploiting variations in cross-country patterns of consumption. This literature is briefly surveyed in Selvanathan and Selvanathan (1993). More specifically they provide details on 13 different studies combining data from anything up to 34 different countries. These studies typically employ the linear expenditure system of Stone (1954) or some variant thereof to analyze the data. The attraction of cross-country consumption analysis 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 thereby facilitating the estimation of important price and income elasticities. This literature was also in part stimulated by a desire to test the controversial hypothesis of Stigler and Becker (1977) that tastes are the same across different countries.

Pollak and Wales (1987) and Selvanathan and Selvanathan test the hypothesis that tastes are identical across countries by pooling international data and testing the acceptability of restricting the commodity share equations of different countries such that they share common parameters. In both cases, the hypothesis of common tastes is rejected. Of course looking at things from a HPF perspective (see later), the results of such tests do not determine whether tastes differ between countries or whether consumption patterns differ as a consequence of differences in the endowment of environmental amenities used in household production. The empirical analysis presented later can be viewed as an attempt to reconcile differences in cross-country consumption patterns by introducing climate and other variables into the analysis in a way that enables the implicit value of climate variables to be inferred.

## 3. Household production theory and demand dependency

The role of environmental variables in determining observed patterns of expenditure can best be motivated by reference to the HPF theory of Becker (1965). In the HPF approach, households combine marketed commodities and environmental amenities using a given 'production technology'. These result in a variety of 'service flows' of direct value to the individual concerned. The overall level of utility is maximised by choice of the level of these 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 of the service flow.

The work of Becker however serves only to motivate the inclusion of environmental amenities into demand analyses. The majority of work has been on identifying those restrictions necessary to ensure that the value of changes in the level of an environmental good may be inferred from observations on the purchase of marketed commodities. In this regard two restrictions have been much discussed in the literature. These restrictions are 'weak complementarity' (Maler, 1974) and 'weak substitutability' (Feenberg and Mills, 1980). Taken together these restrictions imply that if environmental amenities are to be valued using observations on the purchase of marketed commodities then it is sufficient that there exists a price vector for these commodities at which the marginal utility afforded by additional amounts of the environmental amenity is zero.[5] This is the 'demand dependency' assumption of Bradford and Hildebrand (1977). Section 4 discusses alternative methods of introducing environmental variables into individual utility functions in a manner which ensures that demand dependency holds and that the full impact of changes in the level of environmental variables can be retrieved via an econometric analysis of consumer purchases. It is however as well to be aware whether demand dependency *actually* holds is not a testable hypothesis.

## 4. Extending systems of demand equations to reflect the role of environmental amenities

The procedures used here to incorporate environmental variables into systems of demand equations are functionally identical to the methods used to incorporate demographic variables into systems of demand equations. More specifically, the analysis utilises the 'demographic translating' and 'demographic scaling' procedure (see Pollak and Wales, 1981). Using these procedures, the nature of the role played by environmental amenities in combining with marketed goods is made very clear and, critically, established utility functions, whose limitations can constrain the results in ways already well understood, can be used to describe the demand for the various service flows. Smith (1991) has already commented favourably on the suitability of these approaches for determining the value of environmental amenities.

With demographic translating fixed costs are added to or deducted from the operations of the household. Translating replaces the original demand system by

$$q_i = d_i + q^i(p, m - \Sigma_i d_i p_i)$$

[5] The intuition underlying demand interdependency 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. These constants 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).

where $q_i$ is the quantity demanded of good $i$, $p$ the price, $m$ the income and $d$'s are the translation parameters given by

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

In which $z$ is a vector of $k$ environmental amenities. Demographic translating corresponds to a situation in which marketed goods and environmental amenities are combined in a linear production function such that changes in the level of environmental amenities do not alter the price of the service flow, but merely serve to impose a fixed cost upon the household.

In demographic scaling, the effective prices of the commodities are altered. In the context of modelling, the impacts of household composition the scaling factors can be interpreted in terms of 'adult equivalents'. Scaling replaces the original demand system by

$$q_i = m_i q^i(p_1 m_1,\ p_2 m_2,\ \ldots,\ y)$$

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

$$m_i = m_i(z) = \sum \eta_i z_i$$

Demographic scaling corresponds to a situation in which a change in the level of scaling function results in a proportionate change in the effective price of the service flow.[6]

## 5. Data sources

The price and expenditure data is taken from the International Comparisons Project (ICP) during 1975–1990. This project provides quinquennial information on per capita consumption patterns and purchasing power parity (PPP) prices in terms of national currencies per United States dollar.[7] A four-commodity aggregation was adopted: food; clothing; housing; and all other goods and services. The components of these commodity aggregates are given in Table 1. Prices were aggregated using quantity weights (national expenditures divided by PPP prices). Because the data set combines data from different years a convention was adopted whereby a unit was defined by what a United States consumer could buy with a dollar in 1990. This entails using commodity specific United States price indices (United States Bureau of the Census, 1992) to make appropriate adjustments to PPP prices in earlier years. The data set comprises 88 different observations (countries).

Monthly records for precipitation and temperature for each country's major city (or cities) are taken from Landsberg (1969), Pearce and Smith (1994) and miscellaneous Internet sources for some of the smaller Caribbean islands. To arrive at a single index for each

[6] In either of these specifications environmental variables are weak substitutes for marketed commodities.

[7] Countries measure quantities by index numbers defined in value units based on the country's 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 parity prices. Except under the assumption of perfect goods arbitrage these cannot be inferred from market exchange rates.

Table 1
Definition of commodity aggregates

| Commodity aggregate | Commodities included |
|---|---|
| Food | Food<br>Beverages<br>Tobacco |
| Clothing | Clothing<br>Footwear |
| Housing | Gross rent<br>Fuel and power<br>Household furnishings and operations |
| Other | Medical care<br>Transport and communications<br>Recreation and education<br>Other expenditures |

Source: see text.

country the records for major cities are in some instances population-weighted.[8,9] The records (and associated population weights) used to determine the indices for each country are shown in Table 2.

Countries of course differ in many respects other than their climates. The following variables are included alongside temperature and precipitation as additional controls: the percentage of individuals residing in urban areas; the percentage of individuals under the age of 15 years; the percentage of Muslims; the adult literacy rate and a time trend. The rationale behind these choices is as follows.

The costs of living in urban and rural areas may well differ and it is a characteristic of many developed countries that they are highly urbanised. It is well appreciated that the needs of children and adults differ and in many developing countries the proportion of children is much higher. The percentage of Muslims has been included partly because they constitute a relatively homogenous group with particular traits and partly because it is a characteristic of many of the hottest regions of the world such as North Africa and the Middle East that they are predominantly Muslim. So the inclusion of this variable acts as an extremely simple specification test. The literacy rate is a crude proxy for education and knowledge the abundance of which affects the efficiency of household production activities. Literacy rates of course, vary considerably between developed and developing nations. These data are taken from various sources including the World Resources Institute (1994) and the United

[8] This procedure may not work so well in a country where the majority of the population still lives in rural areas.

[9] To deal with the problem of intra-country variation in climate an earlier version of this paper selectively dropped countries from the data set on the basis of their geographical area. But as pointed out by one of the referees a large geographical area does not necessarily imply large intra-country variations in climate particularly for countries in the tropics. And even small countries can exhibit significant intra-country variation in climate depending on their topographical features. Having admitted all this it is then difficult to justify dropping a number of countries from the data set on the basis of their geographical area. Nevertheless future work should strive to deal with climatically homogeneous areas rather than countries.

Table 2
Records Used to Compute Climate Averages

| Country | Climate Record | Population (×1000) |
|---|---|---|
| Argentina | Buenos Aires | 10,728 |
| | Cordoba | 1,055 |
| | Rosario | 1.016 |
| Australia | Sydney | 3,531 |
| | Melbourne | 2,965 |
| | Brisbane | 1,215 |
| | Perth | 1,083 |
| | Adelaide | 1,013 |
| Austria | Vienna | |
| Bahamas | Nassau | |
| Bangladesh | Dacca | 4,770 |
| | Chittagong | 1,840 |
| Barbados | Bridgetown | |
| Belgium | Brussels | |
| Benin | Cotonou | |
| Bolivia | La Paz | |
| Botswana | Francis Town | |
| Brazil | Sao Paulo | 16,832 |
| | Rio de Janeiro | 11,141 |
| | Belo Horizonte | 3,446 |
| | Recife | 2,945 |
| | Porto Alegre | 2,924 |
| | Salvador | 2,362 |
| Cameroon | Douala | |
| Canada | Toronto | 3,427 |
| | Montreal | 2,921 |
| | Vancouver | 1,381 |
| Chile | Santiago | |
| Colombia | Bogota | 4,185 |
| | Medellin | 1,506 |
| Congo | Brazzaville | |
| Costa Rica | San Jose | |
| Denmark | Copenhagen | |
| Dominica | Rouseau | |
| Ecuador | Guayaquil | 1,301 |
| | Quito | 1,110 |
| Egypt | Cairo | 6,325 |
| | Alexandria | 2,893 |
| El Savlador | San Salvador | |
| Ethiopia | Addis Ababa | |
| Finland | Helsinki | |
| France | Paris | 8,510 |
| | Lyon | 1,170 |
| | Marseilles | 1,080 |

Table 2 (*Continued*)

| Country | Climate Record | Population (×1000) |
|---|---|---|
| Germany | Berlin | 3,301 |
| | Hamburg | 1,594 |
| | Munich | 1,189 |
| Greece | Athens | |
| Grenada | Saint George's | |
| Guatemala | Guatemala City | |
| Honduras | Tegucicgalpa | |
| Hong Kong | Hong Kong | |
| Hungary | Budapest | |
| Iceland | Reykjavik | |
| 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 |
| Iran | Tehran | 6,043 |
| | Mashhad | 1,464 |
| Ireland | Dublin | |
| Israel | Haifa | |
| Italy | Rome | 2,817 |
| | Milan | 1,464 |
| | Naples | 1,203 |
| Ivory Coast | Abidjan | |
| Jamaica | Kingston | |
| Japan | Tokyo | 11,829 |
| | Yokohama | 2,993 |
| | Osaka | 2,636 |
| | Nagoya | 2,116 |
| Kenya | Nairobi | |
| Luxembourg | Luxembourg | |
| Madagascar | Antananarivo | |
| Malawi | Lilongue | |
| Malaysia | Kuala Lumpur | |
| Mali | Bamako | |
| Mauritius | Port Louis | |
| Mexico | Mexico City | 18,748 |
| | Guadalajara | 2,587 |
| | Monterrey | 2,335 |
| | Puebla | 1,218 |
| Morocco | Casablanca | |
| Nepal | Katmandu | |
| Netherlands | De Bilt | |

Table 2 (*Continued* )

| Country | Climate Record | Population (×1000) |
|---|---|---|
| New Zealand | Auckland | |
| Nigeria | Lagos | 1,097 |
| | Ibadan | 1,060 |
| Norway | Oslo | |
| Pakistan | Karachi | 5,208 |
| | Lahore | 2,953 |
| | Hyderabad | 1,104 |
| Panama | Balboa Heights | |
| Paraguay | Asuncion | |
| Peru | Lima-Callao | |
| Philippines | Manila | |
| Poland | Warsaw | |
| Portugal | Lisbon | 1,612 |
| | Oporto | 1,315 |
| Romania | Bucharest | |
| Rwanda | Rubona | |
| Saint Lucia | Soufriere | |
| Senegal | Dakar | |
| Sierra Leone | Freetown | |
| South Korea | Seoul | |
| Spain | Madrid | 3,123 |
| | Barcelona | 1,694 |
| Sri Lanka | Colombo | |
| Suriname | Paramaribo | |
| Swaziland | Mbabane | |
| Sweden | Stockholm | |
| Switzerland | Zurich | |
| Syria | Damascus | 1,361 |
| | Aleppo | 1,308 |
| Tanzania | Dar es Salaam | |
| Thailand | Bangkok | |
| Trinidad and Tobago | Saint Clair | |
| Tunisia | Tunis | |
| Turkey | Istanbul | 5,495 |
| | Ankara | 2,252 |
| | Izmir | 1,490 |
| United Kingdom | London | |
| United States | 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 | 3,734 |
| | Houston | 3,642 |
| | Miami | 3,001 |

Table 2 (*Continued*)

| Country | Climate Record | Population (×1000) |
|---|---|---|
| | 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 |
| Uruguay | Montivideo | |
| Venezuela | Caracas | 3,247 |
| | Maracaibo | 1,295 |
| Yugoslavia | Belgrade | |
| Zambia | Lusaka | |
| Zimbabwe | Harare | |

Source: The Phillips Atlas.

States Central Intelligence Agency (2001). The inclusion of a time trend reflects the fact that the observations are drawn from different time periods and allows for the possibility that household technology (as well as the quality of goods) may have altered over the 15-year period from which the data are drawn.

## 6. Empirical specification

Prior to analysing the data set it is necessary to lend a particular functional form to the proposed relationships to provide a basis for estimation. Given the paucity of observations, it would be tempting to adopt the linear expenditure system (LES) of Stone (1954). The underlying demand system however is not an appealing description of preferences and might well obscure any relationship between consumer expenditures and climate. The almost ideal demand system (AIDS) of Deaton and Muellbauer (1980) is far more appealing in this respect but a limitation of even this widely-used model is that it assumes that the expenditure shares are linear in the logarithm of expenditure.[10] This weakness of the AIDS model has led to the development of the 'quadratic' AIDS model (see Banks et al., 1997). As its name suggests the chief feature of this system of demand equations is that it permits expenditure shares to be a quadratic function of the logarithm of expenditure.

[10] The ICP consumption data for 1980 has already been analysed by among others Brenton (no date). 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 AIDS model. 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.

The expenditure share equations associated with the quadratic AIDS model are

$$w_i = \alpha_i + \sum_j \gamma_{ij} \log p_j + \beta_i \log\left(\frac{m}{A}\right) + \frac{\lambda_i}{B}\left[\log\left(\frac{m}{A}\right)\right]^2$$

where $w_i$ is the budget share and $A$ is given by

$$\log A = \alpha_0 + \sum_i \alpha_i \log p_i + \frac{1}{2}\sum_i \sum_j \gamma_i \gamma_j \log p_i \log p_j$$

And $B$ is given by

$$B = \prod_i p_i^{\beta_i}$$

Since they are not of interest in this paper, the restrictions implied by symmetry and homogeneity are imposed on the model

$$\gamma_{ij} = \gamma_{ji}$$

And

$$\sum_i \gamma_{ij} = 0$$

The adding up constraint is met when

$$\sum_i \alpha_i = 1$$

And

$$\sum_j \gamma_{ij} = 0$$

And

$$\sum_i \beta_i = 0$$

And

$$\sum_i \lambda_i = 0$$

Note how the quadratic AIDS model conveniently nests the conventional AIDS model as a special case (corresponding to all $\lambda_s$ equal to zero).

Turning now to the question of how best to incorporate climate variables into the analysis, given that they are the focus of attention this analysis adopts a flexible approach for representing the climate. Most studies have considered some combination of means, extremes and deviations (see for example Cushing, 1987). This analysis follows that convention by including means for temperature and precipitation, their ranges and cumulated linear deviations from the sample mean. Temperature range is defined to be the temperature in the hottest month minus the temperature in the coldest month. Precipitation range is defined analogously. Cumulated linear deviations are calculated on a monthly basis from a base of 18.6 °C for temperature and 94 mm for precipitation corresponding to the sample means.[11] These three climatic concepts are simultaneously included in the model along with the demographic variables and the time trend.

Two alternative models of demand were estimated, firstly with the climate and demographic variables and the time trend as translating variables and secondly with them as scaling variables in the quadratic AIDS model. In order to overcome likely problems associated with heteroscedasticity the system of three equations is estimated in share form by a maximum-likelihood technique.[12]

## 7. Results

Examining the results of the regressions it is evident that the scaling procedure provides a better fit to the data than does the translating procedure and the latter procedure is not considered any further.[13] The main point of interest however is to establish whether the exclusion of all climate variables from the quadratic AIDS-model represents a statistically significant restriction. Using a likelihood ratio test the null hypothesis of no role for the climate variables can be rejected.[14] Furthermore, it is also quite clear that the additional flexibility afforded by the quadratic AIDS model does indeed result in a significant improvement in fit compared to the conventional AIDS model.[15] The parameter estimates of the quadratic AIDS model with scaling variables are given in Table 3. Note that the standard errors are heteroscedastic-consistent.

Some interpretation of the parameter estimates shown in Table 3 may be helpful. As noted earlier the $\lambda$ parameters are what distinguish the quadratic AIDS model from the AIDS model and the significance of these parameters for the food and clothing commodity aggregates is why the quadratic AIDS model is preferred to the AIDS model. More specifically, the results indicate that the budget shares of food and clothing ultimately fall as income rises. This is of course what one would expect to find.

Moving to the scaling variables, the time trend is statistically significant and negatively signed for all commodity aggregates. The interpretation here is that there have been autonomous improvements in the efficiency of household production activities (or alternatively that the quality of goods has improved). The percentage of individuals under the age of 15 years is statistically significant and positive for the commodity category ‘other’

[11] By pure coincidence heating and cooling degree-days are also most often calculated using a temperature base of 18.6 °C (65 °F). Unsurprisingly, heating and cooling degree–days are unavailable for the majority of countries.

[12] As is well known, the adding up property implies singularity of the variance–covariance matrix. This can be dealt with by dropping one of the budget share equations. The estimation technique is such that the parameter estimates that emerge are not affected by the choice of which equation to drop.

[13] The log likelihood is 522.45 for the scaling model compared to 515.22 for the translating model.

[14] The $\chi^2$-statistic is 39.99 against a critical value of 36.42 at the 5% level of confidence with 24 d.f.

[15] The $\chi^2$-statistic is 25.51 against a critical value of 7.81 at the 5% level of confidence with 3 d.f.

Table 3
Parameter estimates of the quadratic AIDS Model with climatic and demographic characteristics as scaling variables

| Commodity | Parameter | Estimate | *T*-statistic |
|---|---|---|---|
| | $\alpha_0$ | −0.641 | 0.418 |
| Food | $\alpha_{Food}$ | 1.311 | 5.661 |
| | $\gamma_{FoodFood}$ | 0.282E-02 | 2.523 |
| | $\gamma_{FoodClothing}$ | 0.552E-04 | 0.297 |
| | $\gamma_{FoodHousing}$ | −0.956E-03 | 1.931 |
| | $\beta_{Food}$ | 0.925E-02 | 0.366 |
| | $\lambda_{Food}$ | −0.945E-02 | 3.675 |
| | $\eta_{Urban}$ | −0.113E-02 | 1.786 |
| | $\eta_{Age}$ | 0.382E-04 | 0.019 |
| | $\eta_{Muslim}$ | 0.833E-03 | 1.636 |
| | $\eta_{Literate}$ | 0.112E-02 | 1.719 |
| | $\eta_{Year}$ | −0.373E-03 | 4.412 |
| | $\eta_{Temp}$ | 0.185E-02 | 0.759 |
| | $\eta_{TempRange}$ | 0.637E-02 | 2.753 |
| | $\eta_{TempDeviations}$ | 0.117E-02 | 3.054 |
| | $\eta_{Precip}$ | 0.810E-03 | 1.963 |
| | $\eta_{PrecipRange}$ | −0.385E-04 | 0.184 |
| | $\eta_{PrecipDeviations}$ | 0.851E-06 | 0.015 |
| Clothing | $\alpha_{Clothing}$ | −0.496 | 4.596 |
| | $\gamma_{ClothingClothing}$ | 0.348E-03 | 1.500 |
| | $\gamma_{ClothingHousing}$ | −0.343E-04 | 0.367 |
| | $\beta_{Clothing}$ | 0.114 | 5.498 |
| | $\lambda_{Clothing}$ | −0.520E-02 | 3.015 |
| | $\eta_{Urban}$ | −0.436E-02 | 1.958 |
| | $\eta_{Age}$ | 0.912E-02 | 2.259 |
| | $\eta_{Muslim}$ | −0.110E-02 | 1.093 |
| | $\eta_{Literate}$ | −0.337E-02 | 1.404 |
| | $\eta_{Year}$ | −0.519E-03 | 3.410 |
| | $\eta_{Temp}$ | 0.938E-02 | 1.644 |
| | $\eta_{TempRange}$ | 0.030 | 3.404 |
| | $\eta_{TempDeviations}$ | 0.275E-02 | 2.332 |
| | $\eta_{Precip}$ | 0.382E-02 | 2.643 |
| | $\eta_{PrecipRange}$ | −0.883E-03 | 1.441 |
| | $\eta_{PrecipDeviations}$ | 0.810E-04 | 0.621 |
| Housing | $\alpha_{Housing}$ | 0.128 | 1.216 |
| | $\gamma_{HousingHousing}$ | 0.848E-04 | 0.244 |
| | $\beta_{Housing}$ | 0.022 | 1.057 |
| | $\lambda_{Housing}$ | 0.295E-02 | 1.657 |
| | $\eta_{Urban}$ | 0.100E-02 | 1.413 |
| | $\eta_{Age}$ | 0.962E-03 | 0.468 |
| | $\eta_{Muslim}$ | 0.600E-04 | 0.133 |
| | $\eta_{Literate}$ | −0.809E-03 | 1.065 |
| | $\eta_{Year}$ | −0.239E-03 | 2.591 |
| | $\eta_{Temp}$ | −0.350E-02 | 1.344 |
| | $\eta_{TempRange}$ | −0.437E-02 | 1.563 |
| | $\eta_{TempDeviations}$ | −0.346E-03 | 1.183 |
| | $\eta_{Precip}$ | −0.388E-03 | 1.027 |

Table 3 (*Continued*)

| Commodity | Parameter | Estimate | *T*-statistic |
|---|---|---|---|
| | $\eta_{\text{PrecipRange}}$ | 0.466E-04 | 0.291 |
| | $\eta_{\text{PrecipDeviations}}$ | −0.516E-05 | 0.122 |
| Other | $\eta_{\text{Urban}}$ | −0.314E-02 | 1.212 |
| | $\eta_{\text{Age}}$ | 0.0155 | 2.840 |
| | $\eta_{\text{Muslim}}$ | 0.140E-02 | 0.816 |
| | $\eta_{\text{Literate}}$ | 0.567E-02 | 1.646 |
| | $\eta_{\text{Year}}$ | −0.149E-02 | 5.406 |
| | $\eta_{\text{Temp}}$ | 0.015 | 1.935 |
| | $\eta_{\text{TempRange}}$ | 0.048 | 3.720 |
| | $\eta_{\text{TempDeviations}}$ | 0.555E-02 | 2.663 |
| | $\eta_{\text{Precip}}$ | 0.829E-02 | 3.402 |
| | $\eta_{\text{PrecipRange}}$ | −0.213E-02 | 2.242 |
| | $\eta_{\text{PrecipDeviations}}$ | 0.224E-03 | 1.169 |

Source: own calculations.

and also for clothing. For the remaining categories of food and housing the percentage of individuals under the age of 15 years is statistically insignificant. In none of the commodity categories are the percentage of the population living in urban areas, the percentage of Muslims or the percentage of literate adults statistically significant.

Turning to the climate variables, temperature deviations and temperature range increase the effective price of food. Extreme temperatures affect nutritional requirements. The effective price of clothing is increased by rainfall as well as by temperature deviations and temperature range. It is especially plausible that temperature range should affect clothing requirements. Perhaps surprisingly none of the climate variables appear to influence the effective price of housing. Note however that fuel and power are typically only a small proportion of overall housing costs. With more observations it would obviously be important to distinguish gross rents and household furnishings from fuel and power. The final commodity category 'other' is also heavily impacted by climate with monthly average precipitation, precipitation range, temperature deviations and temperature range all statistically significant. It is however impossible to interpret the results for this commodity category since the category includes transport, recreation and health care expenditures, all of which are potentially impacted by climate but in different ways. Particularly interesting is the fact that greater precipitation range appears to reduce the effective price of other goods and services. Perhaps the reason for this is that what households are really interested in is the number of rainy days and that for any given level of precipitation a greater precipitation range is associated with fewer rainy days.[16]

These results find ready support in the existing literature. Cushing (1987) shows that temperature extremes provide the single best description of climate closely followed by a measure based on deviations whereas average annual temperature performs poorly. In the

[16] The number of rainy days is not often recorded in less developed countries. Some countries employ different definitions of rainy days e.g. a day on which <0.01 in. of rain fell versus a day on which <0.1 mm of rain fell. There is no obvious way to convert between different measures. Only monthly mean temperature and precipitation are consistently available for all countries.

Table 4
The relative explanatory power of the Constrained and Unconstrained Model of Consumer Demand

| Commodity group | $R^2$-statistics for the quadratic AIDS model without climate variables | $R^2$-statistics for the quadratic AIDS model with climate variables |
|---|---|---|
| Food | 0.823 | 0.872 |
| Clothing | 0.306 | 0.471 |
| Housing | 0.454 | 0.413 |
| Other | – | – |

Source: own calculations.

results presented here temperature extremes and deviations are statistically significant in most of the scaling functions whereas nowhere is mean temperature statistically significant. And just as in Englin (1996), it is found that individuals prefer less precipitation to more but that other things being equal they also prefer greater precipitation range (variance).

The marginal explanatory power of climate in terms of the effect on the $R^2$ statistic is described in Table 4. It appears that the greatest effect of adding climate variables is on the ability to explain cross-country variations in the purchase of clothing. Note however that the ability to explain cross-country variations in the purchase of housing is slightly reduced. But since the same parameters are chosen to fit a system of equations there is nothing strange about such a result.

## 8. Discussion

Consumption patterns are affected to a significant extent by climate variables and furthermore the manner in which climate variables are introduced into the analysis is an important determinant of the fit of the expenditure share equations. In what follows the econometric estimates are used to calculate changes in the cost of living associated with a particular climate change scenario and the reader is reminded of the importance of the demand dependency assumption.

Table 5 records the percentage change in the cost of living for those changes in climate associated with a 2.5 °C increase in global mean temperature for each of the 88 different countries. The predicted change in climate associated with a 2.5 °C in global mean temperature is taken from the global climate model of the United Kingdom Meteorological Office (UKMO). This model predicts changes in mean monthly temperature and average monthly precipitation on a regional basis. Like other global climate models the UKMO model predicts that the temperature increases associated with the enhanced greenhouse effect will be greatest during the winter months and more pronounced at the higher latitudes. It also predicts increases in precipitation for most but not all countries. The fact that the predicted changes in climate are spatially and temporally differentiated over the surface of the globe obviously has important implications for the welfare cost estimates presented in Table 5. Basing the predictions on the output of another global climate model might well result in different estimates of the constant utility change in the cost of living.

The reader is also cautioned that the estimated impacts of climate change depend not only on the change in climate, but also on expenditure levels and relative prices and two

Table 5
Constant utility cost of living indices for changes in climate associated with a 2.5 °C rise in global mean temperature

| Country | Change (%) |
|---|---|
| Argentina | −1.2 |
| Australia | −1.6 |
| Austria | −1.8 |
| Bahamas | 3.2 |
| Bangladesh | 2.6 |
| Barbados | 3.2 |
| Belgium | −3.4 |
| Benin | 7.2 |
| Bolivia | n.a. |
| Botswana | 2.6 |
| Brazil | 3.5 |
| Cameroon | 0.4 |
| Canada | −2.5 |
| Chile | −14.8 |
| Colombia | n.a. |
| Congo | 3.3 |
| Costa Rica | 3.8 |
| Denmark | −3.0 |
| Dominica | 0.9 |
| Ecuador | 70.7 |
| Egypt | 3.1 |
| El Salvador | 1.8 |
| Ethiopia | n.a. |
| Finland | −2.1 |
| France | −2.0 |
| Germany | −2.0 |
| Greece | 0.1 |
| Grenada | 2.2 |
| Guatemala | 10.5 |
| Honduras | 16.3 |
| Hong Kong | 0.8 |
| Hungary | −1.9 |
| Iceland | −2.6 |
| India | 11.0 |
| Indonesia | 1.2 |
| Iran | 0.0 |
| Ireland | −5.2 |
| Israel | 2.6 |
| Italy | −0.6 |
| Ivory Coast | 3.2 |
| Jamaica | 5.3 |
| Japan | −0.4 |
| Kenya | 9.7 |
| Luxembourg | −3.1 |
| Madagascar | 1.9 |
| Malawi | 12.4 |
| Malaysia | 0.0 |
| Mali | 4.8 |
| Mauritius | 4.7 |

Table 5 (*Continued*)

| Country | Change (%) |
|---|---|
| Mexico | 11.8 |
| Morocco | 6.0 |
| Nepal | 1.8 |
| Netherlands | −3.4 |
| New Zealand | −1.3 |
| Nigeria | 3.5 |
| Norway | −1.9 |
| Pakistan | 11.9 |
| Panama | 1.3 |
| Paraguay | 1.5 |
| Peru | −1.2 |
| Philippines | 1.1 |
| Poland | −2.8 |
| Portugal | −2.5 |
| Romania | −1.4 |
| Rwanda | 23.0 |
| Saint Lucia | 1.7 |
| Senegal | 28.4 |
| Sierra Leone | 2.4 |
| South Korea | −0.4 |
| Spain | −1.0 |
| Sri Lanka | 0.9 |
| Suriname | 0.5 |
| Swaziland | 0.4 |
| Sweden | −2.1 |
| Switzerland | −1.1 |
| Syria | 0.4 |
| Tanzania | 6.0 |
| Thailand | 2.7 |
| Trinidad and Tobago | 1.5 |
| Tunisia | 0.6 |
| Turkey | −0.2 |
| United Kingdom | −4.7 |
| United States | −0.3 |
| Uruguay | −1.4 |
| Venezuela | 42.0 |
| Yugoslavia | −0.8 |
| Zambia | 9.6 |
| Zimbabwe | 9.7 |

Source: see text.

countries with an identical climate subjected to the same changes in climate may nonetheless fare differently. Accordingly even if these climate change predictions are realised countries may fare better or worse than suggested below simply because their relative prices and per capita expenditure have changed over intervening years. This point is particularly important because although the 2.5 °C increase in global mean temperature is the benchmark for most climate change impact studies it is not expected to occur in the near future.

Notwithstanding all these caveats it nevertheless appears that all of Northern Europe would benefit from limited climate change at least insofar as amenity values are concerned. These gains are particularly pronounced for the United Kingdom and Ireland. Italy on the other hand appears largely unaffected by climate change. Indeed, among the European countries represented in the data set only Greece is adversely affected by the hypothesised 2.5 °C increase in annually averaged global temperatures and even then only to a trivial extent. Underpinning these results of course is the fact that the majority of the warming is expected to occur during the winter months and less obviously that increases in precipitation totals are offset by increases in precipitation range.

Turning to Asia, a completely different picture emerges with the majority of countries losing from the predicted climate change scenario. Alarmingly the highly populated countries of India and Pakistan are particularly hard hit and would lose substantially from a 2.5 °C rise in globally averaged mean temperature. Malaysia and Iran are unaffected whilst Turkey, Korea and Japan register small benefits from climate change. Most of the countries that are unaffected by or benefit from climate change are countries characterised by very cold winters. Malaysia is an unusual case because although it is a very hot country predicted temperature increases are relatively small and precipitation is actually predicted to decline as a consequence of climate change.

All the African countries represented in the data set appear to lose from predicted global climate change (although results for Ethiopia are unavailable).[17] These losses are least in Cameroon and Swaziland. Although Cameroon is very hot precipitation hardly increases at all whilst in Swaziland, it actually declines. The losses are greatest in Rwanda and Senegal. The reason is that these countries are already very hot and any further increase in either temperatures or precipitation diminishes welfare. In Nigeria, the most populous country in all of Africa, there are also sizeable losses to contend with.

Turning to Central and South America, the southernmost countries of that continent appear to benefit from climate change. Argentina, Uruguay and in particular Chile derive benefit from the predicted changes. These results are due to the temperate climate of those countries and once more to the seasonal pattern of warming. Closer to the equator however the impacts are more severe than for any other country in the data set particularly for Ecuador, Venezuela and Honduras. The result for Ecuador is a consequence of the very large predicted increase in precipitation and a tropical climate that already exceeds the temperature base against which temperature deviations are calculated in each and every month. Brazil also suffers significant losses. Results for Bolivia and Colombia are unavailable.

In both Australia and New Zealand exhibit small gains with the benefit of increased wintertime temperatures outweighing small increases in precipitation. In North America, the United States is largely unaffected by climate change. Further north Canada enjoys a reduction in the cost of living. Mexico on the other hand suffers a large increase in the cost of living as more and more months exceed the temperature base against which temperature deviations are calculated. All of the Caribbean countries in the data set are adversely affected by the predicted changes in climate with the worst affected country being Jamaica and the

[17] For a small number of countries (Ethiopia, Colombia and Bolivia), the scaling function becomes negative for one or more commodities meaning that the cost of living index cannot be calculated.

least affected being Dominica. These losses would be larger but for the fact that the predicted temperature increases are relatively small for the Caribbean.

## 9. Conclusions

Differences in tastes and differences in the distribution of incomes being what they are, it will always be difficult to explain differences in per capita consumption patterns between countries. What this analysis demonstrates however is that climate is a statistically significant determinant of expenditure patterns. Furthermore, if one is prepared to accept the validity of certain restrictions on individuals' utility functions it is possible to obtain a complete measure of the direct welfare effects on households of a change in climate frequently associated with a doubling of carbon dioxide concentrations in the atmosphere. Preliminary results suggest that global temperature increases are at least in some respects likely to confer benefits on high latitude countries. Particularly in countries located in the tropics however any increase in temperatures is likely to result in a large increase in the cost of living.

The research presented in this paper also suffers from certain limitations. First of all the climate variables are in some instances averaged over large and climatically diverse regions. In any future analysis, it would obviously be better to take consumption data from small climatically homogenous regions rather than from countries. With more data it would also be of interest to observe the extent to which greater commodity disaggregation effects the implicit values for the environmental amenities. Such disaggregation would also reveal the precise nature of the role played by climate in household production activities to a greater extent than has been possible in this paper.

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