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Estimating the Amenity Costs of Global Warming in Brazil: Getting the Most from Available Data

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Abstract

This paper develops a theoretically consistent technique for valuing non-marketed local attributes using compensating income differentials in the absence of housing market data. The individual's indirect utility function is identified with aggregate data describing equilibrium location decisions, and this function is used in place of the unidentified equation describing how housing prices are determined. The model is used to value climate amenities in Brazil, where such data problems are prevalent. Similar problems arise in other developing countries, particularly when one looks outside of the largest cities.

Keywords: wage-hedonics, discrete-choice analysis, climate amenity, global warming

JEL: R1, C35, O54

1. Introduction

The anthropogenic release of greenhouse gases, most notably carbon dioxide, methane, clorofluorocarbons, and nitrous oxide, has been scientifically shown to trap radiant energy from the sun in the earth's atmosphere, raising the planet's average temperature. [IPCC (1995a)] International concern over these temperature increases has been evident for more than ten years. Still, most countries have been slow to make credible, binding commitments to significantly reduce their greenhouse gas emissions. This is not surprising. The costs of abating these emissions are substantial, while predictions of the global temperature increases they would induce, as well as the subsequent costs to agriculture, ecosystems, coastal land, human health, and climate amenities, are wide ranging. [Adams (1989), Mendelsohn, Nordhaus, and Shaw (1994), Cropper (1981), Bloomquist, Berger, and Hoehn (1988), IPCC (1995a), Nordhaus (1996), Cragg and Kahn (1997), Mendelsohn (1998)] While the costs of climate change associated with agricultural production are well-defined by market transactions, and while medical costs and coastal land values are easily observable, the costs and benefits arising from ecosystem alteration, discomfort from climate-induced sickness, and changes in climate amenities are not so obvious and have added to the uncertainty surrounding the climate change debate.[1] This research demonstrates a methodology for quantifying the last of these non-marketed effects of global warming, which, unlike traditional techniques, is broadly applicable (given currently available data) to measuring the effects of climate change in developing countries.

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[1] The Intergovernmental Panel on Climate Change (IPCC), in the Summary of the Economic and Social Dimensions of Climate Change contained in its Second Assessment Report, notes that "non-market damage estimates are a source of major uncertainty in assessing the implications of global climate change for human welfare." The report adds that, "these uncertainties, and the resolution of uncertainty over time, may be decisive for the choice of strategies to combat climate change." [IPCC (1995b)]

This extension will prove relevant in the debate surrounding the proper role of LDC's in global greenhouse gas abatement efforts. By the year 2020, LDC's are expected to account for approximately 50% of all greenhouse gas emissions, in contrast to 30% today. [OECD (1997)] The IPCC reports, however, that "the literature on the [social costs of anthropogenically induced climate change] is controversial and mainly based on research done on developed countries, often extrapolated to developing countries." It goes on to state that "analysis of economic and social issues related to climate change, especially in developing countries where little work of this nature has been carried out, is a high priority for research." [IPCC (1995b)] Accurate measurement of the costs and benefits of climate change in these countries is particularly important as bargaining over country-specific emission reduction targets continues in the post-Kyoto era.

Measuring the value of non-marketed commodities like climate amenities is an old problem in environmental economics. The approaches that have typically been employed involve either deducing an individual's willingness to pay with direct survey methods or indirectly observing an individual's behavior in a closely related market where commodities are priced. One such "related market" approach -- the wage-hedonic technique -- recognizes that climate amenities are characteristics of locations in which individuals can choose to live, work, and play. Information about an individual's choice of location, and the tradeoffs between wages, housing costs, and (un)desirable local attributes implicit in that choice, is then exploited in order to put a price on the latter. Use of this technique for valuing non-marketed local attributes in developing countries is often limited by the availability of data; i.e., the relevant tradeoffs in many of these countries take place in less urbanized areas where data on both labor and housing markets are not typically available. Without information on equilibrium prices in either of these markets, the wage-hedonic technique is not applicable. With information on just one of these market prices (e.g., equilibrium wages), traditional hedonic techniques can be applied but will produce biased estimates of the value of local attributes.

This paper illustrates a technique for exploiting observed variation in labor markets, along with information on individuals' location choices, in order to produce unbiased estimates of their willingness to trade consumption opportunities for climate amenities in the absence of housing-market data. In particular, the individual's indirect utility function is recovered, and the information it contains is used in place of the unidentified equation describing housing market equilibrium. While this approach does not allow the direct effect of a change in climate on utility to be disentangled from its welfare effect on consumption via housing prices, it is sufficient for measuring an individual's overall willingness to trade consumption for climate, which is all that is needed to value the predicted amenity effects of global warming.

The paper proceeds as follows. Section 2 briefly reviews the traditional approach to valuing local attributes using wage and housing-price differentials, and demonstrates why such an approach is not applicable to a country like Brazil. Section 3 illustrates an alternative model that can identify the value of non-marketed local attributes with available data. Section 4 discusses a data set describing 363 Brazilian microregions, which is used to recover the parameters of the model described in Section 3, and briefly explains the estimation algorithm. Section 5 reports parameter estimates from that algorithm, simulates values for small changes in climate, and compares those results to values derived from compensating income differentials alone. Section 6 concludes and suggests a number of extensions and goals for future research.

2. Using Wage-Hedonics to Measure the Amenity Value of Climate

The intuition underlying the wage-hedonic measurement of the value of a non-marketed local attribute like climate proceeds as follows. Each individual chooses a place to live that maximizes her utility, given the bundles of attributes that define the locations in her choice set. *Ceteris paribus*, an individual who chooses to live in a location with an "undesirable" climate must do so because she is made as well-off as she would be in a location with a preferable climate by receiving a better bundle of other local attributes. Conditioning upon all non-wage, non-climate attributes, the individual must receive a wage-premium (i.e., a positive compensating wage differential) in return for living in the less-agreeable climate. From these differentials, the value that the individual places on the non-marketed climate attribute can be recovered.

Early work in wage-hedonic valuation derived the marginal willingness to pay for non-marketed local attributes by using only correlations between wages and the attributes. [Nordhaus and Tobin (1972), Meyer and Leone (1977), Getz and Huang (1978)] Subsequent analyses, however, have demonstrated that such an approach ignores a key component of value. [Cropper (1981), Henderson (1982), Hoehn, Berger, and Bloomquist (1987), Bloomquist, Berger, and Hoehn (1988)] In particular, in order to get more of a desirable local attribute by moving to a preferred location, an individual not only has to give up some wage compensation (i.e., by moving into a presumably more heavily-supplied labor market), but also must pay more for a residence in which to live at that popular destination. Indeed, equilibrium in both labor and housing markets must be modeled concurrently before the full hedonic gradient can be recovered.

This is illustrated by Roback (1982). She begins with a function describing the utility that an individual i receives from consumption of a universally traded numeraire commodity (Q_i), housing services (h_i), and vectors of climate (C_j) and non-climate (X_j) local attributes, which are exogenously determined for location j and consumed equally by all of j's residents:

$$U_i \ (Q_i, \ h_i; \ C_j, \ X_j) \tag{2.1}$$

The individual chooses quantities of Q_i and h_i, conditional upon X_j and C_j, so as to maximize utility subject to a budget constraint:

$$Q_i \ + \ P_j^H \ h_i \ = \ INC_{i,j} \tag{2.2}$$

where P_j^H represents the equilibrium price of housing in location j, and $INC_{i,j}$ represents the income that individual i would earn in location j (the model abstracts from individual i's labor-leisure decision and takes $INC_{i,j}$ as given in equilibrium). This determines a pair of demand equations that can be inserted into equation 2.1, yielding the individual's indirect utility function:

$$V_i \ (INC_{i,j}, \ P_j^H; \ C_j, \ X_j) \tag{2.3}$$

Given that individuals can move freely between locations, incomes and housing prices will adjust so that all individuals will achieve a common level of utility, V^*, which any one individual takes as given. From this equilibrium assumption, and with an equilibrium model of firm behavior, Roback (1982) derives the following set of estimating equations, describing the income and housing prices faced by individuals i = 1, 2,...,n, each of whom live in a location j = 1,2,...,J:

$$P_j^H \ = \ f^H(d_{j,r}, \ C_j, \ X_j, \ pop_j, \ \varepsilon_j^H; \ \bar{\delta}) \tag{2.5}$$

$$INC_{i,j} = f^{INC}(d_{j,r},\ C_j,\ X_j,\ z_i,\ pop_j,\ \varepsilon_{i,j}^{INC};\ \bar{\gamma}) \tag{2.4}$$

where

$INC_{i,j}$ = income earned by individual i in location j
P_j^H = price of a unit of housing in location j
$d_{j,r}$ = 1 if location j is in region r, = 0 otherwise
C_j = climate characteristics of location j = {seasonal measures of temperature and rainfall}
X_j = non-climate characteristics of location j = {altitude, distance from sea, latitude (i.e., a proxy for solar flux), longitude}
z_i = characteristics of individual i = {race, education, age, gender}, included because labor market equilibrium need only be achieved within a skill category
pop_j = equilibrium population in location j
$\varepsilon_{i,j}^k$ = unobservable (to the econometrician) idiosyncratic shocks to the income earned or housing price faced by individual i in location j; E[ε] = 0, E[εΔ] = 0, for Δ = X, C, Z, k = INC, H

Presuming equations 2.4 and 2.5 could be estimated, Roback (1982) and Freeman (1993) describe how the individual's complete willingness to pay for a marginal increase in a local climate amenity would be measured by what she would have to additionally pay for housing, plus what she would have to give up in income, in order to live in a location with a marginally greater C_j:

$$WTP_{i,j}^C = h_i \frac{\partial f_j^H}{\partial C_j} - \frac{\partial f_{i,j}^{INC}}{\partial C_j} \tag{2.6}$$

The first difficulty encountered in using this wage-hedonic technique to value local amenities in a developing country like Brazil resides in equation 2.5. In particular, P_j^H, the average price of a unit of housing in microregion j, is not universally observed.[2] With traditional wage-hedonic

[2] While a rental price index for housing does exist for a few of Brazil's most populous cities, a valuation based on these few locations was not used in this analysis because the goal was to exploit the observed variation in climate and income across all Brazilian municipios. The greater cross-sectional variation in climate within sample maintained

techniques, the best that one could do would be to identify the hedonic gradient from the labor market equilibrium alone, which would generate a biased value of the amenity by ignoring the first term in equation 2.6. As Roback points-out, the direction of that bias is not *a priori* clear, but depends upon how the change in C_j affects firms. For "unproductive" (i.e., cost-increasing) amenities, the sign of $\partial f^{H}_{i,j}/\partial C_j$ is not determined by theory, but is an empirical question. The same is true of $\partial f^{INC}_{i,j}/\partial C_j$ when amenities are productive.

The model outlined in Section 3 addresses the difficulties imposed by unobserved housing prices by exploiting information on individuals' equilibrium choices of location, along with data describing labor market equilibria, to derive welfare measurements that are consistent with equilibrium in both the labor and housing markets. That strategy also addresses estimation problems arising from the use of aggregate data (i.e., variables measured at the level of the location j instead of the individual i), which are often the only comprehensive data available in developing countries. In particular, aggregate measures of individual attributes (e.g., the percentage of literate adults in a microregion), like wages, are determined by the way individuals with different characteristics sort themselves geographically. If unobserved individual attributes determine, in part, where individuals choose to live, and if these attributes are correlated with individuals' preferences for leisure as well as with other observable individual characteristics, biased parameter estimates will result. The following model explicitly treats such variables as endogenous, using the sorting process that generates them to increase estimation efficiency.

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by this approach allows for better predictions of the effects of global warming, and it does not ignore the preferences of those who don't live in the largest cities. Moreover, this approach avoids the problem of unobserved substitute locations, which might arise when individuals are modeled as choosing between only a few observed locations.

3. Recovering Indirect Utility With Location Choice

Like the wage-hedonic approach, the alternative estimation technique described below employs an equilibrium model of optimal location choice to (unlike the wage-hedonic model) identify the parameters underlying the individual's indirect utility function. The same information extracted by Roback (1982) from reduced-form relationships between income, housing prices, and local attributes can then be recovered from this estimated indirect utility function, without relying upon housing price data, which are not observed.

The underlying model of optimal individual location choice begins with a specification of utility.[3]

Utility:

The utility, $U_{i,j}$, that an individual i receives from living and optimally spending income in microregion j is assumed to be a Cobb-Douglas combination of consumption of a universally traded numeraire commodity (Q_i), housing (h_i), an exogenously supplied and non-rivalrously consumed vector of climate (C_j) and non-climate (X_j) local attributes, equilibrium microregion population density ($\Delta_j = pop_j/area_j$), an unobserved (by the econometrician) microregion attribute (w_j), and a stochastic component ($\eta_{i,j}$), which is unique to each individual and microregion:

$$U_{i,j} = \alpha_{0,i} \; Q_i^{\alpha_{Q,i}} \; h_i^{\alpha_{h,i}} \; X_j^{\alpha_{X,i}} \; C_j^{\alpha_{C,i}} \; \Delta_j^{\alpha_{\Delta,i}} \; e^{w_j} \; e^{\eta_{i,j}} \qquad (3.1)$$

[3] The following description of the individual location decision is identical to that described in Timmins (1999). In that paper, the same econometric model described here is used to recover estimates of a "true" spatial cost of living index, which measures the amount of income required by an optimizing individual to reach some reference level of utility in every Brazilian microregion. The reader already familiar with that econometric model might skip immediately to the discussion of the results pertaining to climate amenity valuation in Section 5 of this paper.

The parameters of this utility function are given by:

$$\begin{aligned} \alpha_{0,i} &= \varphi_{0,z} + \varphi_{1,z} z_{1,i} + \varphi_{2,z} z_{2,i} & \alpha_{Q,i} &= \varphi_{0,Q} + \varphi_{1,Q} z_{1,i} + \varphi_{2,Q} z_{2,i} \\ \alpha_{h,i} &= \varphi_{0,h} + \varphi_{1,h} z_{1,i} + \varphi_{2,h} z_{2,i} & \alpha_{C,i} &= \varphi_{0,C} + \varphi_{1,C} z_{1,i} + \varphi_{2,C} z_{2,i} \\ \alpha_{X,i} &= \varphi_{0,X} + \varphi_{1,X} z_{1,i} + \varphi_{2,X} z_{2,i} & \alpha_{\Delta,i} &= \varphi_{0,\Delta} + \varphi_{1,\Delta} z_{1,i} + \varphi_{2,\Delta} z_{2,i} \end{aligned} \tag{3.2}$$

Individuals' budget shares are assumed to vary with their characteristics, $z_{1,i}$ and $z_{2,i}$. The model is written in terms of two discrete individual characteristics [i.e., education -- $z_{1,i}$ = 0 (literate), 1 (illiterate), and age -- $z_{2,i}$ = 0 (< 50 years), 1 (≥ 50 years)], but is easily generalizable to more characteristics or finer characteristic-divisions. $z_{1,i}$ and $z_{2,i}$ refer to (unobserved) exogenously determined characteristics of *a particular individual i*. Available data describe the (endogenously determined) joint distribution of these characteristics within each microregion.

The individual solves a two-part problem. First, he determines optimal quantities of Q_i and h_i to consume, subject to the following budget constraint:

$$Q_i + P_j^H h_i = I_{i,j} \tag{3.3}$$

The model abstracts from the individual's labor-leisure decision, taking the income that he could earn in microregion j, $I_{i,j}$, as given, conditional upon his characteristics and the attributes of the microregion. Utility maximization yields the following demand functions:

$$Q_i = I_{i,j} \frac{\alpha_{Q,i}}{\alpha_{Q,i} + \alpha_{h,i}} \qquad h_i = \frac{I_{i,j}}{P_j^H} \frac{\alpha_{h,i}}{\alpha_{Q,i} + \alpha_{h,i}} \tag{3.4}$$

Substituting these expressions back into the utility function yields an indirect utility function:

$$\ln V_{i,j} = A_{0,i} + (\alpha_{Q,i} + \alpha_{h,i}) \ln I_{i,j} - \alpha_{h,i} \ln P_j^H + \alpha_{C,i} \ln C_j + \alpha_{X,i} \ln X_j + \alpha_{\Delta,i} \ln \Delta_j + w_j + \eta_{i,j} \tag{3.5}$$

where

$$A_{0,i} = \ln \alpha_{0,i} + \alpha_{Q,i} \ln \frac{\alpha_{Q,i}}{\alpha_{Q,i} + \alpha_{h,i}} + \alpha_{h,i} \ln \frac{\alpha_{h,i}}{\alpha_{Q,i} + \alpha_{h,i}} \tag{3.6}$$

In the same spirit as Roback (1982), a reduced-form specification is used to describe the income that individual i can earn in microregion j; specifically, the log of income is parameterized by:

$$\ln I_{i,j} = \gamma_{z,1} z_{1,i} + \gamma_{z,2} z_{2,i} + \gamma_X \ln X_j + \gamma_C \ln C_j + \gamma_\Delta \ln \Delta_j + \varepsilon_i^{INC} + \varepsilon_j^{INC} \tag{3.7}$$

where ε_i^{INC} and ε_j^{INC} refer to unobserved (to the econometrician) determinants of income that vary by individual and microregion, respectively, and ε_j^{INC} need not have a zero mean. ε_i^{INC} is assumed to be mean-zero and distributed independently of $z_{1,i}$ and $z_{2,i}$ in the nation as a whole.

A similar reduced-form is used to describe the local price level. In particular, the log of the local price level in microregion j is specified as:

$$\ln P_j^H = \delta_X \ln X_j + \delta_C \ln C_j + \delta_\Delta \ln \Delta_j + \varepsilon_j^H \tag{3.8}$$

where ε_j^H refers to any determinants of the price of housing and other non-traded commodities in microregion j that are not observed in available data. ε_j^H need not have a zero mean.

The parameters of equation 3.7 can be identified with available data describing average income levels and parameterizations of distributions of individual attributes by microregion. Since local price levels are not observable, however, the parameters of equation 3.8 are not similarly identified. Instead, they are combined with the parameters of the indirect utility function:

$$\ln V_{i,j} = A_{0,i} + \pi_{I,i} \ln I_{i,j}(z_{1,i}, z_{2,i}, X_j, C_j, \Delta_j; \bar{\gamma}) + \pi_{X,i} \ln X_j + \pi_{C,i} \ln C_j + \pi_{\Delta,i} \ln \Delta_j + \pi_{I,i} \varepsilon_i^{INC} + \pi_{I,i} \varepsilon_j^{INC} - \alpha_{h,i} \varepsilon_j^H + w_j + \eta_{i,j} \qquad (3.9)$$

where, for example, $\pi_{X,i} = \alpha_{X,i} - \alpha_{h,i}\delta_X$, and $\ln I_{ij}$ (•) describes the deterministic part of equation 3.7. Since the parameters of equation 3.8 are not of direct interest in the measurement of climate amenity values, this reduced-form treatment of the indirect utility function does not present a problem.

A number of simplifying assumptions are made in order to transform equation 3.9 into an expression that is practical for estimation. First, given a vector of parameters (i.e., γ's and π's), an observable location-and-individual specific component of indirect utility ($\theta_{i,j}$) can be defined:

$$\theta_{i,j} = \pi_{I,i} \ln I_{i,j}(z_{1,i}, z_{2,i}, X_j, C_j, \Delta_j; \bar{\gamma}) + \pi_{X,i} \ln X_j + \pi_{C,i} \ln C_j + \pi_{\Delta,i} \ln \Delta_j \qquad (3.10)$$

Next, all location-specific unobservable terms can be aggregated to form a single microregion unobservable attribute (ξ_j), the effect of which on utility should vary by the type of individual:

$$\pi_{\xi,i} \xi_j = A_{0,i} + \pi_{I,i} \varepsilon_j^{INC} - \alpha_{h,i} \varepsilon_j^H + w_j \qquad (3.11)$$

The indirect utility function for individual i in microregion j can then be written simply as:

$$\ln V_{i,j} = \theta_{i,j} + \pi_{I,i} \varepsilon_i^{INC} + \pi_{\xi,i} \xi_j + \eta_{i,j} \qquad (3.12)$$

Predicted Municipio Population:

In the second stage of his optimization problem, the individual chooses the microregion in which to live that maximizes his utility, taking as given the optimal allocation of income between Q_i and h_i wherever that may be. The characteristics of *every* microregion enter into this location decision, and a discrete set of bundles of local attributes is available to each individual. The conditional logit model is well-suited to such a choice problem. [See Cropper et al (1993) for a Monte Carlo-based discussion of the merits of discrete choice valuation methods in the context of property value hedonics] While subject to the usual criticisms associated with the independence of irrelevant alternatives, the conditional logit model is used owing to its computational tractability. $\eta_{i,j}$ is therefore assumed to be distributed i.i.d. type-I extreme value.

These modeling assumptions imply that the probability that individual i chooses to locate in microregion j, conditional upon some unobserved values for $z_{1,i}$, $z_{2,i}$, and ε_i^{INC}, is given by the following expression:

$$P(\ln V_{i,j} \geq \ln V_{i,h} \; \forall \; h \neq j \mid z_{1,i}, z_{2,i}, \varepsilon_i^{INC}) = \frac{EXP\,[\theta_{i,j} + \pi_{I,i}\,\varepsilon_i^{INC} + \pi_{\xi,i}\,\xi_j]}{\sum_{k=1}^{J} EXP\,[\theta_{i,k} + \pi_{I,i}\,\varepsilon_i^{INC} + \pi_{\xi,i}\,\xi_k]} \tag{3.13}$$

so that the equilibrium population in microregion j is given by:

$$pop_j = M \bullet \int\int\int \frac{EXP\,[\theta_{i,j} + \pi_{I,i}\,\varepsilon_i^{INC} + \pi_{\xi,i}\,\xi_j]}{\sum_{k=1}^{J} EXP\,[\theta_{i,k} + \pi_{I,i}\,\varepsilon_i^{INC} + \pi_{\xi,i}\,\xi_k]}\, dF\,(z_{1,i}, z_{2,i})\, dF\,(\varepsilon_i^{INC}) \tag{3.14}$$

where $f(z_{1,i}, z_{2,i})$ is the joint density of $z_{1,i}$ and $z_{2,i}$ in the nation, M is the size of the total population, and $f(\varepsilon_i^{INC})$ is the density of the unobserved individual-specific determinant of income [e.g., ~ i.i.d. N (0, $VAR[\varepsilon_i^{INC}]$)]. The bivariate distribution of $z_{1,i}$ and $z_{2,i}$ in the whole of Brazil is observed and has the following form:[4]

		$z_{2,i}$: 0	$z_{2,i}$: 1	
$z_{1,i}$	0	ρ_{00}	ρ_{01}	$1-P_1$
	1	ρ_{10}	ρ_{11}	P_1
		$1-P_2$	P_2	

National Joint Distribution of $z_{1,i}$ and $z_{2,i}$

Equilibrium population can therefore be calculated with the expression:

$$pop_j = M \sum_{l=0}^{1} \sum_{m=0}^{1} \left[\rho_{lm} \int \frac{EXP\ [\theta_{i,j} + \pi_{I,i}\varepsilon_i^{INC} + \pi_{\xi,i}\xi_j]}{\sum_{k=1}^{J} EXP\ [\theta_{i,k} + \pi_{I,i}\varepsilon_i^{INC} + \pi_{\xi,i}\xi_k]} \, dF(\varepsilon_i^{INC}) \right] \tag{3.15}$$

Note that pop_j, the equilibrium population in microregion j, appears on both sides of this expression; in fact, equilibrium pop_j is a function of not only the equilibrium population density in microregion j, but also of the equilibrium population density in *every other microregion*. Equation 3.15

[4] Note that the estimation could be carried-out with just data on the marginal distributions of individual attributes within the whole of Brazil (which is all that is readily available for certain combinations of individual attributes); doing so simply requires treating one of the cells of the national joint distribution of attributes as a parameter to be estimated. Adding information on the joint distribution of individual attributes, however, increases estimation efficiency.

represents one piece of a simultaneous system of J non-linear equations in J unknowns, where J = 363, i.e., the number of microregions in the data set.

The estimation routine described below treats the observed population of each microregion as the equilibrium population predicted by the model, and solves the non-linear system described in equation 3.15 for the resulting vector of ξ's.[5] This idea [see Berry (1994)] provides a convenient mechanism for recovering estimates of the unobserved microregion attribute (i.e., a structural error term), which can then be used in a maximum likelihood framework to recover parameter estimates.

Predicted Aggregate Individual Characteristics:

The model of optimal location choice described above can also be used to calculate the predicted percentage of the equilibrium population of microregion j with characteristics ($z_{1,i}$, $z_{2,i}$). First, conditional upon ε_i^{INC} and given a vector of ξ's that solve the non-linear system associated with equation 3.15, the equilibrium probability that any one utility-maximizing individual in microregion j has some particular values of $z_{1,i}$ and $z_{2,i}$ (denoted by $\ _1$ and $\ _2$) is determined by Bayes' Rule:

$$P(z_{1,i}=\ _1,\ z_{2,i}=\ _2 \mid \ln V_{i,j} \geq \ln V_{i,h}\ \forall\ h \neq j,\ \varepsilon_i^{INC}) = \frac{P(\ln V_{i,j} \geq \ln V_{i,h}\ \forall\ h\neq j \mid z_{1,i}=\ _1,\ z_{2,i}=\ _2,\ \varepsilon_i^{INC})\ P(z_{1,i}=\ _1,\ z_{2,i}=\ _2)}{\sum_{k=0}^{1}\sum_{l=0}^{1} P(\ln V_{i,j} \geq \ln V_{i,h}\ \forall\ h\neq j \mid z_{1,i}=k,\ z_{2,i}=l,\ \varepsilon_i^{INC})\ P(z_{1,i}=k,\ z_{2,i}=l)} \quad (3.16)$$

Integrating with respect to ε_i^{INC} yields a parameterized prediction of the percentage of individuals

[5] Specifically, ξ_{363} is normalized to 1; the left- and right-hand sides of equations #1 through #362 are then divided by the left- and right-hand sides of equation #363, and the resulting 362 non-linear equations are solved for the 362 free values of ξ.

with attributes $_1$ and $_2$ in microregion j in equilibrium:

$$\rho^{j}_{\ _1,\ _2} = \int P(z_{1,i} = \ _1,\ z_{2,i} = \ _2 \mid \ln V_{i,j} \geq \ln V_{i,h}\ \forall\ h \neq j,\ \varepsilon_i^{INC})\ dF(\varepsilon_i^{INC}) \qquad (3.17)$$

Repeating this process for all attribute-combinations and microregions determines a predicted bivariate distribution of individual attributes for each microregion in equilibrium:

$z_{2,i} \mid \ln V_{i,j} \geq \ln V_{i,h}\ \forall\ h \neq j$

$z_{1,i} \mid \ln V_{i,j} \geq \ln V_{i,h}\ \forall\ h \neq j$	0	1	
0	ρ_{00}^{j}	ρ_{01}^{j}	$1\text{-}P_1^j$
1	ρ_{10}^{j}	ρ_{11}^{j}	P_1^j
	$1\text{-}P_2^j$	P_2^j	

Conditional Joint Distribution of $z_{1,i}$ and $z_{2,i}$ for Municipio j

In the estimation algorithm, parameter estimates are determined so as to match as closely as possible each parameterized joint probability to the proportion of each microregion's population observed to have the corresponding combination of attributes, with the difference between data and prediction being attributed to measurement error in the census data-gathering process.

Predicted Income:

While individual characteristics are incorporated into income and indirect utility in order to account for the fact that inter-locational labor market equilibria need only occur within skill groups, differences between individuals must be integrated-out in order to match available income data, which are not broken-down by individual attributes. Given the parameterization of the equilibrium joint distribution of $z_{1,i}$ and $z_{2,i}$ described in equation 3.17, the expectation of individual income in microregion j is given by:

$$INC_j = \sum_{l=0}^{1} \sum_{m=0}^{1} \rho_{lm}^{j} \int e^{\gamma_{z,1}z_{1,i} + \gamma_{z,2}z_{2,i} + \gamma_C \ln C_j + \gamma_X \ln X_j + \gamma_\Delta \ln \Delta_j + \varepsilon_i^{INC} + \varepsilon_j^{INC}} dF(\varepsilon_i^{INC}) \tag{3.18}$$

Given a vector of parameters and data describing average income by microregion (i.e., INC_j), equation 3.18 represents one of J non-linear equations in J unknowns (i.e., ε_j^{INC} = the unobserved location-specific determinant of income). This system can be solved for these unobservables, which are then used in the estimation routine described in Section 4.

Cost-of-Living-Adjusted Unobservable Attribute Index:

Given a vector of parameters, recovering fitted values for the structural error terms ξ_j and ε_j^{INC}, j = 1,2,...,363 allows fitted values for the remaining sources of unobserved microregion heterogeneity in the model to be backed-out. In particular, rearranging equation 3.11 yields:

$$\pi_{\xi,i}\xi_j - \pi_{I,i}\varepsilon_j^{INC} = A_{0,i} + w_j - \alpha_{h,i}\varepsilon_j^{H} \tag{3.19}$$

The left-hand-side of equation 3.19 consists of magnitudes that are identified by the estimation algorithm described below, while the right-hand-side describes the log of the ratio of the impact of unobserved microregion attributes on utility to the impact on utility of unobserved determinants of the microregion's price-level for non-traded commodities like housing, multiplied by a factor of proportionality that depends upon individual-type:

$$\chi_{i,j} = \pi_{\xi,i}\xi_j - \pi_{I,i}\varepsilon_j^{INC} = \ln\left[e^{A_{0,i}} \bullet \frac{e^{w_j}}{(e^{\varepsilon_j^H})^{\alpha_{h,i}}} \right] \qquad (3.20)$$

4. Data and Estimation

The data used to identify the parameters of the model described in the previous section are summarized in Table 1. Most of the data were obtained from the 1991 Brazilian population census and are self-explanatory. Data were originally reported at the level of the municipio, but were aggregated to the level of the microregion in order to reduce the cardinality of the choice set to a level practical for estimation; population- or land-area-weighted averages of municipio data were used where appropriate. Average head-of-household income (i.e., INC_j) is measured in thousands of cruzeiros; 1 cruzeiro ≈ 1/400th of a $US in 1991, a year of rapid inflation in Brazil. The usable data describe approximately 92% of all Brazilian municipios. Climate measures represent 30 year averages of rainfall and temperature. These measurements were taken at weather stations throughout Brazil, and values were interpolated for the center of each municipio; this process is described in Sanghi et al (1997), from which the data were taken. Land-area-weighted average microregion climate data were then constructed from these municipio data.

Regional designations are used for reporting the results of the following estimation. Figure 1 illustrates the division of Brazil into six geographically and socio-economically homogenous regions (i.e., North, Northeast, Minas Gerais, Center-East, Center, South), which are used for this purpose.

Estimation:

Estimates of the parameters of the model described in Section 3 are recovered by a maximum likelihood procedure. First, given a cross-section of observable microregion data and an initial guess at the vector of parameters, the structural errors in the model (i.e., ξ_j and ε_j^{INC}, j = 1,2,...,363) are recovered from the systems of equations described in equations 3.15 and 3.18. With a vector of fitted ξ's, predicted equilibrium joint probabilities of individual attributes by microregion can be calculated from equation 3.17. Error in the measurement of individual attributes (i.e., in census sampling) leads to the following error terms:

$$\begin{aligned} \varepsilon_j^{1,1} &= P_{1,1}^j - \rho_{1,1}^j & \qquad \varepsilon_j^{1,2} &= P_{1,2}^j - \rho_{1,2}^j \\ \varepsilon_j^{2,1} &= P_{2,1}^j - \rho_{2,1}^j & \qquad \varepsilon_j^{2,2} &= P_{2,2}^j - \rho_{2,2}^j \end{aligned} \tag{4.1}$$

Given the realization of three of these error terms, and the fact that reported census joint distributions must sum to one, the fourth error term is identified. Assuming that three of the measurement errors and the structural errors ξ_j and ε_j^{INC} are jointly distributed according to the multivariate normal distribution, N[M, Ω]:

$$\bar{\varepsilon}_j = \begin{bmatrix} \xi_j \\ \varepsilon_j^{INC} \\ \varepsilon_j^{1,2} \\ \varepsilon_j^{2,1} \\ \varepsilon_j^{2,2} \end{bmatrix} \sim i.i.d.\ N\left[\begin{pmatrix} \mu_\xi \\ \mu_{INC} \\ 0 \\ 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_\xi^2 & \sigma_{\xi,INC} & 0 & 0 & 0 \\ \sigma_{\xi,INC} & \sigma_{INC}^2 & 0 & 0 & 0 \\ 0 & 0 & \sigma_{12}^2 & \sigma_{12,21} & \sigma_{12,22} \\ 0 & 0 & \sigma_{12,21} & \sigma_{21}^2 & \sigma_{21,22} \\ 0 & 0 & \sigma_{12,22} & \sigma_{21,22} & \sigma_{22}^2 \end{pmatrix} \right] \tag{4.2}$$

Structural errors and measurement errors are assumed to be uncorrelated in order to facilitate identification.

The log-likelihood of observing the data given the parameter vector can then be determined:

$$L\ (\overline{X},\ \overline{C},\ \overline{pop},\ \overline{P}_{lm},\ \rho_{lm};\ \overline{\pi},\ \overline{\gamma},\ \overline{\sigma},\ \overline{\mu})\ =$$

$$\sum_{j=1}^{363} \left(-\frac{5}{2}\ln 2\pi - \frac{1}{2}\ln|\Omega| - \frac{1}{2}(\overline{\varepsilon}_j - M)'\ \Omega^{-1}\ (\overline{\varepsilon}_j - M) \right) \tag{4.3}$$

where l,m = 0, 1. The estimation algorithm searches over the 68-dimensional parameter space to maximize this expression, solving two sets (one simultaneous) of 363 non-linear equations each time a parameter value is changed.

5. Results

The estimates reported in Tables 2 (a) and (c) describe the parameters of the income (i.e., equation 3.7) and indirect utility (i.e., equation 3.9) functions discussed in Section 3. All estimates are statistically significant at $\alpha = 0.99$ and tend to have the expected signs. Being over 50 years of age or illiterate, for example, imply that one receives a lower income, while a location with a higher population density (i.e., equivalent, in this model, to a higher quantity of labor supplied) is associated with a higher income. Incomes fall with increasing altitude and distance from the sea (i.e., each proxying for more rural communities), but increase with rainfall, which facilitates more productive agriculture. The marginal utility of income is clearly positive, but is lower for both the illiterate and those over 50 years of age. The illiterate tend to prefer to live in lower altitudes and further from the sea, while the opposite is true for those over age 50. Finally, equilibrium population density enters positively into the indirect utility function. Recall that this term captures both the effect of population density on housing price (which should enter the indirect utility function negatively) as well as any direct amenity effects it might have on utility. For this reduced-form parameter to be greater than zero implies that individuals must receive positive utility from living in more densely populated microregions, a result similar to that found in prior studies of the value of city-size. [Cropper (1981)] While this positive effect of population density is even greater for the illiterate, it tends to be smaller (but still positive) for older Brazilians.

Table 2 (b) reports estimates of the distributional parameters described in the preceding section. The negative correlation between ξ_j and ε_j^{INC} suggests that $COV[\varepsilon_j^{INC}, \varepsilon_j^{H}] > 0$ and/or $COV[\varepsilon_j^{INC}, w_j] < 0$, both of which are plausible. The negative estimated correlations between the errors in the population-attribute variables suggest that overstating one cell of the joint distribution implies that the other will be understated, which is also reasonable. The estimated means of ξ_j and ε_j^{INC} imply that, on average, there are positive intercepts in both the indirect utility and income expressions. In the case of the former, heterogeneity in the intercept arises from the same ξ_j having a different impact on utility for different types of individuals, while in the case of the latter, heterogeneity arises from additional intercepts for the old and the illiterate that are estimated explicitly in the income equation.

In order to evaluate the fit of the model, predicted versus actual aggregate population attributes can be compared across microregions. Figures 2 (a) - (c) illustrate scatter-plots of actual versus predicted percentages of individuals who are (literate, $\geq$ 50 years), (illiterate, < 50 years), and (illiterate, $\geq$ 50 years). In all three cases, the fit is good (correlations of 0.886, 0.619, and 0.545, respectively), with the goodness of fit increasing with the variation in the actual probabilities. These results, along with the statistically significant parameter estimates reported in Tables 2, indicate that the model does a satisfactory job of fitting the data.

The simplest way to interpret the climate-variable coefficients is by deriving marginal rates of substitution between specific climate amenities and income, which reflect an individual's willingness to pay for that amenity (i.e., the quantity of numeraire commodity consumption that the individual would be willing to forego so as to remain equally well-off after a marginal increase in some element of C_j):

$$WTP_{i,j}^{C_j} = -MRS_{C_j,\ I_{i,j}} = \frac{\dfrac{\partial V_{i,j}}{\partial C_j}}{\dfrac{\partial V_{i,j}}{\partial I_{i,j}}}$$

$WTP_{i,j}^{C}$ corresponds to the valuation of an individual with characteristics $z_{1,i}$ and $z_{2,i}$ in microregion j. In order to calculate the average WTP for a particular microregion j, that measure must be integrated with respect to the estimated bivariate distribution of individual characteristics within that microregion.

The Importance of Accounting for Housing Prices:

Table 4 illustrates willingness-to-pay for seasonal increases in temperature and rainfall, reported as population-type-weighted averages over all microregions in each region.[6] In order to get

[6] In all willingness-to-pay calculations, a 4°C temperature increase and a 1% increase in the national average precipitation are considered. These climate changes are well within the predictions of most GCM's of Brazil -- most of these models (e.g., the GISS, GFDL, and UKMO models) predict non-marginal greenhouse-warming-induced

some sense of what has been gained by exploiting the information in locational equilibrium to get around both the lack of data on housing prices and the potential simultaneity of aggregate measures of individual attributes, these results are compared with results derived from a traditional wage-hedonic estimation using only information on cross-sectional income differentials (i.e., from the instrumental variables estimation of equation 2.4, using only aggregate data). Table 3 reports the results of this traditional wage-hedonic regression.

The most noticeable aspect of this comparison is that the *signs* of the average willingness-to-pay differ across the two models for every season except winter. Moreover, the implications of the "Income Differentials Only" model for summer climate are particularly disturbing; that model predicts that individuals would be willing to pay very large sums of money in order to get hotter summers. The same is true for wetter summers, although the result is not very significant. In the spring and fall, on the other hand, the "Income Differentials Only" model predicts that individuals would be willing to pay large sums of money to avoid a warmer climate. This clearly differs from the results of the model described in Section 3.

Measuring the Effects of Individual Heterogeneity:

Table 5 describes how willingness-to-pay to avoid a 4°C temperature increase varies across different types of individuals (i.e., by literacy and age status), by season, and by region. Table 6 similarly describes willingness-to-pay for a 1% rainfall increase. Table 7 describes average fitted income by individual-type for each region (recall that available data only describe the income level,

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increases in both temperature (i.e., between 2 and 7°C) and rainfall (i.e., between 1.0 and 1.8%) in every season, depending upon the particular region and model specification being considered.

averaged over individuals of all types, within each microregion). Willingnesses-to-pay are reported in both percentage of annual income, and in 1000's of 1991 cruzeiros annually.

In the case of temperature, seasonal and regional differences tend to be very important. In particular, individuals of all types are willing to pay a substantial portion of their income to avoid an increase in summer temperature. The literate and those in wealthier regions of Brazil are willing to pay a larger percentage of their income, indicating that cooler summer temperatures are a luxury good. The opposite trend in income elasticity is generally present as one moves from north to south, considering warmer temperatures in the spring and fall seasons; i.e., the illiterate (both old and young) are willing to pay substantially more than their literate counterparts (both in percentage and absolute terms) for increases in fall and spring temperatures. The difference in WTP for a warmer spring might be explained in part by a greater reliance of illiterate workers on income from farm labor, the marginal product of which may rise with a warmer planting season. Looking at the winter season, the model predicts that the literate would actually be willing to pay to avoid warmer temperatures, while the illiterate would be willing to pay to get them. The predicted behavior of the literate is counterintuitive, but we would certainly expect the illiterate, with lower incomes, to own lower-quality housing stock and to be more vulnerable to colder winter temperatures, increasing their willingness-to-pay to avoid them.

Turning to Table 6, which describes willingnesses-to-pay for an increase in precipitation equal to 1% of the national average rainfall for each season, we see immediately that this climate attribute constitutes a disamenity for most Brazilians. The scale of this disamenity tends to be much lower than that of temperature, but this could simply be a result of the size of the rainfall increase being considered. In contrast to temperature, increases or reductions in rainfall are not as easily identified as luxuries or necessities; e.g., young, literate Brazilians in the North and Northeast would be willing to pay a greater percentage of their income than their counterparts in each of the wealthier regions of the country to avoid the increase in summer rainfall. This might have something to do with the role that rainfall plays in agriculture.

That increased rainfall is a disamenity is especially true for December, when the combination of high humidity and warm summer temperatures makes for a very high "heat index". Older individuals are willing to pay more than younger individuals to avoid increased rainfall in the winter and spring, and the illiterate seem to mind wetter falls far less than the literate. The only significant positive amenity values from increased rainfall arise for younger, illiterate Brazilians in the spring. The explanation for this result might be similar to the explanation for why the same group was willing to pay so much to get a temperature increase in the spring season; i.e., increased rainfall leads to increased agricultural output, which might contribute substantially to the wages and general utility of the young, illiterate group. Finally, willingness-to-pay for winter rainfall in the Center region deserves comment -- increased precipitation in that part of Brazil represents a disamenity that compares in magnitude to increased summer temperatures. The Center region, much of which is comprised of the Cerrado, is known for being very dry for most of the year, but for receiving large quantities of rainfall in the winter months, often in very short periods of time. It is, therefore, reasonable to expect that increased precipitation in December could be considered a disamenity.

Cost-of-Living-Adjusted Unobservable Attribute Index:

Recall the discussion at the end of Section 3. From the structural error terms recovered from the estimation algorithm (i.e., ξ_j and ε_j^{INC}), along with the estimate of $\pi_{\xi,i}$, $\chi_{i,j}$, the cost-of-living-adjusted index of the unobservable local attribute, w_j, (i.e., expressed in utility terms) can be recovered. Table 8 describes the average χ for each region of Brazil and for each type of individual. Two trends can be identified. First, the amenity value of the unobservable local attribute is, across the board, higher for the illiterate than for the literate; this might give some indication of what sorts of unobservables χ is controlling for. Second, the cost-of-living-adjusted value of the unobserved attribute falls as one moves from north to south across Brazil (with an exception for older, illiterate individuals in the South region). Without actual data on the prices of regionally non-traded commodities, however, it is impossible to determine to what extent this fall is attributable to an actual reduction in the amenity versus a rise in the cost of regionally non-traded commodities.

6. Conclusions

This paper has illustrated a technique for valuing non-marketed local attributes under the sort of data constraints that are often encountered when studying a developing country. Under such data constraints, traditional wage-hedonic techniques lead to biased measurements of value. A structural assumption about the indirect utility function was used in order to circumvent these biases -- specifically, to avoid problems arising from a lack of (i) microdata describing individual characteristics and (ii) any data describing equilibria in housing markets. While the technique does not permit all of the structural components of the individual's willingness to pay for a non-marketed local attribute to be measured (e.g., the hedonic housing-price gradient), it does allow the overall value that the individual places on the attribute to be measured in a theoretically consistent way, which is important for policy analysis in developing countries like Brazil. Moreover, it accounts for unobservable microregion attributes, which are surely significant given the limitations on available data, in as flexible a manner as possible.

Willingnesses-to-pay were calculated from this model for a climate change similar to that predicted by many GCM's to result from a doubling of global atmospheric CO_2 concentrations over the next 100 years. Moreover, these WTP's are broken down by whether an individual is over age 50 and/or illiterate. In general, warmer summers are found to be a severe disamenity in every part of the country, warmer springs and falls tend to be universally beneficial, and the amenity value of warmer winters differs by literacy status. Temperature amenities, moreover, tend to be identifiable as luxuries or necessities (i.e., cooler summers and warmer springs). The same cannot be said easily of changes in rainfall, but generally, increased precipitation is a disamenity in Brazil, especially in the hot summer months. There are indications that increased spring rainfall, along with increased temperatures in that season, might prove quite beneficial to young, illiterate Brazilians, suggesting an impact on agricultural productivity. On the whole, the impact of the simulated climate change on Brazil was found to be approximately 6% of household income, or 2.5 billion 1991 $US, each year. Note as well that a simple model of compensating wage differentials (i.e., a model that ignores the impact of housing-market equilibrium) produces results that are opposite in sign and much larger in magnitude for many of these seasonal effects.

Finally, as with any structural model, the predictions that this model makes are only as good as the assumptions that underlie it. The next step in this research is therefore to test the robustness of the model's conclusions to alternative functional forms. A possible extension of this research will then be to determine the value of other, climate-related local attributes in Brazil. In particular, policy-makers are interested in the potential effects of global warming on sickness from climate-related diseases ranging from heat-stroke and the common cold to dengue and malaria.[7] Alves et al (1999) empirically describes the correlations between climate and morbidity in Brazil from cross-sectional data; I hope to attach values to the morbidity changes implied by global warming by treating the incidence of disease in a location as a local attribute that is endogenously determined by the location's characteristics, as well as by the attributes of the people who settle there in equilibrium (i.e., adding another set of predicting equations to the model outlined in Section 3). Early results suggest that this technique yields plausible values for the disamenity value of increased exposure to a disease like malaria resulting from global warming, taking into account the separate amenity effects which that such warming might have.

[7] Avenues by which climate can affect morbidity include (i) direct transmission routes (e.g., warmer, wetter climates are more hospitable to mosquitos, and, hence, more conducive to the transmission of malaria), and (ii) indirect routes; for example, favorable climate amenities can induce many individuals to choose to live in a particular location, while high equilibrium population density and low incomes may contribute to the increased likelihood of various respiratory and infectious diseases being spread (e.g., the 1986 outbreak of dengue in Rio de Janeiro).

Table 1-- Descriptive Statistics
Full Data Set, n = 363

	Variable (observed for each municipio)	Mean	Standard Deviation	Minimum	Maximum
INC_j	Monthly Income, Head of Household (1,000 cruzeiros)	80.21	37.82	28.68	225.99
pop_j	Total Population (1,000)	370.75	910.94	20.80	15444.94
$P_{1,1}^j$	% Population, Literate & Under Age 50	0.63	0.12	0.14	0.97
$P_{1,2}^j$	% Population, Literate & Over Age 50	0.07	0.04	0.01	0.34
$P_{2,1}^j$	% Population, Illiterate & Under Age 50	0.22	0.12	0.02	0.58
$P_{2,2}^j$	% Population, Illiterate & Over Age 50	0.07	0.03	0.00	0.16
C_j	December Rainfall (cm)	17.14	9.06	1.67	36.43
	March Rainfall (cm)	18.23	7.99	6.25	56.47
	June Rainfall (cm)	7.34	5.83	0.17	31.14
	September Rainfall (cm)	6.51	4.49	0.25	17.87
	December Temperature (°C)	24.58	2.15	18.96	28.91
	March Temperature (°C)	24.43	1.88	18.75	29.73
	June Temperature (°C)	20.44	4.12	11.69	27.31
	September Temperature (°C)	22.61	3.74	13.79	28.93
X_j	Distance from Sea (km)	250.51	234.63	10.69	1068.84
	Altitude (m)	385.60	276.24	2.50	1014.15
	Area (1,000 km^2)	7.93	15.95	0.31	129.32
	Population Density (persons per km^2)	174.35	466.65	0.49	5009.59
$d_{j,r}$	North	0.107	0.310	0	1
	North-East	0.325	0.469	0	1
	Minas Gerais	0.127	0.333	0	1
	Center-East	0.176	0.382	0	1
	Center	0.088	0.284	0	1
	South	0.176	0.382	0	1
	Latitude	-15.55	8.33	-32.81	2.64
	Longitude	-45.91	6.66	-71.16	-34.85

Tables 2 (a) - (c): Full Model Parameter Estimates
n = 363, Log-Likelihood = 4909.76

Table 2 (a) -- Income Function

Variable	Parameter Estimate	Standard Error	Variable	Parameter Estimate	Standard Error
Old	-0.02488	0.00080	December Rain	0.29774	0.00197
Illiterate	-0.04156	0.00133	March Rain	0.08405	0.00248
December Temp	0.19225	0.00597	June Rain	0.01110	0.00036
March Temp	0.01344	0.00043	September Rain	0.12583	0.00202
June Temp	0.03614	0.00116	Altitude	-0.00011	0.00000
September Temp	-0.02055	0.00066	Var[Altitude]	0.00856	0.00027
Pop Density	0.11799	0.00120	Distance to Sea	-0.00062	0.00002

Table 2 (b) -- Distributional Parameters

Variable	Parameter Estimate	Standard Error	Variable	Parameter Estimate	Standard Error
μ_{ξ}	1.01413	0.01312	σ_{22}	0.04043	0.00088
μ_{INC}	0.73606	0.00552	$\rho_{\xi,INC}$	-0.15295	0.00485
σ_{ξ}	0.36061	0.00659	$\rho_{12,21}$	-0.64915	0.00950
σ_{INC}	0.17702	0.00238	$\rho_{12,22}$	-0.36234	0.01106
σ_{12}	0.03696	0.00034	$\rho_{21,22}$	-0.47376	0.01348
σ_{21}	0.04761	0.00031	$\sigma[\varepsilon_i^{INC}]$	0.89670	0.02876

Table 2 (c) -- Indirect Utility Function[‡]

Variable	Parameter Estimate	Standard Error	Variable	Parameter Estimate	Standard Error
December Temp	-0.07910	0.00254	September Rain	-0.20796	0.20796
-- Old	0.04077	0.00131	-- Old	0.60451	0.00929
-- Illiterate	-0.01112	0.00036	-- Illiterate	-0.25218	0.00599
March Temp	-0.10562	0.00339	Pop Density	0.23775	0.00647
-- Old	0.01266	0.00041	-- Old	-0.15059	0.00336
-- Illiterate	-0.06985	0.00224	-- Illiterate	0.18344	0.00371
June Temp	-0.07234	0.00232	Distance to Sea	0.29843	0.00877
-- Old	0.02514	0.00081	-- Old	-0.00914	0.00029
-- Illiterate	-0.09415	0.00301	-- Illiterate	0.31405	0.00668
September Temp	-0.01015	0.00033	Altitude	-0.26719	0.00740
-- Old	0.03656	0.00117	-- Old	0.17105	0.00476
-- Illiterate	-0.04570	0.00147	-- Illiterate	-0.13454	0.00386
December Rain	0.07350	0.00235	Var[Altitude]	0.10917	0.00344
-- Old	-0.43849	0.00975	-- Old	0.23929	0.00513
-- Illiterate	0.02960	0.00094	-- Illiterate	-0.03596	0.00114
March Rain	-0.21019	0.00670	Income	4.59892	0.05628
-- Old	-0.02743	0.00088	-- Old	-0.05435	0.00174
-- Illiterate	-0.02326	0.00075	-- Illiterate	-1.57204	0.01981
June Rain	0.62983	0.01364			
-- Old	0.25027	0.00673			
-- Illiterate	-0.08327	0.00258			

[‡] Indirect utility function parameter estimates are interpreted as follows: $\pi_{\text{June Temp}}$ = -0.07234 for a literate individual below the age of 50; $\pi_{\text{June Temp}}$ = -0.07234 + 0.02514 = -0.0472 for a literate individual over the age of 50; and $\pi_{\text{June Temp}}$ = -0.07234 + 0.02514 - 0.09415 = -0.14135 for an illiterate individual over the age of 50.

Table 3 : Income-Differential-Only Model Parameter Estimates
Logarithmic Specification, n = 363, R^2 = 0.86, $E'PZE$ = 0.00625

Instrument Vector = {constant, regional dummies, seasonal temperature & rainfall, distance to sea, altitude, latitude, longitude, latitude*longitude, $latitude^2$, $longitude^2$}

Variable	Parameter Estimate	Standard Error	Variable	Parameter Estimate	Standard Error
Constant	-0.2318	2.1769	March Temp	0.7875	1.1026
North	-0.0341	0.0931	June Temp	0.8937	0.5063
Northeast	-0.1315	0.0881	Sept Temp	0.1918	0.5748
Minas Gerais	-0.0254	0.0610	Dec Rain	-0.0762	0.0394
Center-East	0.0845	0.0679	March Rain	-0.2056	0.0745
South	-0.1289	0.0984	June Rain	0.0712	0.0267
Pop Density	0.0148	0.0350	Sept Rain	-0.0152	0.0578
% Illiterate	-1.0158	0.1698	Distance to Sea	0.0734	0.0437
% ≥ 50 Years	-0.4325	0.2043	Altitude	0.0343	0.0256
Dec Temp	-1.1373	1.0134			

Table 4: Annual Willingness To Pay, 4°C Temperature Increase and 1% Rainfall Increase Regional Averages, 1000 cruzeiros

(1) Full Model (2) Income Differentials Only

	Region	Season							
		December		March		June		September	
		(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Temperature	North	-41.53	165.94	5.30	-116.81	-1.89	-136.99	6.47	-27.36
	Northeast	-25.92	99.29	3.85	-69.99	-0.62	-87.12	4.58	-17.74
	Minas Gerais	-50.91	193.34	5.02	-131.12	-4.46	-190.38	7.96	-35.12
	Center-East	-75.74	282.09	6.41	-191.60	-8.26	-286.20	11.67	-53.39
	Center	-55.95	211.28	5.59	-146.64	-4.48	-194.72	8.28	-36.18
	South	-67.40	258.89	5.66	-181.58	-9.15	-314.90	12.16	-57.89
Rainfall	North	-6.20	0.85	-2.43	1.11	-3.87	-0.93	-1.08	0.15
	Northeast	-10.87	1.53	-1.58	1.47	-2.49	-0.52	-2.26	0.31
	Minas Gerais	-3.22	0.45	-6.26	2.42	-13.46	-3.15	-2.28	0.24
	Center-East	-5.55	0.81	-14.24	3.42	-7.97	-1.91	-2.14	0.21
	Center	-3.92	0.58	-6.27	2.18	-23.05	-5.25	-1.90	0.21
	South	-7.58	1.16	-11.55	3.57	-2.17	-0.54	-0.84	0.09

Table 5: Individual Heterogeneity in Annual Willingness-to-Pay for a 4°C Temperature Increase, Regional Averages

Season	Region	Individual Type							
		Literate < 50 Years		Literate ≥ 50 Years		Illiterate < 50 Years		Illiterate ≥ 50 Years	
		%INC	1000 cz	%INC	1000 cz	%INC	1000 cz	%INC	1000 cz
December	North	-4.709	-41.275	-4.945	-42.278	-4.370	-36.744	-4.724	-38.745
	Northeast	-4.687	-26.049	-4.922	-26.682	-4.350	-23.191	-4.702	-24.452
	Minas Gerais	-5.413	-49.954	-5.683	-51.157	-5.023	-44.468	-5.430	-46.890
	Center-East	-5.336	-73.753	-5.603	-75.541	-4.951	-65.646	-5.353	-69.232
	Center	-5.045	-55.105	-5.298	-56.447	-4.682	-49.058	-5.062	-51.737
	South	-5.609	-65.750	-5.890	-67.348	-5.205	-58.531	-5.627	-61.721
March	North	0.261	2.288	0.192	1.642	1.219	10.250	1.131	9.276
	Northeast	0.260	1.445	0.192	1.041	1.217	6.488	1.130	5.876
	Minas Gerais	0.289	2.667	0.213	1.917	1.349	11.943	1.252	10.811
	Center-East	0.285	3.939	0.210	2.831	1.330	17.635	1.235	15.973
	Center	0.275	3.004	0.202	2.152	1.446	15.151	1.192	12.183
	South	0.309	3.622	0.228	2.607	1.285	14.450	1.342	14.720
June	North	-0.577	-5.057	-0.728	-6.224	0.533	4.482	0.323	2.649
	Northeast	-0.611	-3.396	-0.770	-4.174	0.565	3.012	0.342	1.779
	Minas Gerais	-0.788	-7.272	-0.994	-8.948	0.729	6.454	0.441	3.808
	Center-East	-0.801	-11.071	-1.011	-13.630	0.741	9.825	0.448	5.794
	Center	-0.686	-7.493	-0.865	-9.216	0.634	6.643	0.384	3.925
	South	-1.009	-11.828	-1.273	-14.556	0.933	10.492	0.565	6.197
September	North	0.598	5.241	0.387	3.309	1.025	8.618	0.711	5.831
	Northeast	0.644	3.579	0.417	2.261	1.104	5.886	0.765	3.978
	Minas Gerais	0.760	7.014	0.492	4.429	1.302	11.526	0.903	7.798
	Center-East	0.780	10.781	0.505	6.808	1.336	17.714	0.927	11.989
	Center	0.662	7.231	0.429	4.571	1.134	11.882	0.786	8.033
	South	0.963	11.289	0.624	7.135	1.649	18.543	1.144	12.548

**Table 6: Individual Heterogeneity in Annual Willingness-to-Pay for a 1% Rainfall Increase,
Regional Averages**

Season	Region	Individual Type							
		Literate < 50 Years		Literate ≥ 50 Years		Illiterate < 50 Years		Illiterate ≥ 50 Years	
		%INC	1000 cz	%INC	1000 cz	%INC	1000 cz	%INC	1000 cz
December	North	-0.698	-6.118	-0.484	-4.138	-0.739	-6.214	-0.412	-3.379
	Northeast	-1.989	-11.054	-1.379	-7.476	-2.104	-11.217	-1.173	-6.100
	Minas Gerais	-0.356	-3.285	-0.247	-2.223	-0.377	-3.338	-0.210	-1.813
	Center-East	-0.413	-5.708	-0.286	-3.856	-0.436	-5.781	-0.243	-3.143
	Center	-0.365	-3.987	-0.253	-2.696	-0.386	-4.045	-0.215	-2.197
	South	-0.667	-7.819	-0.462	-5.283	-0.705	-7.928	-0.393	-4.311
March	North	-0.038	-0.333	-0.032	-0.274	-0.007	-0.059	0.004	0.033
	Northeast	-0.084	-0.467	-0.069	-0.374	-0.015	-0.080	0.008	0.042
	Minas Gerais	-0.088	-0.812	-0.073	-0.657	-0.016	-0.142	0.009	0.078
	Center-East	-0.080	-1.106	-0.066	-0.890	-0.014	-0.186	0.008	0.103
	Center	-0.062	-0.677	-0.051	-0.543	-0.011	-0.115	0.006	0.061
	South	-0.093	-1.090	-0.077	-0.880	-0.017	-0.191	0.009	0.099
June	North	-0.373	-3.269	-0.516	-4.412	-0.482	-4.053	-0.703	-5.766
	Northeast	-0.369	-2.051	-0.510	-2.765	-0.477	-2.543	-0.695	-3.614
	Minas Gerais	-1.242	-11.462	-1.717	-15.456	-1.608	-14.235	-2.342	-20.224
	Center-East	-0.502	-6.939	-0.694	-9.357	-0.650	-8.618	-0.947	-12.248
	Center	-1.829	-19.978	-2.530	-26.955	-2.368	-24.812	-3.449	-35.251
	South	-0.159	-1.864	-0.220	-2.516	-0.206	-2.316	-0.300	-3.291
September	North	-0.163	-1.429	-0.432	-3.693	0.053	0.446	-0.354	-2.903
	Northeast	-0.560	-3.112	-1.480	-8.023	0.181	0.965	-1.211	-6.298
	Minas Gerais	-0.254	-2.344	-0.671	-6.040	0.082	0.726	-0.549	-4.741
	Center-East	-0.139	-1.921	-0.368	-4.961	0.045	0.597	-0.301	-3.893
	Center	-0.181	-1.977	-0.479	-5.103	0.059	0.618	-0.392	-4.006
	South	-0.068	-0.797	-0.178	-2.035	0.022	0.247	-0.146	-1.601

Table 7: Average Annual Income by Type and Location (1000 cz)

Region	Individual Type			
	Literate < 50 Years	Literate ≥ 50 Years	Illiterate < 50 Years	Illiterate ≥ 50 Years
North	876.505	854.969	840.824	820.164
Northeast	555.761	542.106	533.137	520.038
Minas Gerais	922.855	900.180	885.287	863.535
Center-East	1382.176	1348.216	1325.910	1293.332
Center	1092.271	1065.434	1047.806	1022.061
South	1172.230	1143.428	1124.510	1096.881

Table 8: Cost-of-Living-Adjusted Unobservable Attribute Index ($\chi_{i,j}$)

Region	Individual Type			
	Literate < 50 Years	Literate ≥ 50 Years	Illiterate < 50 Years	Illiterate ≥ 50 Years
North	-1.615	-1.400	0.054	0.269
Northeast	-0.041	0.219	1.451	1.711
Minas Gerais	-0.960	-0.746	0.524	0.738
Center-East	-3.244	-3.093	-1.491	-1.339
Center	-2.419	-2.197	-0.494	-1.679
South	-3.463	-3.339	-1.804	-0.273

Figure 1 -- Map of Brazil[8]

Regional Definitions:

(1) North --Rondonia, Acre, Amazonas, Roraima, Amapa, Para, Tocantins

(2) Northeast --Maranhao, Piaui, Ceara, Rio Grande do Norte, Paraiba, Pernambuco, Alagoas, Sergipe, Bahia

(3) Minas Gerais

(4) Center-East -- Espirito Santo, Rio de Janeiro, Sao Paulo

(5) Center --Mato Grosso, Goias, Mato Grosso do Sul

(6) South --Parana, Santa Catarina, Rio Grande do Sul

[8] Maps and boundary data are copyrighted by FOTW Flags Of The World, http://fotw.digibel.be/flags/geo-copy.
html. Internet, Available 6/20/99, http://www.flagcentre.com.au/fotw/flags/geo-br.html. Regional boundaries added.

Figure 2 (a)
Actual v Fitted % (literate, >50 yrs)

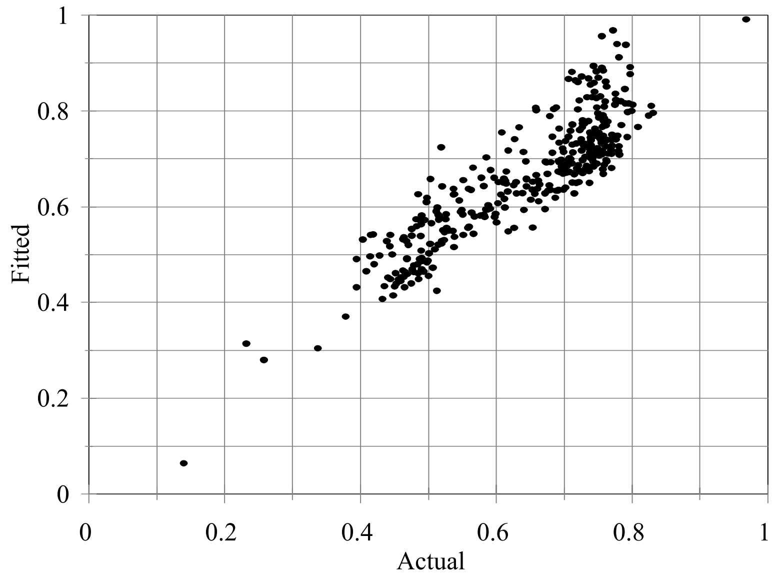


Figure 2 (b)
Actual v Fitted %(illiterate, <50 yrs)

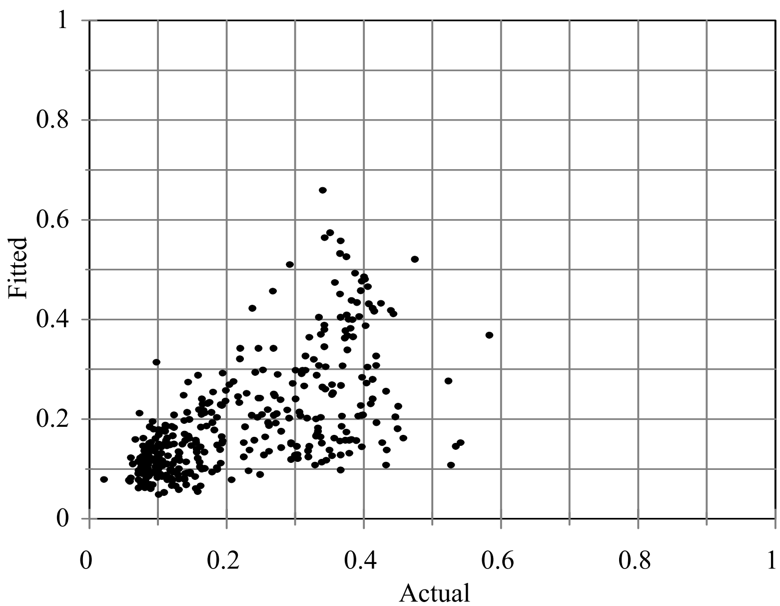
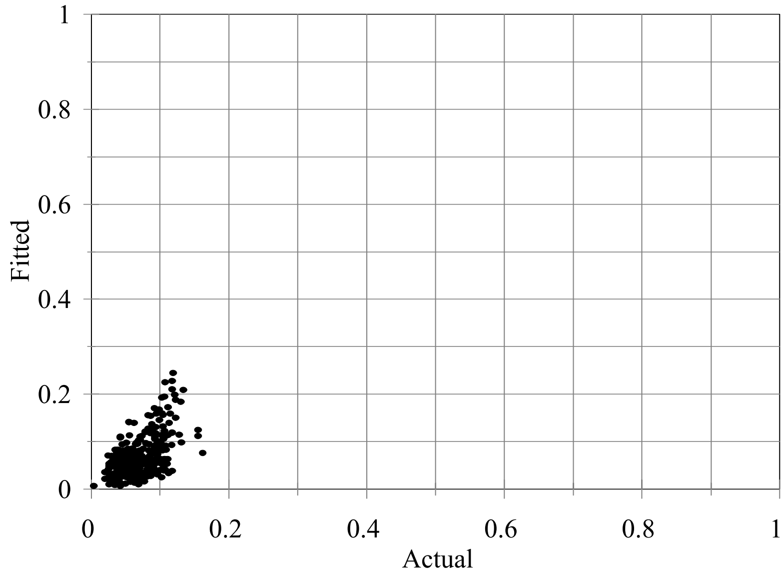


Figure 2 (c)
Actual v Fitted %(illiterate, >50 yrs)



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