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The geographical distribution of the consumption expenditure in Ecuador: Estimation and mapping of the regression quantiles

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The geographical distribution of the consumption expenditure in Ecuador: Estimation and mapping of the regression quantiles

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Abstract

The real consumption expenditure of families provides important information about the welfare of people residing in a given administrative area. State policies designed to alleviate poverty and funding management plans rely on the ability of statistical models to provide detailed and correct information. It can be argued that mean regressions alone do not provide a satisfactory picture of the distribution of the response. We explore the use of nonparametric quantile regression methods for geographically referenced data. The motivating example pertains the distribution of the consumption expenditure in Ecuador, whose shape, conditional on some predictors, varies across the locations and reveals that the spatial heterogeneity has a very different impact on the quantiles of the response.

Keywords: poverty mapping; nonparametric quantile regression; triograms splines; consumption expenditure; Ecuador.

1 Introduction

In 1995, a large and comprehensive survey, the Encuesta Condiciones de Vida (ECV), was conducted in Ecuador to measure the biweekly real consumption expenditure of about 5800 households sampled from 53 counties. The sampling design incorporated both clustering and stratification, based on the main agro-climatic zones (Costa, Sierra, and Oriente), and the rural-urban breakdown of the country (Figure 1). This survey was part of the World Bank's Living Standard Measurement Surveys project that began in 1980. These data have

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been originally analyzed by Petrucci et al. (2003), who applied a logistic spatial regression to assess the poverty rates for each county.

The main purpose of such surveys is to provide a quantitative guideline for the application of policies to ameliorate the living standards of specific population targets. Spatially referenced observations of the real consumption expenditure provide important information on the welfare of people residing in a given administrative area. The effectiveness of poverty alleviation programs relies upon the ability of statistical analysis to inform on the complexity of the structure of the data. The mean regression alone does not provide a satisfactory picture of the distribution of the response. Also, when the assumption of normality for the error distribution is untenable, the use of robust techniques is advisable. We explore the use of nonparametric quantile regression methods to depict more accurately the distribution of the real consumption expenditure across counties in Ecuador. The conditional quantiles of the distribution can be estimated and mapped, and a deeper understanding of the structure of the data can be inferred.

In this analysis, the county represented the lowest level at which it was possible to aggregate the data. We considered its geographical centroid considered as the spatial reference for all families residing in the same county. The ECV database provided information related to the educational level of the families' members. We considered one additional source, the INFOPLAN atlas, that collected demographic and socio-economic variables from the Census of population and households (INEC) conducted in Ecuador in 1990. Slow economic growth and low inflation were reported in Ecuador during the period starting from 1990 to 1995. Based on this stability, we assumed that the ECV and the census data were comparable, although they were collected at different times.

The applications of quantile regression in economic research include demand analysis (Hendricks and Koenker, 1991; Deaton, 1997; Manning et al., 1995), wage and income data (Buchinsky, 1994; Fitzenberger, 1999; Machado and Mata, 2001), and the relation between schooling and wage inequality (Chamberlain, 1991), to mention a few.

The literature on the nonparametric estimation of conditional quantile functions encompasses a remarkable number of papers and since the seminal work of Stone (1977) various methods have been proposed more recently. Koenker et al. (1994) explored a class of univariate splines defined as solutions to a smoothing problem with a L_1 roughness penalty. Yu and Jones (1998) proposed two kernel weighted local linear estimators for estimating conditional distributions. Nonparametric and semiparametric smoothing models represent undoubtedly a powerful tool available to the analyst when unduly restrictive parametric assumptions about the distribution of the response should be avoided. Indeed, the growth of the computational science have led to a paradigm shift in the field of smoothing. Bivariate smoothing splines have been introduced by He et al. (1998). Their formulation leads to bilinear tensor product splines which lack of orthogonal equivariance. Koenker and Mizera (2004) overcame this drawback by means of a smoothing spline variant of the triogram models introduced by Hansen et al. (1998). See also Heagerty and Pepe (1999) for a semiparametric

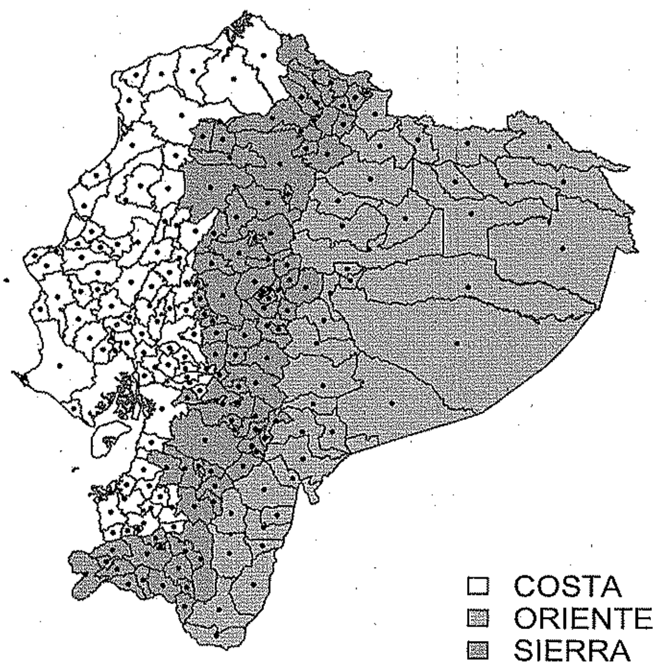

Figure 1: Map of Ecuador. For each county its centroid is marked by a dot

method which combines advantages of both the parametric approach of Cole (1988) and Cole and Green (1992) and the distribution-free methods provided by Koenker and Bassett (1978).

In §2 we introduce the model and some notation. For the Ecuador data analysis, a stepwise modeling approach is considered, starting from a nonparametric spline model and then entering some covariates in a partially linear model. In §3 we conclude the paper with some final remarks. The analysis was performed by using the quantreg library (Koenker, 2006) for the freely available statistical language R (R Development Core Team, 2005).

2 Quantile regression for poverty mapping

2.1 A first simple model

First, we consider a simple regression model without covariates, where the spatial information is modeled through a bivariate smoothing term. Let $y = (y_1, \ldots, y_{53})^\top$ be the biweekly real consumption expenditure per county, averaged over sampled households, adjusted for regional price variation and expressed in thousands Sucre, and $\mathbf{x}_i = (x_{1,i}, x_{2,i})^\top \in \mathbb{R}^2$ be the two-dimensional vector of geographical coordinates of the ith centroid.

Table 1: Summary statistics of the biweekly real consumption expenditure for the Ecuador data

Statistics	*Estimate*
First quartile	360.11
Median	452.71
Mean	449.73
Third quartile	508.79
Standard deviation	122.40
Skewness (Fisher)	0.48

We assume that y can be modeled by

$$y_i = f(\mathbf{x}_i) + \varepsilon_i, \qquad i = 1, \ldots, 53, \tag{1}$$

with independent and identically distributed ε_i. The function $f(\cdot)$ that appears in (1) is assumed to be unknown and any distributional assumption about the error term is avoided. Table 1 reports the descriptive statistics of the response variable. The marginal distribution of y is slightly skewed to the right.

This approach is totally nonparametric and smoothing splines have proven to be very useful in nonparametric functions estimation.

In its general form, the minimization problem can be written as

$$\min_{g \in \mathcal{U}} \left[\sum_i \rho_\tau\{y_i - g(\mathbf{x}_i)\} + R(g) \right], \tag{2}$$

where $\rho_\tau(u) = u\{\tau - I(u < 0)\}$ is the check function of Koenker and Bassett (1978), $R(g)$ is the roughness penalty, and g are functions belonging to an appropriately chosen $\mathcal{U}$. The extension of univariate smoothing splines to bivariate situations raised challenging questions about how to define the roughness penalty of the τth quantile surface. In fact, different penalties lead to different forms of the solution to the problem in (2). Although several alternatives are available, we considered total variation penalties that are more appealing in terms of optimization strategy. Furthermore, the orthogonal equivariance for penalties represents a very desirable property within the applications for geographically referenced data like the one at issue and thus it makes the triograms splines preferable to the bilinear tensor product splines.

Formally, let $\mathcal{H}$ denote a compact region of $\mathbb{R}^2$, and let $\Delta = \{\delta_i : i = 1, \dots, N\}$ be a triangulation, such that $\mathcal{H} = \bigcup_{\delta \in \Delta} \delta$. The continuous functions g on $\mathcal{H}$ that are linear when restricted to $\delta \in \Delta$ are called triograms. The unique total variation penalty $R(g)$ penalizing the gradient of triograms is given by (Koenker and Mizera, 2004, p.150)

$$R(g) = c \sum_k |\nabla g_{e_k}^+ - \nabla g_{e_k}^-|_2 |e_k|_2,$$

where the summation is extended to all the interior edges of the triangulation, $|e_k|_2$ is the Euclidean length of the edge e_k and $|\nabla g_{e_k}^+ - \nabla g_{e_k}^-|$ is the Euclidean length of the difference between gradients of g on the triangles adjacent to e_k. The penalized quantile triograms then can be estimated as a solution of a linear programming problem for a given smoothing parameter λ. Let $\hat{g}_\lambda$ denote such solution.

For the Ecuador data, we estimated several quantiles ($\tau = 0.10, 0.25, 0.50, 0.75, 0.90$) by using the triograms splines. The smoothing parameter λ was chosen over a grid $\lambda = 10^{k/20}$, with $k = -20, -19, \dots, -10$, to minimize the SIC criterion (Schwarz, 1978)

$$\text{SIC}(\lambda) = \log \left[53^{-1} \sum_{i=1}^{53} \rho_\tau \{y_i - \hat{g}_\lambda(\mathrm{x}_i)\} \right] + 0.5 \cdot 53^{-1} p_\lambda \log 53.$$

For $\lambda = 0.11$ the corresponding number p_λ of interpolated observations by the objective function was 21. This value represents a more understandable measure of the dimension of the fit, since it can vary within a known range.

Contour plots of the quantile surfaces are shown in Figures 2-4. A peak in the South of Costa and one in the North of Sierra are conspicuous for the median surface. The 10th and the 25th percentiles show a depression in the South and in the North Sierra. The third quartile shows a peak in the South of Costa and in the North of Sierra. For $\tau = 0.90$, a positive gradient moves toward the inland of Costa and Sierra.

2.2 Inclusion of covariates

We considered a partially linear additive model (Koenker and Mizera, 2002) with four predictors (the proportions, here, refer to the prevalence in the sam-

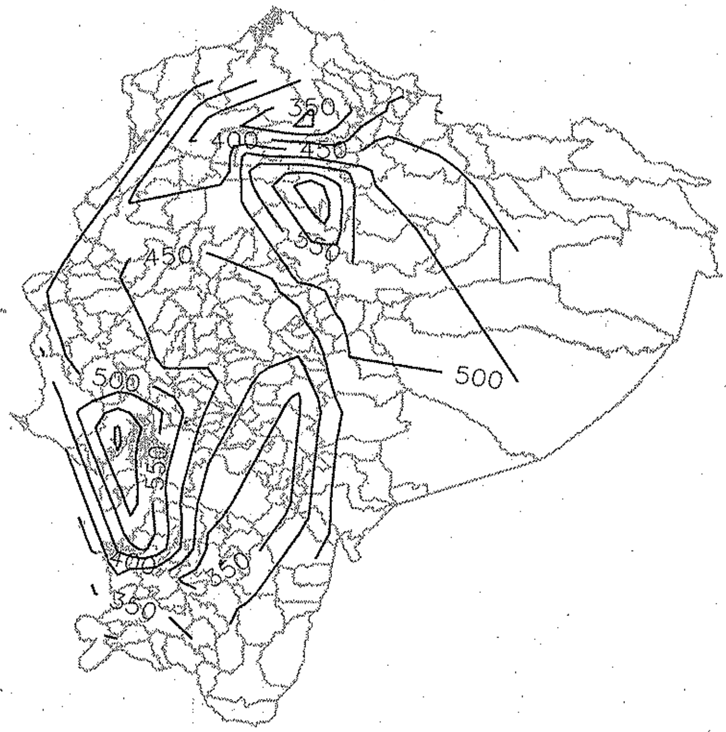

Figure 2: Contour plot of the median surface estimated for the model (1)

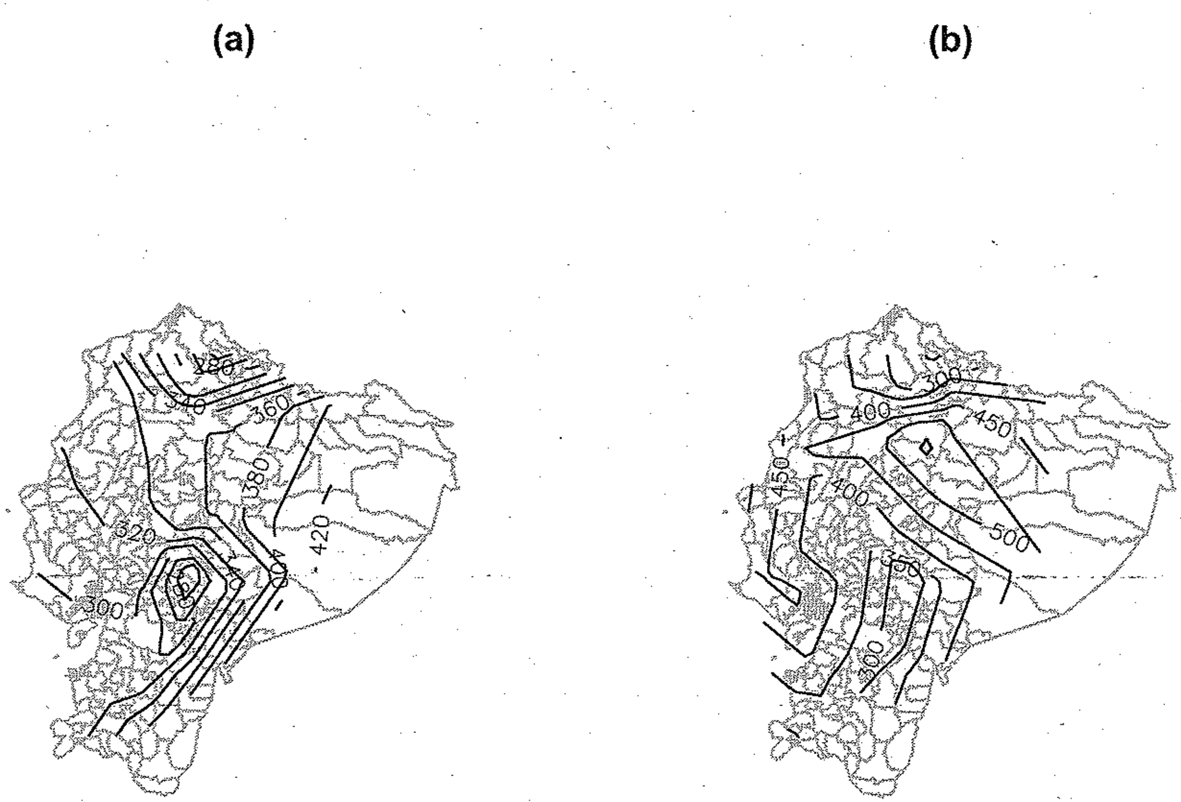

Figure 3: Contour plot of the quantiles $\tau = 0.10$ (a) and $\tau = 0.25$ (b) estimated for the model (1)

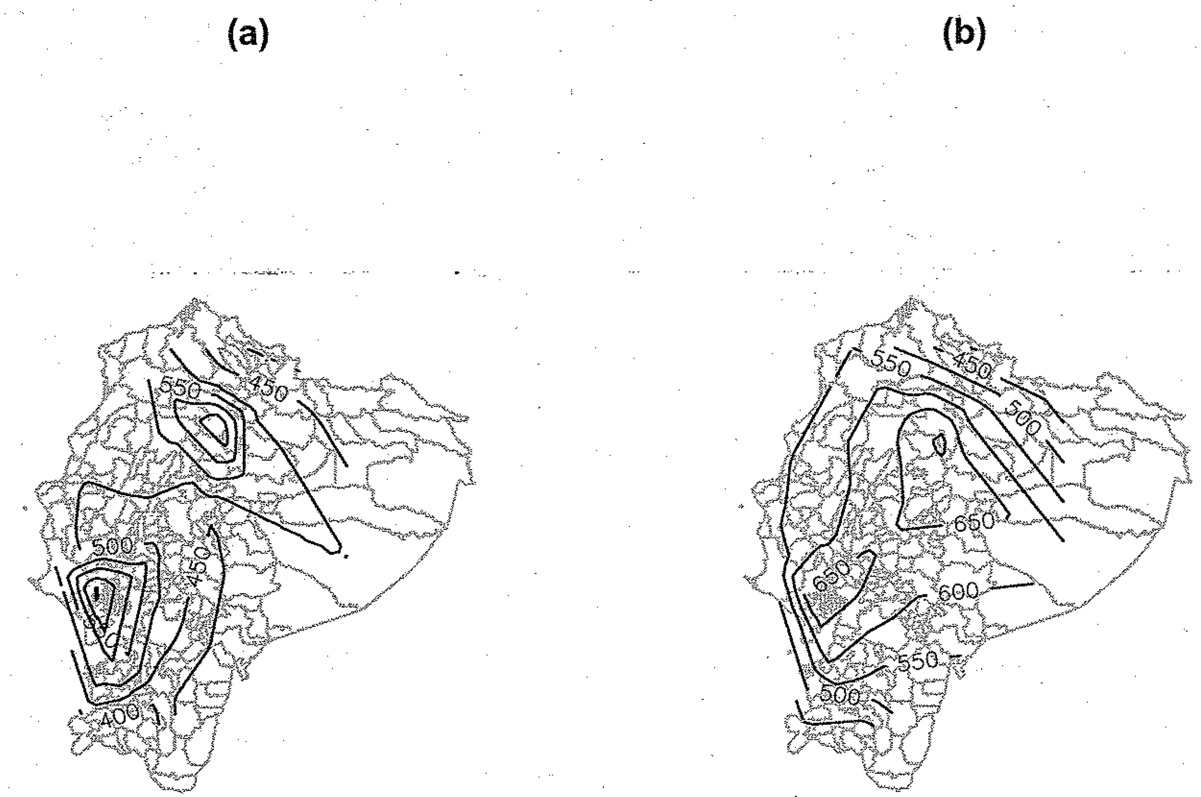

Figure 4: Contour plot of the quantiles $\tau = 0.75$ (a) and $\tau = 0.90$ (b) estimated for the model (1)

ple): proportion of illiterate people, proportion of people with higher education diploma, proportion of families that reside 15 kilometers or more from practicable roads, and level of the agricultural productivity (measured in tons per year). Some descriptive statistics are reported in Table (2).

Table 2: Mean and standard deviation (sd) of the selected covariates for the Ecuador data

Variable	*mean*	*sd*
prop. of illiterate people	0.17	0.07
prop. of people with higher ed. dip.	0.06	0.03
prop. of families $\geq$ 15 km from road	0.06	0.17
agricultural productivity	139.64	301.73

We then fitted the model

$$y_i = g(\mathbf{x}_i) + \mathbf{z}_i^\top \beta^{(\tau)} + \varepsilon_i, \qquad i = 1, \ldots, 53, \tag{3}$$

where $\mathbf{z}_i^\top$ is the ith (row) vector of the design matrix

$$\mathbf{Z} = \begin{bmatrix} 1 & \text{illit}_1 & \text{diploma}_1 & \text{roads}_1 & \text{productivity}_1 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & \text{illit}_{53} & \text{diploma}_{53} & \text{roads}_{53} & \text{productivity}_{53} \end{bmatrix},$$

and $\beta^{(\tau)} = (\beta_0^{(\tau)}, \beta_1^{(\tau)}, \beta_2^{(\tau)}, \beta_3^{(\tau)}, \beta_4^{(\tau)})^\top$ is the τth regression quantile.

Estimated 95% and 90% confidence intervals for $\beta^{(\tau)}$ were obtained by bootstrapping the residuals via the BC_a method introduced by Efron (1987), with a bootstrap sample size equal to 499. We set $\lambda = 0.11$. The results are reported in Table 3.

Table 3: $\beta^{(\tau)}$'s estimates for the Ecuador data

quantile	β_0	β_1	β_2	β_3	β_4
0.10	613.526**	−1298.856**	−80.886	−0.014**	−0.061
0.25	503.719**	−771.503**	278.903	−0.012**	−0.060*
0.50	567.092**	−771.296**	201.015	−0.013**	0.058
0.75	565.866**	−740.147**	860.700**	−0.012*	0.122**
0.90	608.159**	−912.341**	829.755**	−0.017*	0.120

* (**) denotes significance at the 10% (5%) level

For what concerns the factors related to education, we observed that the illiteracy affects negatively the average expenditure level for all the estimated quantiles of the distribution (β_1 significant at the 5% level). The possession of a diploma, however, does not affect the poorest counties (β_2 is not significant for quantiles other than the seventy-fifth and the ninetieth percentiles), where the low profile jobs are presumably performed by people with education degrees lower than diploma. The sign of β_2 is consistent with the well known circumstance that the education has a positive effect on the income level.

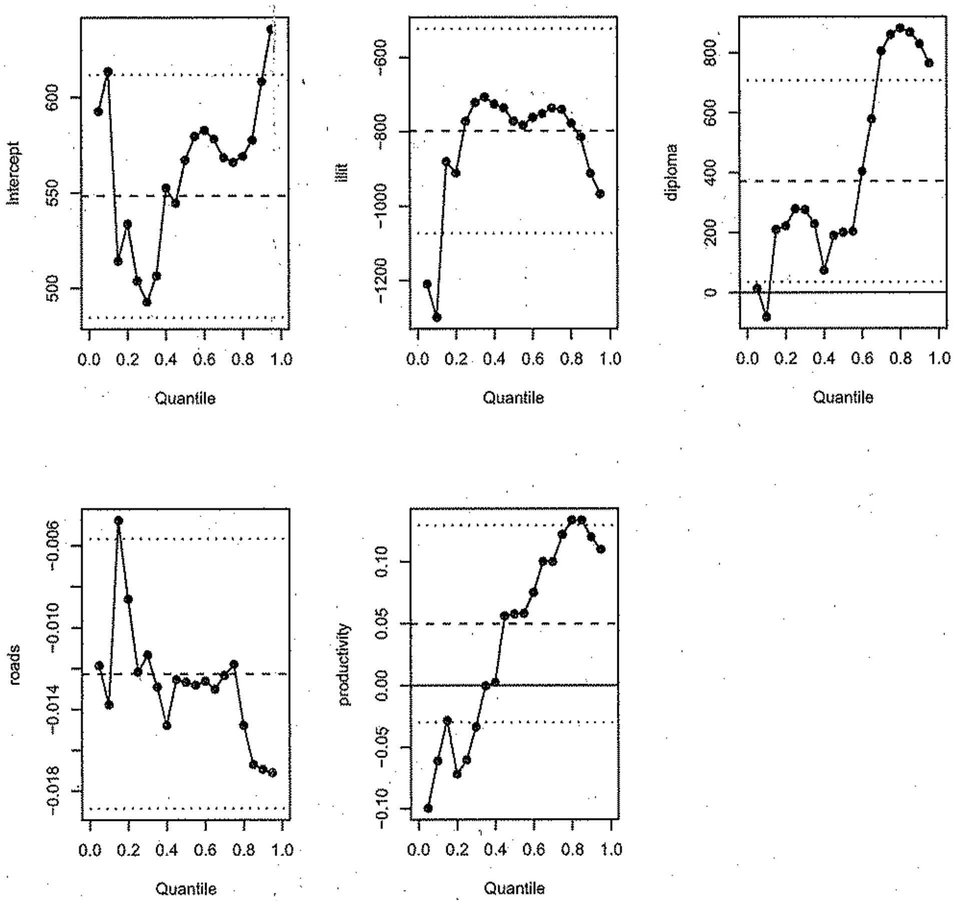

Figure 5: Quantiles for Ecuador data

The distribution of the response variable is sensitive to the proportion of families residing far from practicable roads for all but the last two estimated quantiles, which are marginally significant at the 95% level. At first, this would suggest that the wealthiest families might have access to better forms of transport.

β_4's significance is somewhat sparse across the estimated quantiles. The positive sign associated with this parameter for the third quartile might be due to a capitalization effect of the higher agricultural productivity levels. The low significance of β_4 for the first quartile does not allow a clear interpretation of its sign.

We then concisely described the conditional distribution of the consumption expenditure at a greater extent. In each plot of Figure 5, a solid line interpolates the point estimates (filled dots) of $\hat{\beta}_j^{(\tau)}$, $j = 0, \ldots, 4$, $0.05 \leq \tau \leq 0.95$. The dashed line and the dotted lines represent, respectively, the ordinary least-squares estimate of the mean effect and its 95% confidence interval.

Illiteracy seems to be associated with a rather large negative effect on the consumption expenditure, especially in the lower tail of the distribution.

The effect due to the possession of an higher education diploma strongly affects the distribution at its right, where the estimate's value 'jumps' within the relatively short interval of quantile points comprised between 0.55 and 0.70.

The coefficient related to the distance from roads shows a peak towards zero in correspondence of the quantile $\tau = 0.15$.

The effect of the agricultural productivity has a quasi-monotone trend, encompassing both negative and positive values. The scattered significance of this coefficient for different quantiles admits various interpretations. The agricultural industry affects the poorest and the wealthiest counties of Ecuador only, so the 'body' of the distribution seems to be left to the influence of other industries. This is consistent with the fact that the ordinary least-squares estimate is not significant at the 5% level. Further investigation on the working conditions and the distribution of wealth within the agricultural industry might shed light on the negative sign of β_4 in the left tail.

Contour plots of the fit of the quantile regression surfaces are shown in Figures 6-8. The spatial heterogeneity appears now to be enriched with more details. The median surface shows a saddle in the south, between two peaks along the agroclimatic boundary through Sierra and Oriente. The spatial features associated with the 10th and the 25th quantile surfaces, similar to those associated with the 0.75th and 0.90th percentiles, are more defined. The inclusion of covariates in the model (3), therefore, ameliorated the spatial characterization of the distribution of the response variable.

We conducted a sensitivity analysis of the choice of the bootstrap sample size for the model (3). We considered samples of size 999 and 1999. For both sizes, the results showed a stronger significance of the estimate of the quantiles $\beta_3^{(0.75)}$ and $\beta_3^{(0.90)}$, and a lower significance of the estimate of $\beta_4^{(0.75)}$, in any case not lower than 5%.

A second sensitivity analysis concerned the choice of the value of the smoothing parameter λ. Being the latter a measure of the amount of spatial smoothing introduced in the model, in general we should expect a different fit of the model (3) for different levels of smoothing. We considered somewhat extreme values for λ. For $\lambda = 0.02$ and $\lambda = 0.31$, the number p_λ of interpolated points according to the SIC criterion was, respectively, 51 and 7. In both cases, we observed a higher significance for $\beta_4^{(\tau)}$, $\tau = 0.50, 0.75, 0.90$. Moreover, the estimates of $\beta_3^{(\tau)}$, $\tau = 0.75, 0.90$, were significant at the 5% level for $\lambda = 0.02$, while $\beta_3^{(0.25)}$

turned out to be insignificant for $\lambda = 0.31$. The bootstrap sample size was set equal to 499.

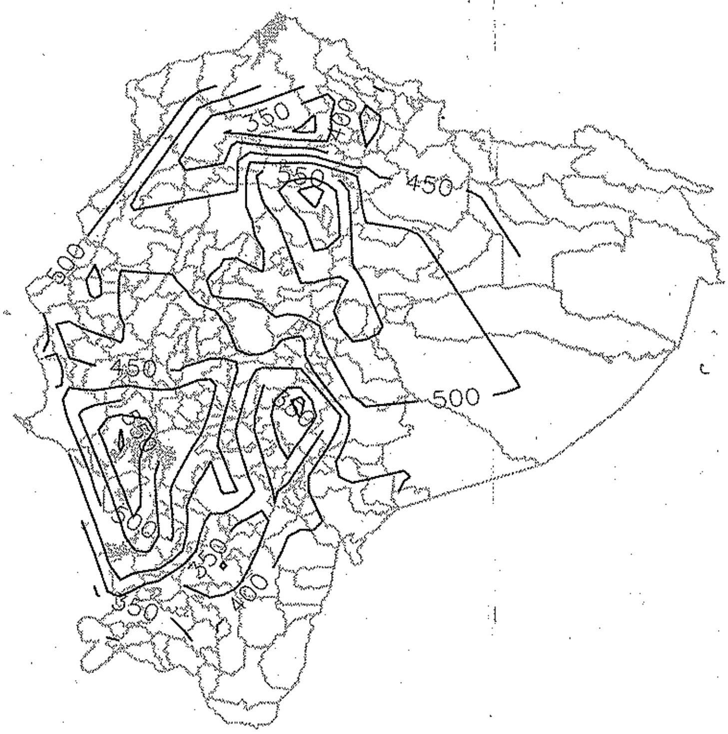

Figure 6: Contour plot of the quantile ($\tau = 0.50$) estimated for the model (3)

3 Final remarks

We applied nonparametric quantile regression methods for mapping the geographical distribution of the real consumption expenditure in Ecuador. To model the spatial heterogeneity, we considered triogram splines for their optimal property of orthogonal equivariance. We argue that, for a deeper understanding of measures such as the consumption expenditure, the 'whole' picture should not be left aside.

The Ecuador data provides a first, promising example of the effectiveness and the potential of quantile regression methods within poverty studies. For instance, should the spatial coordinates for each family be available, it would be possible to gain a greater insight into the understanding of the geographical distribution of wealth.

Another interesting area of development relates the assessment of poverty, which is based on the prediction of economic measures and the comparison of such values with poverty lines. Relative poverty lines can be estimated as functions of specific quantiles of the income distribution and quantile regression

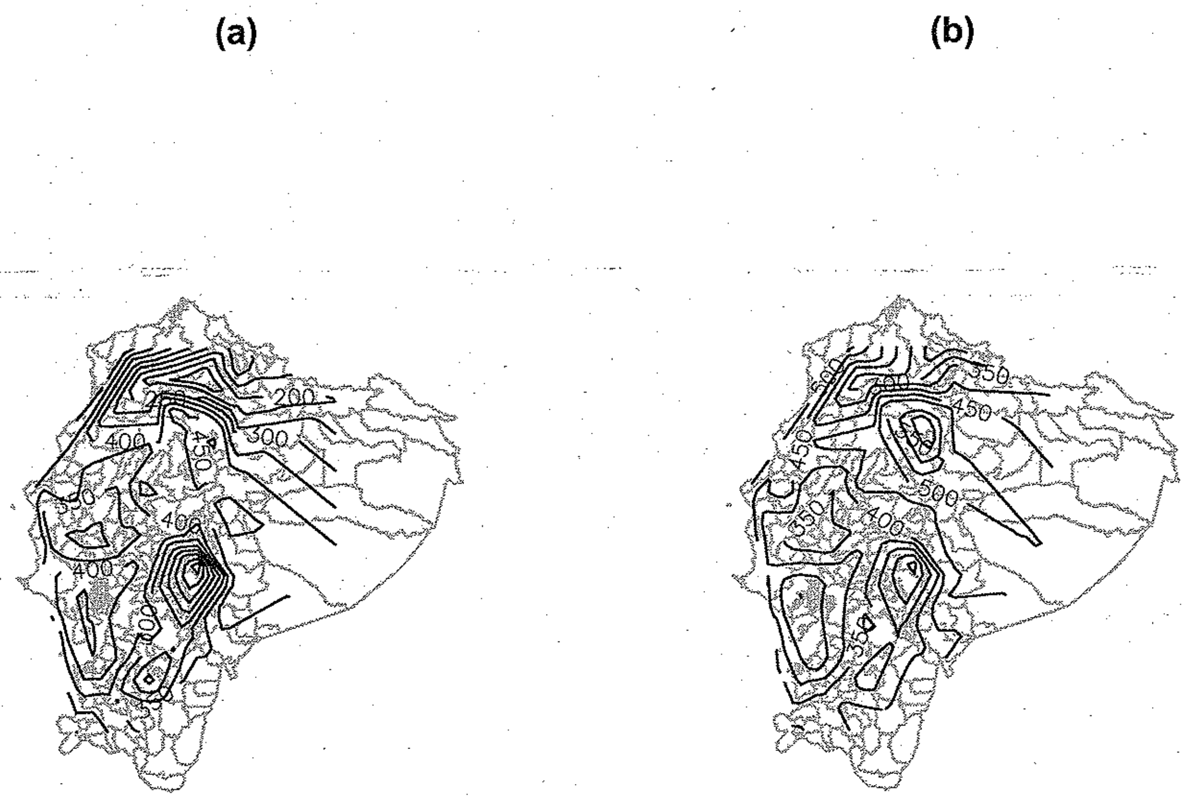

Figure 7: Contour plot of the quantiles $\tau = 0.10$ (a) and $\tau = 0.25$ (b) estimated for the model (3)

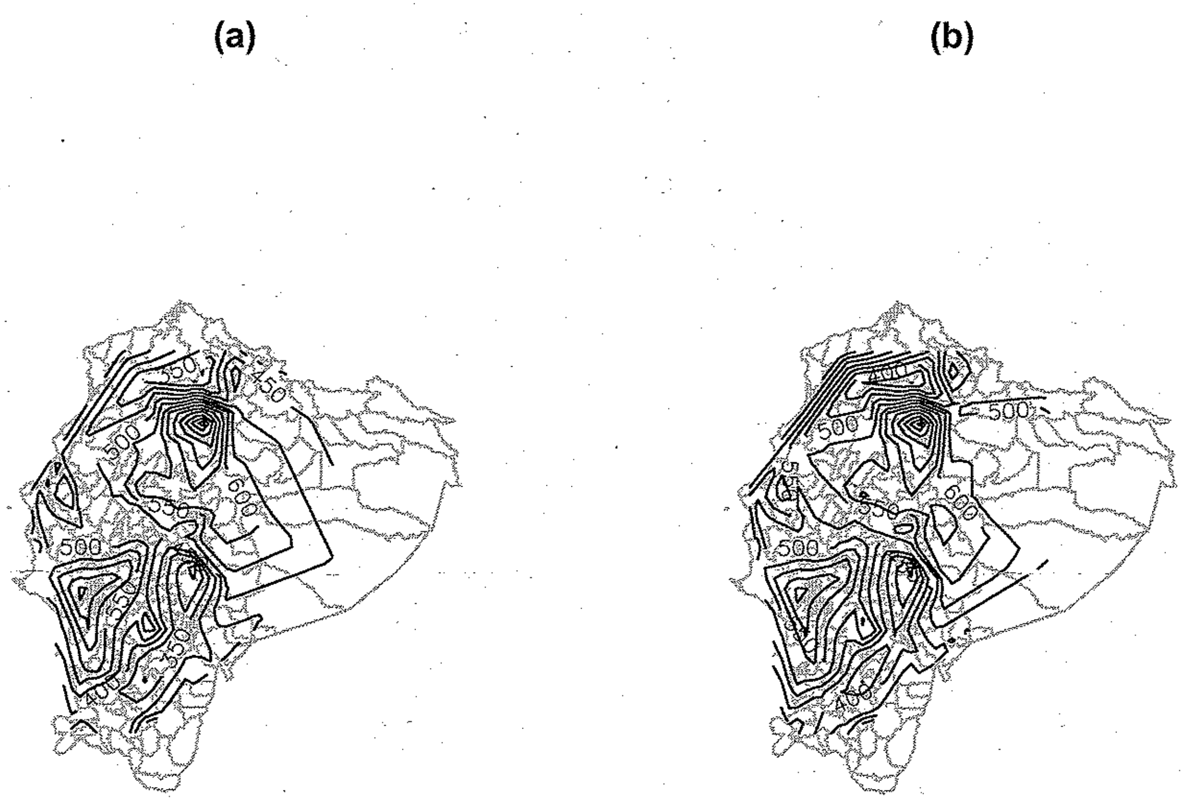

Figure 8: Contour plot of the quantiles $\tau = 0.75$ (a) and $\tau = 0.90$ (b) estimated for the model (3)

methods might be suited for this purpose.

The authors are currently investigating this topics with regard to the Living Standards Measurement Study conducted in Albania in 2002.

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