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Panel regression models for measuring multidimensional poverty dynamics *

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Abstract. This work concerns the studying of poverty dynamics and the analysis of the influencing socio-demographic factors. A fuzzy and multidimensional approach has been chosen in order to define two different poverty measures. A panel regression model has been estimated and particular attention has been paid to the treatment of the unobservable heterogeneity among longitudinal units. The specified model combines autoregression with variance components. The empirical analysis has been conducted using the data set of the British Household Panel Survey (BHPS) from 1991 to 1997.

Keywords: Poverty dynamics, multi-dimensional measures, longitudinal units, panel regression models, unobserved heterogeneity

1 Introduction

Over the last decades many studies have paid increasing attention to the multidimensional aspects of the phenomenon of poverty and living conditions. These aspects are not taken into account in the so called traditional approach to poverty analysis which only considers monetary indicators (e.g. income or consumption expenditure); in this context the theory of fuzzy sets has been introduced by Cerioli and Zani (1990) and developed by Cheli and Lemmi (1995) in order to overcome some limitations of the traditional approach and in order to define multidimensional fuzzy poverty measures. In this paper the fuzzy approach is adopted because we believe that the relative well-being of individuals and/or households is a matter of

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degree; for this reason the division of the population into the dichotomy of the poor and the non poor seems to be an over simplification, since poverty is not a simple attribute that characterises an individual in terms of its presence or absence.

The main contribution of the paper is the comparison of panel regression models based on monetary indicators which in turn are based on supplementary variables in order to study poverty dynamics and the socio-demographic factors influencing it.

A large amount of literature exists which refers to the study of poverty dynamics; one of the first contributions, by Lillard and Willis (1978) concentrated on earning dynamics using variance-component models, applied to the Panel Study of Income Dynamics (PSID). More recently, Stevens (1999) has compared duration models with variance component models using an updated set of the PSID. Jenkins (2000) describes a wide range of multivariate models of income and poverty dynamics, including: *i)* longitudinal poverty pattern models, *ii)* transition probability models, *iii)* variance component models, *iv)* structural models, with an application to the first 6 waves of the British Household Panel Survey (BHPS). Devicenti (2001) starting from Stevens methodology (1999) studies poverty dynamics in Great Britain from 1991 to 1997.

Since our attention concentrates on poverty dynamics, we will illustrate how fuzzy measures can overcome a further limitation of the traditional approach: overestimation of the mobility of the units near the poverty line. Finally, another aspect to be discussed is that in the context of poverty dynamics analysis there is no unanimity in the choice of the longitudinal units; the controversy concerns choosing between individuals or households. In this paper, the household has been chosen as a unit of analysis. Therefore this paper proposes a set of rules which allows us to observe the household dynamics according to the concept of poverty.

The paper is organised as follows. In Sect. 2 two different measures for the definition of the concept of poverty are presented. Sect. 3 discusses the longitudinal units of analysis. The panel regression models are presented in Sect. 4. The empirical analysis, reported in Sect. 5, is based on the data set collected by the BHPS from 1991 to 1997; finally some concluding remarks are made in Sect. 6.

2 Poverty definitions

The adoption of a multidimensional approach leads to two main problems: the choice of the indicators and the aggregation process. Although deprivation is widely recognised as a multidimensional phenomenon, we still believe that indicators based on monetary variables have a fundamental role and therefore are worthy of special treatment. For this reason two different fuzzy measures are considered: the first one is based only on a monetary variable and here it is referred to as Fuzzy Monetary (FM); the second measure is based on several indicators relating to housing conditions, durable goods, etc... and here it is referred to as Fuzzy Supplementary (FS).

The monetary variable used for the FM method consists in the net equivalent household income z_{jt}; making use of the concepts of the fuzzy set theory, the degree of deprivation of any household i at any period t is defined as the membership function to the fuzzy set of poor:

$$\mu(z_{it}) = [1 - F(z_{it})]^{\alpha_t} = I_{it}^{FM} \quad i = 1, \ldots, N \quad t = 0, 1, \ldots, T \qquad (1)$$

where $F(.)$ is the household cumulative distribution function according to the equivalent income. As proposed by Cheli and Lemmi (1995) we determine parameters α_t so that the membership function means are not merely equal to 0.5, but are equal to the proportion of poor units according to the traditional approach (the so called head count ratio H). In order to identify the year-by-year household head count ratios H_t, the poverty line is calculated for the first period only and is kept fixed (in real terms) for the following years.

The FS measure is based on some supplementary variables x_{itk} $(k = 1, \ldots, K)$, such as amenities in the household, ability to afford durable goods, accommodation problems, and any other variables relevant for the multidimensional definition of deprivation. The construction process of this measure is fully described in Betti and Verma (1999). When supplementary variables are ordinal with two or more categories, for each variable k, with ordered categories 1 (least deprived) to M (most deprived), we define the single poverty indicator for all households in category m as follows:

$$s_{itk} = \frac{m-1}{M-1} \, . \qquad (2)$$

When supplementary variables are quantitative, poverty indicators can be calculated in a way similar to Eq. (1). The aggregation process of the single indicators into the multidimensional measure is described by a weighted mean:

$$s_{it} = \frac{\sum_{k=1}^{K} w_k \cdot s_{itk}}{\sum_{k=1}^{K} w_k} = I_{it}^{FS} \, . \qquad (3)$$

The weights w_k are determined by two statistical considerations: *i)* firstly, the weight is determined by the power of the variable to "discriminate" among individuals in the population, that is, by its dispersion; *ii)* from a non-redundant point of view, it is necessary to limit the influence of those characteristics that are highly correlated to the others. For a detailed description of the weights see Betti and Verma (1999).

3 Discussion on longitudinal statistical unit

In the context of analysis of poverty dynamics there is no unanimity in the choice of the longitudinal unit; the controversy is about choosing individuals or households. In fact the identification of a dynamic unit can become difficult when these are complex units, such as households. Persons remain identifiable over periods, but the identification of families is complicated by marriages, divorces, births and deaths of individual family members (Trivellato, 1998). For this reason the most mature household panel survey such as PSID, BHPS identify the individual person, not the family or the household as the 'unit of analysis' and establish such a rule independently of the phenomenon being studied. This differs from the cross-sectional social survey on living conditions which defines households as the unit of analysis.

In fact, the concept of poverty and moreover the multidimensional concept of poverty is related to household variables rather than to individual characteristics; in the FS approach the supplementary variables consider housing conditions, the presence of some durable goods, etc...; moreover in the FM approach the net 'equivalised' household income is considered as the poverty indicator. Furthermore, the choice of the individual as the longitudinal unit generates some complicated econometric problems concerning the specification of the models introduced in Sect. 4 that is: *i)* presence of correlation among members sharing the same household over time; *ii)* introduction of different individual effects for units having exactly the same values for the dependent variable and covariates.

For this reason, it is important to define a concept of longitudinal household, even if in order to follow a complex unit such as the household the definition of a set of rules becomes more and more important. These rules can be simple for individuals sharing the same household across the reference period: one of these can be selected as the member representing the longitudinal unit. In the other cases, it becomes more complicated to construct rules because of longitudinal changes.

The following example can be useful for understanding the problem. Let t_0 be the starting time of a panel survey, the household i at t_0 is composed of three people, between the first wave, t_0, and the second wave, t_1, the household has changed because one member has left. In order to consider the household as a dynamic unit, different ways of following the dynamic unit/s can be defined: they are reported in Table 1. According to the following rule A, the original household i after t_0 has split into two households, so in waves t_1 and t_2 the family i is made up of two members and the new family j of one member. The problem is that according to this rule, the origin of the new household j is not taken into account. For example, supposing that the member that between t_0 and t_1 left the original household i was a son/daughter and that, as in our context, we are analysing poverty dynamics; the status of the new family j and the dynamics of the status are obviously related to the original family, so according to this rule, a piece of information is not considered; anyway this could be partially overcome by the introduction of dummy variables reflecting at least the type of household change. According to the following rule B, any individual having a different history from the other members constitutes a new longitudinal household. In this way we do not come up against the problem related to the origin of the new households; however we partially reintroduce the econometric problems encountered when choosing the individual as the unit of analysis. Finally, according to the following rule C, the main household is considered over time only. Obviously in accordance with this rule the dynamic of the population cannot be followed and the panel sample does not remain representative of both individuals and households. Moreover, in some cases, the choice of the "main" household could be arbitrary. Another problem is that in this way the household with less propensity to change has a higher probability of remaining in the sample over time; a natural consequence is a more and more selected sample over the reference period.

Table 1. Alternative following rules

Rule	Household	t_0	t_1	t_2
A	i	3	2	2
	j		1	1
B	i	3	2	2
	j	3	1	1
C	i	3	2	2

For the reasons described above, a set of rules which are summarised and simplified as in the A rule has been chosen.

4 Poverty indicator model

As I_{it}^{FM} and I_{it}^{FS} range in the interval $[0-1]$, a logit transformation is performed in order to create two variables ranging between $-\infty$ and $+\infty$:

$$y_{it}^{FM} = logit(I_{it}^{FM}), \quad y_{it}^{FS} = logit(I_{it}^{FS}). \tag{4}$$

The poverty indicator function for each indicator is assumed to be:

$$y_{it}^{(\bullet)} = \beta' \mathbf{x}_{it} + \Psi_t + u_{it}, \tag{5}$$

where $\mathbf{x}_{it}$ is a vector of k time-varying exogenous variables observed on individual i representing the effect of observed heterogeneity, $\Psi_t = f^p(t)$ is a polynomial of degree p that represents the effect of time, u_{it} is the error structure and β is a vector of k unknown parameters. The error structure has the following form: $u_{it} = \delta_i + \xi_{it}$, where ξ_{it} has a first-order autoregressive structure, e.g. $\xi_{it} = \rho\xi_{it-1} + \eta_{it}$. Here δ_i represents a random individual component distributed as $N(0, \sigma_\delta^2)$, η_{it} is a purely random component $i.i.d.$ assumed to be distributed as $N(0, \sigma_\eta^2)$ and ρ is the serial correlation coefficient common to all individuals. The random variables δ_i and η_{it} are also assumed to be independent of each other and of $\mathbf{x}_{it}$ and Ψ_t (Lillard and Willis, 1978). The specified model in (5) combines autoregression with variance component so as to obtain a model allowing for both heterogeneity and autocorrelation (Anderson and Hsiao, 1981; Mansour et al. 1985; Goldstein et al. 1994). The individual component of this error structure, δ, represents the effect of individual unobserved (or unobservable) heterogeneity in Eq. (5) and this effect is assumed to persist through the period of observation. The serial correlation term, ρ, represents the rate of deterioration of the effects of random shocks ξ persisting for more than one year; it may also reflect the effect of unobserved individual variables which are serially correlated, i.e., with a slow change over time. In econometric literature such a model is called *serial correlation model* as y_{it} is only affected by x_{it} and not by x_{it-1}, in other words if $\mathbf{x}$ is increased in period t and then returned to its former level, the distribution of y in period $t+1$ is not affected. Past y is informative because it helps to predict the effect of unobservable variables

Table 2. Household membership function means

Wave	1	2	3	4	5	6	7
$E\left[I_{it}^{FM}\right] = H_t$	0.197	0.159	0.157	0.148	0.138	0.126	0.129
α_t	4.165	4.661	4.480	4.677	4.737	4.832	4.874
$E\left[I_{it}^{FS}\right]$	0.418	0.394	0.372	0.354	0.338	0.321	0.304
N	4826	4556	4354	4378	4259	4372	4383

which are serially correlated; this model also implies that y_{it} fluctuates around the equilibrium level $\left(\beta' \mathbf{x}_{it} + \Psi_t + \delta_i\right)$ as do the effects of unobservable variables $\{\xi_{it}\}$ that follow a first-order autoregressive process. As studied in Anderson and Hsiao (1982) contrary to the case of the dynamic model for a single time series, the assumption concerning the initial observations plays a crucial role in interpreting the model and in devising consistent estimates. For this reason a special assumption is made regarding the distribution of the first response on each unit; this is taken to be the marginal distribution:

$$y_{i0} \sim N\left(\beta' \mathbf{x}_{i0}, \frac{\sigma_\eta^2}{1-\rho^2}\right). \tag{6}$$

For $t > 1$ the residual covariance structure has the following form:

$$E\left(u_{it}u_{jt'}\right) = \begin{cases} \sigma_\delta^2 + \frac{\sigma_\eta^2}{1-\rho^2} & i = j \; t = t' \\ \sigma_\delta^2 + \rho^S \frac{\sigma_\eta^2}{1-\rho^2} & i = j \; |t - t'| = S > 0 \\ 0 & i \neq j. \end{cases} \tag{7}$$

As we are dealing with unbalanced panel data due to missing observations, the covariance structure reported in (7) presents no rows and columns which correspond to the missing observations (Jones, 1993).

5 Empirical analysis

The empirical analysis has been conducted using the data set of the British Household Panel Survey from 1991 to 1997 (Waves 1 to 7). The BHPS is a complex panel survey on incomes and other variables at household and individual level in Britain. The derived BHPS data set we work with is the one used by Bardasi et al. (1999); this data set reports incomes deflated to January 1998 prices.

5.1 Cross-sectional poverty indicators

The sample used to construct the household poverty indicators (see Eqs. (1) and (3)) consists of those households in which all eligible adults gave a full interview; in this data set the net equivalent household income is present for all individuals; missing values in the supplementary variables have been imputed using the approach adopted by Raghunathan et al. (2001).

The household distribution function $F(.)$ in Eq. (1) has been estimated parametrically, according to the Dagum model, on the basis of the net equivalent household income[1] from the 1991 data set made up of 4826 households. For the same reference year, the poverty line has been calculated as half of the mean net equivalent household income; the line results as being equal to £ 135.45 per week among the 4826 households. Table 2 reports the percentages of poor households in waves 1-7 according to the traditional approach (the head count ratios H_t) and the values of parameters α_t of formula (1) so that:

$$E\left[I_{it}^{FM}\right] = E\left[1 - F\left(z_{it}\right)\right]^{\alpha_t} = H_t \ . \tag{8}$$

Therefore the head count ratios coincide with the household membership function means calculated year-by-year. These show a declining behaviour pattern from 1991 to 1996, while there is a slight increase in the final year.

In order to evaluate the household membership functions according to the FS measure (formula (3)) several supplementary variables are considered; they refer to housing conditions and to the presence of durable goods; the exhaustive list of poverty symptoms is: house which is not owned; lack of central heating, colour TV, videorecorder, washing machine, dishwasher, home computer, CD player, microwave, car or van.

It should be noted that the indicators reported in the previous list are not proper poverty symptoms: sometimes, it could merely be a matter of choice whether to own a car or not (especially if someone lives in Central London); therefore it would be more informative to know whether or not someone can afford a particular good. Unfortunately, this information is not collected by the BHPS, at least in the first waves.

Let us now analyse household means of the FS indicator; they are reported in the fourth row of Table 2: in this case we can observe a regular decrease of the indicators over seven years.

5.2 *Model specification*

The analysis refers to the unbalanced panel of longitudinal households. The total sample size consists of 5734 households and 30527 repeated measures. The models specified in (5) have been estimated and in each model the dependent variable consists, alternatively, of one of the two poverty indicators. In order to compare results of the parameter estimation they have been standardized (variable names are LGFAST for y_{it}^{FM} and LGFAQST for y_{it}^{FS}). The time indicator is the variable PEPI. A linear trend assumption has been made, e.g. the time dependence is specified as a polynomial of degree $p = 1$. Anyway, it is important to point out that this assumption was made after carrying out different trials using polynomials of a

[1] This is the sum of all individual net incomes deflated by the McClements (1977) equivalence scales.

Table 3. Components of variance; autocorrelated individual component models

	$\widehat{\sigma}_u^2$	$\widehat{\sigma}_\delta^2$	$\widehat{\sigma}_\xi^2$	$\widehat{\sigma}_\eta^2$	$\widehat{\gamma}$	$\widehat{\rho}$
FM	0.687	0.3135	0.373	0.3316	0.456	0.3307
FS	0.623	0.3292	0.294	0.1728	0.528	0.6418

higher degree or a non parametrically time dependence (e.g. using dummy variables as time indicators). The variables considered in the analysis refer to household characteristics. The variables referring to the household head are: a dummy variable for the gender, SEX (1 if male); the age and the age squared, AGE and AGE2; two dummies for the employment status, JBSTA1 (1 if self or in paid employment) and JBSTA2 (1 if unemployed); four dummies for educational level, QUAL1 (1 if first degree or more), QUAL2 (1 if HND, HNC[2] or Teaching qualification), QUAL3 (1 if A level), QUAL4 (1 if O level); a dummy variable for the marital status, MASTA (1 if married or in common law status). Two dummies are also considered for macro regions, WEST (1 if South West, Midlands, Manchester, Merseyside and Wales); NORTH (1 if Yorkshire, the Regions of the North, Yorks & Humber, Tyne &Wear and Scotland), the reference macro region is the Southern regions (London inner and outer, the South-East, East Anglia, East Midlands). Two specifications for the household size are also used, SIZE and SIZE2 (size squared). All variables are time-dependent. All models have been estimated by marginal likelihood estimation using the program MIXREG (Hedeker and Gibbons, 1996).

5.3 Parameters estimates

Maximum likelihood estimates of the parameters are reported in Tables 4. In each model the dependent variable is the poverty indicator $y_{it}^{(\bullet)}$: thus a positive sign for the parameter of a significant covariate, corresponds to a higher deprivation risk. Let's first consider the effect of the trend. As expected, a decreasing behaviour pattern for both measures may be observed: this suggests a decreasing poverty risk from 1991 to 1997, even if a larger downward trend for the FS indicator is noted. A possible explanation for this behaviour is a greater improvement in household conditions with respect to the economic condition in the reference period. Using the likelihood ratio test, all the parameters of the variance components are significantly different from zero (see Table 3[3]). This result suggests that the effect of unobserved heterogeneity, interpreted as the effect of permanent differences among longitudinal units, plays an important role in the analysis of poverty dynamics. Autocorrelation has an evident effect as well. The main difference between the two measures consists in the autoregressive components: according to the FS measure the autocorrelation coefficient is larger than that in the FM. Although a serial correlation model with time-dependence variables cannot be interpreted as a state-dependence

[2] HND stands for Higher National Diploma; HNC stands for Higher National Certificate.

[3] In the Table $\widehat{\gamma}$ is the intra-cluster correlation and measures the proportion of total variance explained by unobserved heterogeneity.

model (Lindsey, 1999), it is plausible that the residuals at time $t-1$ have a higher impact on actual poverty in the FS measure. This is because housing conditions and possession of durable goods are much less volatile than monetary variables. Permanent component patterns are similar in the two measures; this is plausible since permanent components capture the effect of the permanent differences in longitudinal units, however the effect of permanent component is higher in the FS measure (0.528) than in the FM measure (0.456). Differences between the residual error component are more evident; these components include either the effect of transitory variables or measurement errors. The two components cannot be distinguished here; anyway, the highest residual error component in the FM measure is probably due to a large incidence of measurement errors in the monetary variable.

Let us consider now the effect of covariates. Observing Tables 4 we note that for a subset of the covariates considered in the analysis there are more or less no differences between the FS and FM measures and the effect is the one expected. The household head age has a quadratic effect on the degree of deprivation, with a minimum at about fifty years (for the FM measure this is coherent with the life-cycle theory, see Modigliani, 1966). The poverty indicator is lower if the head of the household is employed or self-employed. In the FM measure, the effect of the variable JBSTA2 is, as expected, always positive; the effect of an unemployed head of household is not so obvious according to the FS measure and it is not significantly different from zero. The different effect of JBSTA2 regarding the FM and FS measure is likely to be related to the volatility of the income with respect to durable goods or housing conditions. The effect of the educational level of the household head is the same for the two measures (the degree of deprivation tends to decrease as the educational level increases), even if the coefficients are higher in absolute value for the FM measure. Married heads of household or in common law status make the membership function smaller than other marital status; such an effect is likely to be associated with the age of the head of household and/or with more than one wage earner in the household.

According to the FS measure a quadratic specification of the household size is significant; the membership function decreases with the increase of the household size up to five members. Where there are more than five members, it seems that there are not sufficient economic resources to meet the needs of the household members.

On the contrary, monetary deprivation generally increases as the size of the household increases; it is reasonable to think that the increasing trend of the membership function is associated with the increasing number of children. The SEX variable is always significantly different from zero and its effect is negative; that is, households headed by men are advantageous. The risk of poverty is higher in Northern and Western regions than in Eastern regions. In particular, it seems that the difference is larger between Western and Northern ones for both measures. The only difference is that the effects are stronger in the FS approach. These results can be explained by the evidence that differences across macro regions are concentrated more in durable goods and less in economic resources.

Table 4. Marginal maximum likelihood estimates

Variables	FM measure Estimates (s.e)		FS measure Estimates (s.e)	
Fixed effects				
INTERCEPT	0.8955	(0.044)	2.4632	(0.039)
PEPI	−0.0396	(0.002)	−0.0731	(0.002)
SEX	−0.0616	(0.016)	−0.0350	(0.012)
AGE	−0.0236	(0.002)	−0.0604	(0.002)
AGE2	0.0002	(0.000)	0.0006	(0.000)
JBSTA1	−0.5131	(0.015)	−0.1817	(0.011)
JBSTA2	0.2504	(0.000)	−0.0163	(0.015)
QUAL1	−0.7282	(0.026)	−0.3351	(0.022)
QUAL2	−0.4524	(0.029)	−0.3310	(0.024)
QUAL3	−0.2108	(0.021)	−0.1503	(0.017)
QUAL4	−0.1603	(0.019)	−0.1334	(0.015)
MASTA	−0.2834	(0.0178)	−0.3045	(0.014)
WEST	0.1847	(0.019)	0.2089	(0.018)
NORTH	0.1778	(0.019)	0.1479	(0.019)
SIZE	0.1881	(0.020)	−0.3095	(0.016)
SIZE2	−0.0090	(0.0029)	0.0260	(0.002)
$\widehat{\rho}$	0.3307	(0.008)	0.6418	(0.008)
Random effect				
$\widehat{\sigma}^2_\delta$	0.3135	(0.009)	0.3292	(0.014)
$\widehat{\sigma}^2_\eta$	0.3316	(0.003)	0.1728	(0.001)
log L =	−30863.943		−21909.465	

6 Some final remarks

In conclusion, the definition of a set of rules for following the household in a longitudinal way has allowed us to be coherent with the concept of poverty in a dynamic context. The specified models have been useful for explaining the dynamics of poverty in the UK and have shown the presence of unobserved heterogeneity and autocorrelation. As far as the comparison between the two measures (FM and FS) is concerned interesting results suggest that the FS measure can be used to complement the picture of poverty dynamics, and the simultaneous use of the two measures can help to understand the phenomenon of deprivation better.

From a methodological point of view, it can be added that the model specified can be generalised; for instance some of the hypotheses made, such as stationarity and independence between unobserved heterogeneity and covariates, can be relaxed. Another interesting issue to be analysed relates to the interdependence between the individual labour force process and the poverty process; in fact, in our analysis, we assume that labour force status affects the poverty condition and perhaps this assumption could be considered quite strong. It is also important to point out that it would be interesting to consider dummy variables for household changes such as covariate in the model, since these changes could influence the poverty process.

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