MODELLING THE DISTRIBUTION OF MULTIDIMENSIONAL POVERTY SCORES: EVIDENCE FROM MEXICO*

Valérie Berenger

University of Nice-Sophia Antipolis

Cuauhtémoc Calderón Villarreal

El Colegio de la Frontera Norte

Franck Celestini

University of Nice-Sophia Antipolis

Resumen: El propósito fundamental de este trabajo es aplicar al caso mexicano una nueva metodología de desarrollada por Berenger and Celestini (2006). El nuevo método se basa en la lógica de los conjuntos difusos, que establece un índice de pobreza multidimensional definido entre 0 y el infinito, para caracterizar el modo como socialmente está organizada la pobreza. Utilizamos el XII Censo general de población y vivienda, 2000, de México (INEGI). Se construye una tipología de la pobreza en México y se derivan una serie de propuestas de política económica.

Abstract: The main purpose of this paper is to explore a new methodology already developed by Berenger and Celestini (2006). This theoretical method based on fuzzy sets approach makes it possible to define a multidimensional poverty score lying, as for income, between 0 and infinity in order to characterize the organization of poverty. This method is applied using the data from the XII Census of Mexico, 2000 (INEGI). The results obtained enable us to build a typology of poverty. And we derive public policy implications.

Clasificación JEL/JEL classification: D31, I32.

Palabras clave/key words: fuzzy sets approach, multidimensional measures of poverty, unsatisfied basic needs, enfoque de lógica difusa, medidas de pobreza multidimensional, necesidades básicas insatisfechas

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berenger@unice.fr calderon@colef.mx franck.celestini@unice.fr

1. Introduction

Understanding the concept of poverty is a difficult task. The way in which poverty is defined determines the method employed to measure it, and this has implications on policies to address it. Studies of poverty have witnessed an enlargement of the attributes used to define and measure it. Despite the fact that poverty is recognized as a multidimensional phenomenon, measures are still dominated by the traditional money metric approach partly due to its simplicity and communicational power.

Poverty has been one of the most examined phenomena in Mexico over the last 20 years. As a result, various distinct poverty measures have been developed. Indeed, the poverty line (PL) and unsatisfied basic needs (UBN) seem to be predominant methods used, with a tendency to combine the two approaches leading to a method named integrated poverty measurement method (IPMM). Differences in methodology and in the conceptual definitions used make it difficult to compare results.

Instead of trying to count the number of poor, an alternative and original approach would be to characterize the organization of poverty in a given society by taking into account the continuum of situations between poverty and non-poverty.

The goal of this paper goes in that direction. We propose to implement in a rigorous way a methodology that we have already defined in Berenger and Celestini (2006) and applied using French survey data. The application of this approach has shown that in France, multidimensional poverty scores organize according to an exponential law. This promising finding has motivated the need to explore the validity of this law for the whole population of other countries. As a federal state, Mexico offers a convenient opportunity to achieve such an empirical investigation. This method is applied using the data from the *XII Censo general de población y vivienda, 2000*, (INEGI), of Mexico, to 29 states. The results obtained enable us to build a typology of poverty taking into account its behavior in the different states within the country.

This paper is organized as follows. Section 2 justifies the conceptual principles that underline the goal of our study by outlining briefly the two approaches to poverty measurement predominantly used in Mexico and by considering the main multidimensional approaches to poverty found in the literature. In section 3, the method designed to obtain a poverty score lying between 0 and infinity for each household is presented. In section 4, we apply the method to the different states of Mexico. Section 5 analyzes the relationship between our multidimensional poverty score, income and the marginality index. Concluding comments are then given in section 6.

2. From the Identification of the Poor Based on Thresholds to the Characterization of Multidimensional Poverty Scores

Poverty has been one of the most examined phenomena in Mexico over the last 20 years. As a result various distinct poverty measures have been developed. Indeed, the poverty line (PL) and unsatisfied basic needs (UBN) methods seem to be the ones predominantly used, with a tendency to combine the two approaches (IPMM).[1] The studies devoted to poverty measurement are mainly quantitative and do not include discussion about theoretical definitions of poverty. Official agencies, international organizations and researchers propose their own measurements. Differences in methodology and conceptual definitions used make it difficult to compare results. Some studies measure extreme poverty or indigence in order to justify the use of public policies targeted toward certain groups of the population (just as the World Bank does) or they define an index of marginality in order to measure a rate of marginalized population. These concurrent definitions show that it is impossible to get a consensus to measure poverty objectively.

Whatever the conceptual definition of poverty retained, the measurement of poverty needs to identify the poor and then to derive a global poverty index. The first step refers to the definition of poverty lines, which can be established according to several alternatives (in absolute or relative terms)[2] and permits a partition of the population between poor and non-poor.

As shown by the significant differences in the results obtained,[3] it is difficult to achieve a wide consensus in setting such a limit. For

[1] This conceptual approach was first suggested by Boltvinik (1994b) and originated from the study of Beccaria and Minujin (1988). For more details, see Boltvinik (1998 and 2003) and Boltvinik and Damian (2003).

[2] In the case of Mexico, the main differences are due to different poverty lines, to different variables, to different ways of adjusting for inflation, and to whether the data were adjusted to be compatible with national accounts or not. For a brief description of alternative methods of calculating the poverty line, see Boltvinik (1994).

[3] For Raygoza (1999), 38.4% of Mexicans live under extreme poverty whereas

this reason, the partition is established with imprecision and ambiguity, which makes it relevant to consider the continuum of situations between poor and non-poor. This consideration is all the more justified in a perspective of multidimensional poverty measurement. With such methods, various aspects of poverty can be captured and summarized in a single index.

The basic needs approach, which is favored in Latin America, goes in that direction. It concentrates on the degree of fulfillment of basic human needs in terms of quality of building materials, overcrowding, water supply, sewage disposal, education, and so on. Since the homogeneity of the unity is lost, the identification of unsatisfied basic needs requires the setting of a cut-off point transforming each need into a dichotomic variable. Under this approach, a person is considered to be poor if any one of the basic needs is unsatisfied. As stated by Boltvinik (1998 and 2003), beyond its reductionist approach to well being, UBN has serious drawbacks. According to the criteria used to define the poor, poverty incidence is dependent on the number of indicators included. As proposed by Boltvinik, an alternative to overcome this limitation would be to define a degree of satisfaction for each basic need considering more values than just yes or no (UBN Improved).

However, this leads to another problem, which concerns the derivation of a single index of poverty using information included in each indicator. Indeed, in some cases a person can be in such a state of deprivation that he or she is deemed to be poor while in others he or she certainly should not be classified as poor. It is not clear whether this UBN improved poverty index takes into account information captured by several indicators. The arbitrariness inherent in the identification of the poor according to a poverty line, and the vague aspects imbedded in the concept of poverty, have led to the search for new methodological tools in order to deal with these two aspects.

In the last decade, Cerioli and Zani (1990) followed by Cheli and Lemmi (1995) have been the first to propose a multidimensional measure of poverty based on the theory of fuzzy sets introduced by

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for Szekely, *et al.* (2000) the percentage is 21.2% for extreme poverty and 58.8% for moderate poverty. For 1998, CEPAL (2001) estimated that 18.5% of the population lived under indigence conditions (9.7% urban and 31.3% rural) and 46.9% under moderate poverty (38.9% urban and 58.5% rural). More recent estimates date from the year 2000. According to López Calva and Szekely (2001), 23.3% of Mexicans live under extreme poverty, whereas calculations by Hernández Laos and Velázquez (2002) suggest that 30.1% of the total population experiences extreme poverty and 50.1% moderate poverty.

Zadeh (1965) and developed by Dubois and Prade (1980). Fuzzy sets theory has the advantage of dealing with the vague and complex nature of poverty. Instead of partitioning the population between poor and non-poor, the fuzzy approach takes into account a continuum of situations between these two extremes. This method makes it possible to go beyond the traditional view, which determines poverty as a lack of command over resources, and to overcome problems relative to the definition of a poverty line. Based on indicators covering the various relevant areas of the living conditions of households in a given society, fuzzy poverty approach makes it possible to obtain a poverty score for each household. This score represents the degree of deprivation, or the degree of its membership to the subset of poor. Recently, this approach has gained considerable attention in several studies on well-being and poverty analysis. Some of them are devoted to conceptual aspects (see Qizilbash, 2006; Chiappero-Martinetti, 2000 and 2006), or to mathematical and statistical aspects (Chakravarty, 2006; Dagum and Costa, 2004; Vero, 2006; etc.), while others achieve developments based on empirical investigation on cross sectional and longitudinal data sets (Betti, *et al.*, 2006; Deutsch and Silber, 2005 and 2006; Lelli, 2001; Mussard and Pi Alperin, 2007; Miceli, 2006, etc.).[4]

One difficulty in having a precise measure of poverty is due to the arbitrariness of fixing thresholds. Thus, poverty measurement becomes more accurate when adopting a multidimensional approach. Instead of trying to count the number of poor, an alternative and original approach would be to characterize the organization of poverty in a given society by taking into account the continuum of situations between poverty and non-poverty. At this stage, it is worth remembering that poverty and inequality indices have been preceded by the study of income distribution.

This topic of research has a long tradition, starting with Pareto (1897) who was the first to demonstrate that the distribution of personal income was best fitted by a power law whose parameter could be interpreted as an index of inequality. Although this finding has been largely disputed, it has opened a fruitful area of research consisting in analyzing and identifying theoretical distribution functions associated to income (see Dagum, 1999). Recently, it has gained the interest of econophysicians; among them, Dragulescu and Yakovenko (2001) and Banerjee, Yakovenko and di Matteo (2006) identified an

[4] See Lemmi and Betti (2006) for an exhaustive review of the literature on the potentialities of the fuzzy approach for well-being and poverty analysis.

exponential law for the empirical income distribution in UK, US and Australia.

Surprisingly, no attempt has been made in the context of such multivariate analysis of poverty to characterize the distribution of poverty scores by an appropriate theoretical density function. Such an attempt would make it possible to use graphic devices in order to detect possible laws from data and to obtain some information on the organization of poverty in a given society. The study of the functional distribution of multidimensional poverty scores could have useful applications in poverty comparisons across times, regions and countries.

Due to the existing link between the concept of poverty and the method used to measure it, some considerations about the way in which we will conceive multidimensionality of poverty need to be addressed before exposing our method of measurement. For this purpose, it is helpful to resort to a brief review of multidimensional poverty concepts.

Despite the absence of universal definition of poverty, general definitions[5] appear to be closely associated to the concept of well-being. Multidimensional approaches to poverty have all in common the fact that income is only an indirect indicator to assess well-being. Namely, income refers to the resources that a person owns in order to achieve a certain standard of living or welfare level and does not directly tell us anything about the real achievements of certain needs. According to multidimensional approaches, assessing well-being needs to take into account direct non-monetary indicators that provide more insight about the various manifestations of poverty. At the same time, multiple dimensions of poverty raise the issue of the choice of indicators most relevant to capture the main aspects of the phenomenon. As evidenced by the review of the literature, it is possible to identify two kinds of multidimensional poverty approaches – sociological poverty and human poverty.[6]

The first one stems from the controversial and seminal contribution of Townsend (1979) and underlies several European poverty studies. In order to take into account various aspects of poverty,

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[5] Definitions refer to “the inability to attain a minimum standard of living” (World Bank, 1990) or to the situation “when one or more persons fall short of a level of economic welfare deemed to constitute a reasonable minimum, either in absolute sense or by the standards of a specific society” (Lipton and Ravallion, 1995).

[6] Fusco (2007) has presented an exhaustive survey of multidimensional approaches to poverty.

Townsend (1979) selected several indicators supposed to capture the general living conditions of individuals and to include non-monetary aspects. He made a distinction between relative deprivation[7] and poverty and defined the latter as a situation of relative deprivation due to the lack of command over resources. Afterwards, several contributions have developed and refined the theoretical and empirical work of Townsend and have attempted to measure poverty directly by deprivation. Among them, the works of Mack and Lansley (1985) and of Dickes (1989) unquestionably constitute a reference.

The second approach includes the Basic Needs Approach (BNA) introduced by Streeten (1979) and Hicks and Streeten (1979), and the seminal Capability Approach (CA) developed by Sen (1992). The BNA was originally suggested in order to disregard the GDP or per capita income as key variable in determining the level of development. Despite the fact that the BNA quotes a humanist vision of development that bypasses economic aspects in order to take into account mankind's freedom, dignity and opportunities, its application has usually restricted poverty to a physiological phenomenon. Furthermore, basic needs indicators used are often classified as "commodities" or as indirect ends. The first studies of Sen (1980, 1981) were aimed at developing and expanding the BNA. Sen's Capability Approach provides a theoretical framework in order to analyze poverty. It stresses the distinction between three concepts of commodities, functionings and capabilities. Poverty is then defined as a default of capabilities to convert commodities into functionings. The human capability concept of poverty stresses enhancing people's opportunities and its main contribution lies in the broader concept of well-being. However, the application of this approach raises several difficulties due to the lack of capability indicators at empirical level.[8] The most famous application based on aggregated data is undoubtedly the concept of human development and the construction of the Human Development Index (HDI) (World Bank, 1990).[9]

The common feature of the outlined approaches is that poverty

[7] Relative deprivation corresponds to the inability of a person to achieve a sufficient level of standard of living relative to a minimum acceptable level socially defined in a given society.

[8] An individual's capability refers to potential "beings" and "doings" and includes all the opportunities that this person has but chooses not to take, and is thus not observable, while achieved functionings are at least observable. See the works of Chiappero-Martinetti (2000) and of Qizilbash (2002) for examples of attempts to operationalize CA using Fuzzy Sets Approach.

[9] For a criticism about its composition in reference to the CA concepts, see

and its opposite, well-being, need to be defined and measured by direct indicators. However, this aspect raises the question of how to select indicators. Regardless of the exhaustivity of the definition, three ways to differentiate families of poverty indicators might be identified. The first one refers to the distinction between "means" and "ends" indicators. The second one is based on the distinction of the component concepts of the capability approach. Finally, following Cheli and Lemmi (1995), another distinction can be made between "cause" and "effect" indicators. The "cause" indicators provide a measure of the risk of poverty, while the "effect" indicators capture the degree of real unsatisfied basic living conditions. The distinction can be doubtful for certain indicators as they have sometimes a double status.

Therefore, our methodology refers to a relatively direct multidimensional measure of deprivation and for this reason excludes income from the selected indicators. Despite heterogeneity across and within states, Mexico ranks 54th out of 173 according to HDI and holds the first position among mid-level developing countries with an index value close to that of developed countries. Thus, a relative approach may be justified from this global perspective, although absolute poverty measures are predominantly used in Latin America.

Following Dickes (1989), poverty refers to an accumulation of deprivations and is viewed as an attribute of the living conditions of an individual and not as a characteristic of the person. Although the selection of indicators is constrained by the kind of questions addressed in the census or in the survey, it is based on the distinction made by Cheli and Lemmi and is also defined by the unit of observation, namely the household. Indicators of health and education are not considered in our measure for several reasons. The first reason refers to the retained concept of poverty. Health and education are indicators that concern an individual's attributes: health depends on the age and on the occupation of the person, while education relates more to children. The second reason is that they have a double status, i.e., bad health can be both a manifestation of poverty and a cause of bad living conditions.[10] They can intervene as explanatory variables for assessing poverty profiles. The final reason relates to the household as the unit of analysis considered.

Berenger and Verdier-Chouchane (2007), which proposes indices of standard of living and of quality of life as alternatives.

[10] They can be viewed as components of human and social capital, namely as resources from this perspective.

3. A Method Based the Fuzzy Set Approach: the Determination of a Multidimensional Poverty Score Lying Between *0* and *Infinity*

In order to study the distribution of multidimensional poverty scores, it is necessary to define a method that provides poverty scores lying, as for income, between 0 and infinity. This method is derived from the fuzzy sets approach and was already proposed by Berenger and Celestini (2006 a, b) for the case of France. As stated in section 2, fuzzy sets theory offers an adequate mathematical tool in order to deal with the vague and multidimensional nature of poverty. First applied by Cerioli and Zani (1990) in the context of multidimensional poverty analysis, this methodology has given rise to theoretical refinements by Cheli and Lemmi (1995) who proposed a "totally and relative" procedure to the measurement of poverty called the TFR approach.

Our method satisfies the main principles underlying the TFR method of Cheli and Lemmi. In contrast to the TFR approach, the poverty score or the degree of deprivation for each household is not limited but is defined in a wider range, as is the case for income.

We consider $i \in [1, N]$ households. For each household, we select $j \in [1, v]$ indicators, which reflect the main relevant areas of the living conditions of households. The selection concerns the ownership of durable goods, basic housing characteristics, housing quality and the ownership of assets. These indicators make it possible to assess deprivation on the basis of effective results.[11] They may bring information about the ability of a given household to gain access to adequate living conditions.

For each indicator, a function $a_j^{(m)}$ is defined with $m = 1...M$, the possible values of modalities taken by j rearranged by increasing order, where higher values denote a higher risk of poverty. The value $a_j^{(1)} = 0$ corresponds to the lowest risk of poverty and $a_j^{(M)} = 1$ to the highest risk of poverty associated to the deprivation indicator j.

Once the answers of the N households recorded, we then compute for each indicator the normalised probability density functions $\rho_j(a_j)(1 \leq j \leq v)$.

In the TFR approach, Cheli and Lemmi proposed that the degree of poverty associated to the indicator (or question) j should directly be proportional to the cumulative distribution function:

[11] They also may be viewed *a priori* as reflecting the specific use that a person can make of his income.

$$P_j\left(a_j\right)=\int_0^{a_j}\rho_j\left(x\right)dx \tag{1}$$

This realistic assumption is based on the fact that the feeling of poverty of a household is directly related to the number of households owning a good that it does not own by itself. In other words, this approach stresses and takes into account the relative nature of the poverty feeling. Within the TFR approach, the degree of deprivation $s_j(i)$ of the i-th household with respect to the j-th attribute lies in the interval $[0, 1]$ and increases with risk of poverty. Nevertheless, this range of variation is not adequate in order to study the organization of poverty. As is the case for income or wealth, values taken by the poverty score should not be limited but should naturally lie between 0 and infinity. According to Berenger and Celestini (2006a and 2006b), a possible way of achieving this requirement is to define the degree of deprivation $s_j(i)$ as follows:

$$s_j\left(i\right)=\ln\left(\frac{1}{1-P_j\left(a_j\left(i\right)\right)}\right) \tag{2}$$

Where $P_j(a_j(i))$ denotes the cumulative distribution function of indicator j associated to modalities less or equal to the one of household i.

Following (2), $s_j(i)$ is still an increasing function of $P_j(a_j)$ but is no longer restricted to the interval $[0, 1]$.

Finally, the degrees of poverty assessed according to each of the v deprivation indicators need to be reduced to one dimension in order to obtain the multidimensional score of poverty $s(i)$ of each household i. According to the literature, there are many possibilities for aggregating indicators of deprivation. The most frequently used possibility in the fuzzy sets approach to poverty is that of averaging operators that generalize intersection and union fuzzy sets operators. The unweighted and weighted average operators are examples that introduce the idea of compensation among the various items under consideration. Following Cerioli and Zani, the weighted arithmetic mean has become rather widespread in fuzzy sets theory applied to poverty analysis. In this context, it seems reasonable to attribute different weights to the indicators at issue because some indicators are more important than others in assessing the living conditions of households.

The degree of poverty $s(i)$[12] is then defined as the weighted average with respect to the v indicators:

$$s\left(i\right)=\sum_{j=1}^{v}\omega_{j}s_{j}\left(i\right) \qquad (3)$$

where ω_j is the weight attached to the j-th indicator.

As suggested by Cerioli and Zani and generalized by Cheli and Lemmi, the weight ω_j can be defined as an inverse function of the average degree of poverty: $\overline{s}_j = \frac{1}{N}\sum s_j(i)$. This means that an important weight is given to a variable j associated to a very widespread good in the society. In other words, the more widely a good is owned, the poorer the household that does not own this good. The idea is of the same type as the one used above for justifying the proportionality between $s_j(i)$ and the cumulative distribution $P_j(a_j)$.[13]

The weights ω_j are henceforth represented with the following expression:

$$\omega_j=\frac{\ln\left(1+\frac{1}{\overline{s}_j}\right)}{\sum\limits_{j}\ln\left(1+\frac{1}{\overline{s}_j}\right)} \qquad (4)$$

This expression satisfies the inverse relation between the weight and the mean score and uses another logarithmic function. The form $\ln\left(1+\frac{1}{\overline{s}_j}\right)$ is chosen to prevent the occurrence of negative weights. Indeed, in contrast to the classical TFR approach, scores can be greater than 1. The denominator ensures the normalisation of the weights, avoiding a trivial dependence of $s(i)$ on v. Starting from the $a_j(i)$ functions, a multidimensional poverty score $s(i)$ is evaluated for

[12] At this stage, note that $s(i)$ is not a conventional poverty measure but reflects the degree of deprivation associated to a given household. It can be viewed as a compromise between poverty and exclusion measures.

[13] The main feature characterizing this aggregation is the set of weights. There are two distinct ways to aggregate several indicators into a single measure. The first one brings into play the arbitrariness and the beliefs of the researcher (as is the case for the HDI and for the Borda ranking method). The second one focus on the objectivity of the measure and uses multivariate techniques such as PCA and FA (Nolan and Whelan, 1996; Ram, 1982; Slottje, 1991; Rahman, Mittelhammer and Wandschneider, 2003). The weights suggested by Cheli and Lemmi may be viewed as a compromise between these two approaches.

each of the N households.[14] We then consider the probability density function $\rho(s)$ associated to the computed score in order to extract a well-defined theoretical density distribution.

4. The Identification of the Theoretical Distribution Function of Poverty Scores

We apply the proposed method to the data from the *XII Censo general de población y vivienda, 2000* of Mexico. The latter provides useful information about the living conditions of households in the 32 states of Mexico and offers the opportunity to test the method on a wide range of states. We select the indicators using the criteria and the definition of poverty described in section 2, and we then apply the method to 29 states for which adequate data files were available. The lists of indicators selected and the number of households are given in annexes 1 and 2, respectively.

For each state, multidimensional poverty scores $s(i)$ and the associated probability distribution function $\rho(s)$, have been computed using $v = 18$ indicators of living conditions. As was the case for France in Berenger and Celestini (2006a and 2006b), the application of this method makes it possible to approximate the distribution of multidimensional poverty scores for several states using an exponential law, while for others no clearly theoretical distribution function can be identified.[15] However, for practical reasons, the empirical probability distribution function does not give an accurate description at low poverty score levels.

In order to improve the identification of the nature of $\rho(s)$, we apply the "rank ordering method" frequently used in the analysis of income and wealth distributions. This technique is very close to the construction of a cumulative distribution.

This method reorders the N poverty scores by decreasing values: s_1 and s_N are the largest and the smallest values, respectively. The rank ordering method consists in identifying the relation between the n-th largest value s_n and its rank n. We know[16] that for an exponential probability density function of the form:

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[14] From $s(i)$, it is possible to derive an overall poverty score and to extend the approach suggested by Dagum and Costa (2004) to decompose poverty scores by dimensions and sub-groups of population.

[15] Figures of the density probability functions for each state are available on request from the authors.

[16] See Sornette, 2000:141-143.

$$\rho(s) = \frac{1}{\sigma_s} exp\left({}^{-s}\!/_{\sigma_s}\right) \tag{5}$$

the n-th largest value of s satisfies:

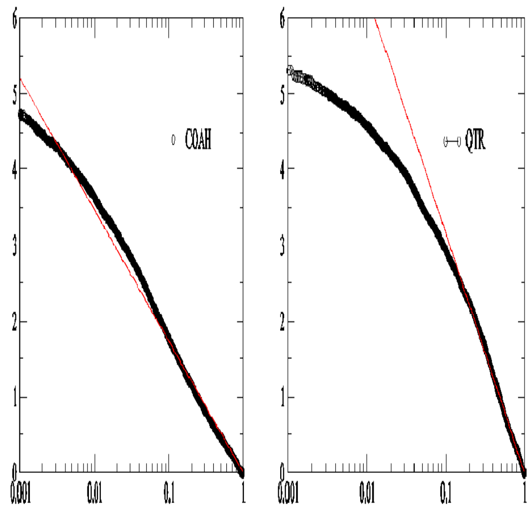
$$s_n = -\sigma_s \ln\left(\frac{n}{N}\right) \tag{6}$$

Using a semi-logarithmic representation in figures 1.a and 1.b, the data points are fitted by a straight line, which confirms the exponential nature of poverty score distribution for the state of Coahuila (figure 1.a). An exponential distribution is a function that is characterized by a single parameter σ_s. Its mean is equal to its standard deviation and is also proportional to its median s_m: $\overline{s} = \sigma_s = {}^{s_m}\!/_{\ln(2)}$. The main property of this organization type is that it can fully characterize the poverty of the sample society by a single parameter.

Figure 1

Rank Ordering of the Multidimensional Poverty Scores with Logarithmic Horizontal Axis

1.a *Coahuila* 1.b *Quintana Roo*

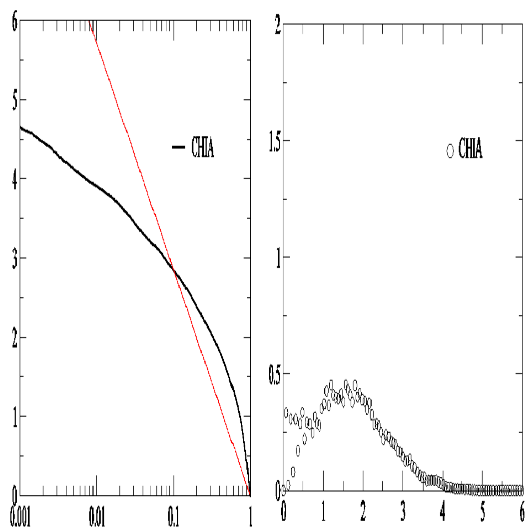


Source: Author's calculations from the *XII Censo general de población y vivienda, 2000*, INEGI. Note: The full line is the best fit to an exponential distribution and circles corresponds to the computed scores.

While the organization of the computed poverty score displays homogeneity in several states, like *Coahuila*, it reveals the presence of a bump for low values of poverty scores followed by a monotonic decrease for high range of poverty scores for several other states, as illustrated by figure 1.b for *Quintana Roo.* Finally, figures 2.a and 2.b show that for certain states, like *Chiapas*, the distribution of poverty score is far from an exponential one.

Figure 2
Rank Ordering and Probability Density Function of the Multidimensional Poverty Scores for Chiapas

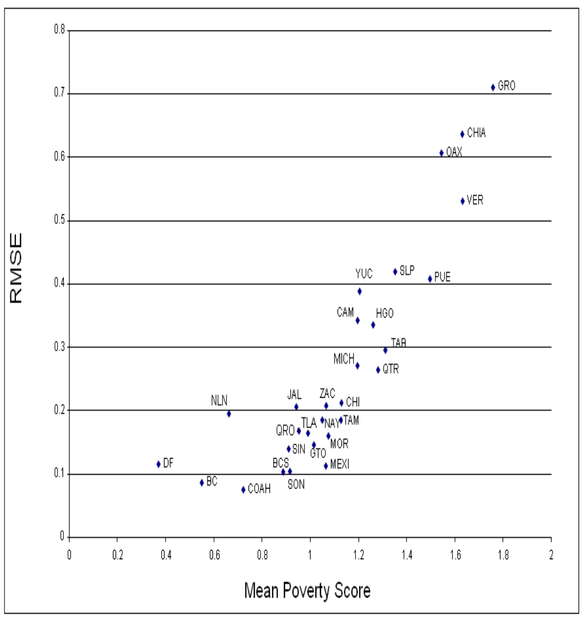
2.a *Rank ordering* 2.b *Probability density function*



Source: Author's calculations from the *XII Censo general de población y vivienda, 2000*, INEGI. Note: In figure 2.a, the full line is the best fit to an exponential distribution and circles correspond to the computed scores.

The use of the rank-ordering technique makes it possible to identify the exponential law for 14 Mexican states. In order to confirm this finding, we can consider the root mean square error (RMSE), which quantifies the adequacy between the observed density function and the theoretical exponential one obtained from the mean poverty score. For each state, we derive the mean score of poverty. If the distribution of poverty is governed by an exponential law, the knowledge of the mean score is sufficient in itself. As a consequence, the lower the value of RMSE is, the better is the agreement between the distribution of poverty scores and an exponential distribution. In figure 3, the values of RMSE in relation to the mean poverty score make it possible to establish a typology of states according to the organization of poverty.

Figure 3
RMSE in Relation to Mean Poverty Score



Source: Author's calculations from the *XII Censo general de población y vivienda, 2000*, INEGI.

Indeed, three types of states can be identified:[17]

[17] Even if the thresholds used seem quite arbitrary, they offer a convenient way of grouping the several states and are in agreement with the identification of the three kinds of patterns for the distribution of multidimensional poverty scores

• Type 1 corresponds to states with value of RMSE lower than 0.2. The exponential law is the best fit for the computed poverty scores for the following states: BC, BCS, COAH, DF, GTO, MEXI, MOR, NAY, NLN, QRO, SIN, SON, TLA, and TAM.

• Type 2 refers to states with values of RMSE lying between 0.2 and 0.3. For states like CHI, JAL, MICH, QTR, TAB, and ZAC, it is not possible to characterize the organization of the overall poverty scores by a well-defined theoretical density function.

• Type 3 concerns states with values of RMSE greater than 0.3. These states are: CAM, CHIA, GRO, HGO, OAX, PUE, SLP, VER and YUC. The distribution of poverty scores is far from an exponential one. According to the results obtained, distributions approximate to a Gaussian one particularly for CHIA (as illustrated in figures 2.a and 2.b for Chiapas), OAX and GRO.

In states of type 1, the organization of poverty is close to the one obtained for France (Berenger and Celestini 2006a and 2006b). We observe that most of these states are located in the north along the border with the United States, while the remaining states are in the central and western region. For such states, our method seems to be relevant to quantify the organization of the degree of poverty relative to each household. In addition, as displayed in figure 4, the comparison of this finding with the ranking of states in terms of Human Development Index suggests at first that the evidence of such an exponential law is dependent on a certain level of socioeconomic development. Indeed, using the three development ranges of the UNDP's World Human Report, these states would be labelled as high and medium-high development countries.[18]

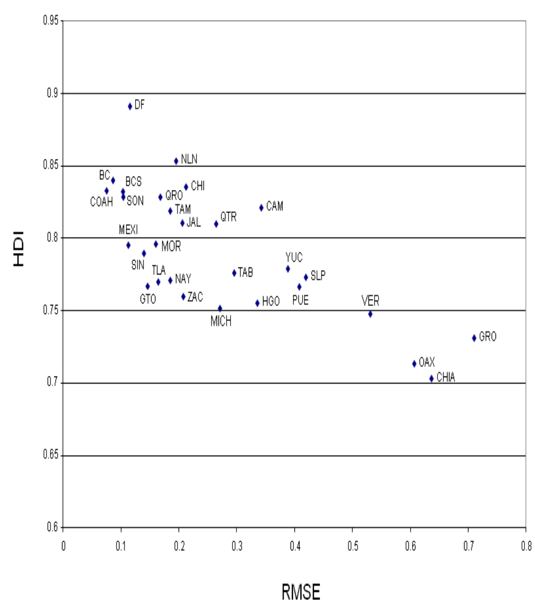
Poverty scores in states of type 3 are not governed by an exponential law but instead by a distribution close to a Gaussian one. Six

from the use of rank ordering method. However, the thresholds makes it difficult to clearly define the membership of CHI, JAL and ZAC to groups of type 1 or 2. For these states, the exponential law does not fit the entire empirical distribution. Only the use of goodness of fit tests and investigation of other laws would solve the question.

[18] According to the ranking of HDI obtained from disaggregated data at state level in Mexico, there are 14 states with high human development, 18 with medium human development and no states with a low development level. For illustrations, DF has an index similar to that of Hong Kong, Israel, Greece or Spain. The index of NLN is close to that of Czech Republic. Among medium-high development states, MEXI and SIN are closer to the level of Panama. For more information, see Human Development Report Mexico 2002, UNDP.

of these states are in the southern part of Mexico, while others are in the central and western region. According to HDI, almost all of them, except CAM, have lower development indices than those states of type 1.[19] For these states, poverty scores seem to be randomly distributed.

Figure 4
Human Development Index of States as a Function of RMSE



These findings suggest two comments. First of all, it suggests that our method allows for the emphasis of strong regional disparities that, even disaggregated at state level, a general HDI can hide. Indeed, although NAY and SLP are very close according to HDI, their distributions of poverty scores are not similar. Along the same line,

19 According to the Human Development Report Mexico, GRO, CHIA, and OAX have HDI indices similar to those of Dominican Republic, El Salvador, and Cape Verde, respectively.

it also reveals that access to basic living conditions is unevenly distributed throughout the country. Secondly, this result may be due to the concept of poverty that the proposed methodology intends to measure. The relative measure of poverty that underlies the method does not seem to be pertinent for such states. All these states have the highest levels of indigenous people living in their traditional areas in Mexico. The manifestations of poverty may show different faces for these social groups, who have a cultural and social identity distinct from that of the dominant society. They are confronted with the highest level of illiteracy and the lowest levels of access to information. From this perspective, the most pressing forms of absolute poverty may represent main social problems in such states. This finding points to the need for further analysis of poverty, in particular to construct comparitive poverty profiles for the states in order to explain the contrast between the results obtained from these states, and the states grouped in types 1 and 2. In states of type 2, we identify the coexistence of the two organization types evidenced above revealing heterogeneity in the distribution of poverty scores. It would be interesting to locate the breakdown in the distribution in order to quantify the proportion of households organizing according to type 1 and type 3 or to explore other laws for modelling these cases. In the same way, these findings motivate the search for factors that could explain such diversity in the shapes of the poverty score's distribution. One possibility would be to decompose the poverty score by sub-groups of population according, for example, to their ethnic membership.

5. Analysis of the Relationship Between Multidimensional Poverty Scores, Income and the Marginality Index

In order to improve the interpretation of our findings, we propose to analyse the relationship between our poverty score, income and a multidimensional measure of poverty namely, the marginality index provided by the Mexican government.

5.1. *The Relationship Between Multidimensional Poverty Scores and Income*

Despite its limitations, income remains the primary money metric measure of poverty. For this reason, we investigate the relation between income and our multidimensional poverty score at first using data concerning each household for each state and then considering the relation at state level. From the same sample census used to establish the poverty scores, we extract the income I(i) of the i-th household. It is the total income coming from the sum of all the individuals composing the household adjusted using the OECD equivalence scale. For each state, poverty scores and incomes are linked by a power law relation as follows:

$$s(i) = R(i)^{\gamma}$$

with $s(i)$ and $R(i)$ respectively the score of poverty and the income relative to i-th household. The parameter γ is the exponent characterizing the relation between poverty score and income. For each state, an estimation of γ is obtained using OLS on the linear expression of the relation. As we can observe in table 1, values of γ are negative. As expected, the higher the level of income is, the lower the score of poverty is. The values of the exponent γ vary roughly according to states in consideration.

Table 1
Mean Poverty Score, Mean Income and Estimations of γ for Each State

State	*Mean score*	*Mean income*	γ
BC	0.55	4771.1	-0.607
BCS	0.887	3907.74	-0.649
CAM	1.196	1832.46	-0.437
CHIA	1.630	1012.21	-0.293
CHI	1.129	2543.78	-0.617
COAH	0.722	2664.88	-0.757
DF	0.370	4143.04	-0.632
GRO	1.758	1122.44	-0.285
GTO	1.015	1918.05	-0.617
HGO	1.261	1419.1	-0.491
JAL	0.942	2422.38	-0.620
MEXI	1.064	2293.85	-0.739
MICH	1.196	1426.88	-0.441
MOR	1.075	1777.99	-0.596
NAY	1.050	1513.85	-0.499
NLN	0.662	3421.39	-0.848

Table 1
(*continued*)

State	*Mean score*	*Mean income*	γ
OAX	1.544	832.63	-0.192
PUE	1.497	1336.79	-0.426
QRO	0.953	3087.93	-0.659
QTR	1.281	3224.5	-0.558
SIN	0.910	2104.94	-0.705
SLP	1.352	1374.12	-0.557
SON	0.915	2483.96	-0.581
TAB	1.311	1618.05	-0.533
TAM	1.127	2474.53	-0.697
TLA	0.990	1338	-0.405
VER	1.632	1283.87	-0.495
YUC	1.205	1279.54	-0.596
ZAC	1.066	1380	-0.426

Source: Author's calculations from the *XII Censo general de población y vivienda, 2000*, INEGI.

Figure 5 illustrates the polarization of the states by displaying the value of γ as a function of RMSE.

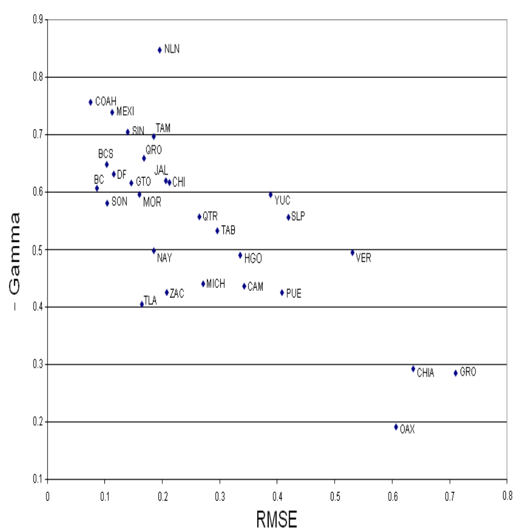
We find high values for most of states of type 1 like COAH with γ = -0.757 and low values, particularly for states of type 3 like OAX with γ = -0.219.

As the relation is of a power law type, the exponent γ can be interpreted in terms of elasticity. The exponent γ is the elasticity of $s(i)$ with respect to $R(i)$. In other words, if income increases by one percent, the poverty score declines by γ percent. The estimations of γ indicate that in states of type 1 like COAH, poverty score is more sensitive to a variation of income than in states of type 3 like CHIA, OAX and GRO.

In other words, the lower values of obtained for CHIA, OAX and GRO mean that an increase of income may have a relatively small impact on the improvement in access to basic living conditions of households. As stressed above, it suggests that deprivation or poverty seems to be more structurally rooted in these states than in the ones of type 1. The former contain the largest indigenous population involved in home farming and artisanal production, and where the family economy is of key significance. These social groups are experiencing chronic poverty that is often transferred intergenerationally. This finding may be of interest in further analyzing causes of poverty and in policy design. As a consequence, social safety net policies may have a greater impact on poverty in states of type 1 for which the elasticity between poverty score and income is high and may be less effective against chronic poverty as in states of type 3. For states like CHIA, OAX and GRO, policies have to be targeted that improve the abilities of individuals to access adequate living conditions by acting on the real causes of poverty. The strategy required for enhancing their capabilities to achieve better living conditions should probably aim at building their social and human capital.

Figure 5

Value of the Gamma Exponent as a Function of RMSE



Source: Author's calculations from the *XII Censo general de población y vivienda, 2000*, INEGI and UNDP Human Development Report Mexico (2002).

Using the results obtained on states' levels reported in table 1, the coefficient correlation between mean poverty score and mean income is equal to -0.75 and means both that a lack of income is sufficiently correlated with deprivation in other dimensions, and that the poverty score captures other aspects than the one based on income.

Indeed, as stressed above, the power law relation between income and poverty score suggests that poverty may take on heterogeneous faces throughout the country meaning that no single solution is equally applicable for all states.

5.2. *The Relation Between Multidimensional Poverty Scores and the Marginality Index*

Finally, we consider the relation between our poverty score and the marginality index provided by the National Population Council (Conapo). The marginality index is a multidimensional measure of poverty at the municipal and state levels. It has been constructed and used by the Mexican government for policy planning purposes, and as part of the targeting mechanism for the *Progresa* (now, *Oportunidades*) antipoverty program. The underlying indicators used to compute the overall index are:

- Access to basic infrastructure services and housing, which includes the percentage of the population living in dwellings, without sanitation, without electricity, without piped water and without sewage service and with dirt floors, and the share of population living in localities with less than 5 000 inhabitants.
- Education and wage indicators, which show the share of illiterate adults (among persons over 15), the share of the population 15 or older without completed primary education, and the share of workers who earn less than two minimum wages.

The value of the marginality index is then derived through a principal components analysis.[20] It provides a ranking of states and municipalities according to their degree of marginality and serves as the first step of the *Oportunidades* program[21] to select localities eligible for the program. As the marginality index measures poverty in

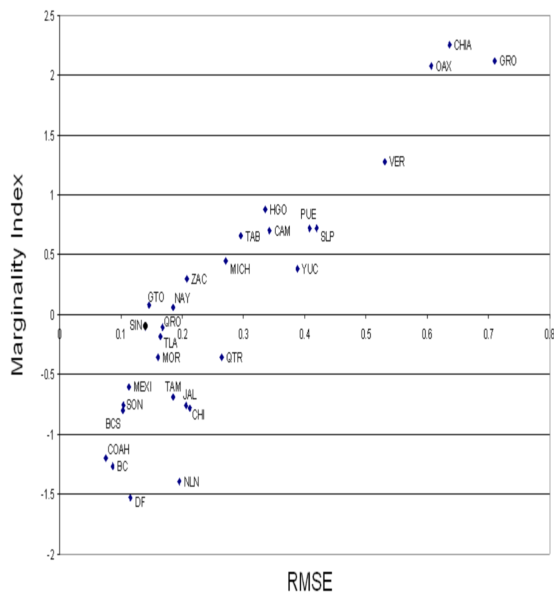
[20] For more details about the methodology see *índices de marginación 2000* available at www.conapo/00cifras/2000.htm

[21] *Progresa* (*Oportunidades*) set up in 1997 is aimed at alleviating poverty by considering multiple dimensions of poverty. Its main characteristic is that cash transfers are targeted directly to households on the condition that they send children to school and visit health centers on a regular basis. For this purpose, the targeting methodology used consists of three steps: selection of localities based

smaller geographical units rather than in households, it is only possible to investigate the relationship between mean poverty scores and the marginality index[22] at state level. The value of 0.90 obtained for the correlation coefficient reveals that mean poverty score is highly correlated with the marginality index. As expected, the main reason is that the two indices include common indicators of deprivation. It follows that exclusion of education from our measure does not affect the validity of our measure.

Figure 6

Relationship Between Index of Marginality and RMSE



Source: Author's calculations from the *XII Censo general de población y vivienda, 2000*, INEGI.

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on the marginality index, selection of beneficiaries households within each locality by resorting to combined methods using the poverty line (PL) to determine UBN standards (revealed UBN standards) in order to identify poor households and finalization of the list of beneficiaries. For more details, see Skoufias, Davis and de la Vega (2001).

22 Data are estimations provided by Conapo from the 2000 Census in Mexico.

Analysis of the relation between RMSE and the marginality index provides more meaningful results. As we can observe in figure 6, the relation can be best fitted by a straight line. The correlation coefficient is equal to 0.91 and is very high. This indicates that high mean score of poverty is associated to high level of RMSE.

Since RMSE provides a measure of the best fit of poverty scores to an exponential distribution, this means that in states for which poverty scores of the overall population are governed by an exponential law, the organization of poverty is relatively homogeneous and, as a consequence, the index of marginality is low. In contrast for states of type 1 like CHIA, OAX and GRO with high values of RMSE, the organization of poverty is more complex and for this reason it seems logical to encounter a high level of index of marginality.

However, as stressed above, the marginality index aggregates data and does not allow analysis of deprivation at a lower scale level. From this perspective, the study of the distribution of households' deprivation scores conveys complementary information that is not well depicted by considering the weighted average of percentages of population that do not satisfy certain needs. It makes it possible to discriminate between states within the country according to the characterization of poverty.

6. Conclusion

The main goal of this paper is to transpose analysis of personal income distribution to a multivariate measurement of poverty. We have dealt with the possibility of extracting a law from multidimensional scores of poverty analogous to the power law identified by Pareto from income data. We then proposed a method derived from the fuzzy set approach in order to define a poverty score lying between 0 and infinity. The application of this method to data from the XII Census of Mexico (INEGI) 2000 to 29 states has enabled us to build a typology of poverty taking into account its behavior in the different states throughout the country. In particular, three types of states have been identified. Results obtained proved that the evidence of an exponential law is dependent on a certain level of socioeconomic development. The analysis of the relationship between our poverty score, income and the marginality index improves and supports the interpretation of our findings. A measurement of the elasticity of poverty score with respect to income is derived which permits us to underline the chronic nature of poverty according to the state considered and to derive policy implications in order to address poverty reduction. The correlation between our multidimensional poverty score and the marginality index shows, in particular, that in states where the organization of poverty is relatively homogeneous, the index of marginality is low. Our findings reveal that Mexico is a country of diversity and contrasts. Access to basic living conditions is unevenly distributed through out the country and needs to be addressed differently according to our typology. However, the promising results of this study suggest a need for further analysis. The evidence of the heterogeneity in the organization of poverty across and within states of Mexico could be improved by locating breakdowns in the distributions that limit the validity of the exponential law to a certain range of poverty scores. In this way, it could be possible to identify different subsets of population according to socio-cultural and ethnic factors.

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Appendix 1

List of Deprivation Indicators Considered for Each Household Using the XII Mexican Census (2000)

Durable goods
• Refrigerator in accommodation: a_1
• Washing machine in accommodation: a_2
• TV in accommodations: a_3
• Telephone in accommodation: a_4
Other Property
• Household member owns vehicle: a_5
• House owned or rented: a_6
Quality of Dwelling
• Shortage of space: number of rooms per individual a_7
• Type and nature of dwelling: a_8
• Building materials of walls in dwelling: a_9
• Building materials of roof in dwelling: a_{10}
• Building materials of floor in dwelling: a_{11}
• Type of combustible used for cooking: a_{12}
• Waste disposal: a_{13}
• Trash collection: a_{14}
• Type of waste water drainage: a_{15}
• Access to running water in the accommodation: a_{16}
• Toilets in the accommodation: a_{17}
• Kitchen in the accommodation: a_{18}
Income
• Household total income from all sources in pesos (monthly)

Appendix 2

List of the Number of Units of Households for Each State of Mexico

State	*Number of Households*
Baja California (BC)	36 390
Baja California Sur (BCS)	9 311
Campeche (CAM)	15 686
Chiapas (CHIA)	96 539
Chihuahua (CHI)	72 906
Coahuila (COAH)	47 433
Distrito Federal (DF)	190 499
Guerrero (GRO)	75 943
Guanajuato (GTO)	81 402
Hidalgo (HGO)	62 016
Jalisco (JAL)	149 135
Mexico (MEXI)	252 961
Michoacan de Ocampo (MICH)	105 453
Morelos (MOR)	37 319
Nayarit (NAY)	18 937
Nuevo Leon (NLN)	82 346
Oaxaca (OAX)	158 123
Puebla (PUE)	133 358
Queretaro de Arteaga (QRO)	28 211
Quintana Roo (QTR)	16 440
Sinaloa (SIN)	41 759
San Luis Potosi (SLP)	58 296
Sinaloa (SON)	60 008
Tabasco (TAB)	40 038
Tamaulipas (TAM)	58 108

(*continued*)

State	*Number of Households*
Tlaxcala (TLA)	30 639
Veracruz (VER)	187 974
Yucatan (YUC)	53 166
Zacatecas (ZAC)	43 956

N.B. Due to illegible datafiles, the states of *Aguascalientes*, *Durango* and *Colima* were not considered in our study.

Appendix 3

Typology of the States According to the Distribution Functions of the Multidimensional Poverty Scores