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Bio-Ecological Diversity vs. Socio-Economic Diversity: A Comparison of Existing Measures — Source link

Carole Juliette Maignan, Gianmarco I.P. Ottaviano, Dino Pinelli, Francesco Rullani

Institutions: World Health Organization, Bocconi University, Eni, Copenhagen Business School

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Maignan, Carole; Ottaviano, Gianmarco; Pinelli, Dino; Rullani, Francesco

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KNOW – Knowledge, Technology, Human Capital

Carole Maignan, *Fondazione Eni Enrico Mattei*
Gianmarco Ottaviano, *Università di Bologna, CEPR London and Fondazione Eni Enrico Mattei*
Dino Pinelli, *Fondazione Eni Enrico Mattei*
Francesco Rullani, *Fondazione Eni Enrico Mattei*

The special issue on *Economic Growth and Innovation in Multicultural Environments (ENGIME)* collects a selection of papers presented at the multidisciplinary workshops organised by the ENGIME Network.
The ENGIME workshops address the complex relationships between economic growth, innovation and diversity, in the attempt to define the conditions (policy, institutional, regulatory) under which European diversities can promote innovation and economic growth.
This batch of papers has been presented at the first ENGIME workshop: *Mapping Diversity.*
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Bio-Ecological Diversity vs. Socio-Economic Diversity: A Comparison of Existing Measures

The purpose of the paper is to enrich the standard toolbox for measuring diversity in economics. In so doing, we compare the indicators of diversity used by economists with those used by biologists and ecologists.
Ecologists and biologists are concerned about biodiversity: the diversity of organisms that inhabit a given area. Concepts of species diversity such as alpha (diversity within community), beta (diversity across communities) and gamma (diversity due to differences among samples when they are combined into a single sample) have been developed (Whittaker, 1960). Biodiversity is more complex than just the species that are present, it includes species richness and species evenness. Those various aspects of diversity are measured by biodiversity indices such as Simpson's Diversity Indices, Species Richness Index, Shannon Weaver Diversity Indices, Patil and Taillie Index, Modified Hill's Ratio.
In economics, diversity measures are multi-faceted ranging from inequality (Lorenz curve, Gini coefficient, quintile distribution), to polarisation (Esteban and Ray, 1994; Wolfon, 1994, D'Ambrosio (2001)) and heterogeneity (Alesina, Baqir and Hoxby, 2000).
We propose an interdisciplinary comparison between indicators. In particular, we review their theoretical background and applications. We provide an assessment of their possible use and interest according to their specific properties.

Keywords: Diversity, Growth, Knowledge

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Address for correspondence:

Dino Pinelli
Fondazione Eni Enrico Mattei
Corso Magenta, 63
20123 Milano
Italy
Phone: +02-52036969
Fax: +02-52036946
E-mail: dino.pinelli@feem.it

1. INTRODUCTION

Our aim is to propose a set of indices of cultural diversity along those dimensions (e.g, language, race, religion, etc.) that are potentially relevant for economic performance in terms of productivity and innovation. In the first part of the paper, we draw from biology and ecology where diversity (and related concepts) plays a central role, the reason being that diversity as such is considered an asset for species and ecosystems. The crucial information that bio-diversity measures must deliver are discussed. Bio-diversity indices are then surveyed and their pros and cons are evaluated in terms of informative content. Here and below, we are not interested in why diversity is important in the different fields. The focus is only on how diversity is measured

In the second part of the paper we turn to measures of diversity in economics. We start with presenting the most frequently used indices. Then we discuss whether the informative requirements of economic indices should be (partially) different from those of bio-ecological measures. Since diversity is much less central in economics than in biology and ecology, the existing literature is much more patchy. Again, we evaluate their pros and cons in the light of the chosen informative requirements[1].

We found that the types (alpha, beta, gamma) and dimensions of diversity (richness and evenness) discussed in bio-ecology are also relevant in socio-economic analyses. With one difference: socio-economic analyses not only deal with qualitative not-rankable variables (such as religions, languages, races). It often deals with quantitative variables (such as income, wages, consumption levels), which can be measured and ranked. The possibility of ranking and measuring adds a new dimension of diversity: the distance between each class or type or individual.

The final section reports an application of the indexes presented to the US Census population data. Individual data for *language spoken at home* and *race* are grouped by SMSA, and both within-SMSA (α-diversity) and across-SMSA diversity (γ-diversity) are measured.

2. BIO-ECOLOGICAL DIVERSITY

2.1 Definitions of bio-diversity

In ecology and biology, diversity is one of the main factors of concerns. But what is exactly bio-diversity?

"A definition of bio-diversity that is altogether simple, comprehensive, and fully operational ... is unlikely to be found." (Noss, 1990). Listed below are several different definitions used by resource managers and ecologists. Together, they should allow us to develop an understanding of the broad concept of bio-diversity.

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[1] We are not interested in why diversity is important in the different fields. The focus is rather on how diversity is measured.

- U.S. Congress Office of Technology Assessment, "Technologies to Maintain Biological Diversity,"1987:

  "Biological diversity is **the variety and variability among living organisms and the ecological complexes in which they occur.** Diversity can be defined as the number of different items and their relative frequency. For biological diversity, these items are organised at many levels, ranging from complete ecosystems to the chemical structures that are the molecular basis of heredity. Thus, the term encompasses different ecosystems, species, genes, and their relative abundance."

- Jones and Stokes Associates' "Sliding Toward Extinction: The State of California's Natural Heritage,"1987:

  "Natural diversity, as used in this report, is synonymous with biological diversity... To the scientist, natural diversity has a variety of meanings. These include: **1) the number of different native species** and individuals in a habitat or geographical area; **2) the variety of different habitats** within an area; **3) the variety of interactions that occur** between different species in a habitat; and **4) the range of genetic variation** among individuals within a species."

- World Resources Institute, World Conservation Union, and United Nations Environment Programme, "Global Biodiversity Strategy," 1992:

  "Biodiversity is the totality of genes, species, and ecosystems in a region... Biodiversity can be divided into three hierarchical categories – genes, species, and ecosystems -- that describe quite different aspects of living systems and that scientists measure in different ways.

  Genetic diversity refers to the variation of genes within species. This covers distinct populations of the same species (such as the thousands of traditional rice varieties in India) or genetic variation within a populations (high among Indian rhinos, and very low among cheetahs)...

  Species diversity refers to the variety of species within a region. Such diversity can be measured in many ways, and scientists have not settled on a single best method. The number of species in a region -- its species "richness" – is one often- used measure, but a more precise measurement, "taxonomic diversity", also considers the relationship of species to each other. For example, an island with two species of birds and one species of lizard has a greater taxonomic diversity than an island with three species of birds but no lizards...

  Ecosystem diversity is harder to measure than species or genetic diversity because the "boundaries" of communities – associations of species -- and ecosystems are elusive. Nevertheless, as long as a consistent set of criteria is used to define communities and ecosystems, their numbers and distribution can be measured..."

Box 1: Genetic and Species diversity: Examples

*In order to understand **genetic diversity**, it helps to first clarify what biologists mean when they refer to a "population." Consider the song sparrows in your neighbourhood. They are a population -- individuals of a species that live together, in the sense that mates are chosen from within the group. The sparrows in the population share more of their genes with each other than they do with other individuals from populations of the same species elsewhere, because individuals in one population rarely breed with those in another. Although each population* *within a species contains some genetic information unique to that population, individuals in all populations share in common the genetic information that defines their species.*

In principle, individuals from one population could mate with individuals from another population of the same species. That is a definition of what a species is -- a collection of individuals that could, in principle, interbreed. In practice, individuals from different populations within a species rarely interbreed because of geographic isolation.

Species diversity *is what most people mean when they talk about bio-diversity. The designation "species" is one level of classification in a taxonomic hierarchy that includes the genus, the family, the order, the class, the phylum, and the kingdom. Consider people, whose species name is Homo sapiens. Homo is the genus, and sapiens designates the species. We happen, now, to be the only living species in the genus Homo. We are in the family Hominidae (apes and man), the order of Primates (femurs, monkeys, apes, and man), the class Mammalia, the phylum Chordata (or vertebrates), and the kingdom animal.*

2.2 Types of diversity

Ecologists recognise three types of diversity (Whittaker, 1960): alpha, beta and gamma diversity.

2.2.1 Alpha diversity

Alpha diversity refers to diversity within a particular sample: **within-habitat diversity**.

If the number of species is taken as the appropriate measure of diversity (see below), *alpha diversity* refers the number of species that live in a homogenous habitat. The size of the habitat determines the number of species because of the species-area relationship[2].

Alpha diversity has the following proprieties:

- it is a small-scale measure of diversity in the sense that it measures local diversity within a small area of homogeneous habitat
- it is sensitive to definition of habitat

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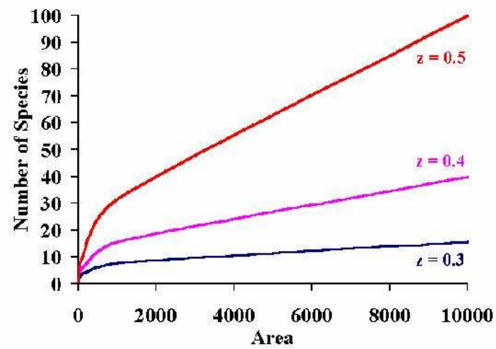
[2] Ecologists have noticed many patterns of diversity. The first of these is the relationship between area and species number. In general the relationship can be expressed as:

$$S = cA^z$$

where S is the number of species, A is the area. The parameters c and z are constants obtained from fitting observed data to a regression equation. As the following figure shows, the number of species increases without limit when larger and larger areas are examined.



2.2.2 *Beta diversity*

Beta diversity refers to diversity associated with changes in sample composition along an environmental gradient: **between-habitat diversity.**

It corresponds to the species turnover in a heterogeneous region. Beta diversity is difficult to measure but it can be estimated by divided gamma (see below) by alpha diversity. When the same species are found in all habitats of a region then gamma and alpha diversity are equal and therefore beta diversity is equal to one.

Beta diversity has the following proprieties:

- it measure the turnover of species as you go from one habitat to the next
- it gives indications of heterogeneity of habitat types: for example, the number of habitats occupied by a particular species

2.2.3 *Gamma diversity*

Gamma diversity refers to differences across samples when they are combined into a single sample. Gamma diversity measures **landscape diversity**.

If the number of species is taken as the appropriate measure of diversity (see below), gamma diversity is given by the number of species that live in a heterogeneous region, ie by the total number of species observed in all habitats within a geographical area.

In general, ecologists often ignore the beta diversity because it reflects something about how samples were collected, not something about communities in nature. Thus, the focus is generally on alpha and gamma diversity.

2.2.4 *Example of diversity types*

Island of St. Lucia in the West Indies:

- ♦ Total of 9 habitats (grassland, scrub, lowland forest, cloud forest, mangrove…)
- ♦ Each habitat had an average of 15.2 species of bird (alpha diversity)
- ♦ The total number of species in all habitats (gamma diversity) was 33 species.
- ♦ On average, the number of species turnovers between habitats = 33/ 15.2 = 2.17 species turnovers (beta diversity)

2.3 Relevant dimensions of diversity

In Section 2.2 we have considered the number of species as an appropriate indicator of diversity. In fact, having only one individual of a species is not the same as having 1000 individuals of another. When we measure diversity (whether it is alpha, beta or gamma) the following aspects or dimensions of diversity should be taken into account:

- Number of different species
- Relative abundance of different species
- Ecological distinctiveness of different species, e.g., functional differentiation
- Evolutionary distinctiveness of different species

In fact, most often formal definitions of ecological diversity and experimental investigations of the relationships among diversity, stability, and ecosystem function tend to ignore aspects of ecological and evolutionary distinctiveness for the basic reasons that the number and the relative abundance of species are easier to value and control. Indices for bio-diversity are indeed focused on species richness (number of different species) and species evenness (relative abundance of different species), discussed more in details below.

2.3.1 Species richness

Species richness is the simplest of all the measures of species diversity. It implies simply counting the species found in a community. It does not take into how the population is distributed across those particular species.

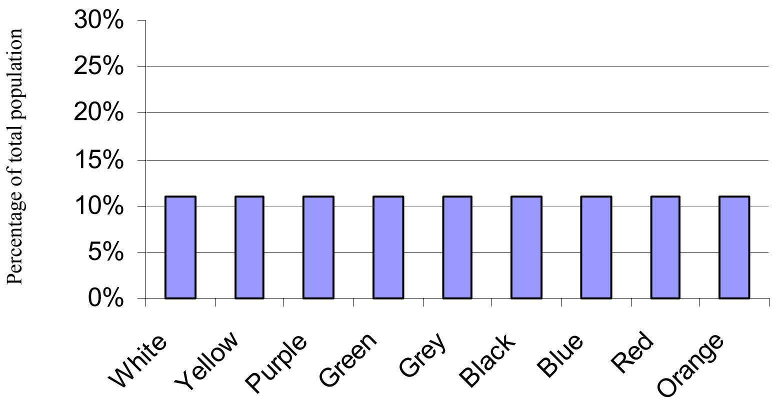
2.3.2 Species evenness

Species *evenness* refers to the relative abundance of species in the population.

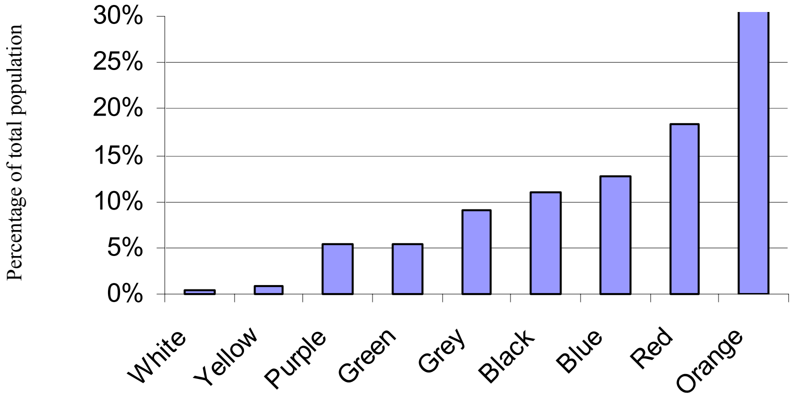
Richness is a parameter that describes an extreme of the distribution (the maximum number of species), it is therefore theoretically unknowable on the basis of samples.

Evenness, on the contrary, describes the vector of species proportions. Because random sampling yields proportions that are unbiased, and because the maximum total proportion that unsampled species comprise can be constrained, if measured properly, evenness can be estimated from small samples with considerable precision.

Evenness is the concept that compares the observed community to a hypothetical community, where the hypothetical community is made of the same number of species but equally abundant.



This is an example of a high evenness in a community of 9 categories.



This is an example of a low evenness in a community of 10 categories.

2.4 Bio-diversity indices

2.4.1 Measuring diversity

In this section, we review all indicators of diversity following Patil and Taillie (1982), who have elaborated a framework allowing all diversity measures to be subsumed into a single diversity spectrum.

They start by defining diversity as the *average rarity of species within a community*. In more formal terms, given a community:

$C = \{s; \pi_1, \pi_2, \ldots, \pi_s\}$, where s is the total number of specie and

$\pi_i = N_i / \Sigma_{k=1}^{s} N_k$ is the proportion of all individuals that are of species i,

and defined $R(\pi_i)$ as a *measure of rarity* for a species *i* with a frequency of occurrence π_i, then the *average rarity of species in the community* is given by:

$\Delta(C) = \Sigma_{k=1}^{s} \pi_k R(\pi_k)$.

Depending on the exact definition of $R(\pi_i)$, all indicators of diversity can be subsumed into $\Delta(C)$.

In what follows we review all indicators, starting from Patil and Taillie's general formulation.

- **General formulation: Patil-Taillie Index**

The general formulation of $R(\pi_i)$ is

$R_{(k)} = (1-\pi_k^{\beta})/\beta$

The average rarity is then defined as:

$$\Delta_\beta(C) = \begin{cases} \sum_{k=1}^{s} \pi_k \left(\frac{1-\pi_k^\beta}{\beta} \right) \text{ when } \beta \neq 0 \\ -\sum_{k=1}^{s} \pi_k \log(\pi_k) \text{ when } \beta = 0 \end{cases}$$

The value β scales the relative importance of richness and evenness, as shown below.

- **Richness index (β=-1)**

Let β=-1, it follows that $R(\pi_k) = (1-\pi_k) / \pi_k$, implying that the rarity of a species is given by the probability that the next species you encounter is different from the one you have just seen relative to the probability of encountering the same species again.

It follows that:

$$\Delta_{-1}(C) \quad = \Sigma_{k=1}^{s}\pi_k[(1-\pi_k)/\pi_k] = s - 1$$

In other words, if (β=-1) the Patil and Taillie index is equivalent to the simple counting of the number of species (minus one), irrespective of relative proportion of population by species.

- **Shannon-Weaver diversity index (β=0)**

Let β=0, then $R(\pi_k) = -\ln(\pi_k)$ .This corresponds, roughly, to saying that a species that is rarely encountered is almost infinitely rare while a species that is commonly encountered is not rare at all. This might be appropriate if we think of $R(\pi_k)$ as measuring how much *value* we place on a species as a *function of its frequency of occurrence* in a community. It follows that:

$$\Delta_0(C) \quad = \Sigma_{k=1}^{s}\pi_k[-\ln(\pi_k)]$$
$$= -\Sigma_{k=1}^{s}\pi_k \ln(\pi_k)$$

Shannon diversity indicators comes from information theory and measure the *order* (or disorder) observed within a particular system. In ecological studies, this order is characterised by the number of individuals observed for each species in the sample plot.

- **Simpson diversity index (β=1)**

Let β=1, then $R(\pi_k) = (1-\pi_k)$ corresponding to the probability that two randomly selected individuals in a community belong to different species. It follows that:

$$\Delta_1(C) \quad = \Sigma_{k=1}^{s}\pi_k(1 - \pi_k)$$
$$= 1 - \Sigma_{k=1}^{s}\pi_k^2$$

The Simpson diversity index is a measure that accounts for both species richness and proportion (percent) of each species as $\Sigma_{k=1}^{s}\pi_k^2$ is influenced by two parameters: the number of species and the equitability of percent of each species present: for a given species richness, $\Sigma_{k=1}^{s}\pi_k^2$ will decrease as the percent of the species becomes more equitable.

The index, first developed by Simpson (1949), can also be found in these alternative versions in published ecological research:

Simpson index: The probability that two randomly selected individuals in the community belong to the same species.

Suppose that $R(\pi_k) = \pi_k$, the probability that the next species you encounter is similar to the one you have just seen, then:

$$\Delta_1(C) = \Sigma_{k=1}^{s}\pi_k(\pi_k) = \Sigma_{k=1}^{s}\pi_k^2$$

Simpson reciprocal index: The number of equally common species that will produce the observed Simpson index.

Suppose that $R(\pi_k) = 1 / \pi_k^2$, then:

$$\Delta_1(C) = \Sigma_{k=1}^{s}\pi_k(1 / \pi_k^2)$$
$$= 1 / \Sigma_{k=1}^{s}\pi_k^2$$

Both Simpson and Shannon-Weaver indexes are affected by the number of species and the evenness of species abundance, but they are affected differently. A rare species contributes much less to diversity in the former than in the latter. Thus, "diversity profiles" can be plotted to compare two or more communities over a range of evenness emphasis from no emphasis at all (species richness) to high emphasis (Simpson index).

2.4.2 Measuring evenness independently from richness

Indicators discussed in Section 2.4.1 measure richness and diversity (compounding information on both richness and evenness). The following two indicators are attempts to measure *species evenness* independently from *species richness.*

- **Shannon evenness**

Using species richness $\Delta_{-1}(C)$ and the Shannon-Weaver index $\Delta_{-0}(C)$, a measure of *evenness* can be computed:

$E = \Delta_0(C) / \ln(\Delta_{-1}(C))$

E is a measure of *how similar the abundance of different species* are. When all species are equally represented, then the E indicators becomes one, but when the abundance are very dissimilar (some rare and some common species) then E decreases.

- **Modified Hill's ratio**

The modified Hill's ratio is a fairly recent evenness index which is relatively unaffected by species richness.

$$\mathbf{E} = \frac{\frac{1}{\lambda} - 1}{e^{\Delta_0(C)} - 1}$$

where

$$\lambda = \sum_{k=1}^{s} \pi_k^2$$

using π_k as above, $\Delta_0(C)$ is the Shannon-Weaver index as above, using natural logs.

2.4.3 Bio-diversity measures: examples

Consider 3 communities A, B and C, made of 3 or 4 species, with the following species representation in the population:

	A	B	C
Black	40	120	80
White	30	60	60
Red	20	20	60
Yellow	10	--	--

The Diversity Indices are then:

	A	B	C
Richness $\Delta_{-1}(C)$	4	3	3
Simpson $\Delta_1(C)$	0.70	0.54	0.66
Shannon $\Delta_0(C)$	0.56	0.39	0.47
Evenness $\Delta_0(C)/\log \Delta_{-1}(C)$	0.92	0.82	0.99

In this example, C is the most even community, whereas A is the richest and the most diverse using both Simpson and Shannon's indexes.

Notice that all of these measure treat species as if they were completely interchangeable with one another. A community in which there were 100 species of sedges, and nothing else, all in equal frequency would receive the same diversity score as one in which there were 10 species of sedges, 10 species of grasses, 10 species of legumes, 10 species of roses, 10 species of buttercups, and 50 species of composites, all in equal frequency.

3. SOCIO-ECONOMIC DIVERSITY

Since diversity is much less central in economics than in biology and ecology, the existing literature is much more patchy. Thus, while in the former section we were able to present an encompassing index, here such an index is not available. Accordingly, we organise the most frequently used measures in terms of fields of application.

In reviewing bio-ecology indexes, we dealt with *species* diversity. Species are qualitative variables. They cannot be ranked. Economics not only deals with qualitative variables (such as industries, firms, religions, languages), it often deals with quantitative rankable variables, such as income and wages.

In what follows, we firstly present indexes constructed for quantitative and rankable variables (such as income, wage, consumption). Then, we turn to indexes for qualitative variables (such as firms, industries, religions, languages). In Section 3.2 we show that indexes developed for quantitative variables may be used to measure diversity *across* sets of observations when indexes for qualitative variables are initially calculated *within* those sets.

3.1 Quantitative variables in welfare economics: diversity of incomes

Welfare economics has studied two important aspects of diversity: diversity of incomes across individuals in a population and the diversity of their preferences and attitudes. In this Section we focus on quantitative variables and particularly on diversity of income.

Within the 'income diversity' literature there are two dimensions that are relevant: *inequality* (how much different are individuals in terms of income levels) and *polarisation* (how differences are distributed across population groups).

In what follows Section 3.1.1 reviews the indicators of income inequality, Section 3.1.2 discusses the indicators used to measure polarisation.

3.1.1 Diversity as inequality

The literature on income inequality is wide and a number of indicators have been produced. There is not an encompassing index such as Patil-Taillie Index reviewed in Section 2. However, a unifying theoretical framework has indeed been developed. Within this framework, all inequality indexes must respect the following criteria:

- The Anonymity Principle:

  This principle states that it does not matter who is earning the income. In other words, permutations of income among people should not matter for inequality judgements.

- The Population Principle

  This principle states that inequality does not depend on the number of individuals but on their proportion, i.e. size does not matter.

- The Relative Income Principle or Scale Invariance Principle

  This principle states that inequality is interested in the percentage of income that is to say in the relative income and not in the absolute income. Income shares are all we need to know for the measurement of inequality. If all incomes increase by the same amount, inequality will not be affected.

- The Pigou-Dalton Principle

  This principle states that any transfer of income from a poor individual to someone richer increases inequality. For example, if you consider a transfer from an individual to one who is initially equally well off or better off, the distribution A can be reached from distribution B using one or more of these regressive transfers then distribution A is more unequal.

- The Lorenz criterion

  If one Lorenz curve is everywhere closer to the diagonal than another, the associated distribution should be judged less unequal for the reason given earlier. An inequality measure is consistent with the Lorenz criterion if and only if it is simultaneously consistent with the anonymity, population, relative income and Dalton principles.

An index is said to be *Lorenz-consistent* when it satisfies all of the five criteria discussed above.

In what follows we review the indexes that are *Lorenz-consistent*. The indexes that are not Lorenz-consistent and more basic indexes are listed in footnote[3].

Figure 1: Lorenz curve, Gini coefficient, Polarisation and Robin Hood index

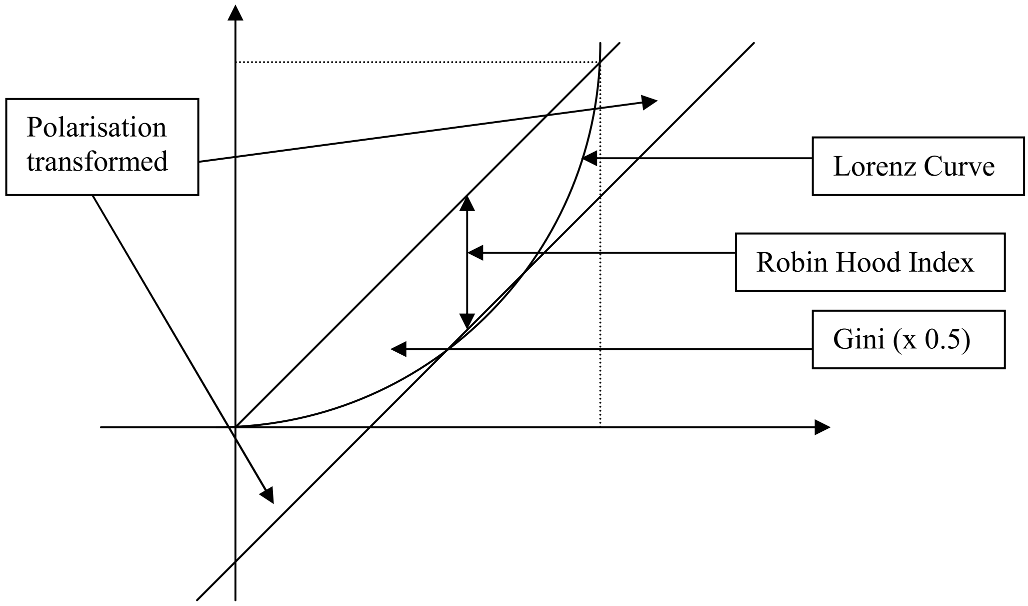


Fig 1 shows the basic methodological tools for the development of most of inequality indicators: the *Lorenz curve,* which allows income distribution to be ranked according to their 'equality'. The *Lorenz curve* plots the cumulative percentages of total income received against the cumulative number of recipients, starting with the poorest individual or household. The *diagonal* represents a perfect equal distribution of incomes: all individuals in the population have the same income. The Lorenz-curves that move farther away from the diagonal indicate progressively more unequal income distribution. The 'corner curve' represents the extreme distribution where one individual owns all wealth.

- **Gini coefficient**

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[3] *Kuznets ratio:* refer either to the share of income owned by the poorest x% of the population or to the ratio of the income share of the richest y% to the income share of the poorest x% ; *Coefficient of variation*: is the standard deviation of income distribution divided by the mean (Lorenz consistent); *Log variance:* variance of the logarithm of incomes.

This is the ratio of the area between the Lorenz curve and the diagonal to the area of the triangle beneath the diagonal. If incomes were equally distributed, the Lorenz curve would follow the 45° diagonal. As the degree of inequality increases, so does the curvature of the Lorenz curve, and thus the area between the curve and the 45° line becomes larger. The Gini is calculated as the ratio of the area between the Lorenz curve and the 45° line, to the whole area below the 45° line.

It is the most commonly used measure of inequality, and it is Lorenz-consistent. However, it is important to note that its use implies a set of value judgements, as with any other Lorenz-consistent indexes.

In more formal terms, suppose there are n individuals or households who earn incomes $y_1 \leq y_2 \leq y_3 \ldots$ where the mean income is μ. Let F_i be the cumulative population share and Θ_i the cumulative income share of individual i.

The definition of the latter is:

$$\Theta_i = \frac{1}{n\mu}\sum_{k=1}^{i} y_k$$

The Gini coefficient is given by

$$G_1 = 1 - \sum_{i=0}^{n-1}(F_{1+i} - F_i)(\Theta_{1+i} + \Theta_i)$$

or alternatively by

$$G_2 = \sum_{i=1}^{n-1}(F_i\Theta_{i+1} - F_{i+1}\Theta_i)$$

where

$$F_0 = \Theta_0 = 0$$
$$F_n = \Theta_n = 1$$

- **Robin Hood Index**

The Robin Hood Index, is equivalent to the maximum vertical distance between the Lorenz curve and the line of equal incomes. The value of the index approximates the share of total income that has to be transferred from households above the mean to those below the mean to achieve equality in the distribution of incomes (See Figure 1.). It is Lorenz-consistent.

- **Atkinson Index**

The Atkinson Index is one of the few inequality measures that explicitly incorporates normative judgements about social welfare (Atkinson 1970). The index is derived by calculating the so-called equity-sensitive average income (y_e), which is defined as that level of per capita income which if enjoyed by everybody would make total welfare exactly equal to the total welfare generated by the actual income distribution. The equity-sensitive average income is given by:

$$y_e = \left(\sum_{i=1}^{n} f(\pi_i).\pi_i^{1-e}\right)^{1/(1-e)}$$

where π_i is the proportion of total income earned by the *i*th group, and e is the so-called **inequality aversion parameter**. The parameter *e* reflects the strength of society's preference for equality, and can take values ranging from zero to infinity. When $e > 0$, there is a social preference for equality (or an aversion to inequality). As *e* rises, society attaches more weight to income transfers at the lower end of the distribution and less weight to transfers at the top. Typically the value of *e* ranges from 0.5 to 2.

The Atkinson Index (*I*) is then given by:

$$I = 1 - \pi_e / \mu$$

where μ is the actual mean income. The more equal the income distribution, the closer π_e will be to μ, and the lower the value of the Atkinson Index. For any income distribution, the value of *I* lies between 0 and 1.

- **Theil's entropy measure**

A measure of inequality proposed by Theil (1967) derives from the notion of entropy in information theory. The entropy measure, *T*, is given by:

$$T = \sum_{i=1}^{n} s_i \left[\log s_i - \log(\frac{1}{n}) \right]$$

where s_i is the share of the *i*th group in total income, and *n* is the total number of income groups. The index has a potential range from zero to infinity, with higher values (greater entropy) indicating more equal distribution of income.

3.1.2 Diversity and polarisation

The concept of inequality and all Lorenz-consistent measures neglect the population frequency in each category and therefore disregard information on how population is distributed across different income categories. Yet, such information may be relevant in analysing, for example, the causes of conflict.

Consider for example two populations, one who is uniformly distributed over ten similar values of income spaced apart equally and another which is a two-spike configuration concentrated equally on two points. Under any inequality measure which is consistent with the Lorenz ordering described briefly above, inequality decreases between the uniformly distributed population over ten values and the two-spikes one[4] (Esteban and Ray, 1994). Yet, we might think that a society deeply split into rich and poor may, for example, exhibit tensions and revolts.

Departing from considerations related to the disappearing of the middle classes and looking for indexes that could catch this new phenomena, Esteban and Ray (1994) have given the following definition of *polarisation*:

"Suppose that a population of individuals may be grouped according to some vector of characteristics into 'clusters', such that each cluster is very similar in terms of the attributes of

[4] The notion of polarisation does not always conflicts with that of inequality.

its members, but different clusters have members with very dissimilar attributes. In that case we say that the society is polarised".

With respect to the inequality criteria developed above, the Pigou-Dalton principle is the one that create problems. The Pigou-Dalton principle says that any transfer of income from a poor individual to someone richer increases inequality. In other words, the principle is a local one in the sense that it is not necessary to take into consideration the original distribution. On the contrary, when measuring polarisation, the effect of a given change depends on factors that are not directly associated with the transfer, but on the *relative size* of the groups.

In what follows we review the indicators of polarisation developed so far in the literature. In 1994 two different indicators of polarisation were developed, the first by Esteban and Ray (1994) and the second by Wolfson (1994). They both gave rise to subsequent refinements. We firstly present the Esteban and Ray (1994) indicator and relative refinements and then the Wolfson (1994) indicator and relative refinements.

Both sets of indicators were firstly developed in the context of income distribution. However, it is not difficult to imagine their application in other fields such as:

- distribution of firms by size in a given industry (for example, to detect clustering in the ICT sector)

- labour market segmentation

- concepts of the dual economy

- racial, ethnic, religious clusters

The last indicator we present, the Reynal and Querol (2001) polarisation index was in fact firstly developed and used to measure religion polarisation.

- **Esteban and Ray (1994) Polarisation Index**

Assuming the existence of well-defined income classes where a number η of person have exactly the same income *y,* the measure that satisfies the axioms introduced by Esteban and Ray has the following theoretical expression:

$$P_{ER}(\eta, y) = K \sum_{i=1}^{N} \sum_{j=1}^{N} \eta_i^{1+\alpha} \eta_j \left| y_i - y_j \right|$$

where:

K is a strictly positive constant that indicates the degree of sensitivity to polarisation, η represents the population share associated with wealth *y*; α is positive and smaller than α^* ($\cong$1.6).

Empirically, we are more likely to have to define income classes where each individual has a different income. We have then to assume that everybody in each given group possesses a wealth equal to the mean of the group. The index of polarisation from ER(94) is therefore computed empirically as follows:

$$P_{ER}(\alpha) = \sum_{i=1}^{N} \sum_{j=1}^{N} \pi_i^{1+\alpha} \pi_j \left| \mu_i - \mu_j \right|$$

where:

π_i represents the relative frequency and μ_i is the conditional mean in group i for a density of the logarithm of wealth f(y) (in other words, the degree of polarisation in a society is computed assuming that everybody in each given group possesses a wealth equal to the mean of the group).

With respect to inequality indicators, the new coefficient is α: it represents the importance of the feeling of “how many people are like you” or, in other words, the importance of the feeling of “community”.

The ER (1994) index tends to overestimate polarisation as the function of distance between two individuals (or two means) is simply equal to the absolute value of their difference, disregarding the inequality existing within each group and the overlapping of the groups. A correction is proposed in the index which follows of Esteban, Gradin and Ray (1998).

- **Esteban, Gradin and Ray (1998) Polarisation Index**

In order to take into account the inequality *within* each group and the *overlapping* of the groups that has the effect of overestimating the level of observed polarisation, Esteban, Gradin and Ray (1998) have proposed the following correction to the ER(1994) index:

$$P_{ER}(\alpha,\beta) = P_{ER}(\alpha) - \beta\varepsilon$$

where

$$\varepsilon = G(f) - G(\mu)$$

In other word, the index is equal to the difference between the Gini coefficient of the normal distribution (i.e. computed on the ungrouped) and the Gini coefficient of grouped data, and β is the parameter that indicates the importance given to the approximation error.

- **D’Ambrosio and Wolf (2001) Polarisation Index**

D’Ambrosio and Wolf (2001) have computed an index of polarisation that does not need to assume that everybody in each group has a wealth equal to the mean. They assume that wealth differences are linked with specific characteristics of the population and use a second characteristic (such as race and religion - different from wealth) to generate the group partition.

The *distance* between the distribution of wealth of each group is taken into consideration, measured by the Kolmogorov measure of variation distance. The polarisation index is therefore expressed as:

$$P_K(\alpha) = \sum_{i=1}^{N}\sum_{j=1}^{N}\pi_i^{1+\alpha}\pi_j Kov_{ij}$$

where

$$Kov_{ij} = \frac{1}{2}\int |f_2(y) - f_1(y)| dy$$

the Kolmogorov measures of distance and of variation distance are measures of the lack of overlapping between groups. *Kov* = 0 if the densities coincides for all values of *y* and *Kov* = 1 if the densities do not overlap.

- **Wolfson (1994) Polarisation Index**

The Wolfson (1994) index was introduced in parallel to the Esteban and Ray's (1994). The index is derived from the Lorenz curve. It is twice the area between the Lorenz curve and the tangent line at the median point (See Figure 1 page 12).

It is written as:

$$P_W = 2(2T - Gini)/(m/\mu) = 2(\mu^* - \mu^L)/m$$

where T = 0.5-L(0.5) and L(0.5) denotes the income share of the bottom half of the population; m is the median income, μ is the mean income, μ^* is the distribution corrected mean income and μ^L is the mean income of the bottom half of the population. The maximum polarisation occurs when half the population has zero income and the other half has twice the mean.

- **Tsui and Wang (1998) Polarisation Index**

Tsui and Wang (1998) base their index on the Wolfson index using the two partial ordering axioms of "increasing bipolarity" and "increased spread" (Zhang and Kanbur, 2001). It is expressed as follows:

$$P_{TW} = \frac{\theta}{N}\sum_{i=1}^{K}\pi_i\left|\frac{\mu_i - m}{m}\right|^r$$

where N is the number of total population, π_i is the number of population in group i, K is the number of groups, μ_i is the mean value in group i and m is the median income. θ is a positive constant scalar and r belongs to (0; 1).

- **Reynal-Querol (2001) Polarisation Index**

This index is built to measure religion polarisation and has the following form:

$$P_{RC} = 1 - \sum_{i=1}^{N}(0.5 - \pi_i)^2 \pi_i / 0.25$$

where πi is the proportion of each religion and N is the number of religions. This index provides a ranking order of the different distributions of the population.

3.2 Qualitative variables: industrial organisation, regional sciences and welfare economics

In Section 3.1 we reviewed diversity measures of quantitative variables.In this section we turn to diversity measures of qualitative variables. In particular, Section 3.2.1 reviews indexes used in industrial organisation (measuring diversity of firms in a industry), Section 3.2.2 look at those that have been used in regional economics (measuring diversity of industries in a region) and finally Section 3.2.3 summarises the indexes used in welfare economics to measure diversity of religions, cultures, languages.

3.2.1 Industrial organisation: diversity of firms in a industry

Industrial organisation studies market structures and relative competition strategies of firms. An important issue is the *market concentration* of the industry: how many firms are on the market and how market shares are divided between them.

The following index is the most used in the field:

- **Herfindal Index**

$$H = \Sigma_{k=1}^{s}\pi_k(\pi_k) = \Sigma_{k=1}^{s}\pi_k^2$$

where π_k is the market share of firm *k* (*k* goes from from *1* to *s*). Herfindal Index captures the concentration degree of markets in a way *specular* to how Simpson Index captures species diversity of natural habitats.

3.2.2 Regional sciences: diversity of industries in a area

In regional sciences diversity has been defined as:

- "the presence in an area of a great number of different types of industries" (Rodgers, 1957; Attaran, 1987; Wagner and Deller, 1993) and/or as
- "the extent to which the economic activity of a region is distributed among a number of categories" (Parr, 1965; Attaran, 1987), and/or
- "in terms of balanced employment across industry classes" (Attaran, 1987).

A specular, often used concept of diversity is *specialisation*: whether an industry is particularly represented in a region.

Sapir (1996) uses Herfindal index to measure country specialisation within the EU. As noted by Amiti (1999), Herfindal Index measures *'absolute specialisation'*: ie, it measures how different the distribution of industry's shares is from a uniform distribution.

The discipline has also developed indexes of *'relative specialisation'*, where the specialisation patterns of regions is compared across the whole set of regions.

Krugman (1991) uses *Industrial Gini Coefficients* to measure how equally an industry is geographically spread (ie, the diversity of regions in terms of the presence of that industry). Amiti (1999) and Helg et al (1995) calculate *Country Gini Coefficients* to measure the degree of industrial diversity within each region, in comparison with the national average.

It is important to note that while Country Gini Coefficients measure diversity *within a given area* (*alpha diversity*), Industrial Gini Coefficients measure diversity across different areas (*beta diversity)*.

Wagner and Deller (1993) note that most diversity measures focus on employment distributions across industries and do not account for those relationships between industries nor for the relative size of the regional economy. They intent to compensate for this lack by relating regional economic diversity not only to the size of the regional economy but also to the inter-industrial linkages[5].

[5] The literature on segregation indices considers also this lack of inter-relationship links by using measures for potential contact or possible interaction between majority and minority groups (see section on heterogeneity).

- **Country Gini Coefficient**

The index is calculated in three steps. Firstly, the following index[6] is calculated:

$B_{ij} \quad = (q_{ij}/q_j)/(q_i/Q)$

where:

q_{ij}/q_j is industry i share in country j and q_i/Q is industry i's share in overall output.

Secondly, the Balassa indexes are ranked in descending order and the plot of the cumulative of the numerator on the y axis against the cumulative of the denominator on the x axis to get the Lorenz curve is constructed. Finally, the Gini Coefficient is equal to twice the area between a 45-degree line and the Lorenz curve.

If the industrial structure of country j matches the industrial structure of the European average, the Gini is equal to zero. The higher the Gini, the more specialised (less diverse) is the country.

- **Industrial Gini Coefficient**

As before, the index is calculated in three steps. Firstly, the Balassa Index is calculated:

$B_{ij} \quad = (q_{ij}/q_i)/(q_j/Q)$

where:

q_{ij}/q_i is country j share in industry i and q_j/Q is country j's share in overall output.

Thereafter, we proceed as before.

The closer the geographical distribution of industry i to that of overall manufacturing in the EU (US), the smaller the index. An industry entirely concentrated in one country (state) with small manufacturing production will have an index close to one (Amiti, 1999)

3.2.3 Welfare economics: diversity of preferences

Individuals are not different only because they have different incomes, they also have different preferences, attitudes, religious and ethnic backgrounds, which may have consequences for their economic and socio-political behaviour. For example, sociologists have often looked at differences across individuals in terms of differences in race, ethnic, income, religion, culture, to understand the possible implication for policy at the local level. In economic models with heterogeneous preferences, the indices of racial, ethnic, and religious heterogeneity are used as proxies for heterogeneity of preferences (Alesina, Baqir and Hoxby (2000). The *heterogeneity indicator* used is quite straightforward and basically constructed on the basis of the Simpson diversity index used in biology (see below).

- **Heterogeneity index**

The index is computed as the probability that two randomly drawn individuals in a county belong to different races/religion/ethnic group:

[6] The index is a realaboration of the Balassa Index, widely used in internation trade analyses.

Heterogeneity Index *ij* = $\mathbf{1 - \sum_{group} (share_{ij}^{group})^2}$

where:

group identifies the group to which the individual belongs to (such as white non-Hispanic, black non Hispanic, Asian and pacific islander, native American, Hispanic, in case of racial heterogeneity index; or christian catholic, christian protestant, islamic in case of religious heterogeneity index);

share is given by the share of the population in county i in state j who identify themselves as a given group (either race, ethnic group or religion).

3.2.4 Welfare economics: diversity and segregation

In contrast with the strand of literature discussed in Section 3.2.3, the literature on *segregation* (residential but also racial, ethnic, social or economic) is very rich in indices. The indices are spatially defined: a metropolitan area is divided up into tracts and the indices are attempts to measure whether different population groups are evenly distributed across space, their degree of concentration in a particular part of the city, the degree of potential interaction across groups etc.

In more formal terms, Massey and Denton (1988) used cluster analysis to measure five key dimensions of segregation: 1. *Evenness* which involves the differential distribution of the subject population across space; 2. *Exposure* which measures potential contacts between groups, 3. *Concentration* which refers to the relative amount of physical space occupied by each group, 4. *Centralisation* that indicates the degree to which a group is located near the centre of an urban area, and 5. *Clustering* which measures the degree to which minority group members live disproportionately in contiguous areas.

The indices that are part of the evenness dimension are dissimilarity, Gini, entropy, and three Atkinson indexes (differing in their shape parameter). The exposure dimension involves the measures of isolation, interaction and correlation. The concentration measures used here are delta, and relative and absolute concentration; the two centralisation measures are relative and absolute centralisation. Finally, the clustering dimension is measured by relative and absolute clustering, spatial proximity, and distance-decay isolation and interaction.

We present here the main indices used to build segregation and diversity tables[7], using the examples of the white vs. hispanic communities in Los Angeles.

- **Dissimilarity Index**

This index is given by the percentage of one group that would have to change residence in order to produce an even distribution of groups across different tracts of the same metropolitan area.

The index is computed as follows:

$$D = \frac{1}{2} * \sum \left| \frac{H_i}{H} - \frac{W_i}{W} \right|$$

[7] These indices are used in particular by the US Census Bureau, and in analysis of occupational gender Segregation.

where:

H = metropolitan population of type H

W = metropolitan population of type W

H_i = population of type H in tract i

W_i = population of type W in tract i

For example, if the Hispanic vs. white dissimilarity index D = 57.65 in Los Angeles, it means that 57.65% (or more) of Hispanics or Latinos would need to move to a different tract in order for these two groups to be equally distributed across space. The value of D is symmetric, meaning that calculation with reference to Hispanics or whites is identical.

- **Isolation Index**

This index measures the probability that a randomly chosen member of one group will next meet another member of the same group. For example, the Hispanic isolation index in the Los Angeles metropolitan area in 2000 is 63.26, which implies that the probability of a Hispanic in Los Angeles area will meet another Hispanic is 63.26%. Like the dissimilarity index, this index ranges from 0 to 100 and it is also symmetric.

$$P = \sum (\frac{H_i}{H})(\frac{H_i}{T_i})$$

where:

H = metropolitan population of type H

H_i = population of type H in tract i

T_i = total population in tract i

- **Exposure Index**

This index measures the probability of a member of a Hispanic group meeting a member of white group. For example, the index of Hispanics exposed to whites in the Los Angeles area in 2000 is only 16.97%, which means the average Hispanic lives in Los Angeles with only 16.97% people from the white group. Unlike the dissimilarity index, the index of exposure is asymmetric since it depends on the overall size of the other group and each group's settlement pattern.

$$E = \sum (\frac{H_i}{H})(\frac{W_i}{T_i})$$

H = metropolitan population of type H

H_i = population of type H in tract i

W_i = population of type W in tract i

T_i = total population in tract i

- **Entropy Index**

This index is a direct measure of diversity, based on the entropy concept, formally calculated as follows (equivalent to the Shannon-Weaver index in Section 2):

$$H = -\sum (P_i \log P_i)$$

where:

$P_i = N_i/N$

N_i = population of the ith group

N = total metropolitan population size.

4. BIO-ECOLOGICAL VS. SOCIO-ECONOMIC MEASURES OF DIVERSITY: SOME COMPARISON

In what follows, we tried to draw some lessons from concerning the measurement of socio-economic diversity (as discussed in Section 3) from the indexes discussed in Section 2.

The comparison is structured along the following three questions:

- Are alpha, beta, gamma diversity types relevant in socio-economics? (see Section 4.1)
- Are richness and evenness relevant? Have they been used, maybe with different names? (see Section 4.2)
- Are there other relevant dimensions? (see Section 4.3)

4.1 Are alpha, beta, gamma diversity types relevant in socio-economics?

Section 2 has introduced alpha diversity (within-habitat diversity), gamma diversity (landscape diversity) and beta diversity (across-habitat diversity) as developed in the biology literature. Alpha, beta and gamma diversity convey information on how diversity is *spatially* organised.

The spatial organisation of diversity is of potential high interest to socio-economic phenomena. For example, the labour market organisation or the organisation of knowledge flows within a region constituted by a series of specialised districts are likely to be different from those within a region constituted by the same number of firms in the same industries, but spread equally across space. Or, the social dynamics and interactions (including knowledge exchanges) in a city whose ethnic communities live separately are likely to be different from those taking place in a city with the same ethnic representations, but mixing together.

In spite of potential interest and relevance of all types of diversity, most of the economic literature reviewed for this paper appears to concentrate attention on *alpha* diversity. For example, scholars in regional sciences have been comparing relative specialisation and diversification of different regions (even if often in comparison to that at the national level). Or, the literature on heterogeneous preferences has empirically evaluated the heterogeneity of preferences within homogeneous habitats.

We found two exceptions. The first is represented by the literature on *segregation*. The indexes developed in that strand of socio-economic literature measure both beta- and gamma-diversity. In particular, the *Dissimilarity, Isolation and Exposure indexes* compare differences across metropolitan tracts (ie, they are measuring *beta-diversity*, where the metropolitan *tracts* are considered equivalent to natural *habitats* in natural sciences) while the *Entropy index* measures the overall diversity of the metropolitan area (ie, it measures *gamma-diversity,* where the metropolitan area is considered equivalent to the *landscape* concept in natural sciences).

The second exception is found in regional sciences, where the Gini coefficients are used to measure the diversity of representation of an industry across different areas (*beta diversity*).

4.2 Are richness and evenness relevant? Have they been used, maybe with different names?

The indices used for diversity in biology and ecology are based on two criteria: richness and evenness. The first one measures the number of species within a habitat. This aspect is important as it gives a first idea of diversity. However, this is not enough: consider a habitat with 10 species of plants, the degree of diversity is greater when all species are well represented with respect to a situation when there are 1000 individuals of one species and the 9 other species are found in very small numbers. Richness alone is not enough to measure the *diversity of the population*. We also need to consider *evenness*. *Evenness* looks at how similar the abundance of species are and therefore enables to compare two communities (across space or over time) when they have the same number of species.

Using richness and evenness we can classify the indexes used in biology as follows:

- Indexes of richness – measuring only the number of species;
- Indexes of diversity – measuring diversity as depending on both the number and the relative proportion of species. Diversity increases when the number of species increases (richness) and when the distribution across species move towards a even distribution (evenness, tending to value the fact that each species is well represented in the population)
- Indexes of evenness – attempting to measure only the evenness of species representation in the population, disregarding the number of species.

Similar concepts can be found in the use of indexes of diversity in economics.

- *Richness and evenness in regional sciences*

  In regional sciences *richness* can be related to the number of industries represented in the region and *evenness* to the relative proportion (in terms of value added or employment) of each industry.

  The industrial *specialisation* of the region is a concepts often used (and measured, as seen above) in regional economics. The concept is very close to the concept of *evenness* in biology, if looked at from the opposite direction. The number of industries represented in the region (richness) is less relevant, as it depends on the classification adopted (which is arbitrary). In terms of indexes, elaboration of *Gini's coefficient* has been used to measure across regions industrial diversity.

- *Richness and evenness in industrial organisation*

  In industrial organisation *richness* can be related to the number of firm represented in the industry and *evenness* to the relative proportion (in terms of market share) of each firm.

  The *market concentration* of the industry is the key concept in the field, the opposite of *diversity* (compounding richness – number of species/firms; and evenness – representation of species/firms in total population) in bio-ecodiversity. Correspondingly, the indexes used in industrial organisation is the complement to one of the Simpson Diversity Index, used in bio-ecology.

- *Richness and evenness and heterogeneity of preferences*

  In the literature looking at heterogeneity of preferences and attitudes (proxied by language, ethnic, religious heterogeneity) *richness* can be related to the number of languages, ethnies, religions represented in the region and *evenness* to their relative proportion in terms of population share.

  Heterogeneity is the concept used and measured in this literature, corresponding exactly to the concept of *diversity* previously expressed. In terms of indicators, the *Simpson index of diversity* has been generally used, while less use has been made of the *Shannon-Weaver* index. In the literature reviewed, no use has been made of the indicators measuring *evenness* independently from *richness* (such as the Shannon and the Modified Hill's Ratio).

4.3 Are there other relevant dimensions?

Species are the base for the calculation of biodiversity indicators. Species are qualitative, discrete variables. When economics deals with discrete qualitative variables as well (such as industries, firms, religions), it is easy to establish parallels and find similarities between biodiversity and economic diversity indexes, as we did above.

However, economics also deals with quantitative continuous variables, such as income, wages, consumption.

Since *income* is a quantitative continuous variable, it can be measured and ranked. It implies that when measuring *diversity of income levels* we need to take into account of something new: the possibility of measuring and ranking alternatives. If in a habitat there are lizards and horses, we can say that there are two species and that they are different, but it is not possible to say how much they are different. A habitat with sparrows and dogs will not show a different diversity level. On the contrary, it is possible to compare two income levels and say how much they are different. A population composed by a rich person having 100Eur and a poor person having 10Eur income will show a different diversity level from that showed by a population composed by a rich person with 70Eur and a poor person with 40Eur income. The *distance* between the upper and lower class/individuals represents a new dimension of diversity.

On the other hand, *richness* is not longer relevant: the number of classes in which the population is divided is completely arbitrary. To some extent, we may draw an equivalence between *distance* for quantitative variables and *richness* for qualitative variables. For example, the *distance* between the richest and the poorest in the distribution of income may reflect the same idea as the *richness* of species in a habitat..

What about *evenness?* In the literature on measuring biodiversity, *evenness* refers to the equal representation of each species in the population. In the economic literature, *polarisation* refers to the unequal representation of income classes in the population. *Evenness* and *polarisation* appears to measure similar phenomena, albeit from a different perspective.

Indeed, polarisation indexes are based on the following assumptions:

1. society is divided into groups
2. each group is sizeable
3. there is a high degree a homogeneity within each group
4. there are clear differences across groups

'Groups' that are homogenous within and different from each other do resemble to 'species': *evenness* and *polarisation* look even closer concepts. Again, with one difference: while the difference between species is not measurable, the difference between income classes is.

In economics or sociology as in biology, another important aspect of diversity is the type of relationships or links between individuals, firms or species[8]. As observed easily, none of these indexes presented in this paper do consider explicitely those relationships.

Nevertheless some authors like Wagner and Deller (1993) as mentioned above did approach this dimension looking at industrial linkages, and in sociology, the exposure index as defined by the US Census Bureau measures the possibility of interaction between minority and majority group members.

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[8] For example, the outcome of diversity is very different if when an area is populated by 2 species, these two species are birds and lizards or two species of lizards.

5. AN APPLICATION

This Section provides a first application of the indexes discussed in Section 2 and 3. Indexes are calculated using the data from United States Current Population Survey for *language* spoken at home and *race*. Individual data are grouped by SMSA, Standard Metropolitan Statistical Area. Data refer to the year 1990.

5.1 α-diversity: measuring diversity within SMSA

This Section show an application of the indexes that can be used to measure α-diversity, ie, the degree of diversity within a single SMSA. For the sake of simplicity, we restrict our attention to the the following indexes: Richness, Shannon-Weaver's Diversity, Simpson's Diversity, Shannon Evenness, Modified Hill's Ratio, Theil's Entropy Measure, Herfindal. Each of them is computed for the variables *language* and *race*. Tables 1 and 2 show the indexes calculated for ten SMSA, respectively for *language spoken at home*, and *race.*

	Richness	Shannon-Weaver's Diversity	Simpson's Diversity or Heterogeneity	Shannon Evenness	Modified Hill's Ratio	Theil's Entropy measure	Herfindal index
Jersey City, NJ PMSA	27	1,378	0,624	0,418	0,559	1,954	0,376
Louisville, KY-IN MSA	22	0,196	0,058	0,064	0,285	2,939	0,942
Memphis, TN-AR-MS MSA	23	0,244	0,076	0,078	0,298	2,934	0,924
Miami, FL PMSA	26	1,013	0,558	0,311	0,721	2,283	0,442
New York, NY PMSA	27	1,377	0,550	0,418	0,412	1,955	0,450
Salinas, CA MSA	21	1,026	0,468	0,337	0,492	2,065	0,532
Salt Lake City-Ogden, UT MSA	24	0,493	0,172	0,155	0,326	2,726	0,828
San Francisco, CA PMSA	26	1,262	0,517	0,387	0,423	2,034	0,483
San Jose, CA PMSA	26	1,206	0,490	0,370	0,411	2,089	0,510
Springfield, MO MSA	13	0,171	0,050	0,067	0,283	2,468	0,950

Table 1: Diversity of languages in the US.

	Richness	Shannon-Weaver's Diversity	Simpson's Diversity or Heterogeneity	Shannon Evenness	Modified Hill's Ratio	Theil's Entropy measure	Herfindal index
Altoona, PA MSA	5	0,085	0,026	0,053	0,303	1,707	0,974
Honolulu, HI MSA	8	1,765	0,793	0,849	0,789	0,433	0,207
Los Angeles-Long Beach, CA PMSA	8	1,229	0,581	0,591	0,573	0,968	0,419
Louisville, KY-IN MSA	8	0,410	0,212	0,197	0,530	1,787	0,788
New York, NY PMSA	8	1,097	0,554	0,528	0,623	1,100	0,446
Salinas, CA MSA	8	1,074	0,499	0,516	0,517	1,124	0,501
Salt Lake City-Ogden, UT MSA	8	0,310	0,116	0,149	0,362	1,887	0,884
San Francisco, CA PMSA	8	1,117	0,497	0,537	0,480	1,080	0,503
San Jose, CA PMSA	8	1,048	0,462	0,504	0,464	1,149	0,538
Springfield, MO MSA	6	0,152	0,051	0,085	0,326	1,794	0,949
York, PA MSA	8	0,186	0,067	0,090	0,350	2,011	0,933

Table 2: Diversity of races in the US.

The comparison of the values of the indexes across SMSAs give interesting insights on the properties of those indicators. For example, New York and New Jersey have have very similar values for the Shannon-Weaver, the Theil's entropy, and the Shannon Evenness indicators. However, results are rather different when looking at the Simpson's index and the Modified Hill's ratio. This fact is due to the fact that the formers are logarithmical measures, whilst the latters are square measures and catch better those little differences that the use of logarithm tends to smooth. Notice that the two SMSA considered have the same richness, consequently the differences in the values of the other indicators are only imputable to the evenness dimension.

It is interesting to notice that sometimes the richness does not have a great influence on the indexes. For example, Louisville and Springfield have very different richness and yet all the other indicators are very close to each other. A confirmation is found in Table 2, where almost all the SMSAs have the same richness (implying that all races are represented in all SMSA, but their population shares vary across SMSAs).

The ability of two indexes to capture different properties of the data is captured by their correlation coefficient. If the coefficient is close to 1, it implies that the indicators tend to capture very similar features of the data, ie we can drop one of them from the analysis without losing many information.

Tables 3 and 4 show the correlation matrix calculated for the selected indicators calculated in Table 1 and 2.

	Richness	Sannon-Weaver's Diversity	Sympson's Diversity or Heterogeneity	Shannon Evenness	Modified Hill's Ratio	Theil's Entropy measure	Herfindal index
Richness	**1**	0,498	0,370	0,340	0,011	0,603	-0,370
S-W Diversity	0,498	**1**	0,965	0,979	0,658	-0,377	-0,965
Sympson's Diversity	0,370	0,965	**1**	0,980	0,828	-0,481	-1,000
Shannon Evenness	0,340	0,979	0,980	**1**	0,752	-0,527	-0,980
Modified Hill's Ratio	0,011	0,658	0,828	0,752	**1**	-0,583	-0,828
Theil's Entropy measure	0,603	-0,377	-0,481	-0,527	-0,583	**1**	0,481
Herfindal index	-0,370	-0,965	-1,000	-0,980	-0,828	0,481	**1**

Table 3: Correlation matrix for language.

	Richness	Sannon-Weaver's Diversity	Sympson's Diversity or Heterogeneity	Shannon Evenness	Modified Hill's Ratio	Theil's Entropy measure	Herfindal index
Richness	**1**	0,351	0,254	0,185	0,006	0,322	-0,254
S-W Diversity	0,351	**1**	0,961	0,979	0,651	-0,768	-0,961
Sympson's Diversity	0,254	0,961	**1**	0,968	0,828	-0,792	-1,000
Shannon Evenness	0,185	0,979	0,968	**1**	0,716	-0,857	-0,968
Modified Hill's Ratio	0,006	0,651	0,828	0,716	**1**	-0,636	-0,828
Theil's Entropy measure	0,322	-0,768	-0,792	-0,857	-0,636	**1**	0,792
Herfindal index	-0,254	-0,961	-1,000	-0,968	-0,828	0,792	**1**

Table 4: Correlation matrix for race.

The following three points emerge:

- the Shannon-Weaver, the Simpson's (and obviously its reciprocal, the Herfindal index) and the Shannon's, show very high correlation coefficients;
- the Modified Hill's ratio and the Theil's Entropy seems to capture different features of the data, as they show low correlation both between them and with the other indexes calculated;
- the Richness measure has a very low correlation with each of the other indexes.

5.2 γ-diversity: measuring diversity across SMSA

The Gini coefficient (calculated across SMSA) measures the level of concentration of a given characteristic. The higher the index the more unequal is the distribution of the characteristic across SMSA. It measures how different are SMSA from each other and can therefore be interpreted as a measure of γ-diversity.

5.2.1 Gini coefficients by language spoken at home

Table 5 shows the Gini coefficient of the main languages spoken in the US. As expected, English is not concentrated. The more concentrated seems to be Portuguese, Albanian, Spanish and Italian.

Languages	Gini
English	0,005
Spanish	0,584
Portuguese	0,710
Italian	0,581
Greek	0,494
Scandinavian	0,480
Dutch	0,435
French	0,380
Celtic	0,642
German	0,192
Polish	0,584
Czech	0,674
Slovac and other Balto-slavic	0,582
Russian, Ucranian, Ruthenian	0,538
Hungarian	0,496
Rumanian	0,626
Albanian	0,872

Table 5: Gini coefficients for the variable *language spoken at home*

For each language is also possible to build the Lorenz curve: the more concave is the curve the more unequal is the distribution of a characteristic. Figures 1 and 2 show the Lorenz Curves for, respectively, English and Spanish. The Lorenz curve for English is close to the diagonal, implying that the English language is equally spread across SMSAs. The curve for Spanish is more concave, implying that a great portions of spanish-speaking people are concentrated in a restricted number of SMSAs.

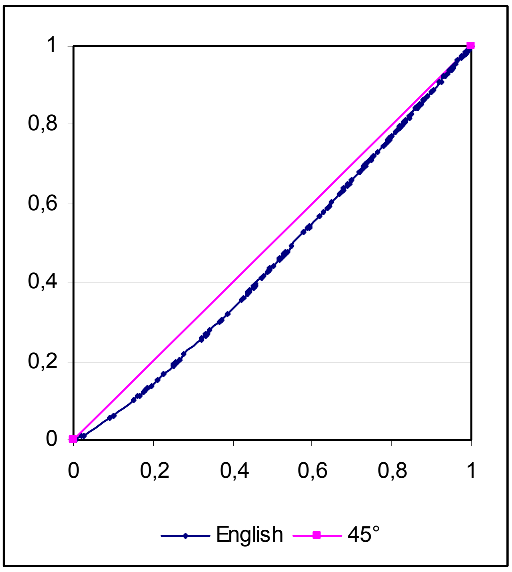

Fig.1: Lorenz curve for English

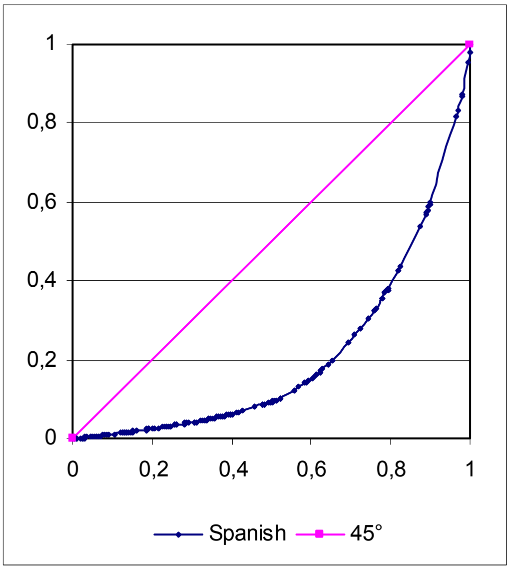

Fig.2: Lorenz curve for Spanish.

5.2.2 Gini coefficients by race

As for variable *language*, we compute the Gini Coefficient for the variable *race,* shown in Table 6. Fig. 3, 4 e 5 show the Lorenz curves for Whites, Japanese and Blacks. Looking at Lorenz Curves for the variable *race*, we can say that white is almost equally distributed, Japanese shows a great concentration, the Gini coefficient is in fact equal to 0,749, and the black case stands in the middle.

Race	**Gini**
White	0,078
Black	0,368
American Indian	0,409
Japanese	0,749
Chinese	0,632
Filipino	0,686
Hawaiian	0,870
Korean	0,550

Table 6: Gini coefficient for the variable *race*

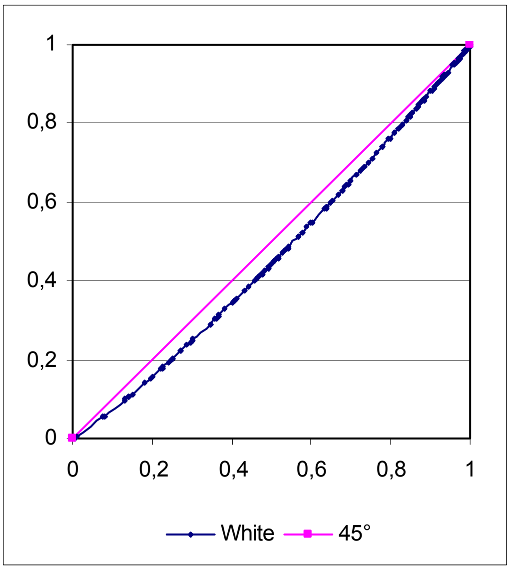

Fig 3: Lorenz curve for whites

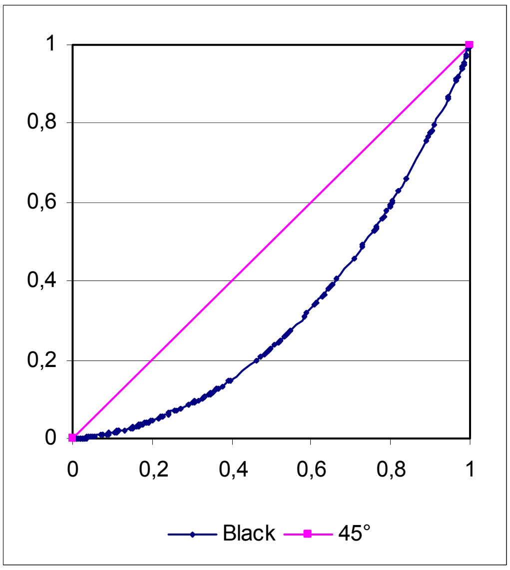

Fig 4: Lorenz curve for Blacks

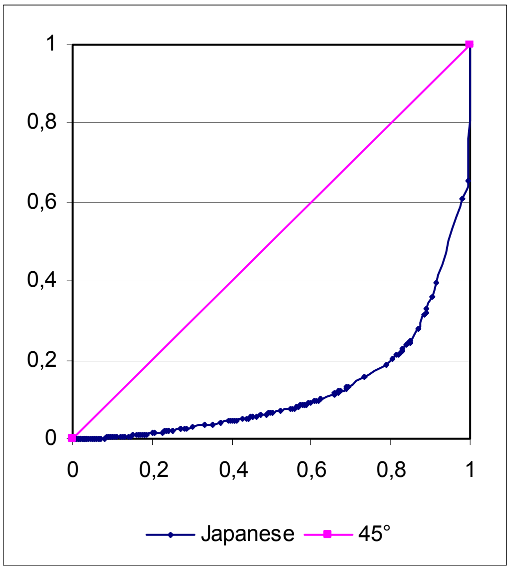

Fig 6: Lorenz curve for Japanese

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(liii) This paper was circulated at the International Conference on "Climate Policy – Do We Need a New Approach?", jointly organised by Fondazione Eni Enrico Mattei, Stanford University and Venice International University, Isola di San Servolo, Venice, September 6-8, 2001

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(lvix) This paper was presented at the ENGIME Workshop on "Mapping Diversity", Leuven, May 16-17, 2002

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