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Local versus overall segregation measures*

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Abstract

This paper proposes a framework in which to study the segregation of a target group in a multigroup context, according either to an evenness perception or to a representativeness view of segregation, and offers a bridge between local segregation and overall segregation. In doing so, this paper first presents an axiomatic set-up within which local segregation measures can be evaluated, and defines local segregation curves. Next, a class of additive segregation indexes, related to the generalized entropy family and consistent with the above curves, is characterized, and decompositions of these measures are proposed. Finally, this paper shows that the axiomatization proposed for measuring local segregation, together with the indexes derived from it, are consistent with the overall segregation measurement of the existing literature. Finally, an empirical illustration with Spanish data is shown.

JEL Classification: J71; J16; D63

Keywords: Occupational segregation; Segregation curves; Inequality measures; Gender

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1. Introduction

Sociologists and economists have devoted a great deal of attention to analyzing segregation of students across schools and occupational segregation in the labor market. Most of these studies focus on the case of two population subgroups (blacks/whites, high/low social position, women/men), either proposing ad hoc measures that are used for empirical analysis (as the popular index of dissimilarity introduced by Duncan and Duncan, 1955; the modified version proposed by Karmel and Maclachlan, 1988; and the Gini index of segregation proposed by Silber, 1989), or axiomatically deriving segregation indexes (Hutchens, 1991, 2004; Chakravarty and Silber, 2007, among others).[1] In this binary context, in studies of school segregation, the distribution of black students is usually compared with that of whites, whereas in studies of occupational segregation, the distribution of female workers is generally compared with that of males. According to the literature, segregation exists so long as one distribution departs from the other, which should be better interpreted as overall or aggregate segregation since both demographic groups are jointly considered.

The study of segregation in the case of multiple categories does not, however, have such a long tradition, even though in recent years this topic has received increasing attention among scholars. In this vein, as shown by Silber (1992) and Boisso et al. (1994), respectively, the segregation index proposed by Karmel and Maclachlan (1988) and that of Gini can be extended to measure (overall) segregation when workers are classified according to more than two categories. Later, Reardon and Firebaugh (2002) extended several inequality measures in order to quantify (overall) segregation in a multigroup context, and evaluated them according to a set of axioms, some of them previously established by James and Taeuber (1985). In recent times, Frankel and Volij (2007) put forward a set of axioms for the measurement of overall school segregation, and characterized, according to this list, an aggregate segregation index for the multigroup case: the mutual information index. This index, which is an extension of that put forward by Theil and Finizza (1971) in the dichotomous case, is actually equal to one of the indexes proposed by Reardon and Firebaugh (2002),[2] and has been recently reinterpreted by Mora and Ruiz-Castillo (2007a) in terms of local segregation.

[1] For a revision of occupational segregation measures, see Flückiger and Silber (1999). James and Taeuber (1985) also offer an interesting discussion of segregation indexes in the case of school segregation.
[2] In this paper we refer to the unbounded version of the Theil index proposed by these authors.

In a context of either two or more than two groups, most segregation measures actually quantify overall segregation rather than the segregation of a particular demographic group. Exceptions to this approach are Moir and Selby Smith (1979) and Lewis (1982). Thus, Moir and Selby Smith (1979) offered a variation of the index of dissimilarity to measure the industrial segregation of female workers in the Australian labor market. By following the same idea, Lewis (1982) explicitly defined a male segregation index, and formally established the relationship between the male and female segregation indexes. In doing so, these authors proposed to compare the distribution of target individuals (female workers in the former case and male workers in the latter) across organizational units with that of total population (i.e., both male and female employment).

The use of a general benchmark, total population, against which to compare the distribution of any population subgroup seems an appealing option, since it facilitates the measurement of segregation when more than two groups are involved. However, papers tackling segregation in the multigroup case have focused on overall segregation rather than on the segregation of each population subgroup. Moreover, even though several properties of overall segregation measurement have been proposed in the literature, in a context of both two (James and Taeuber, 1985; Hutchens, 1991, 2004) and more than two population subgroups (Reardon and Firebaugh, 2002; Frankel and Volij, 2007; Mora and Ruiz-Castillo, 2007b), as far as we know, no axiomatic framework in which to study the segregation of any target population group has been yet proposed. On the other hand, in measuring segregation one can be interested not only in the distribution of a population subgroup across organizational units, which involves an evenness perception of segregation, but also in whether members of one population subgroup are in contact with members of other subgroups. This latter view of segregation, representativeness, which focuses on the distribution of organizational units (occupations, schools, etc.) among population subgroups, has been recently proposed by Frankel and Volij (2007) in a context of overall segregation, even though neither an axiomatic framework nor indexes consistent with it have yet been proposed to measure the segregation of a target organizational unit.

The aim of this paper is precisely to fill these gaps by offering a bridge between the segregation measurement of target groups, either demographic groups or groups of organizational units, and overall segregation. In other words, by following Mora and Ruiz-Castillo's (2007a) terminology, this paper aims to put forward a bridge between local segregation and overall segregation, according to both an evenness and a representativeness perception of segregation.

In doing so, this paper first presents an axiomatic set-up within which local segregation measures can be evaluated. For this purpose, some of the basic properties established in the binary approach by James and Taueber (1985) and Hutchens (1991, 2001) are modified in order to make them suitable to the new framework. Second, a local segregation curve is defined, so that the distribution of the target group is compared with the distribution of total population. Even though our analysis is similar to that previously undertaken by Hutchens (1991) for traditional segregation curves according to an evenness perspective, there are some differences. Thus, in order to link segregation and inequality measurement, we propose to construct a fictitious "income distribution" in a world of "replicants" in such a way that each organizational unit is represented by so many identical individuals as jobs it has, which allows the measurement of segregation in a multigroup set-up.

Third, segregation indexes consistent with these curves are shown. In particular, the traditional Gini index of segregation, and those recently proposed by Chakravarty and Silber (2007) are modified to make them compatible with our approach. Regarding the former, we show that the Gini index proposed by Reardon and Firebaugh (2002) for measuring overall segregation in a multigroup context according to an evenness view, is the weighed mean of our Gini index for each population subgroup in which the economy can be partitioned, which brings additional support to their overall measurement.

Fourth, a class of segregation indexes (related to the generalized entropy family) that satisfies the aforementioned basic properties together with another property, aggregation, is characterized, and decompositions of these indexes are proposed. This family includes a modified version of the indexes proposed by Hutchens (2004) in the dichotomous case, but also new measures. One of these new measures is related to the Theil index proposed by Reardon and Firebaugh (2002) to measure overall segregation according to an evenness view. In particular, Reardon and Firebaugh's index can be written as the weighted mean of our index applied to each of the population subgroups in which the economy can be partitioned. Moreover, the mutual information index recently characterized by Frankel and Volij (2007) can also be written as the weighted mean of our index for each population subgroup, since Reardon and Firebaugh's index and that of Frankel and Volij are proven to be identical. In addition, we show that, according to the representativeness view of segregation, the mutual information index can also be written as the weighted mean of our index for each organizational unit. Therefore, the axiomatization proposed in this paper for measuring the segregation of each target group, either demographic or organizational, together with the indexes derived from it, seems to be consistent with the overall segregation measurement derived from the information theory, whose good properties have been recently emphasized by Mora and Ruiz-Castillo (2007b, c).

This paper is structured as follows. Section 2 proposes an axiomatic framework to evaluate local segregation measures. Section 3 defines a local segregation curve and establishes the relationship between local segregation curves and local segregation indexes satisfying our basic properties. Section 4 characterizes some of these indexes and proposes two types of decompositions. Section 5 shows the relationship that exists between our local segregation indexes and the overall segregation indexes previously proposed in the literature. In particular, this section shows that two of our proposals, one obtained from an evenness view and the other derived from a representativeness view of segregation, are related to the mutual information index used to measure overall segregation. Our segregation measurement is then illustrated in Section 6 by using Spanish labor force data for 2007. Section 7 concludes.

2. Basic axioms for a local measure of segregation

2.1 The evenness and representativeness views of segregation

Following Reardon and O'Sullivan (2004, p. 122), "segregation can be thought of as the extent to which individuals of different groups occupy and experience different social environments. A measure of segregation, then, requires that we (1) define the social environment of each individual, and (2) quantify the extent to which these social environments differ across individuals." Different dimensions of the problem have been described in the literature (Massey and Denton, 1988; Reardon and O'Sullivan, 2004), and among them that of evenness is the most popular (Duncan and Duncan, 1955; James and Taueber, 1985; Reardon and Firebaugh, 2002; Hutchens, 2004; Chakravarty and Silber, 2007). According to this perception, segregation exists if the population subgroups in which the economy can be partitioned (blacks/whites, women/men) are similarly distributed among organizational units (schools, occupations, etc.). Another dimension of segregation, which is receiving increasing attention in the literature, especially in a context of spatial segregation, is that of exposure/isolation. It refers to the extent that members of one population subgroup are in contact with members of other subgroups. This concept has been recently reinterpreted by Frankel and Volij (2007) in a multigroup context as representativeness, and it refers to the extent to which the population composition of an organizational unit differs from that of the whole economy. Evenness and representativeness can be seen as dual concepts, since the former focuses on a social group and quantifies how much its distribution among organizational units differs from that of the economy as a whole, while the latter focuses on an organizational unit and measures the extent to which its social composition differs from that of the economy.

Since this paper intends to analyze the occupational segregation of a target demographic group, we emphasize the evenness dimension.[3] However, one could be also interested in measuring how segregated an occupation is, so that the distribution of employment in this occupation among the population subgroups can be compared with the distribution of total employment among these subgroups (representativeness concept).[4] Therefore, the role played by occupations in the evenness notion is replaced by population subgroups in the representativeness notion, and instead of measuring the segregation of a target demographic group, we measure segregation in a target occupation (or in a group of occupations). The duality between both perspectives is shown in more detail after the notation is introduced.

This paper considers an economy with $J > 1$ occupations among which total employment, denoted by *T*, is distributed according to distribution $t \equiv (t_1, t_2, ..., t_J)$, where $t_j > 0$ represents the number of jobs in occupation j $(j = 1,..., J)$ and $T = \sum_j t_j$. Let us denote by $c^g \equiv (c_1^g, c_2^g, ..., c_J^g)$ the distribution of the target group g in which we are interested $(g = 1,..., G)$, where $c_j^g \leq t_j$. Distribution c^g could represent, for example, the number of women employed in each occupation, but it could also represent the number of individuals of an ethnic group or any other group of citizens in which we are interested. Therefore, the

[3] Note that even though this paper focuses on occupational segregation, our proposal can be used for any kind of segregation.
[4] We could be interested, for example, in analyzing the population composition of an occupation called *Domestic employees and other indoor cleaning personnel* by nationality or race.

economy can be summarized by the following matrix, *E*, which represents the number of individuals of each target group working in each occupation, where rows and columns correspond to population subgroups and occupations, respectively. Note that the total number of workers in occupation j is $t_j = \sum_g c_j^g$, and the total number of individuals of target group g is $C^g = \sum_j c_j^g$.

$$
\begin{array}{c}
G \text{ subgroups} \times J \text{ occupations} \\
E = \begin{bmatrix} c_1^1 & \cdots & c_J^1 \\ \vdots & & \vdots \\ c_1^G & \cdots & c_J^G \end{bmatrix} \rightarrow \begin{bmatrix} \sum_j c_j^1 = C^1 \\ \vdots \\ \sum_j c_j^G = C^G \end{bmatrix} . \\
\downarrow \\
\begin{bmatrix} \sum_g c_1^g = t_1 & \cdots & \sum_g c_J^g = t_J \end{bmatrix}
\end{array}
$$

In order to measure the segregation of a target population group, which involves an evenness perspective, we have to compare the corresponding row, $\left(c_1^g,...,c_J^g\right)$, with the total sum of the rows, $\left(t_1,...,t_J\right)$, both distributions expressed in proportions. In other words, distribution $\left(\frac{c_1^g}{C^g},...,\frac{c_J^g}{C^g}\right)$ is compared with $\left(\frac{t_1}{T},...,\frac{t_J}{T}\right)$. On the other hand, if interested in measuring the segregation of a target organizational unit (representativeness perspective), we have instead to compare the corresponding column, $\left(c_j^1,...,c_j^G\right)$, with the sum of the columns, $\left(C^1,...,C^G\right)$, both distributions expressed again in proportions. Therefore, $\left(\frac{c_j^1}{t_j},...,\frac{c_j^G}{t_j}\right)$ is compared with $\left(\frac{C^1}{T},...,\frac{C^G}{T}\right)$. Given the symmetric role played by rows and columns, even though our proposal in this paper will be presented in terms of evenness, it can also be easily reinterpreted in terms of representativeness.

It should be also noted that if one is interested in overall segregation rather than in the segregation of a particular group, both evenness and representation make sense (see Mora and Ruiz-Castillo, 2007a), since the former notion tackles segregation by taking into account differences among population subgroups (regarding their distributions across occupations), while the latter notion takes into account differences among occupations (regarding their population composition). Overall segregation according to the evenness notion corresponds to differences among rows, while overall segregation in terms of representativeness corresponds to differences among columns. The connections between both perspectives will be also tackled in this paper when analyzing overall segregation in section 5.

2.2 Basic properties for measuring local segregation

In what follows, we show a list of desirable properties for any measure of occupational segregation of target population group g $\Phi : D \to \mathbb{R}$ where $D = \bigcup_{J>1} \left\{ \left(c^g ; t \right) \in \mathbb{R}^J_{+} \times \mathbb{R}^J_{++} : c^g_j \leq t_j \forall j \right\}$. The first axiom is *scale invariance*, which means that the segregation index does not change when the total number of jobs in the economy and/or the total number of individuals of the target group g varies, so long as their respective shares in each occupation remain unaltered. This is an axiom similar to the one considered in the income distribution literature regarding relative inequality measures.

Axiom 1. *Scale Invariance*: Let α and β be two positive scalars such that when $\left(c^g ; t \right) \in D$ vector $\left(\alpha c^g ; \beta t \right) \in D$, then $\Phi\left(\alpha c^g ; \beta t \right) = \Phi\left(c^g ; t \right)$.

As opposed to Hutchens' formulation (1991; 2004), the above property requires compatibility between distributions c^g and t, and this is why not every pair of positive scalars is possible but only those that allow $\left(\alpha c^g ; \beta t \right) \in D$, so that $\alpha c^g_j \leq \beta t_j$.[5] In Figure 1, we can see that αc^g

[5] This axiom also differs from the "weak scale invariance" axiom proposed by Frankel and Volij (2007). They measure overall segregation, rather than the segregation of a single group, which makes them to require that the number of individuals in all population groups in all organizational units are multiplied by the same positive scalar. It is also different from the "composition invariance" axiom proposed by James and Taeuber (1985), since in their proposal only a single population subgroup is allowed to vary, while in our axiom both changes in c^g and t are allowed.

is a distribution located in the ray passing by c^g. We can also see that the only βt distributions compatible with αc^g are those belonging to the ray passing by t that are in the dash line.

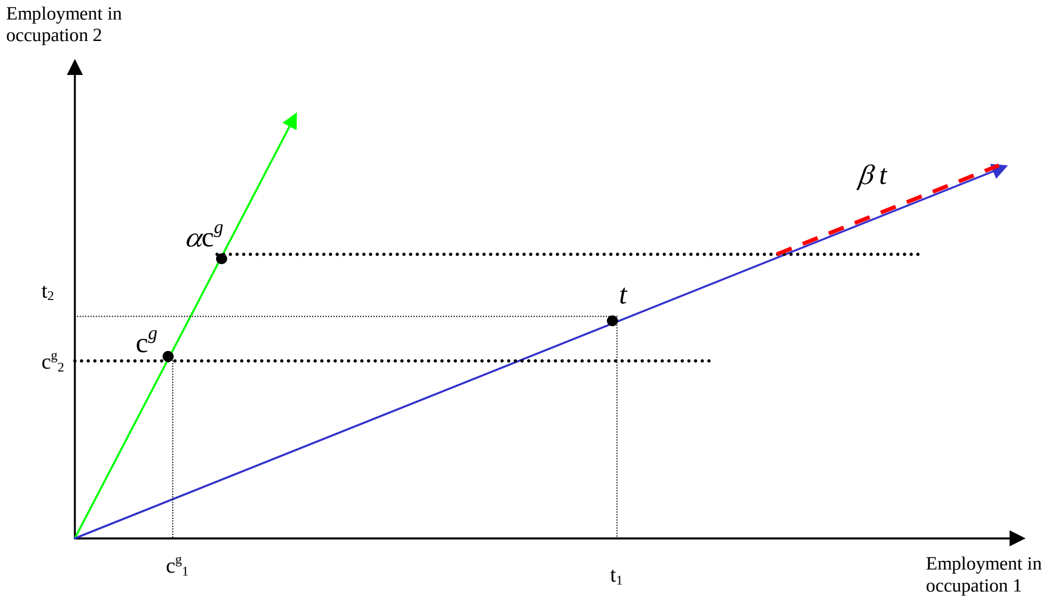

Figure 1. Relationship between αc^g and βt in a two-dimensional case.

Consider, for instance, that we are interested in measuring the occupational segregation of female workers. Since we do not compare the female distribution with the male one, as in the traditional approach, but with the employment distribution, some reflections are in order. If $\beta = 1$ and $\alpha = 2$ are two possible scalars, then vector $(2c^g; t) \in D$ represents a scenario in which total employment has not changed, the female share in each occupation (with respect to the total number of female workers) has not changed either, but the number of female employees has actually doubled. For example, suppose that there are three occupations and that the initial number of women working in each of them is, respectively, 2, 3 and 5, while the number of jobs in each occupation is, respectively, 30, 50 and 20.

	Occupations 1	2	3
Women	2	3	5
Total employment	30	50	20

or equivalently $(c^g; t) = (2,3,5;30,50,20)$.

Assume now that the distribution of total employment remains the same, but the number of women in each occupation doubles:

$$\begin{array}{l} \\ \text{Women} \\ \text{Total employment} \end{array} \overset{\text{Occupations}}{\begin{array}{ccc} 1 & 2 & 3 \\ \end{array}} \begin{pmatrix} 4 & 6 & 10 \\ 30 & 50 & 20 \end{pmatrix} \quad \text{or equivalently} \quad \left(2c^g;t\right) = \left(4,6,10;30,50,20\right).$$

Given that in this example our target group is female workers, we are only interested in the distribution of women among occupations. Since neither the proportion of women in each occupation has changed (20% of female workers are still in the first occupation, 30% in the second, and 50% in the third) nor has the employment structure, any measure of female segregation should remain unaltered, even though the distribution of other groups (in this case, men) have changed. In fact, in our example, some men have lost their previous positions since more women have entered each occupation while the number of jobs has remained the same (the distribution of men among occupations has changed from $\left(28,47,15\right)$ to $\left(26,44,10\right)$). Therefore, the gender rate (i.e., the number of female workers against the number of male workers) in each occupation has actually changed. Certainly, segregation for men could have changed, but that can only be measured by calculating the segregation index for that particular group.

When considering the case where $\alpha = \beta$, the above axiom becomes the s*ize invariance* or *replication invariance* axiom.

Axiom 2. *Size Invariance*: Let α be a positive scalar and $\left(c^g;t\right) \in D$, then $\Phi\left(c^g;t\right) = \Phi\left(\alpha c^g;\alpha t\right)$.

This axiom means that if we have an economy where c^g and t are obtained by the replication of initial distributions, segregation does not change.[6] The next axiom is *symmetry in groups*, which means that the "occupation's name" is irrelevant, so that if we rank occupations in a different order, the segregation measurement remains unchanged.[7]

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[6] Note, however, that this axiom differs from that proposed by James and Taeuber (1985). Consider, for instance, that our target group is that of young male workers. Our formulation requires that when both the number of young male workers and jobs double, segregation remains unaltered. Their formulation requires, instead, that when all subgroups double, segregation is unaffected. Certainly, James and Taeuber's criterion can be considered as an axiom for measuring overall segregation rather than target-group segregation.

[7] The "symmetry" axiom introduced by Frankel and Volij (2007) to measure overall segregation requires symmetry in both organizational units (schools, occupations, etc.) and in population subgroups, since evenness and representativeness are jointly considered.

Axiom 3. *Symmetry in Groups* (Hutchens, 1991): If $\left(\Pi(1),...,\Pi(J)\right)$ represents a permutation of occupations $\left(1,...,J\right)$ and $\left(c^g;t\right)\in D$, then $\Phi\left(c^g\Pi;t\Pi\right)=\Phi\left(c^g;t\right)$, where $c^g\Pi=\left(c^g_{\Pi(1)},...,c^g_{\Pi(J)}\right)$ and $t\Pi=\left(t_{\Pi(1)},...,t_{\Pi(J)}\right)$.

The next axiom is *movement between groups,* which requires that when an occupation with a lower number of target individuals than another (but with the same employment level) loses target jobs in favor of the latter, segregation must increase. This property is similar to the Pigou-Dalton principle of the income distribution literature.

Axiom 4. *Movement between Groups*: If vector $\left(c^g{}';t'\right)\in D$ is obtained from vector $\left(c^g;t\right)\in D$ in such a way that **a)** $c_i^g{}'=c_i^g-d$ and $c_h^g{}'=c_h^g+d$ $\left(0<d\leq c_i^g\right)$, where *i* and *h* are two occupations with the same employment share, $\frac{t_i}{T}=\frac{t_h}{T}$, and $\frac{c_i^g/C^g}{t_i/T}<\frac{c_h^g/C^g}{t_h/T}$; and **b)** $c_j^g{}'=c_j^g \quad \forall j\neq i,h$, and $\frac{t'_j}{T'}=\frac{t_j}{T} \quad \forall j$; then $\Phi\left(c^g{}';t'\right)>\Phi\left(c^g;t\right)$.[8]

Note that since occupations *i* and *h* have the same employment share, condition $\frac{c_i^g/C^g}{t_i/T}<\frac{c_h^g/C^g}{t_h/T}$ is equivalent to condition $c_i^g<c_h^g$. In other words, occupation *i* has initially the same number of jobs as occupation *h* but a lower number of positions for the target group. Therefore, a movement of some of these citizens from occupation *i* to occupation *h* is a disequalizing movement.

In order to highlight the possible consequences of these disequalizing movements, we will analyze three different scenarios in the case of female segregation. First, consider the case where the total number of jobs does not change and the employment distribution does not change either. Therefore, a movement of women between *i* and *h* means that female

[8] Note that this axiom differs from that of Hutchens (2004) not only because we compare the female distribution with the total employment distribution, but also because our definition allows the possibility of changes in the job distribution, so long as the employment shares in each occupation remains unaltered. In Hutchens' definition, however, disequalizing movements involve only changes in the female population, while the other distribution (that of males) remains necessarily unaltered. In our approach, when the female distribution changes, the benchmark distribution (total employment) could change. This is why we invoke specific assumptions about those changes. In particular, it is required that the proportion of employment in each occupation does not change, which involves changes in the distribution of men.

employment in occupation *i* has been replaced by male employment, while the opposite holds for occupation *h*. Second, suppose that the total number of jobs increases while shares remain the same. Now, employment in each occupation does increase, so that when occupation *i* loses some women, even more men than before enter this occupation. And third, consider the case where the total number of jobs decreases, even though employment shares do not change. Then, occupation *i* loses both women (who move to occupation *h*) and men (due to the employment reduction). Therefore, a disequalizing movement may involve not only changes in the female distribution but also in other population subgroups. In any case, we should keep in mind that, since we compare the distribution of the target group with the distribution of jobs among occupations, when an occupation *i* with a worse position than another *h* (i.e. $\frac{c_i^g / C^g}{t_i / T} < \frac{c_h^g / C^g}{t_h / T}$), faces a decrease in the number of individuals belonging to the target group, any segregation measure of that group should increase independently of changes in the distribution of other groups of individuals. As mentioned before, segregation for those other groups could have changed, but that can only be measured by calculating segregation indexes for those particular groups.

Finally, we present the axiom of *insensitivity to proportional divisions*, which means that subdividing an occupation in several categories of equal size, both in terms of total employment and in terms of individuals of the target group, does not affect segregation measurement.[9]

Axiom 5. *Insensitivity to Proportional Divisions* (Hutchens, 2004): If vector $\left(c^g{}';t'\right) \in D$ is obtained from vector $\left(c^g;t\right) \in D$ in such a way that **a)** $c^g{}'_j = c^g{}_j$, $t'_j = t_j$ for any $j = 1,...,J-1$; and **b)** $c^g{}'_j = c_J^g / M$, $t'_j = t_J / M$ for any $j = J,...,J+M-1$, then $\Phi\left(c^g{}';t'\right) = \Phi\left(c^g;t\right)$.

As a consequence of the above axiom, segregation remains constant if two occupations with the same number of target individuals and the same number of jobs are combined into a single occupation.

[9] This axiom differs from the “school division” property proposed by Frankel and Volij (2007), since they measure overall segregation and this is why they require that each of the subunits in which the organizational unit (school) is divided keeps the same population composition.

The axioms presented in this section appear as reasonable properties for a local segregation measure and that is why they will be invoked in later sections. These axioms have been formulated according to an evenness view but, given the duality between the evenness and representativeness notions, they can be easily redefined in terms of representativeness by swapping rows and columns in matrix *E*.

3. Local segregation curves and indexes

3.1 Local segregation curves

In the traditional approach, the occupational segregation curve is obtained by comparing the distribution of the female workers among occupations with that of males.[10] In particular, this curve, S, represents the cumulative proportion of female workers corresponding to the cumulative share of male workers, once occupations have been ranked by increasing gender ratios (the number of women divided by the number of men in each occupation).[11]

This paper proposes instead a segregation curve for each target demographic group by comparing the distribution of that group with the distribution of total employment. Thus, to calculate our segregation curve, denoted by S^g for group g, we plot the cumulative proportion of employment, $\sum_{i \le j} \frac{t_i}{T}$, on the horizontal axis and the cumulative proportion of individuals of the target group, $\sum_{i \le j} \frac{c_i^g}{C^g}$, on the vertical axis, once occupations are lined up in ascending order of the ratio $\frac{c_j^g / C^g}{t_j / T}$, which is equivalent to ranking according to $\frac{c_j^g}{t_j}$. This leads to the next definition.

Definition. Denoting by $\tau_j \equiv \sum_{i \le j} \frac{t_i}{T}$ the proportion of cumulative employment represented by the first *j* occupations ranked according to the above criterion, the segregation curve is

[10] These segregation curves were initially proposed by Duncan and Duncan (1955).

[11] A segregation curve is, therefore, similar to the Lorenz curve obtained when having groups of homogeneous income recipients, instead of individual data, so that the distribution of incomes between groups is compared with that of population. In this case, groups would be first ranked by their average income, and later the cumulative proportion of population would be plot on the horizontal axis, and the cumulative proportion of income on the vertical axis.

$$S^g_{(c^g;t)}(\tau_j) = \frac{\sum_{i \le j} c_i^g}{C^g}.$$

Therefore, the benchmark distribution we propose is a general one, total employment, so that it does not depend on which is the target group considered.[12] This allows measuring the segregation of any target group in a multigroup context. If we swapped rows and columns in matrix E, an analogous segregation curve S_j $(j = 1,...,J)$ for each occupation could be defined, which would involve a representativeness notion of segregation. However, for the sake of simplicity, only the evenness notion of segregation will be developed in detail in this paper.

Definition. As with Lorenz curves, we say that $\left(c^g;t\right) \in D$ *dominates in occupational segregation* $\left(c^g{}';t'\right) \in D$ if the segregation curve of the former lies at no point below the latter and at some point above, which can be denoted as $S^g_{(c^g;t)} > S^g_{(c^g{}';t')}$.

Definition. According to curve S^g, *complete integration* for the target group occurs when $\frac{c_j^g}{C^g} = \frac{t_j}{T}$ $\forall j$ (i.e. when $\frac{c_j^g}{t_j} = \frac{C^g}{T}$). This distribution is called the equalitarian distribution.

In measuring segregation by sex, complete integration happens when the female and male distributions among occupations coincide. Therefore, in a 2-group framework, when there is complete integration according to our approach, there is also complete integration in the traditional approach, and vice-versa. However, both approaches differ about what complete segregation is.

Definition. For a given employment structure, *complete segregation* according to curve S^g occurs when the target group works in a single occupation.

According to curve S, however, complete segregation by gender occurs not only in the above

[12] For a comparison between our segregation curve and the traditional one in a context of two population subgroups see Alonso-Villar and Del Río (2007).

case but also when women work in several occupations with no men, i.e., when there is perfect complementary between the two sexes' occupations. Notice that this implies the existence of complete segregation of both female and male workers.

3.2 Relationship between local segregation curves and indexes

In what follows, we show the relationship between our segregation curve S^g and segregation indexes satisfying the basic properties proposed in a previous section.[13]

Lemma 1. *A segregation index satisfying scale invariance, symmetry in groups, movement between groups, and insensitivity to proportional divisions can be interpreted as a relative inequality index satisfying symmetry, the Pigou-Dalton transfer principle, and population invariance.*

Proof:

For simplicity, let us assume that vector $\left(c^g;t\right) \in D$ is ordered according to shares $\frac{c_j^g}{t_j}$ from low to high values. From the above vector we can build a hypothetical "income distribution" so that we have t_1 "replicants" with an individual "income" of $\frac{c_1^g}{t_1}$, t_2 "replicants" with an individual "income" of $\frac{c_2^g}{t_2}$, and so on. Therefore, we have a fictitious (ordered) income distribution $(\underbrace{\frac{c_1^g}{t_1},...,\frac{c_1^g}{t_1}}_{t_1 \text{ replicants}},...,\underbrace{\frac{c_J^g}{t_J},...,\frac{c_J^g}{t_J}}_{t_J \text{ replicants}})$ in a world of $T = \sum_j t_j$ replicants where total income is $C^g = \sum_j t_j \frac{c_j^g}{t_j}$. An inequality index evaluated at this distribution can be defined as the segregation index evaluated at the original vector $\left(c^g;t\right)$, i.e., $I(\frac{c_1^g}{t_1},...,\frac{c_1^g}{t_1},...,\frac{c_J^g}{t_J},...,\frac{c_J^g}{t_J}) := \Phi(c^g;t)$. Since Φ satisfies the axiom of insensitivity to proportional divisions, the above inequality index is well defined. Certainly, a given distribution of replicants can be obtained from different vectors $\left(c^g;t\right)$, having the same

[13] This analysis would be easily extended to a representativeness view of segregation.

number of jobs (T) and individuals belonging to the target group (C^g), depending on the way the occupations had been grouped. Note, however, that all these vectors have the same segregation level, since they can be obtained from each other through proportional divisions.

If segregation index Φ satisfies axioms 1, 3, 4 and 5, then index *I* satisfies the basic properties of a relative inequality index:

a) *I* is scale invariant since $I(\alpha \frac{c_1^g}{t_1},...,\alpha \frac{c_1^g}{t_1},...,\alpha \frac{c_J^g}{t_J},...,\alpha \frac{c_J^g}{t_J}) = \Phi(\alpha c^g;t)$, which is equal to $\Phi(c^g;t)$ because Φ is a scale invariant segregation index.

b) *I* satisfies the replication invariance axiom since a k-replication of the fictitious distribution leads to a k-replication of vector $\left(c^g;t\right)$ and Φ satisfies the corresponding axiom, as a particular case of axiom 1.

c) *I* is symmetric since any permutation of the replicants distribution leads to the same ordered vector $\left(c^g;t\right)$ or to another ordered vector that is segregation-equivalent.

d) *I* satisfies the Pigou-Dalton transfer principle. Any possible regressive transfer in this fictitious economy of replicants corresponds to a situation where an occupation *i* transfers individuals of the target group to another occupation h where $t_i = t_h$ and $c_i^g < c_h^g$. Since Φ satisfies the movement between groups axiom, this second situation leads to a higher segregation index, and therefore, to a higher value of *I*. □

Theorem 1. *Let us consider two vectors* $\left(c^g;t\right),\left(c^g\,';t'\right) \in D$. $S^g_{\left(c^g;t\right)} > S^g_{\left(c^g\,';t'\right)}$ *if and only if* $\Phi\left(c^g;t\right) < \Phi\left(c^g\,';t'\right)$ *for any local segregation index* Φ *satisfying axioms 1, 3, 4 and 5.*

Proof:

On one hand, from lemma 1, any segregation index Φ satisfying axioms 1, 3, 4 and 5 leads to a relative inequality index satisfying symmetry, the Pigou-Dalton transfer principle and replication invariance. On the other hand, note that the local segregation curve for vector$\left(c^g;t\right)$ is like the Lorenz curve for the fictitious distribution $(\frac{c_1^g}{t_1},...,\frac{c_1^g}{t_1},...,\frac{c_J^g}{t_J},...,\frac{c_J^g}{t_J})$ obtained as in lemma 1's proof. Given the relationship between Lorenz curves and relative inequality measures established by Foster (1985), the Lorenz curve of a distribution dominates another if and only if any relative inequality measure satisfying the above three basic properties takes a lower value at the former distribution. Therefore, $\Phi\left(c^g;t\right)<\Phi\left(c^{g}';t'\right)\Leftrightarrow S^g_{\left(c^g;t\right)}>S^g_{\left(c^{g}';t'\right)}$, which completes the proof. □

3.3 Some indexes related to local segregation curves

The Gini index is an inequality measure satisfying scale invariance, replication invariance and the Pigou-Dalton transfer principle, and it is therefore consistent with the Lorenz criterion (Foster, 1985). This measure is equal to twice the area between the Lorenz curve and the 45º line. Given the similarity between segregation curves and Lorenz curves, an adequate version of the classic Gini index works as a local segregation measure, according to an evenness view, consistent with non-intersecting S^g curves:[14]

$$G^g=\frac{\sum_{i,j}\frac{t_i}{T}\frac{t_j}{T}\left|\frac{c_i^g}{t_i}-\frac{c_j^g}{t_j}\right|}{2\frac{C^g}{T}}.$$

If there is complete integration (i.e. if $\frac{c_j^g}{C^g}=\frac{t_j}{T}\ \forall j$), then the G^g is equal to zero, while if there is complete segregation so that all target citizens work in a single occupation, for example in occupation one, G^g is equal to $\frac{T-t_1}{T}$.

Following Flückiger and Silber (1999), we can think of this segregation measurement as the degree of conformity between “a priori” and “a posteriori” employment shares. In our case, no segregation exists so long as the proportion of target individuals in each occupation, $\frac{c_j^g}{C^g}$ (the “a posteriori” share), coincides with the employment share that the respective occupation represents, $\frac{t_j}{T}$ (the “a priori” share).[15]

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[14] The representativeness version would be $G_j=\frac{\sum_{g,g'}\frac{C^g}{T}\frac{C^{g'}}{T}\left|\frac{c_j^g}{C^g}-\frac{c_j^{g'}}{C^{g'}}\right|}{2\frac{t_j}{T}}$.

[15] Other approaches in a multi-group context interpret segregation in terms of alternative “a priori” and “a posteriori” shares in order to measure overall segregation. See, for example, Silber (1992), who generalized Karmel and Maclachlan’s index, and Boisso et al. (1994), who extended the Gini index.

The index of dissimilarity proposed by Duncan and Duncan (1955), the most popular segregation measure, is also related to the traditional segregation curve since it equals the maximum vertical distance between the traditional curve S and the 45º line. It can be interpreted as "the proportion of male workers plus the proportion of female workers who would need to change occupations in order to have the same proportion of women in every occupation (and the same proportion of men in every occupation but with a different value)" (Anker, 1998, p 90). This measure can also be conveniently adapted to make it related to our local segregation curve S^g so that it can be written as follows:[16]

$$D^g = \frac{1}{2}\sum_j \left| \frac{c_j^g}{C^g} - \frac{t_j}{T} \right|.$$

It is easy to see that the value of this index coincides with that of Gini's when there is either complete segregation or complete integration. This index was previously proposed by Moir and Selby Smith (1979) to measure female segregation and by Lewis (1982) to measure male segregation.

By following an axiomatic approach, Chakravarty and Silber (2007) have recently proposed relative segregation indexes bounded between zero and one that are consistent with the ordering produced by traditional segregation curves. These measures can also be conveniently modified to make them consistent with our local segregation curves according to an evenness view as follows:[17]

$$\bar{K}_\alpha^g = 1 - \left[\frac{1}{J}\sum_j \left(\frac{c_j^g}{C^g}\right)^\alpha \left(\frac{t_j}{T}\right)^\alpha \right]^{\frac{1}{2\alpha}},\ \bar{K}^g = 1 - \left[\prod_j \left(\frac{c_j^g}{C^g}\right)^{0.5} \left(\frac{t_j}{T}\right)^{0.5} \right]^{\frac{1}{J}} ,$$

where parameter α is such that the lower its value, the larger the increase of the index due to disequalizing movements between occupations. As noticed by the authors, one limitation of their measures is that they are not suitable when either the target group or the population of reference has a zero value in at least one occupation. Certainly, the use of these indexes in a

[16] The representativeness version would be $D_j = \frac{1}{2}\sum_g \left| \frac{c_j^g}{t_j} - \frac{C^g}{T} \right|$.

[17] Representativeness versions: $\bar{K}_{j_\alpha} = 1 - \left[\frac{1}{G}\sum_g \left(\frac{c_j^g}{t_j}\right)^\alpha \left(\frac{C^g}{T}\right)^\alpha \right]^{\frac{1}{2\alpha}},\ \bar{K}_j = 1 - \left[\prod_g \left(\frac{c_j^g}{t_j}\right)^{0.5} \left(\frac{C^g}{T}\right)^{0.5} \right]^{\frac{1}{G}}$.

framework as the one proposed here, where the distribution of reference is total employment instead of a particular population group, reduces that problem.[18]

4. Aggregative indexes consistent with local segregation curves

In the literature of income distribution, scholars usually invoke another axiom, *aggregation*, in order to characterize the class of relative inequality indexes satisfying some basic axioms. This axiom can also be invoked here as follows.

Axiom 6. *Aggregation* (Hutchens, 2004): Let us assume that occupations can be partitioned in two mutually exclusive classes such that $(c^g;t)=(c^{g1},c^{g2};t^1,t^2)$, where the number of jobs in class 1 (2) is denoted by T^1 (T^2), while C^{g1} (C^{g2}) represents the number of individuals of the target group who work in those occupations. Φ is aggregative if there exists a continuous aggregator function A such that $\Phi\left(c^g,t\right)=A\left(\Phi(c^{g1};t^1),\frac{C^{g1}}{T^1},T^1,\Phi(c^{g2};t^2),\frac{C^{g2}}{T^2},T^2\right)$, where A is strictly increasing in the first and fourth argument.

Theorem 2. *Let Φ be a continuous local segregation index that takes a zero value at the equalitarian distribution (i.e., when $\frac{c_j^g}{t_j}=\frac{C^g}{T}$ $\forall j$). Then, Φ is an aggregative local segregation measure satisfying scale invariance, symmetry in groups, movement between groups, and insensitivity to proportional divisions if and only if there exists a strictly increasing function $F:\left[0,\infty\right)\to\mathbb{R}$, with $F(0)=0$, such that $F(\Phi)=\Phi_a$ for some parameter a, where*

[18] Note that the indices proposed by Chakravarty and Silber (2007) in the traditional approach may not take a zero value when there is no segregation. In fact, if $\alpha=0.5$, and if the distribution of females across occupations coincides with that of males, then $\bar{K}_\alpha=1-\left[\frac{1}{J}\sum_j\left(\frac{c_j^g}{C^g}\right)^\alpha\left(\frac{t_j-c_j^g}{T-C^g}\right)^\alpha\right]^{\frac{1}{2\alpha}}=1-\frac{1}{J}$, where g refers to women. The same problem has the modified version $\bar{K}_\alpha^g$ when the distribution of female workers coincides with the occupational structure of the economy.

$$\Phi_a(c^g;t)=\begin{cases}\dfrac{1}{a(a-1)}\sum_j \dfrac{t_j}{T}\left[\left(\dfrac{c_j^g/C^g}{t_j/T}\right)^a-1\right] & \text{if } a\neq 0,1\\ \sum_j \dfrac{c_j^g}{C^g}\ln\left(\dfrac{c_j^g/C^g}{t_j/T}\right) & \text{if } a=1\end{cases}$$

Proof: See Appendix.

Note that these indexes are related to the generalized entropy family used in the income distribution literature. The case $a\neq 0,1$ is similar to that proposed by Hutchens (2004), except that our indexes compare the female distribution with that of total employment, while his indexes compare the female distribution with that of males. The case $a=1$ does not appear, however, in his analysis. Φ_1 can also be interpreted in terms of "a priori" and "a posteriori" shares as follows: If assuming that the initial distribution is $\dfrac{c^g}{C^g}\equiv\left(\dfrac{c_1^g}{C^g},\ldots,\dfrac{c_J^g}{C^g}\right)$ and that one would like eventually reaching final distribution $\dfrac{t}{T}\equiv\left(\dfrac{t_1}{T},\ldots,\dfrac{t_J}{T}\right)$, the index can be thought of as the distributional change resulting from the difference between "a posteriori" and "a priori" shares, weighted by the "a priori" shares (Cowell, 1980, expression (5)).

If we had considered segregation indexes defined on the space of employment distributions $(c^g;t)$ where all components of vector c^g were strictly positive, rather than positive, then another index would have appeared: $\Phi_a(c^g;t)=\sum_j \dfrac{t_j}{T}\ln\left(\dfrac{t_j/T}{c_j^g/C^g}\right)$ if $a=0$. As opposed to the case $a=1$, Φ_0 transforms "a priori" shares, $\dfrac{t_j}{T}$, into "a posteriori" shares, $\dfrac{c_j^g}{C^g}$, in such a way that the difference between the "a posteriori" and the "a priori" is weighed by the "a priori" shares (see Cowell, 1980, expression (7)).

The above theorem proposes a family of relative segregation indexes that are consistent with our segregation curves S^g since they satisfy the basic properties. However, these measures are not necessarily bounded between zero and one, which could be helpful in some empirical analyses. In the next corollary we propose aggregative segregation measures that are bounded within this interval.

Corollary. $\tilde{\Phi}_a(c^g;t) = 1 - \sum_j \left(\frac{c_j^g}{C^g}\right)^a \left(\frac{t_j}{T}\right)^{1-a}$, with $a \in (0,1)$, is a family of relative and aggregative segregation indexes consistent with segregation curves S^g and is bounded between zero and one.

Proof:

Note that $\tilde{\Phi}_a(c^g;t) = F^{-1}[\Phi_a(c^g;t)]$ with $F(y) = \frac{1}{a(1-a)} y$. Therefore, by theorem 2, $\tilde{\Phi}_a$ is a relative segregation index satisfying the basic axioms and, by theorem 1, it is then consistent with our segregation curves. Trivially, $\tilde{\Phi}_a$ is up bounded by 1. To show that it is low bounded by 0, note that if $\sum_j \left(\frac{c_j^g}{C^g}\right)^a \left(\frac{t_j}{T}\right)^{1-a} > 1$ and using that $a \in (0,1)$, then $\sum_j \frac{t_j}{T} > 1$, which is impossible. Therefore, $\sum_j \left(\frac{c_j^g}{C^g}\right)^a \left(\frac{t_j}{T}\right)^{1-a} \le 1$, which completes the proof. □

Remark 1. $\tilde{\Phi}_a$ never reaches the upper bound, since $\tilde{\Phi}_a(c^g;t) = 1$ if and only if $c_j^g = 0 \ \forall j$, which is impossible. In Section 3, we saw that segregation is maximal when all individuals of the target group work in the same occupation. Without loss of generality, assume that this happens in occupation one, i.e., $(c^g;t) = (c_1^g, 0, ..., 0; t_1, t_2 ..., t_J)$. Then $\tilde{\Phi}_a(c^g;t) = 1 - \left(\frac{t_1}{T}\right)^{1-a}$. Therefore, the lower the weight of that occupation in terms of employment, the higher the segregation level.

Remark 2. One of the advantages of this class of indexes is that its members are additively decomposable. They can be decomposed by subgroups of occupations and by subgroups of individuals, which corresponds to the decompositions of inequality by subpopulations and by factor components, respectively (Shorrocks, 1980, 1982):

i) *Decomposition by subgroups of occupations.* Given a partition of occupations in K categories, $(c^g;t) = (c^{g1}, ..., c^{gK}; t^1, ..., t^K)$, our indexes can be decomposed as follows:[19]

[19] These decompositions follow from the aggregator function defined in the Appendix (proof of Theorem 2).

$$\Phi_a(c^{g1},...,c^{gK};t^1,...,t^K)=\sum_k\left(\frac{C^{gk}}{C^g}\right)^a\left(\frac{T^k}{T}\right)^{1-a}\Phi_a(c^{gk};t^k)+\Phi_a(C^{g1},...,C^{gK};T^1,...,T^K)\ \text{ if } a\neq 0$$

where the first addend of the above formula represents the *within* component, i.e. the weighted sum of segregation inside each occupation class, while the second addend reflects the *between* component.

ii) *Decomposition by subgroups of individuals.* In order to analyze segregation differences between individuals of the target group, let us classify them into several mutual exclusive subgroups. Without loss of generality, consider that there are only two subgroups *A* and *B* such that $(c^g;t)=(c^{gA}+c^{gB};t)$. Then the contribution of subgroup *A* to the segregation level of the whole target group according to index Φ_2 is

$$IC_A=\rho_A\left(\frac{C^{gA}}{C^g}\right)\sqrt{\frac{\Phi_2(c^{gA};t)}{\Phi_2(c^g;t)}}\ ,$$

where ρ_A is the correlation between $(\underbrace{\frac{c_1^g}{t_1},...,\frac{c_1^g}{t_1}}_{t_1\text{ replicants}},...,\underbrace{\frac{c_J^g}{t_J},...,\frac{c_J^g}{t_J}}_{t_J\text{ replicants}})$ and $(\underbrace{\frac{c_1^{gA}}{t_1},...,\frac{c_1^{gA}}{t_1}}_{t_1\text{ replicants}},...,\underbrace{\frac{c_J^{gA}}{t_J},...,\frac{c_J^{gA}}{t_J}}_{t_J\text{ replicants}})$, which represent two fictitious income distributions in the world of replicants.[20] Analogous expressions can be employed for subgroup *B*. Therefore, $IC_A+IC_B=1$.

Remark 3. Given the duality between the evenness and representativeness notions shown in Section 2, the above indexes can be easily redefined to measure the segregation in an occupation, rather than the segregation of a target group. In this case the expressions would be:[21]

$$\Psi_a(c_j;C)=\begin{cases}\dfrac{1}{a(a-1)}\sum_g\dfrac{C^g}{T}\left[\left(\dfrac{c_j^g/t_j}{C^g/T}\right)^a-1\right] & \text{if } a\neq 0,1\\ \sum_g\dfrac{c_j^g}{t_j}\ln\left(\dfrac{c_j^g/t_j}{C^g/T}\right) & \text{if } a=1\end{cases}\ ,$$

[20] This decomposition follows from the relationship between segregation and inequality measurement shown in a previous section.

[21] As in the evenness case, if occupation j has workers of all population subgroups, another index could be defined: $\Psi_0(c_j;C)=\sum_g\frac{C^g}{T}\ln\left(\frac{C^g/T}{c_j^g/t_j}\right)$ if $a=0$.

where $c_j \equiv \left(c_j^1,...,c_j^G\right)$ denotes the distribution of jobs in occupation j among the population subgroups, and $C \equiv \left(C^1,...,C^G\right)$ is the distribution of total employment among the population subgroups. These indexes could be decomposed in a similar manner to indexes Φ_a.

5. Local versus overall segregation

In this section, the relationship between our local segregation indexes and several indexes proposed in the literature to measure overall segregation is formally established. In particular, the overall segregation indexes proposed by Silber (1992), Reardon and Firebaugh (2002), and Frankel and Volij (2007) in a multigroup context can be written as weighted means of our local indexes, whose axiomatic properties have been studied in previous sections.

First, it is easy to see that the index of dissimilarity proposed by Duncan and Duncan (1955) in the binary case, D, can be written as the weighed mean of index D^g for each population subgroup. In fact, following Lewis (1982), the female segregation index can be written as $D^f = \frac{C^m}{T} D$, where f represents female workers and m males (there is an analogous expression for D^m). Therefore,

$$D = \frac{1}{2\frac{C^f}{T}\frac{C^m}{T}}\left(\frac{C^f}{T} D^f + \frac{C^m}{T} D^m\right).$$

Second, Karmel and Maclachlan (1988) proposed an index closely related the above that has been extended to the multigroup case by Silber (1992). It is easy to prove that this extended version, which he denoted as I_p, can also be written as the weighted mean of our index D^g for each population subgroup in which the economy can be partitioned:

$$I_p = \sum_g \frac{C^g}{T} D^g .$$

Third, the Gini index, G, proposed by Reardon and Firebaugh (2002) to measure overall segregation is the weighted mean of our index G^g for each population subgroup:[22]

$$G = \sum_g \frac{C^g}{T} G^g \ .$$

Therefore, G can be interpreted as twice the weighted mean of the areas between the local segregation curves of the population subgroups, S^g, and the 45º line. Recently, Chakravarty et al. (2008) offered another graphical representation of this overall segregation index in a one by one square by building an aggregate curve resulting from the sequence of segregation curves for each population subgroup, each of them drawn in a square whose size is not equal to 1 but instead proportional to the number of individuals included in the group. Another alternative generalization of the Gini index for measuring overall segregation in a multigroup context is the one proposed by Boisso et al. (1994). As also illustrated by Chakravarty et al. (2008), this index is associated with a curve in a one by one square whose "distance" to the diagonal is equal to half the value of the index. This curve accumulates ratios $\frac{c_j^g}{T}$ against ratios $\frac{C^g}{T}\frac{t_j}{T}$ once elements $g \times j$ ($g = 1, ..., G$ and $j = 1, ..., J$) have been ranked according to ratios $\frac{c_j^g}{C^g t_j}$ (or equivalently to $\frac{c_j^g / T}{C^g t_j / TT}$) in ascending order. Note that our proposal differs from the above, since we measure the segregation for each target group, rather than overall segregation, so that local curve S^g accumulates shares $\frac{c_j^g}{C^g}$ against shares $\frac{t_j}{T}$ for each group g, once occupations have been ranked according to ratios $\frac{c_j^g}{t_j}$ ($j = 1, ..., J$).

Finally, we show that the mutual information index can also be written as the weighted mean of our entropy indexes, according to both the evenness and representativeness views. The mutual information index proposed by Frankel and Volij (2007) to measure overall segregation is[23]

[22] Actually, the index proposed by Reardon and Firebaugh (2002) is bounded between 0 and 1, since it is divided by its maximum value, but we refer only to their unbounded version.
[23] These authors use logarithms to the base two.

$$M = \sum_g \frac{C^g}{T} \log\left(\frac{T}{C^g}\right) - \sum_j \frac{t_j}{T}\left[\sum_g \frac{c_j^g}{t_j} \log\left(\frac{t_j}{c_j^g}\right)\right],$$

which is characterized by the aforementioned authors in terms of some basic axioms concerning aggregate segregation, and defended by Mora and Ruiz-Castillo (2007b,c) in terms of its decomposability and statistical properties. This index can be rewritten as follows:

$$M = -\sum_g \frac{C^g}{T} \log\left(\frac{C^g}{T}\right) + \sum_j \frac{t_j}{T}\left[\sum_g \frac{c_j^g}{t_j} \log\left(\frac{c_j^g}{t_j}\right)\right] =$$

$$-\sum_j \frac{t_j}{T}\left[\sum_g \frac{c_j^g}{t_j} \log\left(\frac{C^g}{T}\right)\right] + \sum_j \frac{t_j}{T}\left[\sum_g \frac{c_j^g}{t_j} \log\left(\frac{c_j^g}{t_j}\right)\right] =$$

$$= \sum_j \sum_g \frac{c_j^g}{T} \log\left(\frac{c_j^g / C^g}{t_j / T}\right) = \sum_g \frac{C^g}{T} M^g,$$

where

$$M^g = \sum_j \frac{c_j^g}{C^g} \log\left(\frac{c_j^g / C^g}{t_j / T}\right)$$

is interpreted by Mora and Ruiz-Castillo (2007a) as a local index of segregation in group g according to an evenness notion, even though no axiomatic approach is given for this local index. Note than when using the natural logarithm rather than the base-two logarithm, M^g is precisely index $\Phi_1\left(c^g;t\right)$ characterized in Section 3. In other words, from an evenness perspective, if we define overall segregation, $\bar{\Phi}_1$, as the weighted mean of the local segregation indexes $\Phi_1\left(c^g;t\right)$ according to their demographic weights, it follows that

$$\bar{\Phi}_1\left(c^1;...;c^G;t\right) = \sum_g \frac{C^g}{T} \Phi_1\left(c^g;t\right) = M .$$

It can be also proved that the index proposed by Frankel and Volij (2007) is equal to one previously proposed by Reardon and Firebaugh (2002), that based on Theil index.[24] In other words, the Theil index proposed by Reardon and Firebaugh is also the weighted mean of index $\Phi_1\left(c^g;t\right)$ for each population subgroup g, whose properties have been studied in Section 4.

Note that index M can also be rewritten as

[24] As mentioned above, we use the unbounded formulation proposed by Reardon and Firebaugh (2002).

$$M = \sum_j \frac{t_j}{T} M_j ,$$

where, according to the representativeness notion, M_j is interpreted by Mora and Ruiz-Castillo (2007a) as a local segregation index in organizational unit j (school in their case, occupation in ours):

$$M_j = \sum_g \frac{c_j^g}{t_j} \log\left(\frac{c_j^g / t_j}{C^g / T} \right).$$

Subsequently, if we define overall segregation, $\bar{\Psi}_1$, as the weighted mean of the segregation in occupations (with weighs equal to their employment shares) we again obtain the mutual information index, since

$$\bar{\Psi}_1 \left(c_1;...;c_J;C \right) = \sum_j \frac{t_j}{T} \Psi_1 \left(c_j;C \right) = M \ .$$

From all the above, it follows that the axiomatic approach proposed in this paper to derive local segregation measures is consistent with several of the overall segregation measures recently developed in the literature in the multigroup case. We should keep in mind that in this paper we have used overall segregation measures that are built by aggregating local indexes in a particular manner: each group is weighted by its demographic weight. However, by using our local indexes, more aggregated indexes could be defined, which should be explored in future research.

6. An empirical illustration

To illustrate the above ideas, our segregation indexes and curves are calculated by using labor force data from the *Encuesta de Población Activa* (EPA) conducted by the Spanish Institute of Statistics (INE) by following EUROSTAT's guidelines. This survey offers labor market information of a representative sample of Spanish households and is commonly used for international comparisons. Our data corresponds to the second quarter of 2007 and occupations are considered at a two-digit level, so that the list includes 65 occupations.[25] Our target group is workers between the ages of 16 and 40. This group has been partitioned into two groups in order to determine whether the distribution of young females and young males

[25] Armed forces have been excluded from the analysis.

differs across occupations. Occupations have been divided into three categories of similar sizes, according to their average wage. Since the EPA does not gather any salary data, this information comes from the earning survey (*Encuesta de Estructura Salarial*) conducted by the INE in 2002, which is the most recent available year.

In Spain, workers in this range of age, whom we shall call young workers for the sake of simplicity, represent 56.7% of total employment, from which 24.16% corresponds to women and the remaining 32.54% to men. Within this group, the education level of women is higher than that of men. In particular, the proportion of young females with a secondary school education or a college degree is 26.71% and 43.73%, respectively, while those of males are 25.23% and 30.75%.

As shown in Table 1, the occupational segregation level of young females is much higher than that of males. In fact, according to index Φ_a with $a = 0.1$ and 0.5, the segregation of females doubles the segregation of males.[26] In fact, as shown in Figure 5, the segregation curve S^g for young males dominates that of young females, which means that any segregation index satisfying scale invariance, symmetry in groups, movement between groups and insensitivity to proportional divisions, would take a higher value for the female group. On the other hand, we also observe that the segregation of young workers is much lower than that of the two population subgroups, which suggests that the occupational distribution pattern of young males and females must be complementary since they balance in the aggregate.

Table 1. Occupational segregation indexes for Spanish young workers.

	$\Phi_{0.1}$	$\Phi_{0.5}$	Φ_1	Φ_2	D^g	G^g	$\bar{K}^g_{0.5}$
Young workers	0.0207	0.0203	0.0198	0.0191	0.0812	0.1111	0.9847
Young female workers	0.5580	0.4171	0.3321	0.2792	0.3337	0.4268	0.9862
Young male workers	0.2438	0.2154	0.1949	0.1825	0.2583	0.3446	0.9854

[26] The index proposed by Chakravarty and Silber (2007) seems to show extraordinary high values in both cases (Table 1, column 7). The behavior of this index was also shown by these authors in their empirical analysis based on USA data.

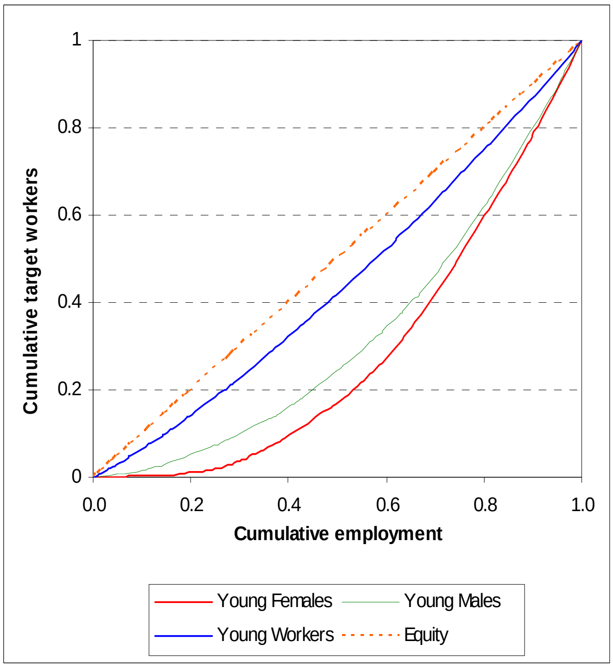

Figure 5. Segregation curves S^g for Spanish young workers

Table 2. Distribution of young workers in Spain and decompositions of segregation index Φ_1.

	Φ_1	Contribution of each occupational category to the within component Φ_1	Within-Between decomposition Φ_1	Target group weight in each occupational category	Distribution of the target group between categories
YOUNG WORKERS	0.0198		88.38% - 11.62%		
Low-wage occupations	0.0172	41.41%		59.00%	41.94%
Intermediate-wage occupations	0.0091	18.08%		58.92%	34.79%
High-wage occupations	0.0304	40.51%		50.34%	23.27%
YOUNG FEMALE WORKERS	0.3321		99.32% - 0.68%		
Low-wage occupations	0.4202	50.35%		23.70%	39.53%
Intermediate-wage occupations	0.3796	41.92%		26.29%	36.43%
High-wage occupations	0.1061	7.73%		22.17%	24.05%
YOUNG MALE WORKERS	0.1949		98.00% - 2.00%		
Low-wage occupations	0.2339	53.56%		35.30%	43.73%
Intermediate-wage occupations	0.1805	31.72%		32.63%	33.58%
High-wage occupations	0.1239	14.72%		28.17%	22.69%

In Table 2, we can see that young workers represent between 50% and 59% of total employment in the three occupational categories considered, those with low, intermediate and high wages (see fourth column).[27] We also observe that the proportion of young female workers working in the high- and intermediate-wage category is higher than that of males (see fifth column). When comparing the value of index Φ_1 in each occupational category, we observe that the values for the low- and intermediate-wage categories are much higher for young females, while in the high-wage category differences between sexes are lower (see first column). In fact, the contribution of these two categories, jointly considered, to explain female segregation is higher than their contribution to male segregation (see second column).

The decomposition of index Φ_1 in the within-between components shows that the classification of occupations by wage explains around 11.62% of the segregation of young workers across occupations (Table 2, third column). However, the value of the between component reduces to 2% in the case of young males and even to 0.68% for female workers. This suggests again that the distributions of young males and females across occupations must substantially differ since the earning variable appears as relevant for young workers but not for each population subgroup.

The decomposition of index Φ_2 by population subgroups, which is not included in the above tables, shows that women contribute to 25.4% of the segregation of young workers, while the contribution of males is 74.6%. The reason for this disparity is that, even though the segregation level of the former is much higher, young male workers represent a higher proportion of youth employment, and its correlation with youth employment is also higher.

7. Conclusions

When occupational segregation in the labor market is analyzed, the indexes commonly used quantify overall segregation. However, one can be interested not only in measuring aggregate segregation, but also in exploring the segregation of a target group, since the factors affecting the distribution of a demographic group across occupations can be rather different from those concerning other groups. This paper has tackled this matter in a multigroup context by

[27] If considering the range 16 to 35 years old, the proportion of young workers in the high-wage category would decrease to 35% and in the others it would be approximately 45%.

proposing an axiomatic framework in which to study the occupational segregation of any population subgroup. Within this new set-up, basic axioms for a local segregation measure according to an evenness view of segregation have been defined. In addition, local segregation curves have been proposed and new indexes consistent with them have been characterized. The above segregation notion has also been extended in order to measure the segregation of occupations, rather than segregation of demographic groups, which involves a representativeness concept. Both perceptions of segregation have been finally used to define overall segregation, which allowed us to connect our local measures with overall measures existing in the literature. In particular, our approach brings support to several overall measures proposed in the multigroup case, since they can now be expressed as weighed means of local segregation indexes derived axiomatically.

This proposal has been illustrated with Spanish data for 2007. Several measures have been used to analyze whether the generations of young female workers (who have a higher human capital level than men) have an occupational segregation level similar to that of young males. We found that, even though young workers have a certain level of segregation among occupations, perhaps as a result of their life cycle, segregation in this group of age is much higher for women.

Appendix

Proof of Theorem 2.

First step: *Any segregation index* Φ *satisfying axioms 1, 3, 4, 5 and 6 can be written as a strictly increasing monotonic transformation of* Φ_a.

In order to prove this implication, we make use of the relationship between segregation and inequality, and also of Shorrocks' (1984) theorem, which characterizes aggregative relative measures as reinterpreted by Foster (1985).

Lemma 1 shows that any segregation index Φ satisfying axioms 1, 3, 4 and 5 gives rise to an inequality index I satisfying scale invariance, symmetry, the Pigou-Dalton transfer principle and replication invariance, where $I(\frac{c_1^g}{t_1},...,\frac{c_1^g}{t_1},...,\frac{c_J^g}{t_J},...,\frac{c_J^g}{t_J}) := \Phi(c^g;t)$. Also, it is easy to see that if Φ is a continuous function, so too is *I*. In what follows, we show that *I* is an aggregative inequality index. For the sake of simplicity, assume that class 1 includes occupations $j = 1,...,i$, while class 2 is the complementary. By definition

$$I\left(\underbrace{\frac{c_1^g}{t_1},...,\frac{c_1^g}{t_1},...,\frac{c_i^g}{t_i},...,\frac{c_i^g}{t_i}}_{\text{class 1}}\underbrace{\frac{c_{i+1}^g}{t_{i+1}},...,\frac{c_{i+1}^g}{t_{i+1}},...,\frac{c_J^g}{t_J},...,\frac{c_J^g}{t_J}}_{\text{class 2}}\right) = \Phi(c^g;t)\,.$$

On the other hand, since Φ is an aggregative segregation index:

$$\Phi(c^g;t) = \Phi(c^{g1}, c^{g2}; t^1, t^2) = A\left(\Phi(c^{g1};t^1), \frac{C^{g1}}{T^1}, T^1, \Phi(c^{g2};t^2), \frac{C^{g2}}{T^2}, T^2\right).$$

Note that $\Phi(c^{g1};t^1) = I(\frac{c_1^g}{t_1},...,\frac{c_1^g}{t_1},...,\frac{c_i^g}{t_i},...,\frac{c_i^g}{t_i})$, and $\Phi(c^{g2};t^2) = I(\frac{c_{i+1}^g}{t_{i+1}},...,\frac{c_{i+1}^g}{t_{i+1}},...,\frac{c_J^g}{t_J},...,\frac{c_J^g}{t_J})$. Therefore,

$$I\left(\underbrace{\frac{c_1^g}{t_1},...,\frac{c_1^g}{t_1},...,\frac{c_i^g}{t_i},...,\frac{c_i^g}{t_i}}_{\text{class 1}}\underbrace{\frac{c_{i+1}^g}{t_{i+1}},...,\frac{c_{i+1}^g}{t_{i+1}},...,\frac{c_J^g}{t_J},...,\frac{c_J^g}{t_J}}_{\text{class 2}}\right) = A\left(I(\frac{c_1^g}{t_1},...,\frac{c_1^g}{t_1},...,\frac{c_i^g}{t_i},...,\frac{c_i^g}{t_i}), \frac{C^{g1}}{T^1}, T^1, I(\frac{c_{i+1}^g}{t_{i+1}},...,\frac{c_{i+1}^g}{t_{i+1}},...,\frac{c_J^g}{t_J},...,\frac{c_J^g}{t_J}), \frac{C^{g2}}{T^2}, T^2\right),$$

where $\frac{C^{g1}}{T^1}$ (respectively, $\frac{C^{g2}}{T^2}$) represents the average income of replicants in class 1 (respectively, 2), while T^1 (respectively, T^2) is the number of replicants in that class. Therefore, the inequality index *I* is aggregative.[28]

Finally, note that *I* is equal to zero when all replicants have the same income or, put another way, when all occupations have the same shares of the target group (i.e., when $\frac{c_j^g}{t_j} = \frac{C^g}{T} \;\; \forall j$).

Following Shorrocks (1984) and Foster (1985), any continuous inequality measure *I* taking a zero value at the egalitarian distribution and satisfying scale invariance, replication invariance, the Pigou-Dalton transfer principle, symmetry and aggregation can be written as $I(x) = F^{-1}(I_a(x))$ for some parameter *a*, where *F* is a strictly increasing function such that $F:[0,\infty) \to \mathbb{R}$, with $F(0) = 0$ and

[28] An inequality index $I(x)$ is defined as aggregative if there exists a continuous function *A*, which is strictly increasing in the first and fourth argument, so that $I(x) = A(I(x^1), \mu(x^1), n(x^1), I(x^2), \mu(x^2), n(x^2))$, where $\mu(.)$ represents the average of the corresponding distribution, $n(.)$ is the number of individuals and x^i represents class *i*. This definition can be seen in Shorrocks (1984).

$$I_a(x)=\begin{cases}\dfrac{1}{na(a-1)}\sum_i\left[\left(\dfrac{x_i}{\frac{1}{n}\sum_k x_k}\right)^a-1\right] & \text{if } a\neq 0,1\\ \dfrac{1}{\text{n}}\sum_i\left[\dfrac{x_i}{\frac{1}{n}\sum_k x_k}\ln\left(\dfrac{x_i}{\frac{1}{n}\sum_k x_k}\right)\right] & \text{if } a=1\\ \dfrac{1}{\text{n}}\sum_i \ln\left(\dfrac{\frac{1}{n}\sum_k x_k}{x_i}\right) & \text{if } a=0\end{cases}$$

The above inequality indexes are the well-known generalized entropy family. In our case, our "income" distribution is $x=(\underbrace{\frac{c_1^g}{t_1},...,\frac{c_1^g}{t_1}}_{t_1 \text{ replicants}},...,\underbrace{\frac{c_J^g}{t_J},...,\frac{c_J^g}{t_J}}_{t_J \text{ replicants}})$, and the average of that distribution is equal to $\frac{C^g}{T}$. Therefore, $\Phi(c^g;t)=I(x)=F^{-1}(I_a(x))=F^{-1}(\Phi_a(c^g;t))$ for $a\neq 0,1$ or $a=1$. The case where $a=0$ is discarded because when an occupation *j* has no employees belonging to the target group (i.e., when $c_j^g=0$), the index value would be infinite.[29]

Second step: $F^{-1}(\Phi_a)$ *is a segregation index satisfying scale invariance, symmetry in groups, movement between groups, insensitivity to proportional divisions, and aggregation.*

In order to prove this, it suffices to show that Φ_a satisfies the above properties, which is done in what follows. It is easy to see that Φ_a verifies scale invariance, symmetry, and insensitivity to proportional divisions.

To demonstrate that any disequalizing movement from occupation i to h, where $t_i=t_h$ and $c_i^g<c_h^g$, leads to a higher value of Φ_a, note that this movement from $(c^g;t)$ to $(c^{g}{}';t')$ implies moving from distribution $x=\left(\frac{c_1^g}{t_1},...,\frac{c_1^g}{t_1},...,\frac{c_i^g}{t_i},...,\frac{c_i^g}{t_i},...\frac{c_h^g}{t_h},...,\frac{c_h^g}{t_h},...,\frac{c_J^g}{t_J},...,\frac{c_J^g}{t_J}\right)$ in the

[29] The case where $a=1$ does not have the same problem since $\lim_{c_j^g\to 0}\frac{c_j^g/C^g}{t_j/T}\ln\left(\frac{c_j^g/C^g}{t_j/T}\right)=0$

world of replicants to distribution $x' = \left(\frac{c_1^g}{t_1},...,\frac{c_1^g}{t_1},...,\frac{c_i^g - d}{t_i},...,\frac{c_i^g - d}{t_i},...,\frac{c_h^g + d}{t_h},...,\frac{c_h^g + d}{t_h},...,\frac{c_J^g}{t_J},...,\frac{c_J^g}{t_J} \right)$. Since $\Phi_a(c^g;t) = I_a(x)$, $\Phi_a(c^g{}';t') = I_a(x')$ and I_a is an inequality measure satisfying the Pigou-Dalton transfer principle, it follows that $\Phi_a(c^g{}';t') > \Phi_a(c^g;t)$ (x' can be obtained from x by a finite sequence of regressive transfers).

To prove that Φ_a is aggregative, note that it can be written as $\Phi_a(c^{g1}, c^{g2}; t^1, t^2) = A\left(\Phi_a\left(c^{g1};t^1\right), \frac{C^{g1}}{T^1}, T^1, \Phi_a\left(c^{g2};t^2\right), \frac{C^{g2}}{T^2}, T^2 \right)$ since

$$\Phi_a(c^{g1}, c^{g2}; t^1, t^2) = \begin{cases} -\frac{1}{a(a-1)} + \left[\begin{array}{l} \left(\frac{T^1}{T}\right)^{1-a} \left(\frac{C^{g1}}{C^g}\right)^a \left(\Phi_a\left(c^{g1};t^1\right) + \frac{1}{a(a-1)} \right) + \\ + \left(\frac{T^2}{T}\right)^{1-a} \left(\frac{C^{g2}}{C^g}\right)^a \left(\Phi_a\left(c^{g2};t^2\right) + \frac{1}{a(a-1)} \right) \end{array} \right] & \text{for } a \neq 0,1 \\ \frac{C^{g1}}{C^g}\left[\Phi_a(c^{g1};t^1) + \ln\left(\frac{C^{g1}}{T^1}\frac{T}{C^g} \right) \right] + \frac{C^{g2}}{C^g}\left[\Phi_a(c^{g2};t^2) + \ln\left(\frac{C^{g2}}{T^2}\frac{T}{C^g} \right) \right] & \text{for } a = 1 \end{cases}$$

and $T = T^1 + T^2$ and $C^g = C^{g1} + C^{g2}$, which completes the proof. □

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