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The measurement of occupational segregation and its component dimensions

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The paper reviews different approaches to, and current knowledge of the measurement of occupational segregation, using the case of gender segregation. It shows that most popular segregation 'indices' are actually statistics of association in a 2x2 table, often with distorting weightings. The dimensions of segregation comprise a vertical dimension measuring inequality and an orthogonal horizontal one measuring difference without inequality. Together, the dimensions make up segregation as generally understood; so segregation and its dimensions require consistent measurements. Conditions for suitable measures are considered, and the limitations of the various measures noted. The alternative conception of segregation, where all occupations are treated as though they were the same size, is shown to be seriously flawed. The most useful measures are selected and shown to be related as Lorenz curves. Since all segregation measures vary with the number of occupations considered, standardisation on 200 occupations is introduced for the chosen measures.

Keywords: Occupational segregation; gender; measurement; dimensions; standardisation; inequality

The segregation of populations is an important feature of all societies.[1] The two main bases of segregation, at least as recognised in the industrially developed countries, are ethnicity and gender. Ethnic segregation is frequently measured in relation to residential location. That is, the ethnic segregation is concerned with the extent to which the various ethnic minorities are concentrated in particular areas. Also, ethnic segregation is found in employment, where different ethnic groups tend to work in separate occupations. Gender segregation is also concerned with the tendency to work in different occupations, in this case the separation involving women and men. Nurses, for instance, are predominantly women whereas engineers are mostly men, and occupational gender segregation measures the extent of such separation over all occupations being considered. Gender segregation, however, is not concerned with residential areas. Here, we are concerned with the measurement of segregation. It is considered in relation to gender segregation, though it should be appreciated that most of the discussion is also relevant to ethnic segregation, particularly when considering two ethnic groups. The principles of measurement are the same.

The purpose of this paper is to review the current state of knowledge on the measurement of segregation and indicate the way forward. Over the years many

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authors have contributed to a valuable body of useful research, with various developments in measurement.[2] However, developments have not been fully integrated, and there has been no agreement on the most appropriate methodological approaches. Furthermore, the treatment of inequality has generally been inadequate. Accordingly, the present account draws together the important methodological developments in the analysis of occupational gender segregation, including measurements of inequality and difference, thereby providing a sound basis for further research.

Sometimes the term segregation has been applied to a hypothetical situation where all occupations have the same number of workers (e.g. Charles & Grusky, 2004; Jacobs & Lim, 1992). Such an approach analyses occupations, treating all as equivalent regardless of size but differentially gendered. This conceptualisation of segregation, focused on occupations rather than people, is quite common in the USA. However, the present discussion concerns the employment of men and women in real labour markets, with wide variations in the size of occupations. Nevertheless, for completeness of methodological understanding, the strengths and weaknesses of the equal occupation approach will also be considered, after the measures for women and men.

Gender segregation is inherently symmetrical (Siltanen, Jarman, & Blackburn, 1995). In so far as women are separated from men, so are men separated from women in the employment structure under consideration. Similarly the segregation of any two ethnic groups is symmetrical, whether it be in employment or residence.[3]

Sometimes segregation has been used as a broad concept to include concentration (e.g. Anker, 1998; Lewis, 1985; Walby, 1997). However, concentration is really a distinct concept which measures the proportion of women (or men) in a particular occupation or group of occupations (such as the percentage of nurses who are women), and is not gender symmetrical. Segregation may be seen as the net result of all the measures of concentration in the relevant occupations. The distinction between segregation and concentration appears now to be usually accepted.

The dimensions of segregation

While there has been extensive research on segregation, there has been relatively little consideration of the *dimensions* of segregation. Yet an adequate understanding of the nature and significance of segregation requires the measurement of its component dimensions. The *vertical* dimension measures the *inequality* entailed in the segregation,[4] while the *horizontal* dimension, being orthogonal to the vertical, measures *difference without inequality* (Figure 1). The resultant of these two dimensions is segregation as generally understood, which is also known as *overall segregation* to distinguish it from vertical segregation and horizontal segregation (Blackburn, Jarman, & Brooks, 2000). The conception of component dimensions is important, as together they constitute the overall segregation. Therefore, the measurements of the dimensions and their resultant must be comparable. Then we can see how much each dimension, inequality or difference, contributes to the overall segregation.

There are many forms of inequality with corresponding vertical and horizontal dimensions. The most widely recognised inequalities, at least in social science, are income and stratification (class and status), which I use here with stratification measured by CAMSIS (Cambridge Social Interaction and Stratification scale; see www.camsis.stir.ac.uk).

It is important to appreciate that the vertical dimension of segregation is not simply a measure of the level of inequality in a society. While there is some tendency for the vertical value to vary with the mean difference between women and men on the relevant inequality variable, the vertical measure goes beyond mean difference to include the structure of inequality. It measures the extent to which the segregation in different occupations (or areas) entails inequality. The possible range of vertical segregation values is from zero (segregation entirely horizontal) to the value of overall segregation (segregation entirely vertical). Thus, in principle the vertical dimension can have any value from 0 to 1 (the overall maximum).

In keeping with the usual expectations, we give a positive value to the vertical measure when men are advantaged (e.g. women earn less than men) and a negative value if women are advantaged, as in social stratification. This is not the popular perception, but of 17 industrial countries only Austria has a positive value on CAMSIS, 0.075, while at the other extreme Russia has a value of −0.414. Also contrary to popular conceptions, the vertical dimension is negatively related to overall segregation, meaning women gain from greater segregation.

Similarly, the horizontal dimension measures the structural extent of equality on the relevant variable. Horizontal segregation simply measures the extent to which the overall segregation does not disadvantage either sex. The possible range is 0–1 (when vertical segregation is 1–0). It is interesting to note that the horizontal component is generally larger than the vertical, and strongly related to overall segregation, at least in industrial countries.

While it has become quite usual to refer to ‘vertical’ segregation, effective measurement has been less common and it is still unusual to treat it as a component *dimension* of overall segregation. Semyonov and Jones (1999, p. 242) use a sound measure of occupational inequality but do not treat it as an aspect of segregation. They argue ‘occupational segregation and occupational inequality should be viewed as two distinct concepts’. More generally inequality is seen as integral to segregation, but even when it is measured directly it is typically not done in a way compatible with overall segregation.

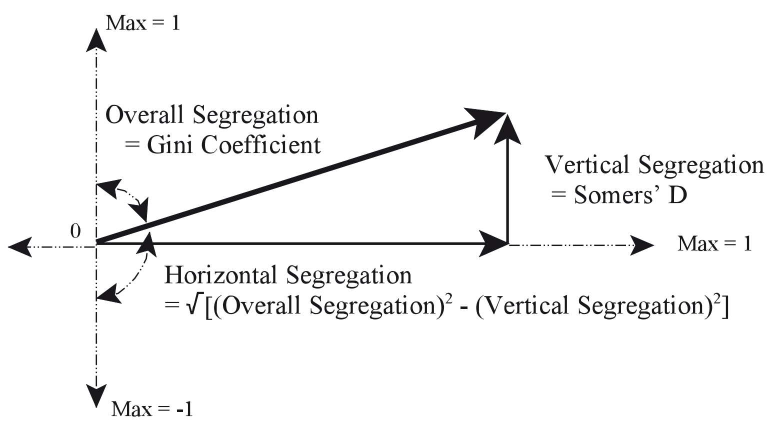

Figure 1. Dimensions of segregation.

The term ‘horizontal segregation’ has been used less frequently. In so far as it has been used, it has usually been used to refer to overall segregation, with the confusing consequence that the ‘horizontal’ has a vertical component. A stranger, but rarer, definition of ‘horizontal’ is the distinction between manual and non-manual occupations (Charles, 2003; Charles & Grusky, 2004; Parashar, 2008), which is roughly a vertical dichotomy. Only in the approach discussed here (in terms of dimensions) has the term been used in the usual mathematical and common sense way, for a dimension orthogonal to the vertical dimension. Only when vertical and horizontal segregations are measured as orthogonal dimensions of overall segregation can we see the extent of inequality and difference entailed in the segregation.

For occupational segregation, whether ethnic or gender, the vertical dimension measures the desirability of the occupations. This is most usefully done with pay or a social stratification measure such as CAMSIS (Blackburn, Brooks, & Jarman, 2001; Blackwell & Guinea-Martin, 2005). For residential segregation the areas included in the analysis have also to be ranked by some measure of desirability. This has not been attempted, but provided occupational data are available, measures of mean pay and stratification can be calculated for the economically active in each area. Other possible social measures for geographical areas include crime rates, unemployment levels and lifestyle attainment scores.[5] The point is that suitable measures for the purpose can be devised.

The horizontal dimension is not measured directly. It is deduced from the values of overall and vertical segregation, following Pythagoras, i.e. $O^2 = V^2 + H^2$ (where O, V and H represent overall, vertical and horizontal segregation, respectively). Since the vertical and horizontal dimensions are orthogonal, once O and V are known the calculation gives the only possible value of H. Thus, for example, in the USA overall gender segregation $O = 0.667$ while for pay $V = 0.207$ giving $H = 0.634$. The horizontal dimension is dependent on the vertical dimension; it represents the extent of difference in the absence of the sort of inequality measured by the vertical dimension.

The following discussion is in terms of the measurement of occupational gender segregation. This is the area where relevant work on the dimensions of segregation has been done. However, the logic can equally be applied to ethnic segregation (Blackwell, 2003).

Measures of segregation

There are several measures that have been used in the most influential studies of the occupational segregation of men and women. The different formulae for these segregation measures are related, and they may be simplified, as shown below. This enables us to see just how they are related to each other. It then becomes apparent which measures are most useful. It has also been demonstrated that the Gini coefficient is a limiting case of the correlation measure Somers’ D (Blackburn, Jarman, & Siltanen, 1994). This provides the necessary basis for consistent measurement of overall segregation and its vertical and horizontal dimensions. Before considering the vertical and horizontal dimensions, the main measures of overall segregation are examined. It has been usual to refer to them as indexes, but they are simple measures of association.

Firstly, it is necessary to set out the notation to be employed throughout. I also set out the abbreviations for the segregation measures. The suffix i, as in F_i, denotes a single occupation, varying from 1 to n, to which the variable (F, M or N) relates.

n = total number of occupations
F = number of women in the labour force
M = number of men in the labour force
N = total number of workers, men and women, in the labour force ($F+M$)
F_i = number of women in occupation i, a single occupation (i ranges from 1 to n)
M_i = number of men in occupation i
N_i = number of workers in occupation i
G = Gini coefficient for segregation for numerous occupations
MM = marginal matching measure
ID = index of dissimilarity
SR = Sex Ratio
SR* = standardised sex ratio
WE = women in employment (WE) index
IP = IP index (also known as the Karmel–Maclachlan index)
A = The Charles and Grusky measure

Most of the segregation measures can be expressed in terms of relations in the Basic Segregation Table (Table 1). The table was introduced as early as 1993 by Blackburn, Jarman, and Siltanen (1993),[6] who have used it regularly since then, but most writers still stick to the old, clumsy formulae. The table makes it much simpler to compare the nature of the various measures and appreciate their limitations.

In this table 'Female' occupations are defined as those with a higher proportion of women workers than the proportion in the labour force; F_i/N_i is greater than F/N. Similarly 'Male' occupations have a higher proportion of men than does the labour force; M_i/N_i is more than M/N.

This gives a consistent useful grouping of occupations into just two categories. If occupations are ordered by the proportion of women (or men) workers, the cutting point (dividing occupations into 'male' and 'female') is where $F_i/N_i=F/N$. F_f then denotes the sum of 'female' F_i, where $F_i/N_i>F/N$, and thus the sum of all women in the 'female' occupations. Similarly M_m is the sum of men in 'male' occupations, with corresponding values for F_m and M_f. N_f and N_m are then the totals of workers in 'female' and 'male' occupations. These values (F_f, F_m, M_m and M_f) vary over time and 'female' occupations can change to 'male' or, more usually, 'male' occupations can become 'female'.

Table 1. Women and men in 'Female' and 'Male' occupations.

	Women	Men	
'Female' Occupations	F_f	M_f	N_f
'Male' Occupations	F_m	M_m	N_m
	F	M	N

Note: M_f denotes the number of men in 'female' occupations, etc.

In the approach where priority is given to the female and male proportions, with all occupations treated as though they were the same size, the table has a somewhat different meaning. N_f, N_m and N are the numbers of female, male and total occupations, respectively, instead of the numbers of workers in these occupations. The other values (and N) are the relevant cumulative proportions. Thus M_f is the sum of the proportions who are men in female occupations, M is the sum of the male proportions in all occupations and so on.

In general, analyses of segregation have not considered a division into 'female' and 'male' occupations, and consequently have not considered the cutting point. Nevertheless, every index that distinguishes occupations by gender entails a cutting point implicitly. All the most popular measures are those that can be defined in terms of the Basic Segregation Table, with an implicit cutting point at the proportion of the labour force who are women ($F_i/N_i = F/N$). This approach is understandable, though it has the disadvantage that the number of women in a labour force, and so the cutting point, varies with demography and many other things. There are, in fact, any number of possible cutting points. Without reflection 50:50 might seem as the equality division, and this has been suggested but not used (Hakim 1979). The problem with using 50:50 as a dividing point is that a labour force is not likely to be composed of 50% men and 50% women, so it is an unrealistic measuring point. A more useful cutting point is suggested below when we come to the discussion of marginal matching (MM).

To demonstrate how the various segregation measures are related to the Basic Segregation Table, we start with the traditional complicated formulae and show the mathematical transformation. Other names have sometimes been used for the measures, but the ones used here are the most usual. I start with the traditional index of dissimilarity (ID) and measures related to this index, and then the MM measure which uses a different cutting point in order to overcome some problems. Then the Gini coefficient is introduced, which is the overall measure needed when we turn to the vertical and horizontal dimensions. Margin-free measures and equal-sized occupations raise different measurement issues and are considered after criteria for satisfactory measures.

Index of Dissimilarity

This index, introduced by Duncan and Duncan (1955), is the most widely used measure of segregation and is particularly dominant in American literature. It has, in fact, reached a level of popular acceptance where it is often presented as *the* way to measure segregation, as though it were completely unproblematic. The index is defined as:

$$\mathrm{ID} = \frac{1}{2}\sum_{1}^{n} |F_i/F - M_i/M|$$

$$\left(\text{in future where the range of } \sum \text{ is 1 to } n \text{ it is not indicated}\right),$$

where the modulus | | indicates the positive value of the difference enclosed. The mathematical expression using Σ and the modulus appears compact but conceals a far less compact reality. The formula has a separate term for every occupation, which gives well over 300 terms in many data-sets, whereas a single difference of proportions is all that is needed.

The occupations (i) may be divided into 'female' occupations (j) – occupations where $F_j/N_j > F/N$, and 'male' occupations (k).

Thus $\Sigma F_j = F_\mathrm{f}$ and $\Sigma M_k = M_\mathrm{m}$.
In 'female' occupations $F_j/F > N_j/N > M_j/M$.
Therefore $F_j/F - M_j/M > 0$.
Similarly $M_k/M - F_k/F > 0$.

Thus

$$\mathrm{ID} = 1/2 \sum |F_i/F - M_i/M|, \tag{1.1}$$

$$= 1/2\left\{\sum(F_j/F - M_j/M) + \sum(M_k/M - F_k/F)\right\}, \tag{1.2}$$

$$= 1/2\{(F_f/F - M_f/M) + (M_m/M - F_m/F)\}, \tag{1.3}$$

$$= F_\mathrm{f}/F - M_f/M \; (= M_m/M - F_m/F), \tag{1.4}$$

$$= D_c, \tag{1.5}$$

the *difference of proportions between columns* of the Basic Segregation Table (c indicating columns for women and men in the table).

The basic weakness of ID is well known. Changes in the size of occupations (the rows of the table) alter the value of ID, even when the gender ratios are unchanged.

The WE index

This index was introduced by the Organisation for Economic Co-operation and Development (OECD) in European analysis (OECD 1980, 1985). It is called WE after the OECD's *Women in Employment* report (1980). Gorard and Taylor (2002) use 1/2WE, which they call the segregation index. WE may be measured by the formula:

$$\mathrm{WE} = \sum |F_i/F - N_i/N|.$$

Again the formula has, potentially, a huge number of terms. With similar algebraic manipulations to those used for ID, grouping occupations as 'male' or 'female' we obtain:

$$\mathrm{WE} = 2(F_\mathrm{f}/F - N_\mathrm{f}/N), \tag{2.1}$$

$$= \frac{2[(F+M)F_{\mathrm{f}} - F(M_{\mathrm{f}} + F_{\mathrm{f}})]}{FN}, \tag{2.2}$$

$$= \frac{2M}{N}\left[\frac{MF_{\mathrm{f}} - FM_{\mathrm{f}}}{FM}\right], \tag{2.3}$$

$$= \frac{2M}{N}\left[\frac{F_{\mathrm{f}}}{F} - \frac{M_{\mathrm{f}}}{M}\right], \tag{2.4}$$

$$= \mathrm{ID} \times 2M/N. \tag{2.5}$$

This measure is not symmetrical between women and men. As it is based on female-dominated occupations we may think of it as the female version. The corresponding male version is

$$\mathrm{ID} \times 2F/N,$$

and the mean of the two versions is ID.

The weighting term ($2F/N$ or $2M/N$) has nothing to do with segregation. It varies independently of segregation and is a distorting term which affects the whole range of values (including the upper limit). Thus it is better omitted, leaving ID.

The Sex Ratio

Sex ratio (SR) was used by Hakim in one of the gender segregation analyses of the British labour force. Hakim (1981, p. 523) described this measure as 'the difference between the level of over-representation [of women] in typically female jobs and the level of under-representation in typically male jobs'. Thus, SR may be thought of as the ratio given by the observed proportion of workers who are women in female occupation ($F_{\mathrm{f}}/N_{\mathrm{f}}$) divided by the expected proportion of women in these occupations if there were no segregation (F/N) less the equivalent ratios (observed: expected) of women in male occupations. Thus, put formally

$$\mathrm{SR} = \frac{F_{\mathrm{f}}/N_{\mathrm{f}}}{F/N} - \frac{F_{\mathrm{m}}/N_{\mathrm{m}}}{F/N}, \tag{3.1}$$

$$= (N/F)(F_{\mathrm{f}}/N_{\mathrm{f}} - F_{\mathrm{m}}/N_{\mathrm{m}}), \tag{3.2}$$

$$= N/F \times D_{\mathrm{r}}, \tag{3.3}$$

where D_{r} is the difference of proportion between rows of the Basic Segregation Table (r indicating the rows of men and women in 'male' and 'female' occupations).

Again we see this is a 'female' version, with a corresponding 'male' version

$$\mathrm{SR_m} = N/M \times D_{\mathrm{r}}.$$

Here, however, the mean is not D_{r} but $N^2/2MF \times D_{\mathrm{r}}$.

As with WE, the weighting terms are a distortion which is better omitted.

*Standardised Sex Ratio SR**

The SR may be standardised to measure segregation without the inappropriate weighting, and so to occupy a range from 0 to 1 (Blackburn, Siltanen, & Jarman, 1995; Siltanen, 1990). The standardised form is

$$\mathrm{SR}^* = D_{\mathrm{r}}.$$

Thus, we have established that ID and SR* are the two differences of proportions in the Basic Segregation Table.

The IP index

This index, introduced by Karmel and Maclachlan (1988), also has a multi-term formula which we can simplify.[7] The usual formula is

$$\mathrm{IP} = \frac{1}{N}\sum\left|M_i - \frac{M}{N}(M_i + F_i)\right|, \tag{4.1}$$

$$= \frac{1}{N}\sum\left|M_i\frac{F}{N} - \frac{M}{N}F_i\right|, \tag{4.2}$$

$$= \frac{MF}{N^2}\sum\left|\frac{M_i}{M} - \frac{F_i}{F}\right|, \tag{4.3}$$

$$= \frac{2MF}{N^2} \times \mathrm{ID}. \tag{4.4}$$

Similarly

$$\mathrm{IP} = \frac{2N_{\mathrm{m}}N_{\mathrm{f}}}{N^2} \times \mathrm{SR}^*.$$

Once again we see there is an undesirable, distorting weighting which is better omitted, leaving ID or SR*.

It is interesting to note that the weighting of ID in the formula for IP is the inverse of the weighting of the mean of female and male values of SR, illustrating their fundamental difference.

Marginal Matching Measure (MM)

MM was originally introduced to measure inequality in education (Blackburn & Marsh, 1991). Subsequently it was realised that the inequality relationship between class background and type of school could be conceived as a form of segregation, and the Marginal Matching procedure was introduced to overcome the weaknesses of other segregation measures, particularly lack of marginal independence (Siltanen et al., 1995). As explained below, changes in the marginal totals of the segregation table can have effects on segregation measures independently of any changes in segregation (conditions 6 and 7). MM is one approach to solving this.

Like other segregation measures, MM can be expressed in a complicated summation formula;

$$\mathrm{MM} = 1/2\left[\sum_{1}^{p}(F_i/F - M_i/M) + \sum_{p+1}^{n}(M_i/M - F_i/F)\right],$$

where occupations are ordered so that $F_i/M_i \geqslant F_{i+1}/M_{i+1}$, and the value of p is determined by

$$\sum_{1}^{p} N_i = F.$$

However, as with the other measures, it is simpler to understand in relation to a segregation table.

It uses a Modified Segregation Table. This is the same as the table shown above, apart from the new definition of male and female occupations, giving different values for N_m and N_f and their components M_m, F_m, M_f and F_f. On the axis of occupations ordered by F_i/N_i we select a new cutting point. Instead of dividing occupations at the cutting point where $F_i/N_i = F/N$, the cutting point is chosen to provide matched distributions in the two sets of marginals of the segregation table. This is where 'female' occupations are those employing the highest proportions of women which together contain the same number of workers as there are women in employment, while 'male' occupations are those occupations which together contain the same number of workers as there are men in employment.[8]

Thus $N_f = F$ and $N_m = M$, and it follows that $F_m = M_f$.

In this symmetrical segregation table several statistics of association now coincide with the same values,[9] and are known as MM.

$$MM = D_c = D_r = \phi^2 = \eta = \tau_b.$$

Also the Gini is MM, as shown in Figure 2.

If and only if the table is symmetrical, i.e. with matched marginals, does τ_b meet the requirements for a completely satisfactory, undistorted correlation coefficient. It can therefore be interpreted as measuring the extent to which the two variables vary together, i.e. the extent to which the female occupations are actually staffed by women and the male occupations by men. The essential point is that the interpretation is the same for all tables as the numbers of men and women vary.

Variations in the sex composition of the labour force are found from country to country and occur over time. These variations affect the marginals of the segregation table for all the segregation measures. The important difference with MM is that we keep the marginals matched. Changes in the relation between the two sets of marginal totals introduce undesirable changes in the relationships within the table which define the segregation measures. By keeping constant the relationship between the two sets of marginal totals, the matching of the marginals avoids varying marginal effects of changing marginals on measured segregation. In this way we have a measure independent of the marginal totals. This reveals appreciable national variation in measured segregation, ranging in Europe from 0.44 in Romania to 0.61 in Finland.

Now we have consistency in the measurement of segregation. However, as with the other measures we have considered, MM is only suitable for measuring overall segregation. Measures of vertical segregation cannot be dichotomised without a serious loss of information. Therefore, when we break segregation down into vertical and horizontal components we need to use the Gini coefficient for the full range of occupations.

Gini coefficient (G)

The measures based on the Segregation Table (Basic or Modified) are all dichotomous, grouping occupations into 'female' and 'male' categories. In contrast, the Gini coefficient (Silber 1989, 1992; Lampard, 1994) treats all occupations separately. The Gini coefficient is valuable for relations with the dimensions of segregation, as explained below. The occupations are ordered by the proportions of men and women workers, as for the other measures, but there is no grouping into two categories of 'Male' or 'Female' occupations; all the information on the separate occupations is retained.

There are several formulae for the Gini coefficient, all of which appear complicated but we can derive a simpler form. In the formula presented here, t is used to denote an occupation included in the cumulative total.

$$G = \sum_{i=2}^{n} \left\{ \sum_{1}^{i-1} F_t/F \sum_{1}^{i} M_t/M - \sum_{1}^{i} F_t/F \sum_{1}^{i-1} M_t/M \right\}, \tag{5.1}$$

$$= [1/FM] \sum_{i=2}^{n} \left\{ \sum_{1}^{i-1} F_t \left(\sum_{1}^{i-1} M_t + M_i \right) - \left(\sum_{1}^{i-1} F_t + F_i \right) \sum_{1}^{i-1} M_t \right\}, \tag{5.2}$$

$$[1/FM] \sum_{i=2}^{n} \left\{ M_i \sum_{1}^{i-1} F_t - F_i \sum_{1}^{i-1} M_t \right\}. \tag{5.3}$$

This may seem complicated, but is only the ordering of pairs of men and women by the 'femaleness'/'maleness' of their occupations. Such ordering of pairs is a common tactic in measuring association (e.g. Anderson & Zelditch, 1968). We follow the usual convention that P represents all pairs 'consistently' ordered and Q represents 'inconsistent' pairs. In this case, P includes all pairs of a man and a woman where the occupation of the woman has a higher proportion of workers who are women than does the man's occupation (i.e. the ordering is consistent with segregation); Q includes pairs where the reverse holds. Then

$$G = \frac{P - Q}{FM}. \tag{5.4}$$

This is Somers' D where the 'independent' variable has only two values (here male and female).[10] Thus we see that G *is also a statistic of association*.

When the occupations are grouped into the two categories of the Basic Segregation Table, Somers' D becomes a difference of proportions; and similarly for the grouping of the modified table. Thus we have

$$G = D_{\mathrm{c}} = \mathrm{ID} \text{ and also } G = \mathrm{MM}.$$

These forms of the Gini coefficient are the most suitable for overall segregation analysis. When we measure the vertical and horizontal dimensions of segregation we need to use every occupation; otherwise, there would be a serious loss of information on the two dimensions. Therefore, we use the full Gini coefficient for overall segregation. However, when we are only interested in overall segregation the dichotomous measures are suitable, and potentially somewhat better (Blackburn et al., 1994; Siltanen et al., 1995). The two variables, gender and gendered occupations, are internal to the relationship (unlike vertical variables such as pay) and so there is no loss of information in grouping occupations as male or female.[11] Variations in the level of segregation are seen in the variations on the diagonal of the table.

Measuring the dimensions

The study of overall segregation is important and worthwhile. However, for a full understanding of segregation, and what it entails, we need to consider its orthogonal dimensions of inequality and difference without inequality. Yet, as noted above, this has rarely been done.[12]

If we want to identify the inequality and difference entailed in segregation we need to be able to measure the vertical and horizontal dimensions. In order to do so it is necessary to use measures compatible with the measure of overall segregation. Dichotomous measures such as ID and MM are not suitable for the overall measure as their use would entail the loss of most of the inequality information on the corresponding vertical measure. The only measure we are considering which can be split into vertical and horizontal components is G, the Gini coefficient.

Since this is an instance of Somers' D, we use Somers' D to measure the vertical dimension, thus achieving measurement consistent with overall segregation. The difference between overall segregation, O, and vertical segregation, V, lies in the ordering of occupations. When Somers' D is the Gini coefficient the ordering of occupations maximises D; that is the ordering of occupations is in terms of the ratio of the non-occupation variable – the gender ratio. The ordering is from the highest to the lowest proportion of women (or vice versa). For the vertical dimension the data are the same but the ordering of occupations is now by the measure of inequality – which most usefully is pay or the stratification measure CAMSIS. For instance, occupations are ordered from the lowest paying to the highest paying (or vice versa). As indicated above, the horizontal measure is then deduced using $H^2 = O^2 - V^2$.

Conditions for a suitable measure

In order for a segregation measure to be entirely satisfactory there are a number of conditions which should be satisfied.[13] We have already noted unmet conditions, but we need to apply criteria systematically to select among the measures that have been described. Since the dimensions are components of overall segregation, their suitability depends on the overall measure and need not be considered separately.

Gender symmetry

It is logically the case that men and women are equally segregated from each other. This requirement of symmetry is met by ID, SR*, MM and the Gini coefficient (G). It is also met by IP, but not by other indexes involving weighting by the marginal totals of the Basic Segregation Table, i.e. WE and SR, for which we have seen there are female and male versions.

Constant upper limit

The value of the upper limit, representing total segregation, should be fixed. The value of this limit is set at 1, or sometimes scaled to 100. Again ID, MM, SR* and G meet this condition. However, IP, WE and SR have variable upper limits depending on weightings based on the marginal totals. Such variability is not confined to the upper limit; the variable weighting actually affects the whole range of potential values, making meaningful comparison of values impossible, which is clearly unsatisfactory. They are weighted versions of ID. The weightings could equally well be applied to MM, but there is no apparent gain in doing so.

Constant lower limit

All the measures considered meet this criterion. Since it is meaningless to think of negative amounts of separation, the lowest possible segregation value has always been taken to be zero, representing no segregation. In practice, if only due to random factors, even the most egalitarian and gender-blind country may be expected to have some degree of segregation. This led Cortese, Falk, and Cohen (1976a, 1976b) to advocate measurement from an 'expected' value. (They were writing about ethnic segregation but the reasoning is the same for gender.) While there is good logic in this point, the matter is not entirely straightforward, as Taeuber and Taeuber (1976) pointed out. In fact the zero point is essential for measuring vertical segregation, as shown below, so it is necessary to stick with the usual convention of zero.

Size invariance

The total number of workers should not affect the measured level of segregation. It is the relative sizes of values in a segregation table that matter, not the absolute sizes. This is essential for comparing populations, such as the work-forces in different countries, or different samples of a population. All the indexes meet this criterion.

Occupational equivalence

If two or more occupations have the same gender composition (proportions of women and men), it should not affect the measure of segregation whether these occupations are treated separately or combined in one. This is met by all our measures. In practice the subdivisions of an occupational category very rarely have the same gender composition and this variation does affect measurement; the more a broad occupational category is subdivided, the higher the measured segregation. It is because of this pattern of increase with the number of occupations that standardisation on 200 categories was introduced, on the assumption of random variation in the gender composition of the subdivided categories.

Sex composition invariance

This requires that the level of measured segregation is not directly affected by the overall gender composition of the labour force. What is important for segregation is the extent of separation of women and men, not their numbers. The requirement is that the ratio of F/M should not affect the measure of segregation. It is immediately clear that WE, SR and IP do not meet the criterion, as they have weightings $2M/N$, N/F and $2MF/N^2$, respectively. Any change in F or M will necessarily affect SR* so again the criterion is not met. For ID, if changes in F and/or M do not alter the relative distributions in female and male occupations (columns multiplied by constants), the values are unaltered. For G, the corresponding condition is that the gender ratio (F_i:M_i) in all occupations changes proportionately. The condition for ID has generally been given as the same as for the Gini, proportionate changes in all occupations, but in fact it is the less stringent requirement of proportionate changes in gendered groups, F_f and F_m and/or M_f and M_m.

Gendered occupations invariance

Here we are concerned with changes in the numbers of workers in occupations. For measures based on a segregation table it concerns the relative numbers in male and female occupations, N_f/N_m, while for G it concerns all occupations. While changes in occupational sizes are likely to be accompanied by changes in segregation, it is important that changes in the size of occupations should not have additional effects on the measurement of segregation. Such occupational changes alter ID and G in ways which do not necessarily represent changes in segregation, with the many occupational categories of G making effects more likely. WE, IP and SR are distorted by changing proportions of women and men (marginal totals F and M) as these vary with the changes in numbers in female and/or male occupations. SR* may be unchanged, but as the ratio F/M is changed this may cause some occupations to be reclassified from male to female or vice versa.

It is most unlikely that changes in the numbers of men and women will not affect segregation, as any change in the marginal totals is likely to accompany changes in the distribution of men and women across occupations. However, the possibility of no effect is sufficient to ensure that any observed changes in segregation are real. Conditions 6 and 7 specify marginal independence. Measures are said to have marginal independence if the measure is unchanged when columns or rows of the Basic Segregation Table are multiplied by a constant. No measures based on this table satisfy both conditions, though ID meets one of them, and SR* may meet the other, depending on the actual labour-force changes. However, MM is quite different, as multiplying rows or columns of the relevant segregation table would destroy the matching of marginals. Thus the cutting point determining male and female occupations is adjusted, and if MM is unchanged (which is quite possible) the level of segregation is unchanged, so both conditions are met.

The odds ratio as a margin-free measure

An approach that attempts to avoid undesirable marginal effects is to use the odds ratio ($F_f M_m / F_m M_f$ in the Basic Segregation Table). Generally this has been used in log-linear analyses (e.g. Semyonov, 1980). Although the approach has had wide popularity in sociology, it has had only limited application to segregation (Jacobs, 1993), though Charles and Grusky's A (see below) may be seen as a development of this approach. The odds ratio has the disadvantage of ranging from 0 to ∞. Yule's classic measure Q (= $(F_f M_m - F_m M_f)/(F_f M_m + F_m M_f)$) deals with this by creating a form with a range from 0 to 1. This might well have been adopted as a segregation measure if it were not that researchers have thought in terms of indexes rather than measures of association. However, this still leaves the disadvantage that the maximum occurs when either F_m or M_f is zero while total segregation requires both to be zero, and the values tend to be inflated when either F_m or M_f approaches zero.

What cannot be solved is the failure of marginal independence. Because the odds ratio does not entail the marginal totals, measures based on the odds ratio are assumed to be independent of the marginals. Like ID, the measure is independent of changes in the numbers of men and/or women in constant proportions. Unfortunately, and contrary to popular beliefs, this is not so for the other marginals in segregation measures. Proportionate changes in the numbers of workers in female and/or male occupations do not change the odds ratio directly. However, as noted for SR*, the changes also affect the relative numbers of men and women in the labour force. This in turn changes the definition of the male and female categories of occupations, and so changes the cells of the table. Hence the measure of segregation is changed. It appears that the advantage of the odds ratio is an illusion.

Occupations of equal size

For size-standardised occupations the limitation noted above applies more clearly. Changes in the size of occupations can have no effect, as occupation sizes are constantly equalised. On the other hand, uniform changes in the proportion of women and/or men in each occupation change the gender ratio in each occupational category, and hence the measure of segregation.

The usual size-standardised index is the version of the index of dissimilarity, IDS, also known as the size-standardized index. Whereas ID lacks marginal independence with regard to gendered occupations, IDS lacks marginal independence with respect to gender, sex-composition invariance. It also fails the criterion of gender symmetry.

Perhaps the most complex attempt to measure segregation for equal-sized occupations is Charles and Grusky's (1995, 2004) use of A. Like the Gini, A has a separate term for each occupation, but there is no corresponding vertical dimension. It uses the ratio of women to men in an occupation, with the following formula

$$A = \exp\left([1/n]\sum_{i=1}^{n}\left\{\ln(F_i/M_i) - [1/n]\sum_{i=1}^{n}\ln(F_i/M_i)\right\}^2\right)^{1/2}. \quad (6.1)$$

Unfortunately this approach has weaknesses, like size-standardised IDS. Most clearly, changes in the gender composition of the labour-force change A. Furthermore it is not gender symmetrical; the corresponding alternative would use $\ln(M_i/F_i)$. It fails criteria Gender symmetry, Occupational equivalence and Sex composition invariance. In view of the fact that IDS and A measure a different conception of segregation, and have substantial limitations, they are not considered further.[14]

Choice of measures

All measures of occupational segregation of men and women are attempting to measure the same thing yet all give different values, and so give different estimates of the degree of segregation. Thus, for the UK we have IP = 0.25, MM = 0.51 and G = 0.68 (Blackburn, Racko, & Jarman, 2009; European Union, 2011). It is important to appreciate that there can be no 'true' measure of segregation. All measures define the variable they measure. Thus there is a sense in which all the various measures are correct, each measuring and defining its own concept. Yet, this is inconsistent with the fact that all aim to be measuring the same thing, namely segregation as we have defined it. That is, the aim is to measure the extent to which women and men are occupationally separated in the labour force under consideration. The various measures which include weightings from the marginal totals cannot be seen as consistent with this aim; they are measuring something else. On the other hand, the Gini coefficient and its two 2×2 versions, ID and MM, are consistent with the definition of segregation. In their different ways they are measures of segregation, and if used consistently they tend to tell the same story about gendered employment.

ID has been the most widely used measure of overall segregation, and despite its known limitation it is a quite good measure, so it is always worth using it for comparability with other research. MM is technically superior but is less easy to calculate and has been used less extensively; nevertheless it is the best measure when the concern is overall segregation. Comparing the two gives an indication of how far they are measuring the same thing, giving confidence in the findings. What matters is not giving precisely the same value but consistency in the way they vary. When we need to measure the component dimensions of segregation (inequality and difference) we have to use the Gini coefficient, G, which is also a good measure which tends to vary with MM and ID.

The Lorenz curve

It is useful to visualise the main segregation measures graphically, and this can be done with a Lorenz curve. The Lorenz curve is well known in economics where it is used to display the Gini coefficient by plotting income or wealth against persons. It plots the proportion of the population's total income which accrues to increasing proportions of the population. However, it can usefully be adapted for segregation analysis, where it has been termed the segregation curve (James and Taeuber, 1985). Here the axes are rather different, being the proportions of the male and female members of the labour force, from 0 to 100%. The curves, which represent concentration, enclose areas corresponding to segregation, as measured by the Gini coefficient. Occupations are ordered from the most female to the most male (F_i/M_i decreasing). The curve plotted is not a presentation of these values directly but of the cumulative proportion of women plotted against the cumulative proportion of men as we move through the occupations in order. Starting from the left, the curve is very shallow as the occupations employ many women and few men; the curve gets steadily steeper as the proportion of men in the occupations increases, and finally rises very steeply as the male-dominated occupations are included. Since in a 2×2 table the Gini coefficient is simply the difference of proportions, with just two occupational categories, both ID and MM can be represented on a Lorenz curve.

Figure 2 illustrates the three measures, together with zero and total segregation. The diagonal OB represents zero segregation[15] and the triangle OAB, suitably scaled to give a value of 1, represents total segregation. The area between OB and the curve OMDB, measured as a proportion of total segregation triangle OAB, corresponds to the Gini coefficient for many occupations. For a smooth curve the number of occupations tends to infinity, and so a pure curve is not possible for segregation or any other purpose. Nevertheless, for many occupations the curve provides an approximation.[16] The two triangles OMB and ODB are shown representing the same number of occupations grouped into just two occupational categories in each case. The plotted point (M or D) represents the more female category (F_f, M_f) while, the plots being cumulative, the more male category is at the 100% point. The triangle OMB as a proportion of triangle OAB corresponds to MM. AM is the diagonal perpendicular to OB, so that M

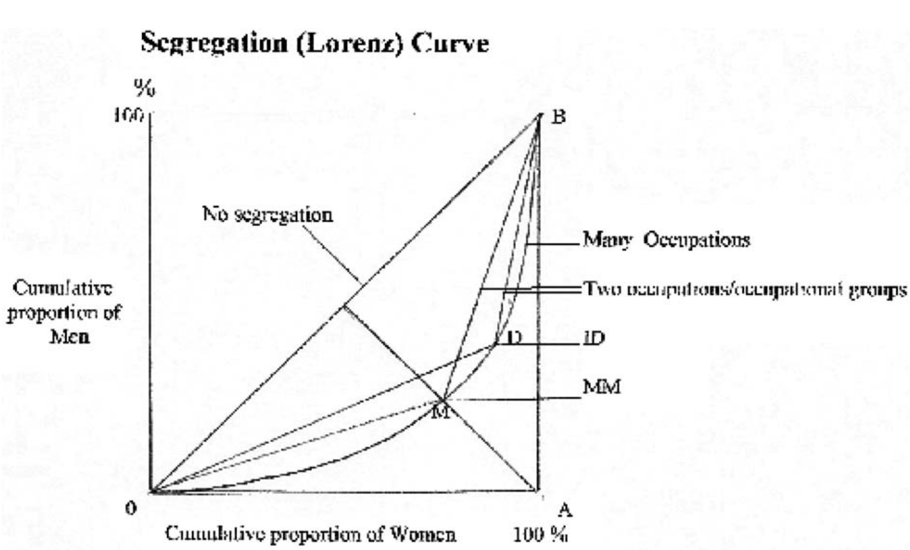

Figure 2. Segregation (Lorenz) curve.

is equidistant from OA and AB, as $M_f = F_m$. Similarly ID is represented by triangle ODB divided by triangle OAB. The position of *D* is the point where the enclosed triangle has the maximum area as the dividing point between male and female occupations provides the largest possible difference of proportions in a segregation table.

We may note that the area under the curve OMDB is greater than the area of either triangle. Points *M* and *D* lie on the curve because the actual number of occupations is the same for all three measures. However, the grouping of occupations into two categories (male and female) reduces the values of the Gini when it is MM or ID. While the number of occupations determines the curve, it does so by defining points on the curve (one less than the total occupations plus *O* and *B*). With many occupations their joining up almost coincides with the curve, and the area they enclose – the Gini – is approximately that area enclosed by the curve. However, any grouping of occupations reduces the enclosed area, as we see in the extreme of grouping into two categories, for MM and ID.

The curve OMDB varies with the number of occupational categories, such that the area between the diagonal and the curve increases as the number of occupations increases. This illustrates the fact that the value of the Gini coefficient increases with the number of occupational categories and illustrates the reason for standardising segregation measures for the number of occupations. The same logic applies for standardising MM, while the fact that the area of triangle OMB is less than the area enclosed by the curve means that a different formula is required.

Standardising measures

Having selected the useful measures, we need to standardise them (Blackburn, Jarman, Brooks, & Dermott, 1998). Standardisation has not normally been undertaken, though Anker (1998) introduced an alternative formula. Standardisation is necessary because, as we have noted, all measures of segregation increase with the number of occupational categories. We decided to standardise on 200 categories because it is within the range of available data-sets and it is at a level where further increases in the number of occupations have only a small and declining effect. While not strictly relevant to standardisation, it is large enough for possible measurement errors to be small. That is to say, the way the occupations are grouped into categories has little effect on the observed measure. For small numbers of categories there can be considerable variance depending on the particular grouping. For most purposes we may regard 20 as the appropriate minimum, though this is a far smaller number than is really desirable. Where there is no alternative it is possible to use just 20 or even fewer categories, but with very cautious limits on interpretation. Where there are a large number of categories (150+) we may regard measures as approximately correct, and deviations, with fewer categories, from the standardised value with many categories, are seen as error.

Firstly we estimated the standardisation equation for MM,[17] which can be directly adapted for ID. Subsequently we used the same procedure to estimate the standardisation of G. Then we estimated standardisation for the vertical and horizontal dimensions.

Standardising MM

To standardise MM (Blackburn et al., 1998; Jarman et al., 1999), we estimated an equation to relate the 'expected' value of MM to the number of occupations, using a wide range of national data-sets. Of course the actual 'observed' value of MM for each country differed from the estimated 'expected' value for the number of occupations in the data-set for that country. For each country the observed to expected ratio was calculated. Then this ratio was applied to the estimated value for 200 occupations. This gave a set of comparable estimates of segregation level for a notional set of 200 occupations in each country.

Our initial estimating equation was

$$\mathrm{MM}_{nE} = 1 - \frac{1}{1 + \alpha(\log_{10}(n+\gamma)/(1+\gamma))^{\beta}}, \tag{7.1}$$

where n is the number of occupations and α, β and γ are the three parameters that are possible in the estimation equation.[18] E indicates the expected value, according to the estimated equation, for the particular number of occupations n (or 200).

However, it turned out that the estimate of γ was approximately 0 in all the equations providing a good fit. Therefore, it was dropped from our estimating procedure, leaving the simpler equation

$$\mathrm{MM}_{nE} = 1 - \frac{1}{1 + \alpha(\log_{10} n)^{\beta}} \quad \alpha > 0,\ \beta > 0. \tag{7.2}$$

We estimated that the optimal values are $\alpha = 0.60$ and $\beta = 0.93$. Thus the final equation arrived at was

$$\mathrm{MM}_{nE} = 1 - \frac{1}{1 + 0.6(\log_{10} n)^{0.93}}. \tag{7.3}$$

Standardising on 200 occupations, we have for country 'i' with 'n' occupations

$$\mathrm{MM}_{200i} = \mathrm{MM}_{200E} \times \mathrm{MM}_{ni}/\mathrm{MM}_{nE}$$

and we have

$$\mathrm{MM}_{200E} = 0.56567.$$

Standardising Gini

Similar procedures were followed to standardise the Gini coefficient. Again a wide range of national data-sets of varying sizes was used. Thus we obtained the formula[19]

$$G_{nE} = 1 - \frac{1}{1 + 1.7(\log_{10} n)^{0.93}}. \tag{8.1}$$

Then

$$G_{200i} = G_{200E} \times G_{ni}/G_{nE} \quad \text{and} \quad G_{200E} = 0.78678.$$

Standardising the vertical and horizontal dimensions

Once we have standardised the measure of overall segregation (*G*), we need to standardise the component dimensions. Since there is no reason why standardisation should change the ratio of vertical to horizontal components, *V*/*H*, the ratios of *V* and *H* to overall segregation remain the same. Thus

$$V_{200i} = V_{ni} \times G_{200E}/G_{nE} \quad \text{and} \quad H_{200i} = H_{ni} \times G_{200E}/G_{nE}.$$

Thus we have consistent measurement of segregation and its two dimensions, regardless of the number of occupations in the data-set.

Conclusion

Occupational segregation is a significant aspect of contemporary societies. Its measurement, however, is not entirely straightforward, and there have been various attempts to optimise the measurement. Taking the example of occupational gender segregation, I have attempted to set out the basic considerations and to demonstrate adequate approaches.

Most measures of overall segregation have serious weaknesses, including those that treat occupations rather than people. Almost all measures can be shown to be based on a dichotomy between male and female occupations. Of these MM is the most satisfactory, followed by ID which has the advantage of having been widely used, allowing comparison of findings. There is no loss of information in these measures which dichotomise occupations since the two variables are internal to the relationship.

However, to measure the vertical dimension requires an external measure of inequality such as pay or CAMSIS. Therefore, we need data for all occupations, as grouping would lose information. Accordingly, we use Somers' D, which for overall segregation is the Gini coefficient. Thus we have consistent measurement for overall segregation and its dimensions.

Measures of segregation increase with the number of occupations. To obtain comparability across data-sets we therefore standardise on 200 occupations. Validity and reliability increase with the number of occupations, and it is desirable to have at least 100 and preferably more. Even if occupations are grouped as in MM, the substantial number of occupations is appropriate.

The value of good measurement is not merely greater accuracy, as it can significantly advance our understanding. Three particular results from measuring the dimensions of segregation are worth mentioning, as they are not otherwise apparent

(Blackburn & Jarman, 2006; Blackburn et al., 2009). Firstly, we may note that overall segregation is not the measure of gender inequality it has generally been assumed to be. In fact vertical segregation, the actual measure of inequality, is inversely related to overall segregation; the higher the overall level, the higher the horizontal component while the vertical component tends to be lower. Secondly, inequality is not even a major aspect of segregation; the horizontal dimension of difference without inequality tends to be substantially larger than the vertical dimension. Thirdly, when the vertical component is measured by pay there is a consistent advantage to men as expected; however, when measured with a stratification measure such as CAMSIS the result is almost invariably negative, at least in the industrialised countries, indicating an advantage to women. Knowledge depends on sound methodology.

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Notes

1. Segregation is often used to indicate total separation (the sheep from the goats, etc). However, the technical term, as used here, refers to a variable ranging over values from 0 to total separation (from 0 to 1, or sometimes 0–100%). A population comprised solely of monks and nuns, for example, would have total segregation and so a value of 1.
2. See Charles and Grusky (2004) and Anker (1998) bibliographies.
3. Here we are concerned with segregation of two groups. To explore the separation of several groups at once requires a different methodology, see for instance Elliot (2005), Silber (1992).
4. As a measure of inequality, the vertical dimension cannot be gender symmetrical, unlike the resultant segregation.
5. A measure exists composed of the type of tenure of the house, whether centrally heated, the density of people per room and the number of cars available to the household (Blackburn, Dale and Jarman, 1997, p. 255). The measure is based on the data available in the 1991 British Census.
6. It was actually introduced in the working paper Blackburn, Siltanen, and Jarman (1990), but the journal article was not published till 1993.
7. IP may be expressed as $\mathrm{IP}=2\alpha/N$, where α is the difference between observed and expected values in the table (expected being the values if there were no relationship). Unlike the other measures this appears to be independent of the marginal totals. However, this is an illusion as the possible size and the significance of α depend on the expected values, and so on the marginal totals.
8. For precise matching the cutting point may require splitting an occupation (Siltanen et al., 1995) though with many occupations this is hardly necessary. This also applies to determining p and N_i above.
9. These values of D_{c} and D_{r} should not be confused with ID and SR* as they are based on a different table.
10. Lieberson's (1976) index of net difference is the same as Somers' D, and so the Gini coefficient.
11. Recall that ID has traditionally been expressed as summation of terms for every occupation and MM can be similarly expressed.
12. Exceptions include Blackburn and Jarman (1997, 2004, 2006), Blackburn et al. (2001), Brooks, Jarman, and Blackburn (2003).
13. For extensive discussion of such criteria see James and Taeuber (1985), Siltanen et al. (1995). The present brief discussion updates these accounts.
14. For technical limitations see also Siltanen et al. (1995), Watts (1998a, 1998b).

15. Strictly the ordering of occupations to create the axes is not possible with no segregation, but any ordering would suffice. The diagonal is the limiting position of the curve as segregation tends to zero.
16. The number of occupations must be less than or equal to the number of workers. If occupations equaled workers there would be total segregation (triangle OAB) while more occupations is impossible. In practice 200 or more occupations gives a good approximation to the curve.
17. A detailed discussion of the estimation process for standardizing MM may be found in Jarman, Blackburn, Brooks, and Dermott (1999, Appendix).
18. We should note that this meets three basic criteria: $MM_E = 0$ when $n = 1$; MM_E increases as n increases; and $MM_E \to 1$ as $n \to \infty$. The third criterion here is not precisely what is required, but the difference is negligible.
19. Earlier standardization for Canada and UK were estimated on limited data. The formula given here is more soundly based and so is to be preferred. The result is not greatly different but is more precise.

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