# Universidade de Vigo
## Departamento de Economía Aplicada


Documento de Traballo
**0902**

# Measuring geographic concentration: Lorenz curves and their decompositions

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# Documentos de Traballo

Marzo 2009



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# Measuring geographic concentration:

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**Abstract**

This paper first reveals the basic properties behind the spatial concentration measurement when using "employment Lorenz curves". This involves axioms adapted not only from the literature on income distribution but also from that on occupational segregation. Second, additive decompositions of this curve by subsectors and by groups of locations are proposed since, as far as we know, no decompositions of these curves have yet been suggested in the field. This approach is finally used to analyze the concentration of the Spanish manufacturing industry. In particular, we study whether the technological intensity of an industry affects the extent of its spatial concentration level.

**JEL Classification:** R12; D63

**Keywords:** Inequality measures; Segregation; Geographic concentration; Axioms

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* Financial support from the *Xunta de Galicia* (INCITE08PXIB300005PR) and from FEDER is gratefully acknowledged.

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# 1. Introduction

The literature of regional science offers a variety of measures in order to quantify the geographic concentration of economic activity. Some of them are formally derived from location models, as those proposed by Ellison and Glaeser (1997), Maurel and Sédillot (1999), and Guimarães et al. (2007). Others are borrowed instead from the literature on spatial statistics, as is the case of the distance-based measures put forward by Marcon and Puech (2003) and Duranton and Overman (2005). However, some of the most widely used spatial concentration measures are derived from the literature on income inequality. Thus, the Gini index has been adapted to analyze spatial location patterns of manufacturing industries (Krugman, 1991; Amiti, 1999; Brülhart, 2001; and Suedekum, 2006, among many others), and some of the indexes included in the generalized entropy family have been adapted as well (Brülhart and Traeger, 2005; Mori et al., 2005; Brakman et al., 2005; Pérez-Ximénez and Sanz-Gracia, 2007; and Cutrini, 2009).

In the literature on income distribution, these inequality indexes have been shown to be consistent with non-crossing Lorenz curves i.e., if the Lorenz curve of an income distribution lies at no point below the other and at some point above, the Gini index and the generalized entropy family will lead to a lower inequality level at the former distribution, which makes the measurement of inequality by using Lorenz curves a rather robust procedure. In addition, the Lorenz curve has been characterized in that field in terms of basic axioms. However, a modified version of this curve has been proposed to measure the spatial concentration of employment without characterizing it axiomatically. This implies that the properties which regional economics implicitly assume when using employment Lorenz curves to compare the geographic concentration of two different sectors have been not identified yet.

To fill this gap, this paper first reveals the basic properties behind the spatial concentration measurement when using "employment Lorenz curves". These axioms are borrowed not only from the literature on income distribution but also from that of occupational segregation (Hutchens, 1991, 2004; and Alonso-Villar and Del Río, 2007). Second, additive decompositions of this curve by subsectors and by groups of locations are proposed, since even though additive decompositions of the generalized entropy family of indexes have been used to measure industrial concentration (Brülhart and Trager, 2005), as far as we know, no decompositions of the employment Lorenz curves have yet been suggested. One of the decompositions parallels that proposed by Bishop et al. (2003) in a context of income distribution. Third, the employment Lorenz curves and their decompositions are finally used to analyze the spatial concentration of manufacturing industries in Spain in 2008. In particular, we study whether the technological intensity of an industry affects the extent of its spatial concentration level. An advantage of using these curves is that it allows comparisons among spatial distributions (whose Lorenz curves do not cross) by using the lesser number of value judgments, which makes this measurement rather appealing and robust.

The paper is structured as follows. Section 2 presents some basic axioms and characterizes the employment Lorenz curves in terms of them. Section 3 offers two decompositions of the employment Lorenz curve; one by groups of sectors and another by groups of locations. This approach is later used in Section 4 in order to analyze the concentration of the Spanish manufacturing industry. Thus, on one hand, manufacturing industries are grouped by technological intensity in order to determine whether this characteristic affects the extent of concentration of an industry. On the other hand, the location units are grouped by their human capital level in order to go deeper into the analysis. Finally, Section 5 presents the main conclusions.

## 2. Measuring geographic concentration with Lorenz curves

Consider an economy with $L > 1$ location units (counties, regions, countries, etc.). In measuring the geographic concentration of a sector this paper follows a *relative* notion, so that the distribution of this sector is compared with that of reference. Let $t \equiv (t_1, t_2, ..., t_L)$ denote this benchmark, and $T = \sum_l t_l$. If concerned, for example, with the geographic concentration of manufacturing industries, $t$ could represent the distribution of total manufacturing employment among regions (as in Amiti, 1999; and Brülhart, 2001). If concerned with a broader perspective, $t$ could represent instead the distribution of overall employment, services included (as in Brülhart and Traeger, 2005). Let us denote by $x \equiv (x_1, x_2, ..., x_L)$ the employment distribution of the sector in which we are interested, and by $X$ its employment level ( $X = \sum_l x_l$ ). In this paper, an index of geographic concentration is a function $I_c : D \to \mathbb{R}$ such that $I_c(x;t)$ represents the concentration level of the sector having distribution $x$ when comparing it with the distribution of reference $t$, where $D = \bigcup_{L>1} \left\{ \left( x;t \right) \in \mathbb{R}^{L}{}_{+} \times \mathbb{R}^{L}{}_{++} : x_l \leq t_l \forall l \right\}$.

In this section we characterize the employment Lorenz curve of a sector in terms of basic axioms borrowed from the literature on income distribution and occupational segregation.

## 2.1 Basic axioms

**Axiom 1:** *Symmetry in locations*. If $\left(\Pi(1),...,\Pi(L)\right)$ represents a permutation of locations, then $I_c\left(x\Pi;t\Pi\right) = I_c\left(x;t\right)$, where $x\Pi = \left(x_{\Pi(1)},...,x_{\Pi(L)}\right)$ and $t\Pi = \left(t_{\Pi(1)},...,t_{\Pi(L)}\right)$.

This axiom means that if locations are enumerated in a different order, the concentration index should remain unchanged.[1]

**Axiom 2:** *Movement between locations*. If $\left(x';t\right) \in D$ is obtained from $\left(x;t\right) \in D$ in such a way that:

(i) Location *i* loses employment in the sector of study, while the opposite happens to location *h*, i.e., $x'_i = x_i - d$, $x'_h = x_h + d$ $(0 < d \leq x_i)$, where *i* and *h* are two locations satisfying that $t_i = t_h$, and $x_i < x_h$;

(ii) The employment level of the sector of study does not change in the remaining locations, i.e., $x'_l = x_l \ \forall l \neq i,h$;

then $I_c\left(x';t\right) > I_c\left(x;t\right)$.

In other words, if location *i* has initially the same manufacturing employment level as location *h*, but a lower employment level in chemicals, then a movement of employment in chemicals from location *i* to location *h* would be considered a disequalizing movement fostering the concentration of the sector.[2]

[1] In the income distribution literature, this axiom is called "symmetry" or "anonymity", and it requires that the inequality index does not change when individuals' incomes swap. In the literature on occupational segregation, it is named "symmetry in groups" (see Hutchens, 1991).

[2] This axiom corresponds to the Pigou-Dalton principle of transfers, which requires a transfer of income from a poorer to a richer person to increase inequality. It has also been adapted to measure occupational segregation, where it is called "movement between groups" (Hutchens, 2004).

**Axiom 3:** *Scale Invariance*. If the distribution of the sector of study, $x$, is multiplied by a positive scalar, $a$, and the distribution of reference, $t$, is multiplied by another positive scalar, $b$, in such a way that $ax_l \leq bt_l$, then the concentration level of the sector does not change; i.e., $I_c\left(ax;bt\right)=I_c\left(x;t\right)$.

This property means that the value of the concentration index should not change when the employment level of the distribution of reference and/or that of the sector under consideration vary, so long as the weight that each location represents in distributions $t$ and $x$ remains unaltered. In other words, this axiom means that in measuring spatial concentration it is only employment shares that matter, not employment levels. [3]

The next axiom we present, *insensitivity to proportional subdivisions of locations,* is not borrowed from the literature on income distribution but from that on occupational segregation.[4] This axiom requires that subdividing a location into several units of equal size, both in terms of aggregate employment and in terms of employment in the sector of study, does not affect the concentration level of the sector. Without loss of generality, the subdivision in the next axiom is written for the last location in order to make notation easier.

**Axiom 4:** *Insensitivity to proportional subdivisions of locations.* If $\left(x';t'\right)\in D$ is obtained from $\left(x;t\right)\in D$ in such a way that:

(i) All locations except the last one remain unaltered both in terms of aggregate employment and employment in the sector of study, i.e., $t'_l=t_l$ and $x'_l=x_l$ for any $l=1,...,L-1$;

(ii) The last location is subdivided in $M$ location units without introducing any difference among them in terms of employment shares, i.e., $x'_l=x_L/M$, $t'_l=t_L/M$ for any $j=L,...,L+M-1$,

then, $I_c\left(x';t'\right)=I_c\left(x;t\right)$.

[3] In the literature on income distribution, an index is said to satisfy this property if and only if inequality remains unaltered when multiplying all incomes by the same positive scalar. In a context of occupational segregation, a similar axiom has been proposed by Alonso-Villar and Del Río (2007).

[4] The corresponding axiom is named “insensitivity to proportional divisions” (see Hutchens, 2004).

## 2.2 Characterizing employment Lorenz curves

In this subsection, we show that *symmetry in locations, movement between locations, scale invariance,* and *insensitivity to proportional subdivisions of locations* (i.e., axioms 1-4) are the basic properties of the concentration measurement behind employment Lorenz curves, since any concentration measure satisfying these axioms is consistent with non-crossing employment Lorenz curves.

The Lorenz curve of the employment distribution of a sector is usually constructed as follows. First, locations are lined up in ascending order of the ratio of the Hoover-Balassa index $\frac{x_l/X}{t_l/T}$, which is equivalent to ranking according to $\frac{x_l}{t_l}$.[5] Next, the cumulative proportion of aggregate employment, $\sum_{i\le l}\frac{t_i}{T}$, is plotted on the horizontal axis and the cumulative proportion of employment in the sector of study, $\sum_{i\le l}\frac{x_i}{X}$, is plotted on the vertical axis. Therefore, if we denote by $\tau_l \equiv \sum_{i\le l}\frac{t_i}{T}$ the proportion of cumulative aggregate employment represented by the first $l$ locations ranked according to the above criterion, the employment Lorenz curve can be written as follows:

$$L_{(x;t)}(\tau_l) = \frac{\sum_{i\le l} x_i}{X}.$$

The first decile of the distribution represents 10% of aggregate employment, and it includes those locations where the sector of study has the lowest relative presence. The second cumulative decile represents 20% of aggregate employment, and it also includes locations where the sector has the lowest relative presence, and so on. Each point of the employment Lorenz curve indicates the proportion of employment in the sector corresponding to each cumulative decile of aggregate employment. In other words, the curve shows the under-representation of the sector with respect to aggregate employment, decile by decile. In the case where a sector of study was distributed across locations in the same manner as the distribution of reference, the employment Lorenz curve would be equal to the bisector and no concentration would exit.

[5] See, for example, Brülhart (2001). Alternatively, Krugman (1991) and Amiti (1999) rank locations in descending order, but it is the ascending order that is consistent with income distribution literature.

As with standard Lorenz curves, we can say that distribution $(x;t)\in D$ *dominates in geographic concentration* distribution $(x';t')\in D$ if the employment Lorenz curve of the former lies at no point below the latter and at some point above.

**Proposition 1**. Distribution $(x;t)$ *dominates in geographic concentration distribution* $(x';t')$ *if and only if* $I_c(x;t)<I_c(x';t')$ *for any concentration index* $I_c$ *satisfying symmetry in locations, movement between locations, scale invariance, and insensitivity to proportional subdivisions of locations (i.e., axioms 1-4).*

*Proof:*

*Step 1*

First, we prove that if the concentration index $I_c$ satisfies axioms 1-4, then inequality index $I$ evaluated at the fictitious "income distribution" $y\equiv\left(\underbrace{\frac{x_1}{t_1},\dots,\frac{x_1}{t_1}}_{t_1},\dots,\underbrace{\frac{x_L}{t_L},\dots,\frac{x_L}{t_L}}_{t_L}\right)$ as $I(y):=I_c(x;t)$, works as an inequality index satisfying scale invariance, symmetry, the Pigou-Dalton principle, and replication invariance .

a) $I$ is well defined. Note that several vectors $(x;t)$ can be reached after grouping individuals in the fictitious "income distribution" who belong to the same location depending on how many locations are considered. However, by axiom 4, all these vectors have the same spatial concentration level, since they can be obtained from each other by proportional subdivisions.

b) Scale invariance. This property is certainly satisfied by index $I$ since $I(\theta\frac{x_1}{t_1},\dots,\theta\frac{x_1}{t_1},\dots,\theta\frac{x_L}{t_L},\dots,\theta\frac{x_L}{t_L})=I_c(\theta x;t)$, which is equal to $I_c(x;t)$ because $I_c$ satisfies axiom 3 (case where $a>0,\ b=1$).

c) Symmetry. This property requires that individuals play symmetric roles in the inequality index. This is satisfied by $I$ since $I_c$ satisfies axioms 1 and 4.

d) The Pigou-Dalton transfer principle. From axiom 4, any regressive transfer in this fictitious economy can be expressed as a sequence of employment transfers in the sector of study from a location *i* to another location *h*, where $t_i=t_h=1$ and $x_i<x_h$.

Since $I_c$ satisfies axiom 2, the second situation leads to a higher concentration index and, therefore, to a higher value of $I_c$ . As a consequence, the regressive transfer leads to higher inequality.

e) Replication invariance. This means that when replicating the economy k-times, so that for every individual in the previous economy there are now $k$ identical individuals, income inequality is not altered. This axiom is satisfied here since a k-replication of the fictitious distribution leads to a k-replication of vector $(x;t)$, and $I_c$ satisfies axiom 3 (case where $a = b$ ).

*Step 2*

The Lorenz curve of an income distribution dominates another if and only if any inequality measure satisfying scale invariance, symmetry, the Pigou-Dalton transfer principle and replication invariance takes a lower value at the former distribution (Foster, 1985). Since the Lorenz curve for employment distribution $(x;t)$ is like the Lorenz curve for our "income distribution" $y \equiv (\frac{x_1}{t_1},...,\frac{x_1}{t_1},...,\frac{x_L}{t_L},...,\frac{x_L}{t_L})$, from Step 1, it follows that $I_c(x;t) < I_c(x';t')$ if and only if the former distribution Lorenz dominates the latter, which completes the proof. □

The Lorenz criterion, when conclusive, has the advantage of allowing comparisons among spatial distributions by using the lesser number of value judgments, which makes this measurement rather appealing. However, when employment Lorenz curves cross, it is necessary to make use of concentration indexes. We should be aware of the fact that in these cases, even when using concentration indexes satisfying axioms 1-4, such as the locational Gini coefficient and the generalized entropy family, the results do not necessary coincide since each of them focuses on a different aspect of the employment distribution.

## 3. Decomposing employment Lorenz curves

While additive decompositions of the generalized entropy family of indexes have been proposed in the literature of industrial concentration (Brülhart and Traeger, 2005), as far as we know, no decompositions of the employment Lorenz curves have yet been suggested. In what follows, we offer two forms of decomposition of these curves: one by groups of locations, and the other by subsectors.

**Proposition 2.** Assume that locations can be classified into $K$ mutually exclusive groups so that the distributions $x$ and $t$ can be expressed as $(x;t)=(x^1,...,x^K;t^1,...,t^K)$, where $x^k$ denotes the employment distribution of the sector across locations in group $k$, and $t^k$ is that of aggregate employment ($k=1,...,K$). Then, the employment Lorenz curve, $L_{(x;t)}$, can be decomposed as follows:

$$L_{(x;t)}(\tau_l)=\sum_k \frac{X_k}{X}\tilde{L}_{(\tilde{x}^k;t)}(\tau_l),$$

where $X_k$ is the employment level of the sector in group $k$, $\tilde{L}_{(\tilde{x}^k;t)}(\tau_l)$ is like the employment Lorenz curve of distribution $(\tilde{x}^k;t)$ except that locations are ranked according to ratios $\frac{x_l}{t_l}$, and $\tilde{x}^k$ is an L-dimensional vector resulting from enlarging vector $x^k$ with zero-values for those locations that are not included in group $k$.

*Proof:*

Define indicator $G_l^k$ so that $G_l^k=1$ if location (region) $l$ belongs to group (country) $k$ and $G_l^k=0$ otherwise ($l=1,...,L$, and $k=1,...,K$). By using vector $x^k$, we can build $\tilde{x}^k$ as follows $\tilde{x}^k=(x_1G_1^k,...,x_LG_L^k)$. In other words, $\tilde{x}^k$ is a fictitious employment distribution having the same dimension as the original distribution $x$ so that it can be compared to the distribution of total employment $t$. By keeping locations ranked in ascending order of the ratios $\frac{x_l}{t_l}$ ($l=1,...,L$), and maintaining $\tau_l\equiv\sum_{i\le l}\frac{t_i}{T}$, we could define $\tilde{L}_{(\tilde{x}^k;t)}(\tau_l)$ as the proportion of employment in the sector corresponding to the locations ranked before $l$ that are included in group $k$. In other words, $\tilde{L}_{(\tilde{x}^k;t)}(\tau_l)=\frac{\sum_{i\le l}x_iG_i^k}{X_k}$. Then, the employment Lorenz curve corresponding to distribution $(x;t)$ can be decomposed as $L_{(x;t)}(\tau_l)=\frac{\sum_{i\le l}x_i}{X}=\sum_k\frac{X_k}{X}\frac{\sum_{i\le l}x_iG_i^k}{X_k}=\sum_k\frac{X_k}{X}\tilde{L}_{(\tilde{x}^k;t)}(\tau_l)$, which completes the proof. □

Consequently, expression:

$$\frac{X_k}{X}\frac{\tilde{L}_{(\tilde{x}^k;t)}(\tau_l)}{L_{(x;t)}(\tau_l)} \tag{1}$$

measures the contribution of group $k$ to the value of the employment Lorenz curve in the corresponding percentile. Assume, for example, that our location units are the European regions and that we are interested in grouping them by country. Consider again that we focus on the chemical sector. As mentioned above, the first decile of the employment distribution includes those regions where the chemical industry has the lowest relative presence, and it accounts for 10% of manufacturing employment in Europe. By using the above decomposition for the first decile, one could determine whether the regions with the lowest employment in chemicals belong to Spain, France, Italy, etc.[6] Note that both cumulative and non-cumulative percentiles can be decomposed according to a given location classification.[7] If we want to decompose non-cumulative deciles, for example, we have to use instead the following expression:

$$\frac{X_k}{X}\frac{\tilde{L}_{(\tilde{x}^k;t)}(\tau_l+0.1)-\tilde{L}_{(\tilde{x}^k;t)}(\tau_l)}{L_{(x;t)}(\tau_l+0.1)-L_{(x;t)}(\tau_l)} \ . \tag{2}$$

Note, on the other hand, that function $\tilde{L}_{(\tilde{x}^k;t)}$ also enables one to determine how the sector of study in country $k$ is distributed among non-cumulative deciles by using expression :

$$\tilde{L}_{(\tilde{x}^k;t)}(\tau_l+0.1)-\tilde{L}_{(\tilde{x}^k;t)}(\tau_l), \tag{3}$$

which indicates the proportion of employment in the sector in country $k$ in each (non-cumulative) decile. This analysis would permit one, for example, to find out whether the distribution of chemicals in France across the deciles of manufacturing employment in Europe differs from that of Germany.[8] Note that this decomposition allows going deeper into the analysis within each percentile of the total employment distribution, but it does not allow one to conclude which group of sectors is more agglomerated by comparing their corresponding curves $\tilde{L}_{(\tilde{x}^k;t)}(\tau_l)$ since these curves are obtained by ranking locations according to a common criterion: $\frac{x_l}{t_l}$ ratios. If one were interested in that analysis, the Lorenz curve for each group of locations (countries, for example) would have to be calculated.

[6] In the empirical section, Section 4, we only have data for one country, Spain, so that another classification of locations is considered. In particular, three groups of locations are built according to their human capital level.
[7] For the sake of simplicity, in Section 4, we have chosen only to decompose non-cumulative deciles.
[8] In the empirical section, we analyze if the distribution of provinces with high human capital level across ventiles differs from the distribution of the remaining groups.

Next, without loss of generality, let employment in the sector be classified into two mutually exclusive subsectors, *A* and *B*, so that $(x_1,...,x_L)=(x_1{}^A+x_1{}^B,...,x_L{}^A+x_L{}^B)$. Denote by $X^A$ (respectively $X^B$) the employment level of subsector A (respectively B).

**Proposition 3.** If the sector can be partitioned into two mutually-exclusive subsectors *A* and *B* so that $(x;t)=(x^A+x^B;t)$, then the employment Lorenz curve, $L_{(x;t)}$, can be decomposed as follows:

$$L_{(x;t)}(\tau_l)=\frac{X^A}{X}\tilde{L}_{(x^A;t)}(\tau_l)+\frac{X^B}{X}\tilde{L}_{(x^B;t)}(\tau_l),$$

where $\tilde{L}_{(x^A;t)}(\tau_l)$ is like the employment Lorenz curve corresponding to $(x^A;t)$, and $\tilde{L}_{(x^B;t)}(\tau_l)$ is like the employment Lorenz curve corresponding to $(x^B;t)$, except that locations have been ranked according to ratios $\frac{x_l}{t_l}$.

*Proof:*

Let us define $\tilde{L}_{(x^A;t)}(\tau_l)=\frac{\sum_{i\le l}x_i{}^A}{X^A}$ and $\tilde{L}_{(x^B;t)}(\tau_l)=\frac{\sum_{i\le l}x_i{}^B}{X^B}$. The proof is immediate by noting that the employment Lorenz curve corresponding to distribution $(x;t)$ can be decomposed as

$$L_{(x;t)}(\tau_l)=\frac{X^A}{X}\frac{\sum_{i\le l}x_i{}^A}{X^A}+\frac{X^B}{X}\frac{\sum_{i\le l}x_i{}^B}{X^B}=\frac{X^A}{X}\tilde{L}_{(x^A;t)}(\tau_l)+\frac{X^B}{X}\tilde{L}_{(x^B;t)}(\tau_l).$$ □

This decomposition can also be easily generalized to more than two subsectors so that expression:

$$\frac{X^A}{X}\frac{\tilde{L}_{(x^A;t)}(\tau_l)}{L_{(x;t)}(\tau_l)} \tag{4}$$

measures the contribution of subsector *A* to the employment Lorenz curve of the sector in each cumulative decile. This analysis would permit one, for example, to determine whether in the first decile chemical employment corresponds mainly to pharmaceutical products, manufacture of pesticides and other agrochemical products, manufacture of manmade and synthetic fibers, etc. If we want to decompose each non-cumulative decile, rather than each cumulative decile, we have to use, instead, this expression:

$$\frac{X^A}{X}\frac{\tilde{L}_{(x^A;t)}(\tau_l+0.1)-\tilde{L}_{(x^A;t)}(\tau_l)}{L_{(x;t)}(\tau_l+0.1)-L_{(x;t)}(\tau_l)}. \quad (5)$$

Furthermore, expression:

$$\tilde{L}_{(x^A;t)}(\tau_l+0.1)-\tilde{L}_{(x^A;t)}(\tau_l) \quad (6)$$

enables one to determine how subsector *A* is distributed among (non-cumulative) deciles of the whole employment distribution.[9] In particular, this would allow one to determine whether a given subsector of the chemical industry is located mainly in regions where the chemical industry has a high presence or, on the contrary, it follows a different location pattern than the sector as a whole. It also allows, for example, studying whether the distribution of pharmaceutical products among European regions differs from that of manufacturers of manmade and synthetic fibers.[10]

# 4. An empirical illustration

The data used in this paper comes from the Labor Force Survey (*EPA*) conducted by the Spanish Institute of Statistics (*INE*) by following EUROSTAT's guidelines. Our data corresponds to the second quarter of the year 2008. Manufacturing industries are considered at a two- and three-digit level of the National Classification of Economic Activities (*CNAE-1993 Rev_1*), and the territorial scale is that of provinces (nuts III).

When studying the geographic concentration of manufacturing industries at the two or more digit level, scholars usually find evidence of remarkable concentration levels both in sectors that can be classified as high-tech and in others that are included in the low-tech group (see, for example, Maurel and Sédillot, 1999, in France; Bertinelli and Decrop, 2005, in Belgium; Guimarães et al., 2007, in Portugal, among others). In this section, we are interested in using employment Lorenz curves in order to analyze whether the set of high-tech industries are concentrated at a higher extent than other industries with lower technological intensity. By

[9] This decomposition is used in the empirical section when decomposing each technological group by subindustries.

[10] Note again that this decomposition allows going deeper into the analysis within each percentile of the total employment distribution, but if one were interested in comparing the spatial concentration of two subsectors, the employment Lorenz curve for each subsector would have to be calculated.

following the OECD and *INE* classification of manufacturing industries by technological intensity, four groups of sectors have been considered (see Table 1).[11]

| | |
|---|---|
| ***High-technology group*** | *Aircraft and spacecraft* (**353**)<br>*Pharmaceuticals* (**244**)<br>*Office, accounting and computing machinery* (**30**)<br>*Radio, TV and communications equipments* (**32**)<br>*Medical, precision and optical instruments* (**33**). |
| ***Medium-high-technology group*** | *Motor vehicles, trailers and semi-trailers* (**34**)<br>*Building/repairing of ships and boats, railroad equipment and transport equipment n.e.c.* (**351**)<br>*Electrical machinery and apparatus n.e.c.* (**31**)<br>*Machinery and equipment n.e.c.* (**29**)<br>*Chemicals excluding pharmaceuticals* (**24-244**) |
| ***Medium-low- technology group*** | *Rubber and plastic products* (**25**)<br>*Metallurgy* (**27**)<br>*Fabricated metal products (machinery and equipment excluded)* (**28**)<br>*Coke, refined petroleum products and nuclear fuel* (**23**)<br>*Other non-metallic mineral products* (**26**) |
| ***Low-technology group*** | *Paper industry* (**21**)<br>*Publishing, graphic arts, and reproduction of recorded supports* (**22**)<br>*Food products and beverages* (**15**)<br>*Tobacco* (**16**)<br>*Wood and cork industry, except furniture* (**20**)<br>*Textile industry* (**17**)<br>*Clothing and fur industry* (**18**)<br>*Leather and footwear* (**19**)<br>*Manufacture of furniture and other manufacturing industries n.e.c.* (**36**)<br>*Recycling* (**37**) |

**Table 1**. Classification of manufacturing industries by technological intensity.

Figure 1 shows the employment Lorenz curves of the four groups. We can see that high-tech industries are the most concentrated group since the corresponding Lorenz curve is clearly dominated by those of the remaining groups. This means that according to any concentration index consistent with the Lorenz criterion such as the locational Gini coefficient and any of the members of the generalized entropy family of concentration indexes, the high-tech group is the most concentrated industry, which suggests that this is a rather robust result. Note also that the employment Lorenz curve of the medium-high technology group is dominated by that of the low technology group.

However, since the employment Lorenz curve of medium-low-tech industries crosses those of low- and medium-high-tech industries, we cannot rank these industries according to their concentration level in a robust way. We have to make, instead, use of concentration indexes in order to know which one is more concentrated. For this purpose, seven different inequality-based concentration indexes have been calculated: the locational Gini index and five members of the generalized entropy family (GE henceforth) ($\Psi_\alpha$, $\alpha = -1, 0, 0.1, 0.5, 1, \text{and } 2$).[12] As Table 2 shows, except for the case $\Psi_{-1}$, which pays more attention to the lower tail of the

[11] The *INE* includes *building and repairing of ships and boats* in the medium-high group, while the OECD classifies this industry in the medium-low-tech group. We choose to follow the *INE* classification.
[12] The expressions of these concentration indexes are given in the Appendix.

employment distribution (i.e., where the sector is more underrepresented), we find that the higher the technological intensity of the group, the higher its spatial concentration.[13]

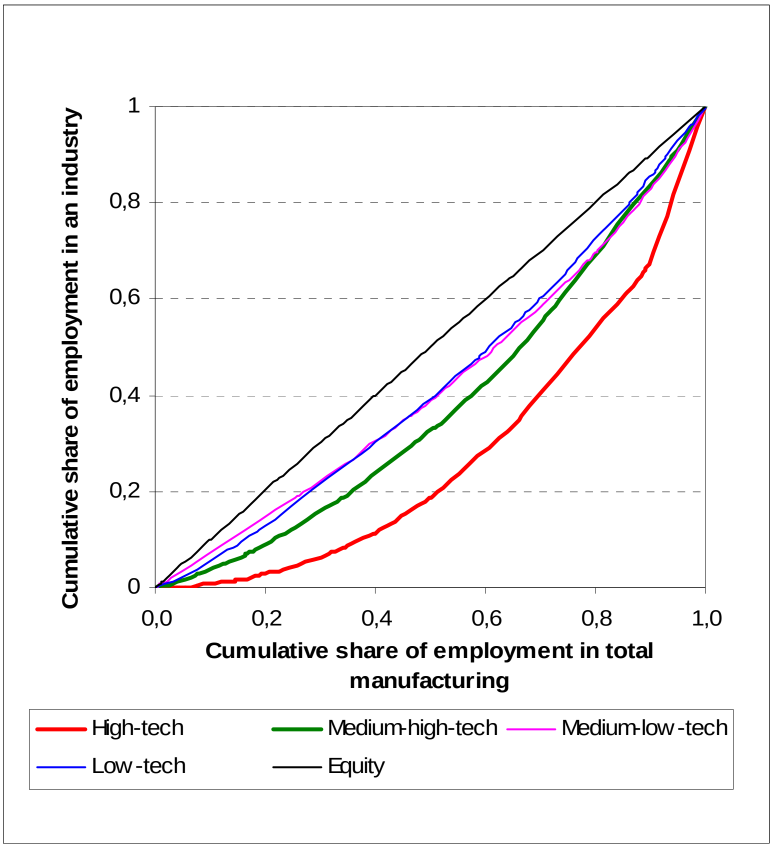


**Figure 1**. Employment Lorenz curves for four large sectors

| | $\Psi_{-1}$ | $\Psi_0$ | $\Psi_{0.1}$ | $\Psi_{0.5}$ | $\Psi_1$ | $\Psi_2$ | **Gini** |
|---|---|---|---|---|---|---|---|
| ***High-tech*** | * | * | 0.767 | 0.389 | 0.341 | 0.372 | 0.441 |
| ***Medium-high-tech*** | * | * | 0.098 | 0.091 | 0.086 | 0.082 | 0.231 |
| ***Medium-low-tech*** | 0.040 | 0.041 | 0.041 | 0.042 | 0.044 | 0.048 | 0.159 |
| ***Low-tech*** | 0.043 | 0.039 | 0.039 | 0.038 | 0.037 | 0.036 | 0.151 |

**Table 2**. Concentration indexes

When analyzing high-tech sectors in more detail, we find that there are important differences among them in terms of spatial concentration. Thus, Figure 2 shows that both the Lorenz curve of *aircraft and spacecraft* (353), and that of *office, accounting and computing machinery* (30) are dominated by those of the remaining high-tech sectors, with suggests that the geographic concentration of these two sectors is especially intense.

[13] Some members of the GE family cannot be calculated for those sectors that do not have employment in a location.

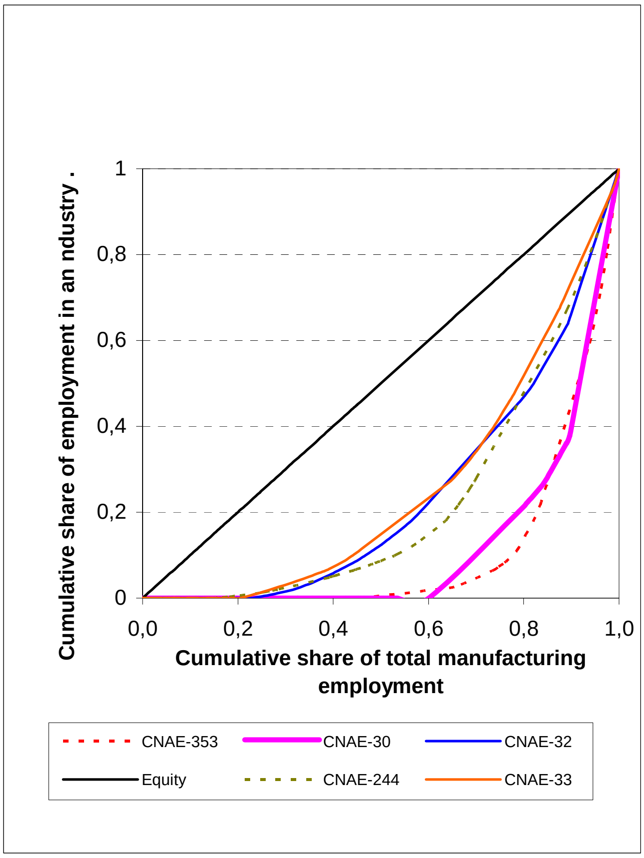


**Figure 2**. Employment Lorenz curves of high-tech industries

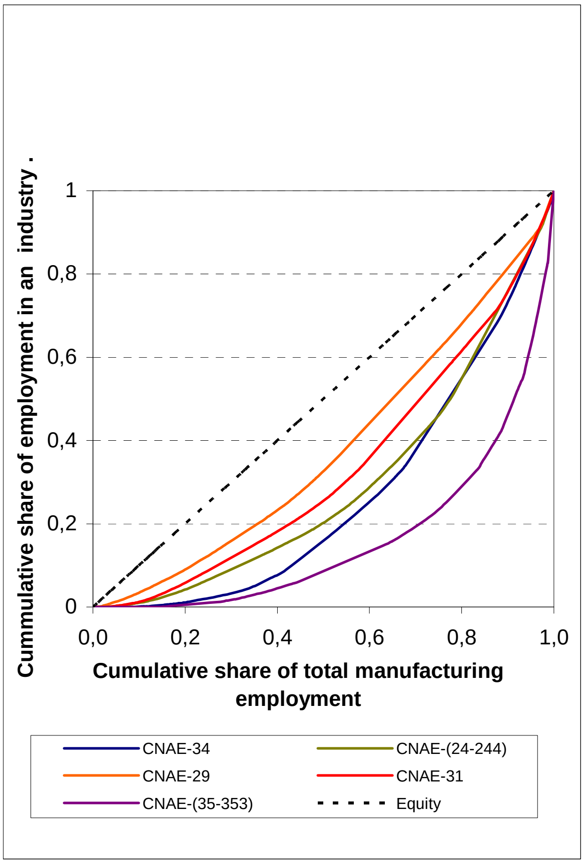


**Figure 3**. Employment Lorenz curves of medium-high-tech industries

In fact, as Figure 4 shows, when using the decomposition of the non-cumulative deciles by subindustries, as explained in expression (5), we find that sectors **353** and **30** tend to appear from the fifth decile onwards. In other words, these two sectors tend to show up in provinces with a high presence of high-tech industries. Moreover, the decomposition of the high-technology industry by subindustries (using expression (6) for ventiles; i.e., $\tilde{L}_{(x^A;t)}(\tau_l+0.2)-\tilde{L}_{(x^A;t)}(\tau_l)$ ) shows that almost 57% of the employment of sector **353** is in the fifth ventile of the manufacturing employment distribution (i.e., it is located in the most high-tech provinces of the country), and in the case of sector **30**, over 68% of its employment is in the fifth ventile (see Figure 5). However, for those groups with lower technology intensity, the agglomeration of their industries is not so intense since they are distributed across ventiles in a more homogenous way (see Figures A1-A3 in the Appendix).

Within the class of medium-high technology industries, we find that the *manufacture of other transport material*, aircraft excluded, (**35-353**), is by far the most concentrated sector (see

Figure 3), while in the medium-low tech industry it is the *manufacture of coke, refinement of petroleum and treatment of nuclear fuels* (**23**) the one experiencing the highest concentration level (Figure 6). Finally, note that differences among low-technology industries are not as strong as in the previous groups; see Figure 7.

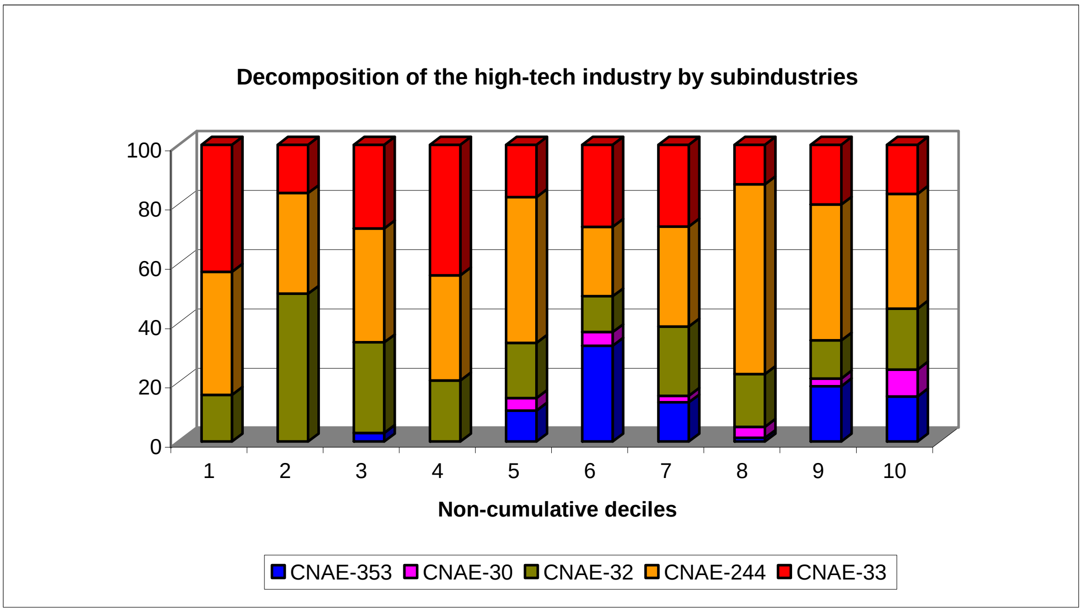


**Figure 4**: The high-tech-industry: Decomposition by subindustries (expression (5)).

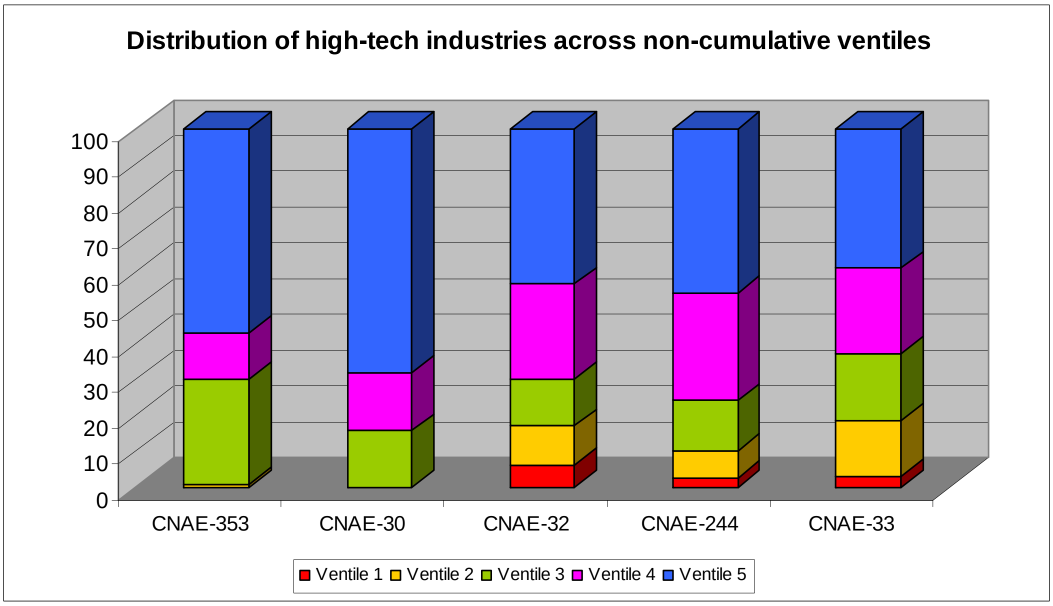


**Figure 5**: Decomposition by subindustries (expression (6)).

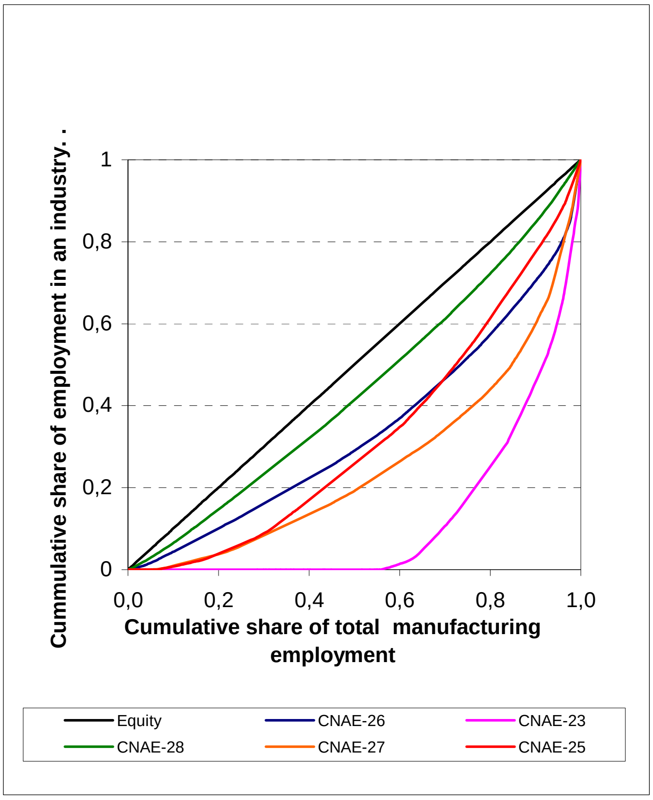


**Figure 6.** Employment Lorenz curves of medium-low-tech industries

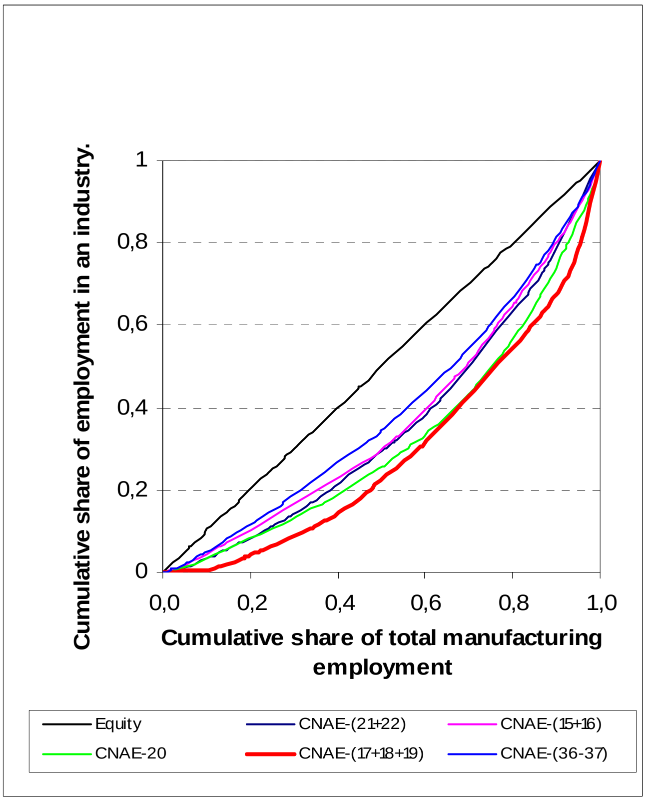


**Figure 7**. Employment Lorenz curves of low-tech industries

In what follows, we are interested in determining whether human capital affects the location patterns of high-tech industries, and also if this variable is more relevant for this industry than for industries with lower technological intensity. For this purpose, the 52 Spanish provinces are classified into three groups according to their human capital level.[14] By using the decomposition by groups of locations (see expression (2))**,** it is possible to determine whether each industry tends to concentrate in those locations with higher human capital. Figure 8 shows that the high-tech employment included in the first decile of the distribution (which represents 10% of the total manufacturing employment and includes those provinces with the lowest presence of high-tech industries), corresponds to locations with an intermediate human capital level, while the high-tech employment that is included in the top (non-cumulative) decile (which includes provinces with the highest presence of the sector) is located in the provinces with the highest education level. Moreover, even though the relationship between presence of high-tech industry and education level is not monotonic, we find that the

[14] The level of human capital of a province has been determined by the proportion of individuals aged 30-65 having a university degree or a degree in "formación profesional superior" (vocational training, 2nd technical college).

proportion of provinces with high human capital level is larger in the last deciles than in the first ones. In other words, it seems that high-tech industries tend to concentrate in locations with the highest human capital levels of the country.

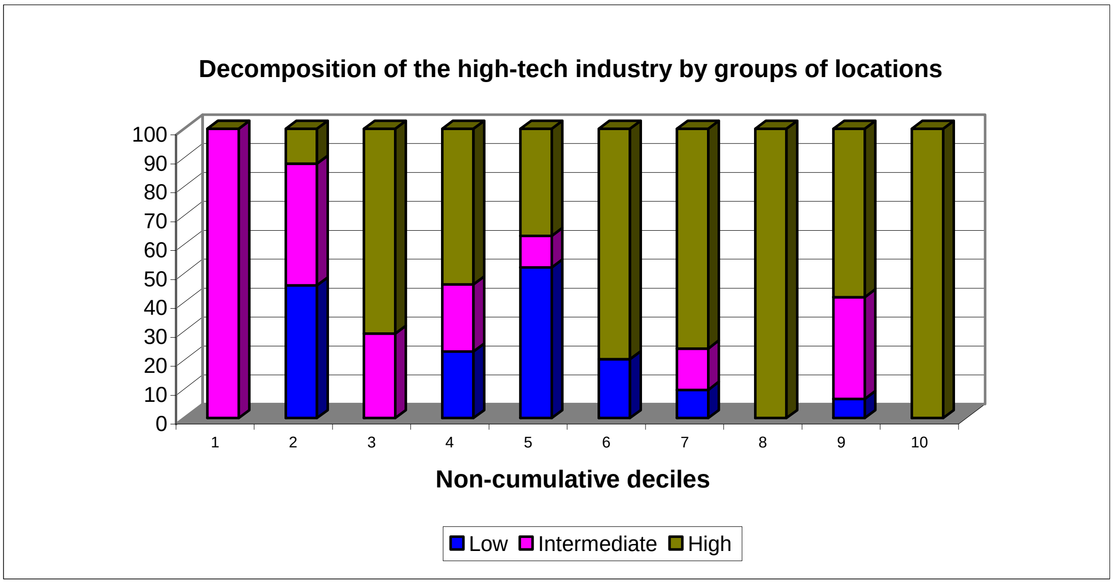


**Figure 8**: The high-tech industry: Decomposition (2) by groups of provinces (education).

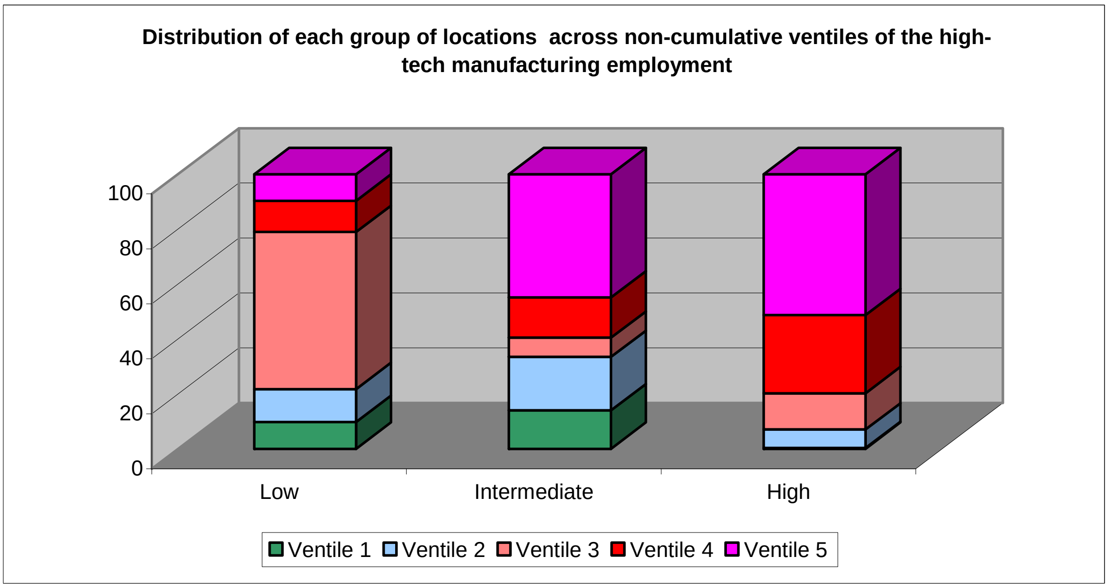


**Figure 9**: The high-tech industry: Decomposition (3) by groups of provinces (education)

On the other hand, as shown in Figure 9 (using expression (3) for ventiles; i.e., $\tilde{L}_{(\tilde{x}^k;t)}(\tau_l+0.2)-\tilde{L}_{(\tilde{x}^k;t)}(\tau_l)$), while over 51% (44%, respectively) of the high-tech employment located in provinces with high (intermediate, respectively) education are concentrated in the fifth ventile of the high-tech industry, less than 10% of the high-tech employees located in provinces with low human capital are in the fifth ventile. In other words, the high-tech industry located in provinces with high and intermediate level of education tends to agglomerate at a higher extent.[15]

Regarding the medium-high-tech industry, we find that the relationship between localization and human capital is weaker, even though this sector tends to concentrate in provinces with intermediate and high human capital level (Figure 10).[16] With respect to the medium-low-tech industry, we find that in this industry the weight of provinces with low human capital is much higher than in the remaining industries (the low-tech included), even though this weight decreases in the top deciles (Figure 11). Finally, we see that the low-tech industry tends to concentrate in provinces with low and intermediate levels of human capital (Figure 12).

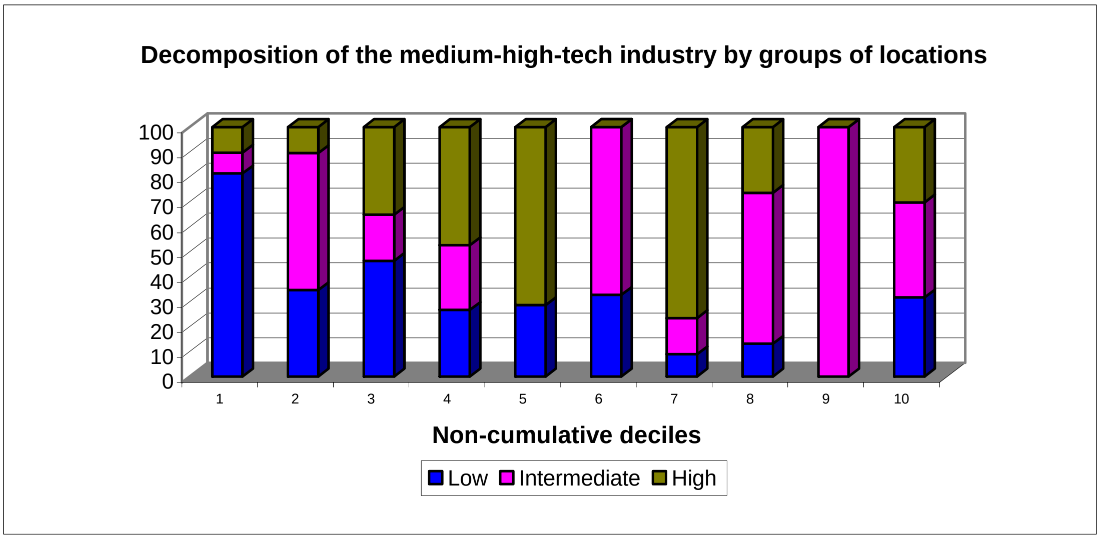


**Figure 10**: The medium-high-tech industry: Decomposition (2) by groups of provinces (education).

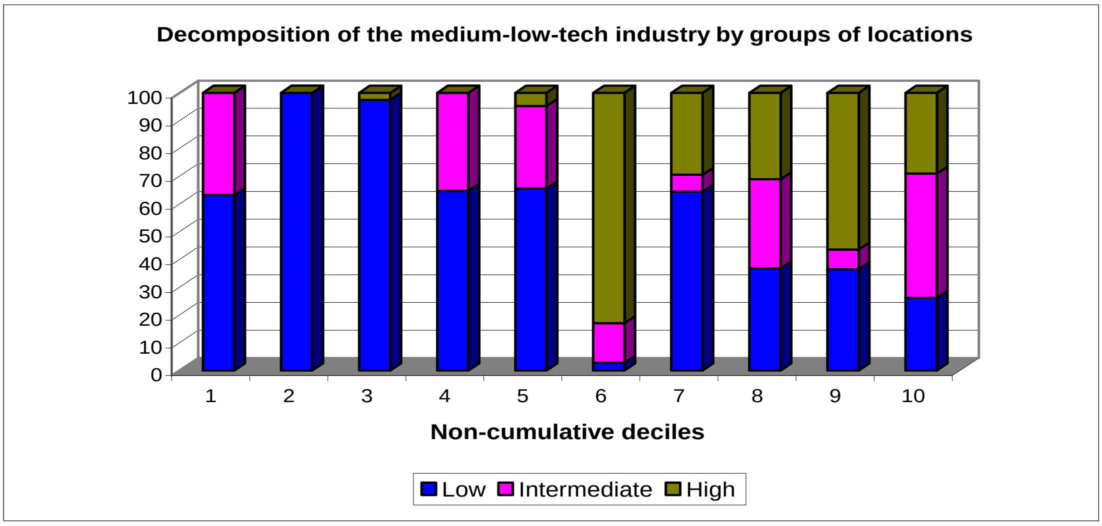


**Figure 11**: Medium-low-tech industry: Decomposition (2) by groups of locations (education level).

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[15] When using decomposition (3) for the remaining industries, we find that in general, the concentration intensity tends to be lower in the group of provinces with lower human capital (see Figures A4-A6 in the Appendix).

[16] In Figure 10, locations are ranked according the corresponding ratio for the medium-high-tech group.

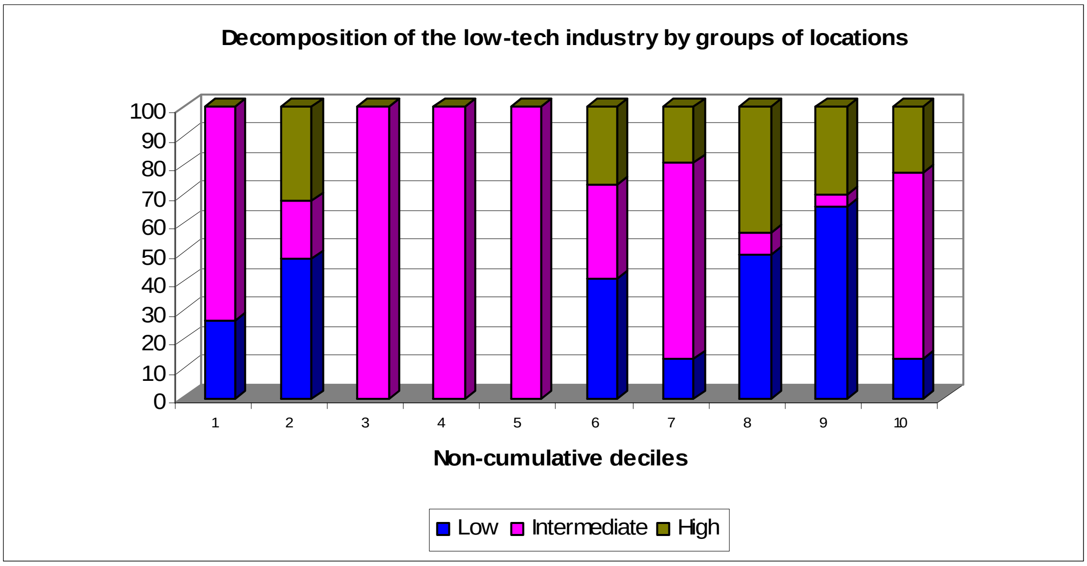


**Figure 12**: Decomposition of the low-tech industry by groups of locations.

## 5. Conclusions

This paper has characterized the Lorenz curves used to measure the geographic concentration of economic activity in terms of basic axioms. This analysis has allowed us to unveil the properties that the literature on regional economics is implicitly assuming when using these curves. This paper has also offered two decompositions of these curves since, as far as we know, no decompositions have yet been suggested in the field. One is obtained when locations are partitioned into different groups, while the other is obtained by classifying the sector into several subsectors.

These curves and their decompositions have been used to analyze the concentration of manufacturing industries in Spain in 2008. By grouping industries according to their technological intensity, we find evidence that in Spain the high-tech industry tends to concentrate in space at a higher extent than the remaining industries, especially in the case of *aircraft and spacecraft* and *office, accounting, and computing machinery*.

This result is in line with that previously obtained by Alonso-Villar et al. (2004) by using other concentration measures, which suggests that our finding for Spain seems rather robust. This pattern departs, however, from what was suggested by other scholars when studying the geographic concentration of manufacturing industries in other countries at a two-or-more digit level, since those studies find either evidence of remarkable concentration levels both in high- and low-tech sectors (as Maurel and Sédillot, 1999, in France; Bertinelli and Decrop, 2005, in

Belgium; and Guimarães et al., 2007, in Portugal), or did not find evidence of higher concentration for high-tech industries (as pointed out by Devereux et al., 2004, in the UK).

Finally, even though the relationship between technological intensity and spatial concentration does not seem monotonic, we have shown that high-tech industries in Spain tend to concentrate in locations with the highest human capital level in the country, while the low-tech industry tends to do it in provinces with low and intermediate levels. This finding is line with those obtained by García Muñiz et al. (2009) and Baptista and Mendonça (2009), since the former find that in Spain high and medium technological sectors are more efficient than the remaining sectors and foster knowledge diffusion in the system, while the latter give evidence of the importance of local access to knowledge and human capital to explain the entry of knowledge-based firms. All the above suggests that the agglomeration of high technology industries is a detectable phenomenon in Spain, and also that knowledge spillovers may be working as an important source of agglomeration in this kind of sector.

## Appendix

### *A) Expressions of the locational Gini index and the GE family*

$$G = \frac{\sum_{l,l'} \frac{t_l}{T}\frac{t_{l'}}{T}\left|\frac{x_l}{t_l} - \frac{x_{l'}}{t_{l'}}\right|}{2\frac{X}{T}}$$

$$\Psi_\alpha(x;t) = \begin{cases} \frac{1}{\alpha(\alpha-1)}\sum_l \frac{t_l}{T}\left[\left(\frac{x_l/X}{t_l/T}\right)^\alpha - 1\right] & \text{if } \alpha \neq 0,1 \\ \sum_l \frac{x_l}{X}\ln\left(\frac{x_l/X}{t_l/T}\right) & \text{if } \alpha = 1 \end{cases}$$

### *B) Decomposition by subsectors*

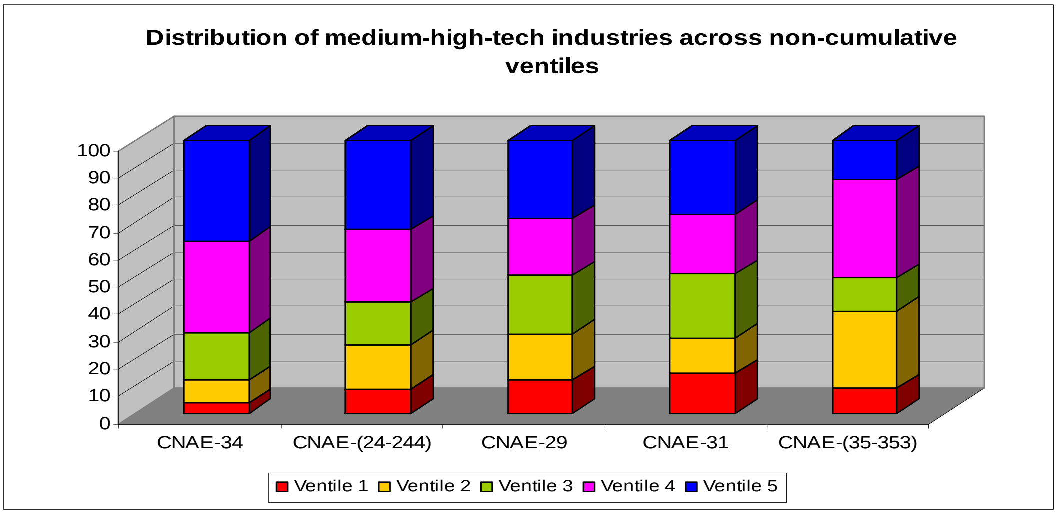


**Figure A1**: The medium-high-tech industry: Decomposition by subindustries (expression (6)).

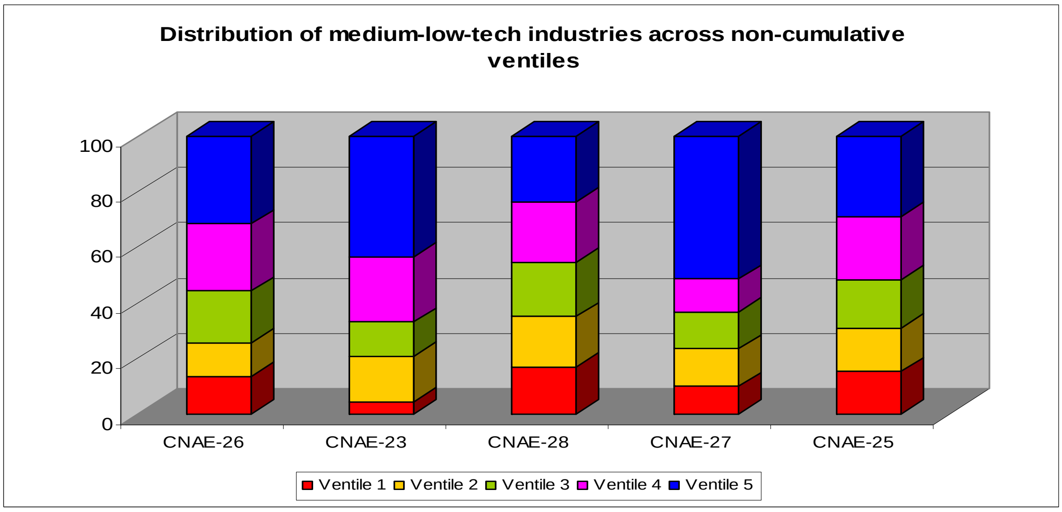


**Figure A2**: The medium-low-tech industry: Decomposition by subindustries (expression (6)).

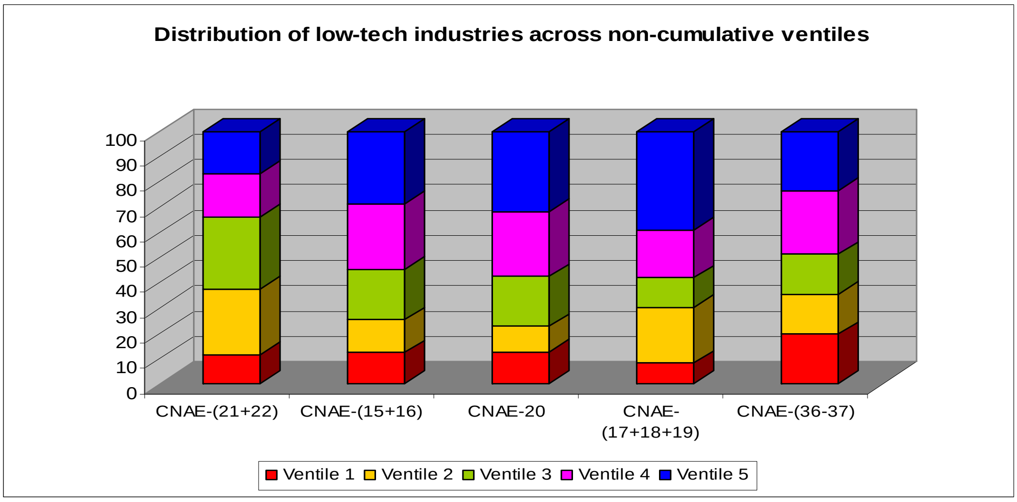


**Figure A3**: The low-tech industry: Decomposition by subindustries (expression (6)).

### *C) Decomposition by locations*

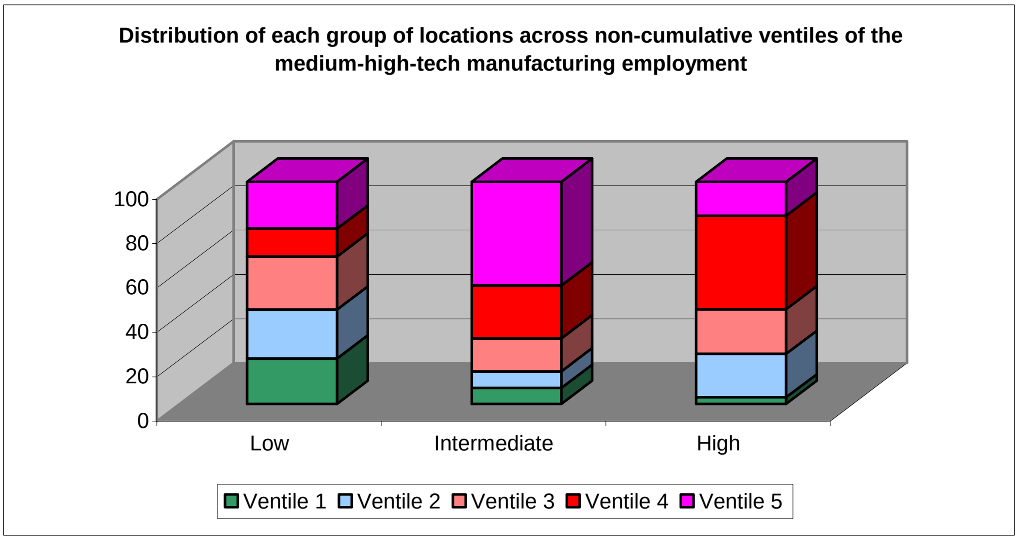


**Figure A4**: The medium-tech industry: Decomposition (3) by groups of provinces (education)

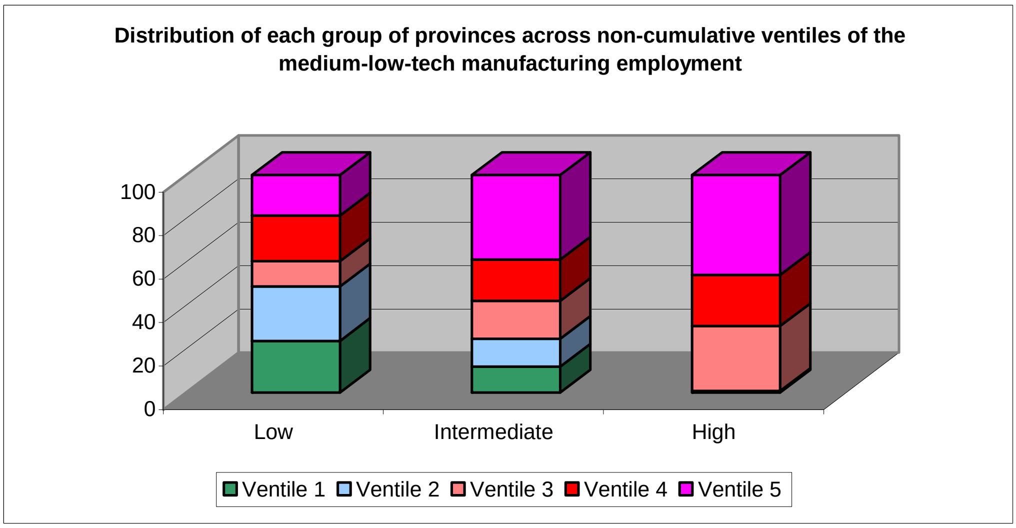


**Figure A5**: The medium-low-tech industry: Decomposition (3) by groups of provinces (education)

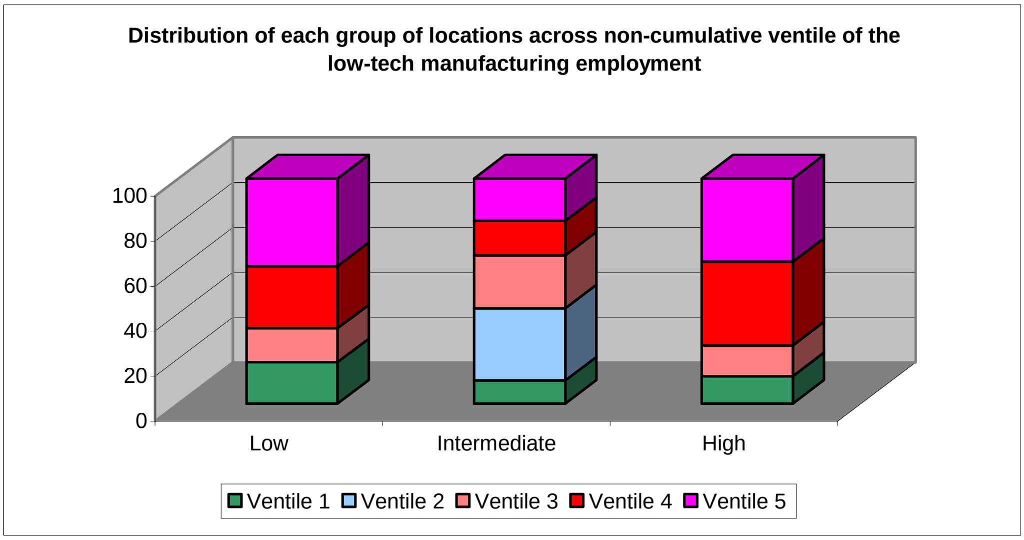


**Figure A6**: The low-tech industry: Decomposition (3) by groups of provinces (education)

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