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On the automatic application of inequality indexes in the analysis of the international distribution of environmental indicators

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Abstract

In recent years traditional inequality measures have been used to quite a considerable extent to examine the international distribution of environmental indicators. One of its main characteristics is that each one assigns different weights to the changes that occur in the different sections of the variable distribution and, consequently, the results they yield can potentially be very different. Hence, we suggest the appropriateness of using a range of well-recommended measures to achieve more robust results. We also provide an empirical test for the comparative behaviour of several suitable inequality measures and environmental indicators. Our findings support the hypothesis that in some cases there are differences among measures in both the sign of the evolution and its size.

JEL codes: D39; Q43; Q56.

Keywords: international environment factor distribution; Kaya factors; Inequality measurement

1. Introduction

In recent years inequality measures have increasingly been used to analyse the international distribution of environmental indicators. Among others, the following studies have been made: Heil and Wodon (1997, 2000), Sun (2002), Alcántara and Duro (2004), Hedenus and Azar (2005), Padilla and Serrano (2006), Duro and Padilla (2006), Ezcurra (2007), Cantore and Padilla (2010) or Duro, Alcántara and Padilla (2010).[1]

The literature on the measurement of inequality, which initially focused on the analysis of income distribution, has a long tradition and was strongly influenced by the work of Theil (1967), Atkinson (1970), Sen (1983) and Cowell (1995). Among its main prominent features, this literature focuses on analysing the properties of the different measures and determining whether these satisfy a set of minimum requirements (i.e. axioms). In addition to these basic properties, the literature has paid attention to an additional feature that can be used to make a stricter selection of measures for the convenience of the researcher: the weight they attach to the place where distributional changes occur.

Indeed one of the main differences among inequality indexes is how the different segments of the distribution are treated. For example, the well-known Gini coefficient (Gini (1912)) weights further changes in the observations located around the mean. The Theil family of inequality indexes (Theil (1967)) gives different measures precisely in the way observations are treated, from the most "progressive" measures—that is the ones which are more sensitive to changes in the lower part of the distribution (such as T (0))—to the less sensitive. A similar situation occurs with the family of Atkinson measures (Atkinson (1970). The coefficient of variation, a measure associated with a statistical conceptualization of inequality, is neutral in this regard, and treats the different observations uniformly, regardless of their location on the distribution.

Progressive indexes, which attach more weight to the changes in the lower ranks of the distribution, have been specially valued by researchers performing income distribution

[1] The international distribution of environmental indicators has also been analyzed on the basis of other distributive approaches that are radically different to the inequality approach, as is the case of the polarization approach (Duro and Padilla (2008)) and mobility (Ezcurra (2007)).

analysis. Therefore, certain measures from the Atkinson or Theil family of indexes would be potentially more attractive than the most widespread measures.

This preference, however, is more open to discussion in the case of environmental applications. Some researchers may disagree with focusing attention on those countries with lower levels of pollution in order to reduce their differences from the mean (for example, in terms of per capita CO_2 emissions) and even may suggest the attractiveness of regressive measures (i.e. those that attach greater importance to changes in income distribution at the top, where the economic cost of reducing emissions may be lower).

In such circumstances, where there is no strong preference between progressive and regressive measures, neutral indexes like the coefficient of variation may be an interesting choice, in the sense that there is no obligation to favour any observation of the distribution.

Therefore, it would seem reasonable to consider working with a battery of measures that are sufficiently heterogeneous in their treatment of the observations. This procedure will make the analysis more robust and avoids conclusions that may be biased. Scientific literature, however, does not seem to have paid much attention to this aspect so far. Researchers have been using alternatives without being aware of the implications.

Given this scenario, this paper wishes to make a methodological contribution to the literature on environmental inequality by reviewing the main features of several commonly used measures, providing an empirical illustration of the use of a selection of samples for various well-known environmental indicators—all related to the Kaya identity (1989)—and assessing whether the patterns are sensitive to the measures used.

The paper is organized as follows. The second section analyses the main methodological issues associated with the need to manage an array of indicators on environmental distributional analysis. The third section gives an empirical illustration for international cases and various environmental indicators such as CO_2 per capita, carbonization index and energy intensities for the period 1971-2006. Finally, the last section draws conclusions.

2. Methodological issues

The literature on the measurement of inequality (Theil (1967), Atkinson (1970), Sen (1983) and Cowell (1995)) has identified a number of basic properties that an index of inequality should satisfy: scale independence, population size independence and the principle of transfers.[2] Two other appealing properties have also been added: first, the particular sensitivity of the different indexes to the point of the distribution where redistributive changes take place, the central topic of this paper, and, secondly, the possibility that they can be decomposed into factors (Duro and Padilla (2006)).

Among the indicators that meet the basic properties are the well-known Gini coefficient (Gini (1912)), the Theil family of indexes (Theil (1967)), the Atkinson family of indexes (Atkinson (1970)) and the coefficient of variation, which comes from the field of statistical research. With regard to the first additional property, the choice of the best index lies in the hands of the researchers, and ultimately depends on their value judgement. In any case, the applied literature in the field of income distribution, which is the most profuse, has given particular value to more progressive rates because they are more sensitive to improvements in the observations located at the bottom of the scale distribution.

At this point we feel that it would be useful to review how the most widely used and recommended measures in the literature on inequality measurement treat the different segments of income distribution.

The most widely used measurement is the Gini coefficient (Gini (1912)). Based on the well-known Lorenz curve, it is defined as twice the area between the curve and the line of perfect equality. It can be expressed as follows:

[2] *Scale-independent*: the inequality measure remains unaltered by changes of the same proportion in all the observations. This property means that inequality can be considered as a relative problem.
Population-independent: the inequality measure remains unaltered by changes of the same proportion in the number of observations at every level of the variable.
Principle of transfers: any transfer from an observation with a high level of a variable to an observation at a lower level that does not invert the relative rankings should reduce the level of the inequality measure.

$$G = \frac{1}{2\mu}\sum_i \sum_j p_i p_j \left| y_i - y_j \right| \qquad (1)$$

where p_i and p_j are the relative weights of the observations, y_i is the realization of the variable for the observations (income, emissions, etc) and μ is the sample average.

Although this measure satisfies the basic axioms, one of its properties is that it places greater emphasis on distributional changes that take place in the centre of the distribution, and gives a symmetric weight to changes at the ends. Thus, it seems reasonable not to agree on this kind of behaviour. In the analysis of income, for example, researchers often wish to use measures that are more "sensitive" to what happens at the bottom of the distribution (progressive measures). If this is the case, we will have to shift our attention to such alternative measures as the Theil family of indexes, which also provide a general framework within which this issue can be dealt with.

Theil (1967) proposed a very interesting family of inequality measures based on the concept of entropy used in information theory. Its general expression is given by:

$$T(\beta) = \frac{1}{\beta(\beta - 1)}\sum_i p_i \left[\left(\frac{y_i}{\mu} \right)^{\beta} - 1 \right] \qquad (2)$$

The β parameter precisely captures what we are looking for: the sensitivity of the measure to the place where distributional changes occur. In particular, the smaller this value is, the more sensitive the measure is to changes at the bottom of the ranking of observations (more progressive). At the limit, when β tends to $-\infty$ the index only pays attention to what happens at the lower end of the distribution. In contrast, the larger the parameter is, the more sensitive the measure is to changes at the top of the distribution. In fact, for values of β greater than 2 the index only seems to show sensitivity to the equalization among the richest of the distribution[3.]

[3] In fact, as we will see below, T(2) is already a neutral index and ordinally equivalent to the coefficient of variation.

The measures in this family that have been most studied are T(0) and T(1), whose algebraic expressions are:

$$T(\beta = 0) = -\sum_i p_p \log\left(\frac{\mu}{y_i}\right) \qquad (3)$$

$$T(\beta = 1) = \sum_i p_p \left(\frac{y_i}{\mu}\right) \log\left(\frac{y_i}{\mu}\right) \qquad (4)$$

In order to have different perspectives, it seems useful, then, to use both T(0) and T(1) as reference indexes, the first being more progressive than the second.

Another family of indexes that has been the subject of considerable attention in the literature is the group of distributive-based social welfare functions, among which is the Atkinson index (Atkinson (1970)). Restricting the analysis to one particular type of function, the author defines a family of normative indexes given by the following general expression:

$$A(\varepsilon) = 1 - \left[\sum_i p_i \left(\frac{y_i}{\mu}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} \qquad (5)$$

where ε is defined as the parameter of the degree of social inequality aversion.

For ε = 0 there is no aversion to inequality (i.e. the Benthamite welfare function). As the value of ε increases so does aversion, and in the limit as ε tends to infinity, social welfare only considers the poorest observation (i.e. the Rawlsian criterion).

In fact, the Theil indexes are an increasing monotonic transformation of the Atkinson indexes, for ε> 0 and ε different from 1. Thus, A(ε) and T(β) for ε> 0 and β = 1 - ε are ordinally equivalent rates. Note that values of ε> 0 imply β <1, so high levels of inequality aversion lead to very negative β values. To put it in another way, our T(0) is ordinally equivalent to a (1). Thus, if we wish to consider a wide range of indexes we should select values of ε not only between 0 and 1 but also greater than 1. In the empirical section we propose that A(0.5) be used as a representative of a low degree of aversion to inequality and A(2) as indicative of high aversion.

Finally, we should point out the advantages of the coefficient of variation (CV) as a summary measure of dispersion. The coefficient of variation is the division of the sample average by the standard deviation of the distribution, and satisfies the three basic axioms mentioned earlier. If we take the square of the CV and divide it by two, the measure is ordinally equivalent to T(2). An important feature of this measure is that it values redistributive changes inside the distribution uniformly. Therefore, it is irrelevant to the computations where the observations are in the distribution. This distributive neutrality, assessed in a rather negative way by most income distribution studies, is not so negative in environmental applications, in which the results provided by this measure may be valuable for interpreting the results.

$$CV_{\omega} = \frac{\sigma_{\omega}}{\mu} \qquad (6)$$

where σ_w is the weighted standard deviation and μ the average value.

Therefore, the most widely used inequality measures differ in the attention they give to changes in the different segments of income distribution. This is clearly significant in applications on the income space but it is even more important in extensions to environmental analysis since, in these cases, the preference for indexes that are more dependent on changes at the bottom of the ranking is even more questionable. We understand, then, that in studies that analyze the behaviour of distributional indicators such as per capita CO_2 emissions or energy intensities, it is especially appropriate to compare the patterns suggested by a wide range of inequality indexes, because this would make the analysis more robust. The use of a single category, without specifying the reason for its use, can generate biased results, the more so because the patterns revealed different measures that are not very consistent.

Table 1: Properties of the most frequently used inequality indexes

	Satisfaction basic axioms	Sensitivity	Decomposable capacity
Gini	Yes	Distributive mean	Difficult
Theil indexes	Yes	Varied	Easy
Atkinson indexes	Yes	Varied	No
Variation coefficient	Yes	Neutral	Difficult

Source: own elaboration

The literature on the international distribution of environmental factors has increased significantly in recent years. Without being exhaustive, we can cite the work of Heil and Wodon (1997 and 2000), Sun (2002), Alcántara and Duro (2004), Hedenus and Azar (2005), Padilla and Serrano (2006), Duro and Padilla (2006), Ezcurra (2007) and Duro, Alcántara and Padilla (2010). In all cases, the authors have applied inequality measures to the analysis of distributional issues associated with environmental magnitudes. Specifically, Heil and Wodon (1997) use the Gini index of inequality to analyze international per capita CO_2 emissions. In a later study, the same authors (Heil and Wodon (2000)) used the same measure to analyse future emissions inequality using the predictions for the year 2100. Sun (2002) examines international disparities, but focuses on energy intensities across OECD countries and takes the average deviation (unweighted) as a measure of inequality. Meanwhile, Alcántara and Duro (2004) re-evaluate the differences in energy intensities, but use the decomposable T(0) Theil index. Hedenus and Azar (2005) use the Atkinson Inequality index to analyze the evolution of inequality in various natural resources. Padilla and Serrano (2006) use concentration indexes, the Gini coefficient and the Theil index to show the contribution of four groups to Income Inequality. Duro and Padilla (2006) decompose the international inequality of CO_2 emissions into several factors and interaction terms by using T(0), and they also make a between- and within-groups analysis of countries to explain the main source of inequality in emissions. Ezcurra (2007) performs an analysis of the international distribution of energy intensities using, among other descriptive tools, the CV and the standard deviation of logarithms. Duro, Alcántara and Padilla (2010) use T(0) to analyse the inequality of energy intensity levels between OECD countries.

With such diversity, and given the fact that little attention has been paid to this issue up to now, we believe that it may be useful to assess the robustness of the distributional outcomes when different inequality measures are used.

3. Some empirical results

This section analyzes the distributional international inequalities for a number of very familiar environmental indicators such as per capita CO_2 emissions, the carbonization index or energy intensities (following Kaya's approach (1989)), and using a variety of inequality measures widely used in the literature on inequality measurement. We have chosen the Gini coefficient (which focuses on the observations of the distribution medium); the two commonly used Theil indexes, the more progressive T(0) and the less progressive T(1); two indexes from the Atkinson family, A(0.5) (only slightly progressive) and A(2) (very progressive); and the CV, because it is neutral. The data, which consists of 117 observations, come from the IEA and cover the period 1971-2006.

Figure 1 reproduces the calculations associated with international inequality in per capita CO_2 when they are weighted heterogeneously (through population-shares) and the weighting is uniform. A simple look at the results reveals two points of immediate interest: first, the evolution of A(2) is far more stable than that of the rest of the indicators. According to A(2), in the period 1971-2006 international inequality in per capita emissions decreased by 6.4%, but according to the rest it decreased by much more. Secondly, the overall magnitude of the reduction is not too equivalent. Thus, while the Gini shows a decrease of 20%, the T(0) decreases by twice as much. In Table

2 we have reproduced some examples of disparities. Without being spectacular, for example, it can be observed that in the 1995-2000 sub-period T(0) reveals a fall in inequality of almost 3% while, in contrast, CV reflects an increase of 2.4%. Indeed, the 2001-2006 period of observation of T(1) and CV shows a marked reduction of over 12% in international disparities in per capita emissions when A(2) also rises, although by only a slight 0.4% .

When the entire sample of countries is attributed uniform weights, A(2) is once again revealed to be stable over time. For the other measures, although the trend is decreasing, there are discrepancies in the magnitude of the decline, which is more pronounced in the case of CV (-43%). Again, detailed observation shows changes in rates of opposite sign, as is the case of the sub period 1994-2006, in which T(0) falls by 10% while the CV increases by about 1%.

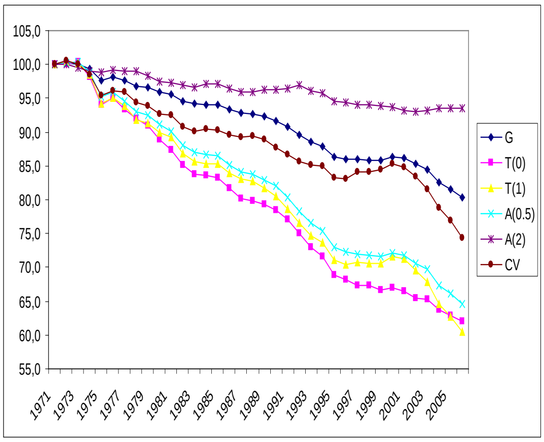
When international disparities are analysed by the carbonization index, each country is assigned a relative weight in terms of TEP. Again discrepancies are found in the temporal patterns depending on the measure used. Thus, in the years 1988-1990 G falls 1.5%, while T(0) rises by 6.4%. The use of the entire sample with a uniform weight also shows some episodes where patterns emerge that are fundamentally divergent in terms of the measures.

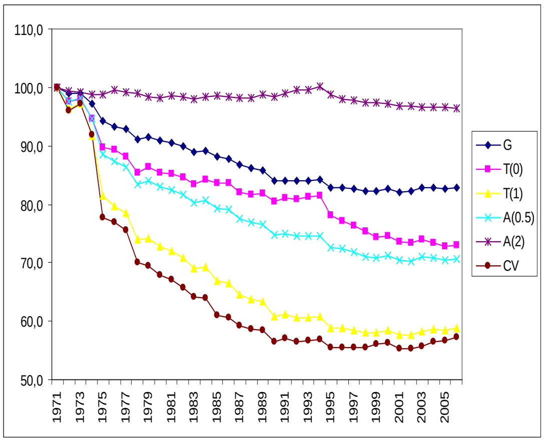
In the sub period 1979-1991, the analysis of international differences in energy intensities (weights are now based on the GDP-shares) shows that T(0) shows a fall of almost 10% in disparities while CV reveals a negligible 0.1% increase and A(2) a decrease of 15%.

In short, when the temporal dynamics of the various measures discussed above are observed in detail, significant differences arise and not only in the scale. In overall terms, the evolution of the A(2) measure, which takes particular account of the convergence recorded in the observations located at the bottom of the scale distribution, is quite different to that of other measures.

Figure 1: International inequality of per capita CO_2 emissions, 1971-2006

a) Weighted computations *b)Non-weighted*

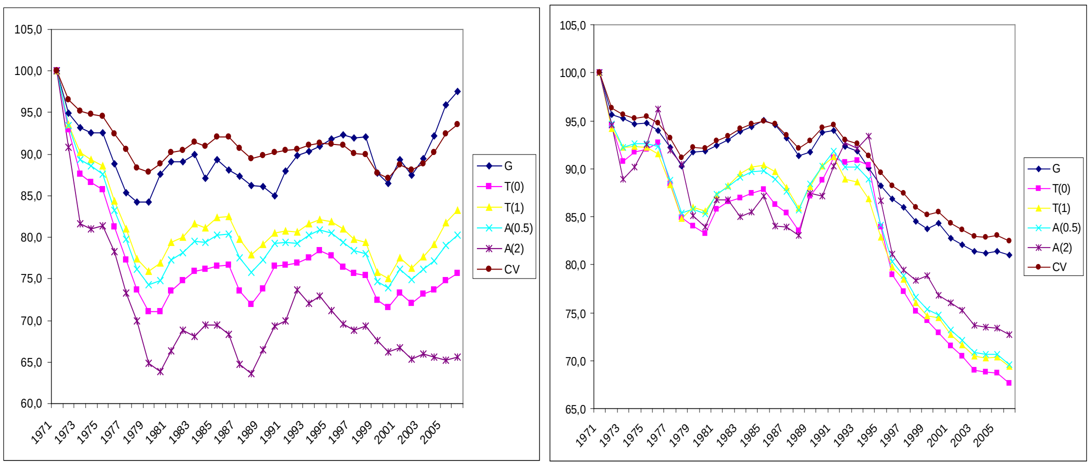




Source: Own elaboration based on International Energy Agency data (2008)

Figure 2: International inequality of carbon indexes, 1971-2006

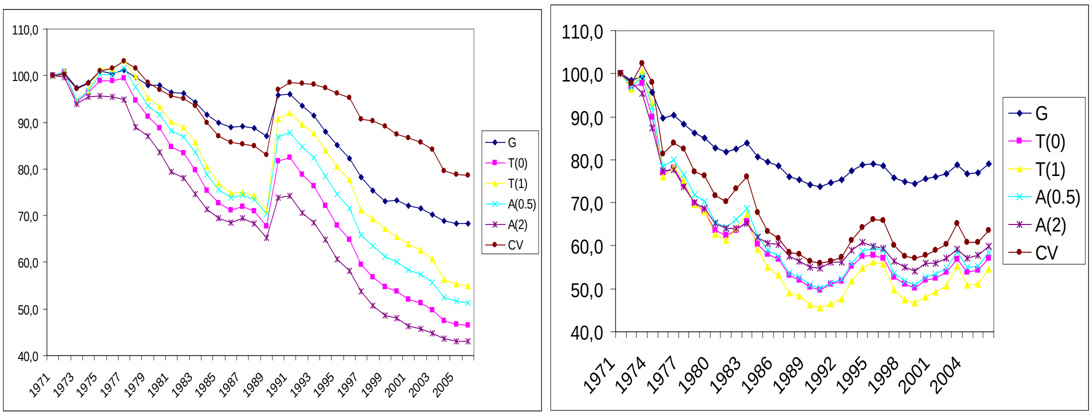
a) Weighted computations b) Non-weighted



Source: Own elaboration based on International Energy Agency data (2008)

Figure 3: International inequality of energy intensities, 1971-2006

a) Weighted computations *b) Non-weighted*



Source: Own elaboration based on International Energy Agency data (2008)

Table 2: Examples of differences among inequality estimates according to several environmental indicators

	G	T(0)	T(1)	A(0.5)	A(2)	CV
CO_2 per capita emissions						
Weighted						
1995-2000	-0.1%	-2.7%	0.7%	-1.0%	-0.8%	2.4%
2001-2006	-6.7%	-6.6%	-15.0%	-10.1%	0.4%	-12.3%
1971-2006	-19.7%	-37.9%	-39.5%	-35.4%	-6.4%	-25.6%
Non weighted						
1983-1994	-5.4%	-2.4%	-11.8%	-7.0%	2.1%	-11.3%
1994-2006	-1.6%	-10.4%	-3.1%	-5.2%	-3.7%	0.9%
1971-2006	-17.1%	-27.1%	-41.1%	-29.3%	-3.5%	-42.7%
Carbon indexes						
Weighted						
1988-1990	-1.5%	6.4%	3.4%	4.7%	8.9%	0.8%
1992-1998	2.4%	-1.8%	-1.6%	-1.6%	-6.0%	-0.7%
1971-2006	-2.4%	-24.3%	-16.7%	-19.7%	-34.4%	-6.5%
Non.weighted						
1973-76	-1.3%	2.1%	-0.8%	0.2%	8.2%	-0.9%
1978-1980	1.8%	-2.0%	1.0%	-0.1%	-7.2%	1.1%
1985-1994	-5.2%	2.9%	-3.9%	-1.0%	7.1%	-3.9%
Energy intensities						
Weighted						
1972-1979	-2.6%	-9.5%	-5.5%	-7.2%	-12.7%	-1.8%
1979-1991	-1.9%	-9.6%	-3.3%	-6.1%	-14.7%	0.1%
1991-2003	-4.8%	-7.4%	-4.9%	-6.2%	-7.7%	-0.4%
Non.weighted						
1972-1974	-2.7%	-7.1%	-3.4%	-4.8%	-10.7%	0.3%
1983-2006	-5.8%	-13.0%	-19.0%	-15.1%	-8.1%	-16.6%
1971-2006	-21.0%	-42.8%	-45.6%	-41.6%	-40.1%	-36.5%

Source: Own elaboration based on International Energy Agency data (2008)

4. Concluding remarks

In recent years some traditional inequality measures have been used to quite a considerable extent to examine the international distribution of environmental indicators. Among the battery of well-recommended inequality indexes, the inequality measurement literature has traditionally focused on the properties of the Gini, the Theil index family, the Atkinson family and the coefficient of variation. In this sense, one of its main characteristics is that each measure weights the places at which distributional changes occur differently and, consequently, the results they yield can potentially be very different. The scientific literature produced in the field of the environment to date seems to have paid little attention to this issue. Therefore, this paper proposes to use a broad range of inequality measures in order to capture comprehensive evidence of reality and to provide results that are sufficiently robust. In addition to making theoretical recommendations on the use of multiple measures in studies of the international distribution of environmental factors, we wanted to provide a comparative empirical exercise for three environmental factors linked to the Kaya identity (1989) in the international scenario. In this regard, and although there are no dramatic discrepancies we have found that in some cases the magnitude of the change and even the direction of the change can differ significantly depending on the inequality measure used.

Therefore, given the impossibility of recommending an ex-ante superior measure, it seems reasonable to observe how different suitable measures behave. Obviously, assessing other properties, such as their ability to decompose, can help us to further restrict the recommended measures (Duro and Padilla (2006)).

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APPENDIX

Table A.1. International inequalities on per capita CO_2 emissions (selected years 1971-2006)

	G	T(0)	T(1)	A(0.5)	A(2)	CV
Weighted						
1971	0.6769	1.1252	0.8538	0.3986	0.8914	1.5115
1975	0.6615	1.0586	0.8046	0.3795	0.8804	1.4418
1980	0.6496	0.9999	0.7675	0.3633	0.8689	1.4001
1985	0.6361	0.9364	0.7277	0.3446	0.8650	1.3656
1990	0.6207	0.8831	0.6874	0.3269	0.8574	1.3266
1995	0.5848	0.7747	0.6068	0.2906	0.8427	1.2589
2000	0.5840	0.7540	0.6108	0.2878	0.8358	1.2887
2006	0.5438	0.6982	0.5166	0.2576	0.8340	1.1241
Non-weighted						
1971	0.6934	1.1850	0.9870	0.4170	0.9211	2.1092
1975	0.6531	1.0634	0.8040	0.3695	0.9095	1.6403
1980	0.6302	1.0118	0.7187	0.3463	0.9052	1.4306
1985	0.6113	0.9908	0.6597	0.3310	0.9083	1.2862
1990	0.5830	0.9529	0.6007	0.3119	0.9070	1.1915
1995	0.5748	0.9251	0.5810	0.3026	0.9091	1.1717
2000	0.5727	0.8837	0.5773	0.2967	0.8947	1.1883
2006	0.5745	0.8642	0.5817	0.2951	0.8891	1.2094

Source: Own elaboration based on International Energy Agency data (2008).

Table A.2. International inequalities on carbon indexes (selected years 1971-2006)

	G	T(0)	T(1)	A(0.5)	A(2)	CV
Weighted						
1971	0.1162	0.0603	0.0381	0.0230	0.2287	0.2433
1975	0.1076	0.0517	0.0338	0.0201	0.1860	0.2302
1980	0.1018	0.0429	0.0293	0.0172	0.1459	0.2161
1985	0.1038	0.0462	0.0314	0.0184	0.1589	0.2240
1990	0.0987	0.0461	0.0307	0.0182	0.1585	0.2194
1995	0.1068	0.0469	0.0312	0.0185	0.1628	0.2220
2000	0.1005	0.0432	0.0286	0.0170	0.1514	0.2120
2006	0.1134	0.0457	0.0318	0.0185	0.1501	0.2275
Non-weighted						
1971	0.2881	0.2287	0.1534	0.0882	0.5198	0.5071
1975	0.2730	0.2105	0.1415	0.0816	0.4811	0.4841
1980	0.2646	0.1904	0.1313	0.0752	0.4362	0.4674
1985	0.2738	0.2009	0.1386	0.0792	0.4529	0.4817
1990	0.2701	0.2031	0.1384	0.0796	0.4529	0.4782
1995	0.2541	0.1920	0.1271	0.0742	0.4502	0.4541
2000	0.2429	0.1668	0.1142	0.0659	0.3991	0.4338
2006	0.2333	0.1547	0.1064	0.0614	0.3777	0.4183

Source: Own elaboration based on International Energy Agency data (2008).

Table A.3. International inequalities on energy intensities (selected years 1971-2006)

	CV	G	T(0)	T(1)	A(0.5)	A(2)
Weighted						
1971	0.2678	0.1287	0.1227	0.0607	0.2407	0.5216
1975	0.2707	0.1273	0.1243	0.0609	0.2301	0.5269
1980	0.2623	0.1142	0.1145	0.0557	0.2014	0.5062
1985	0.2410	0.0936	0.0943	0.0460	0.1672	0.4544
1990	0.2564	0.1051	0.1112	0.0528	0.1777	0.5064
1995	0.2278	0.0874	0.0987	0.0453	0.1462	0.5023
2000	0.1960	0.0692	0.0804	0.0365	0.1157	0.4558
2006	0.1829	0.0599	0.0673	0.0311	0.1039	0.4097
Non-weighted						
1971	0.4108	0.2911	0.3353	0.1434	0.4303	1.0769
1975	0.3679	0.2240	0.2551	0.1124	0.3332	0.8757
1980	0.3396	0.1853	0.2101	0.0940	0.2801	0.7710
1985	0.3263	0.1686	0.1842	0.0847	0.2608	0.6819
1990	0.3028	0.1448	0.1529	0.0720	0.2353	0.6032
1995	0.3249	0.1679	0.1885	0.0853	0.2577	0.7130
2000	0.3108	0.1513	0.1616	0.0756	0.2406	0.6235
2006	0.3245	0.1664	0.1826	0.0838	0.2578	0.6842

Source: Own elaboration based on International Energy Agency data (2008).