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Juan Antonio Duro
Jordi Teixidó-Figueras

Document de treball n.27- 2013

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ROVIRA I VIRGILI
DEPARTAMENT D'ECONOMIA

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Edita:

Departament d'Economia
www.fcee.urv.es/departaments/economia/public_html/index.html
Universitat Rovira i Virgili
Facultat d'Economia i Empresa
Avgda. de la Universitat, 1
43204 Reus
Tel.: +34 977 759 811
Fax: +34 977 300 661
Email: sde@urv.cat

CREIP
www.urv.cat/creip
Universitat Rovira i Virgili
Departament d'Economia
Avgda. de la Universitat, 1
43204 Reus
Tel.: +34 977 558 936
Email: creip@urv.cat

Adreçar comentaris al Departament d'Economia / CREIP

Dipòsit Legal: T - 1398 - 2013

ISSN edició en paper: 1576 - 3382
ISSN edició electrònica: 1988 - 0820

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Juan Antonio Duro and Jordi Teixidó-Figueras

Depart of Economics and CREIP, Universitat Rovira i Virgili, Av. de la Universitat, 1, 43204 Reus, Spain. Email: juanantonio.duro@urv.net

Abstract

Up until now, analyses of the international distribution of pollutant emissions have not paid sufficient attention to the implications that, in terms of social welfare, the combined evolution of the global world average entails. In this context, this paper proposes the use of environmental welfare indices, taken and adapted from the literature on social welfare and inequality, in order to make a comprehensive examination of the international equity factor and the mean factor in this field. The proposed methodology is implemented empirically in order to explore the evolution in distributive-based environmental welfare on a global level for the three main pollutants with greenhouse gas effects: CO_2, CH_4 and NO, both globally and for selected years during the period of 1990-2005. The main results found are as follows: firstly, typically, the environmental welfare associated with the overall greenhouse gases decreased significantly over the period, due primarily to the role of CO_2; secondly, in contrast, the global welfare associated with CH_4 and NO improved; and thirdly, typically, the evolutions can be attributed to a greater extent to the mean component than to the distributive component, although there are exceptions. These results would seem to be relevant in policy terms.

JEL codes: D39; Q43; Q56.

Keywords: environmental welfare: greenhouse gases; environmental equity:

1. Introduction

In recent years, a significant number of papers have appeared analysing the international distribution of environmental indicators based on the approach of inequality or convergence. Some examples of these, though by no means an exhaustive list, are Heil and Wodon (1997, 2000), White (2000, 2007), Sun (2002), Strazicih and List (2003), Alcántara and Duro (2004), Hedenus and Azar (2005), Padilla and Serrano (2006), Aldi (2006), Duro and Padilla (2006), Ezcurra (2007), Cantore and Padilla (2010), Jobert et al. (2010), Steinberger et al. (2010), Cantore (2011) and Duro (2012).

Essentially, the approach entails establishing a correlation between the evolution of inequality, typically obtained from different synthetic indices consistent with the approach of Lorenz (Lorenz, 1902), and the degree of the global environmental problem. In this way, the higher the inequality, or the greater it grows, the worse the global scenario in terms of equity and, therefore, the possibility of reaching global agreements to control or reduce emissions. In the case in which the Lorenz curves do not intersect, the Lorenz dominance criterion associated with their position is sufficient to order the distributions according to their inequality, with no ambiguity. However, in the event that the curves do intersect, a scenario that could be likely, synthetic indices would be needed, with their sensitivity explained in relation to the different distribution paths (Duro, 2012). In any event, the Lorenz dominance criterion (if it can be established) and the comparison of inequality indices as elements for establishing conclusions in terms of welfare are based on the supposition that that global mean figures do not vary. However, this does not typically happen in reality. In particular, it is well known that this was not the case, for example, for the total CO_2, whose global levels progressed by 24% in the 1990-2005 period (or 20% in the case of total greenhouse gases). It might therefore be found that the Lorenz dominance of one distribution compared to another (i.e. lower inequality without intersections) does not necessarily imply dominance of the mean (i.e. in our environmental context, lower global pollution), meaning that conclusions in welfare terms are ambiguous. In these circumstances, it would be useful to have a conceptual framework that would allow both parameters to be brought together in one measurement, i.e. equity-preference and mean-preference, and be able to make a global evaluation of the different social situations.

In this respect, two approaches have emerged associated with the social welfare functions that might be useful in this context. Firstly, the usefulness of the so-called general Lorenz curves should be highlighted (Shorrocks, 1983), which would involve re-scaling the traditional Lorenz curves, taking world mean figures into account. Secondly, a complementary approach would be to cardinalize the associated level of welfare by abbreviated welfare indices, also arising from the specification of different welfare functions (Sen 1973; Kakwani 1986, and Atkinson 1970). Indeed, the use of these abbreviated indices would imply, as in the case of traditional inequality indices, overcoming the situations in which, in this case, the general Lorenz curves intersect and hence the general Lorenz dominance criterion is also insufficient. In particular, Sen (1976) and Kakwani (1986) suggest the validity of using welfare indices which, apart from the mean, also depend on the Gini coefficient as a measurement of equity preference. By the same token, one should point out the appeal associated with welfare indices deriving from Atkinson's approach (Atkinson,1970) which, in particular, incorporates the added value of being able to modulate, in each measurement, the size of the equity preference and hence the sensitivity of society to the inequality, in our case international environmental inequality.

This paper aims to carry out two tasks. The first of these is to extend the focus on welfare and distribution, traditionally associated with an analysis of income, in order to explore the international distribution of pollutants, particularly those associated with greenhouse gases. As far as we know, this is the first endeavour in this respect. This extension, in any event, requires an adaptation of the pollution variable, given that this is a negative factor and not a positive factor. The proposed adaptation consists, specifically, in deriving individual environmental welfare (by country) through the inverse of its pollution level. Secondly, it intends to make an empirical implementation of the different environmental welfare measurements proposed to analyse the international distribution of greenhouse gases and their three main components: CO_2, CH_4 and NO, for the period 1990-2005.

The paper is structured as follows: the second section reviews the main methodological aspects associated with the proposal to apply the Distributive Social Welfare Approach and the associated environmental welfare indices. The third section makes an international application of various global pollutants associated with the greenhouse gas effect. Finally, the last section contains the main conclusions drawn from this work.

2. Methodological aspects

Until now, studies of the analysis of international pollutant distribution have not paid enough attention in their comparative analyses to the effect, in welfare terms, that variations in global mean figures may have; in this case, world figures. Thus, to take a hypothetical example, it may be the case that one international distribution of pollutants is unequivocally more equal than another (i.e. the Lorenz curves do not intersect) but that the former displays a higher world level of contamination. In this situation, i.e. when the mean figure varies in a direction that is not consistent with inequality, the Lorenz dominance criterion cannot give an exact answer in terms of welfare.

Indeed, one might find oneself at an empirical level with three possible solutions, if the adaptation to the international distribution analysis has already been made; for example, of the level of greenhouse gases per capita. Firstly, it is possible to find an international distribution of pollutant emissions that dominates another one in the sense of Lorenz, i.e. a Lorenz curve closer to the equality line (without intersections), and a global mean figure of pollutants lower than the latter one; secondly, it might be the case that the Lorenz curve dominates (lower inequality with no ambiguity) but with the former reflecting a higher global mean figure; and thirdly, it may be that the Lorenz curves intersect and hence the Lorenz domination criterion cannot be applied. If the situation is similar to the first one, Atkinson (1970) demonstrated that the first distribution dominates the second one in terms of welfare, given reasonable social welfare functions[1]. In this case, therefore, the order of distributions based on the Lorenz criterion matches the order in welfare terms. The problem arises with the second and third of these scenarios. Shorrocks (1983), in a well-known paper, introduced the general dominance criterion as a useful element in these cases (especially in the second scenario). Specifically, this solution would consist of reordering the Lorenz curves, multiplying each point by the mean global distribution. In this case, this author demonstrated that an unambiguous ranking in terms of welfare would result if the general Lorenz curves did not intersect. Thus the Shorrocks Theorem (1983) shows that if one distribution dominates another in the general Lorenz sense, and the analyst is averse to inequality and sensitive to the mean (in our case, wants less pollution), the social welfare of the first situation will be greater than the second. In any event, in a scenario of intersections (not the general Lorenz dominance), it would be necessary to explain the value judgements of the researcher by using different consistent indices, which obviously may provide differing results, this being the case of the inequality indices associated with the standard Lorenz curves (Duro, 2012).

In this context, therefore, it would be interesting, at an analytical level, to be able to derive the social welfare levels implicit in environmental pollution and its international distribution based on the relationship between them and inequality and the world mean figure. In this respect, the literature has already studied this topic, based on the so-called normative or ethical inequality approach (Kolm, 1976a and 1976b; Atkinson, 1970; Sen, 1976; and Blackorby and Donaldson 1978)[2].

It would start by hypothesizing an international environmental welfare function, with a distributive base, in the following way:

$$W = W(y) = W(y_1, ... y_n) \qquad (1)$$

[1] For example, according to this author, the welfare dominance would arise in the case of utilitarian welfare functions and concave utility functions.

[2] In this respect it is worth referring to the survey by Blackorby et al. (1999).

where y_1 would be indicators of environmental welfare attributable to each country. In this context, i.e. the analysis of pollutants, it would be sufficient to assume that the environmental welfare of each country is measured using the formula $y_1 = 1/C_1$, where C_1 is the environmental pollutant level analysed in country 1. By means of this transformation it is possible to instantly adapt the analysis of welfare typically used for income to an environmental analysis with a positive attribute. It can therefore be assumed that $1/C_n$ makes a reasonable summary of the environmental welfare of each country. The assumption is based on homogenous countries so these would have the same environmental evaluations.

Let us assume that this function W(y) is a useful instrument for analysing world environmental policy. As part of these functions, the analysis would focus on abbreviated welfare functions, whereby two basic behavioural criteria are established. In the first place, it is assumed that society prefers a situation dominated by a more equitable distribution of national levels of environmental welfare, this being the equity preference. Less inequality and hence greater equality strengthens global cohesion and provides a basis for achieving international agreements on emission control; secondly, it is assumed that this world welfare would have a positive dependence on the global mean figure, this being the mean-preference, and hence less world pollution. This latter condition would specifically imply that the welfare function would be of a utilitarian type; i.e. additive to the observations of countries. This being the case, social welfare would typically depend on the mean and the inequality (or the equity, whichever way it is looked at).

Sen (1976), for example, proposes a social welfare index with the Gini coefficient as a basis, which would be expressed in the following equation:

$$W_S(y) = \mu(y)(1 - G(y)) \qquad (2)$$

where $\mu(y)$ is the overall world welfare average (in our case the inverse of global emissions) and G(y) is the Gini coefficient applied to this measurement by country.

Therefore, world environmental welfare would depend negatively on the mean global pollutant (i.e. positively to its inverse) and negatively to the level of inequality of this mean figure between countries. Note that taking the Gini coefficient as a benchmark inequality index agrees with an equity-preference centred on observations (countries) located around the distributive mode.

Kakwani (1984), likewise, varying the suppositions of the welfare function, derives quite a similar synthetic welfare index in which the previous qualitative ratios are fulfilled, whose equation, adapted to the scope of this study, would be expressed as follows:

$$W_K(y) = \frac{\mu(y)}{(1-G(y))} \quad (3)$$

In any event, and as a global framework for analysis, the more general social welfare functions considered by Atkinson (1970) have enjoyed a lot of attention, from which a family of inequality indices can be directly derived. It is well known that Atkinson's social welfare functions take the following form:

$$W(\varepsilon) = \frac{1}{1-\varepsilon} \sum_i p_i y_i^{1-\varepsilon} \quad \text{for} \quad \varepsilon \geq 0, \varepsilon \neq 1 \qquad (4)$$

$$W(\varepsilon) = \sum_i p_i \ln y_i \quad \text{for} \quad \varepsilon = 1$$

Indeed, the parameter ε approaches the level of inequality aversion explicit in the social welfare function. The higher it is, the higher the inequality aversion. In particular, this parameter is related to the concavity in the social welfare function, and hence the equity-preference. In this sense, depending on the chosen parameter, it is possible to derive a ratio between the previous welfare function and Atkinson's different inequality indices. Specifically, taking values for the parameters equal to 0.5, 1 and 2, indicative of low, average and high inequality aversion, the following aggregate welfare indices could be derived:

$$W_{A0.5}(y) = 4\mu(y)(1 - A_{0.5}(y)) \qquad (5)$$

$$W_{A1}(y) = \mu(y)(1 - A_{1}(y)) \qquad (6)$$

$$W_{A2}(y) = \mu(y)(1 - A_{2}(y)) \qquad (7)$$

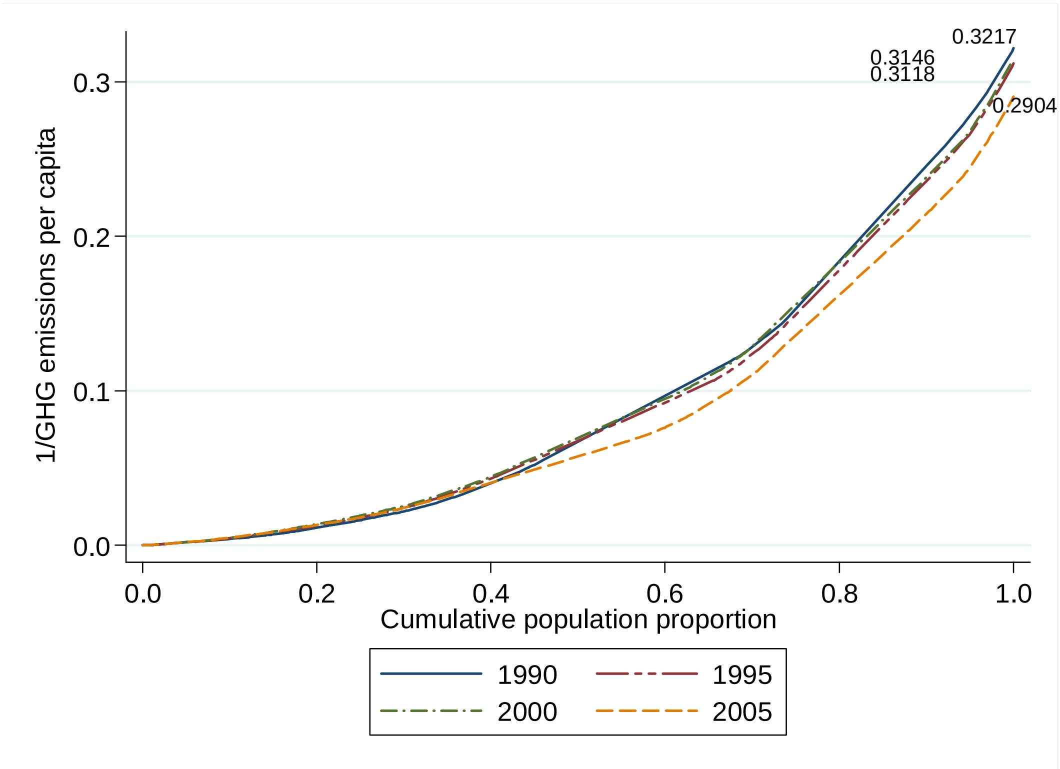
3. Main Empirical Results

The basic data used was provided by the IEA. The analysis was conducted for 140 countries, which represents almost 98% of the world's GDP generation and 97% of CO_2 generation. Given the available data, the analysis covers the period of 1990-2005. As well as examining the evolution in environmental welfare associated with the global evolution in greenhouse gases, it also provides a detailed analysis of its three main components. The analysis provides particular detail for CO_2, which is responsible for more than 70% of global greenhouse gas pollution; for CH4 (methane, over 15% of the total); and for nitrous oxide (almost 10% of the total).

Before setting forth the results associated with the different synthetic welfare indices, the profiles of the different general Lorenz curves are reproduced. In this respect, according to the Shorrocks Theorem (1983), if one general Lorenz curve dominates another one, and it is understood that there is a social inequality aversion between countries and a mean-preference (i.e. lower pollution at a world level), it can be concluded that the social welfare goes in the same direction. However, this theorem would not work, in general terms, if the curves were to intersect. In this case, the general Lorenz approach would not be sufficient to order the social welfare states and, therefore, the synthetic or abbreviated indices mentioned above would become particularly relevant which, in turn, would entail an explanation of judgement values, such as inequality aversion[3].

Figure 1 shows the international general Lorenz curves for the years in this period relating to environmental welfare, this being taken as the inverse of greenhouse gas emissions in each country.

Figure 1: General Lorenz Curves for International Environmental Welfare, 1990-2005



Source: drawn up by the authors based on IEA data (2012)

Although at first sight this may seem complicated, the fact is that in all the bilateral comparisons of the curves there are intersections and, therefore, there

[3] In any event, despite the fact that the general Lorenz curves do not intersect, the indices allow the evolution of welfare to be cardinalized beyond the matter of their order.

are no situations of general Lorenz-type domination[4]. Indeed, Table 1 details the number of intersections and the cutting points for all the bilateral comparisons. It is noteworthy that there are numerous different comparisons. For example, the comparison between the years 1995-2000, 2000-2005 and 1995-2005 include intersections in the lower part of the distribution. Thus indices with a very strong equity-preference in the lower distributive part, such as those based on Atkinson indices with high parameters, can order the distributions in a different way to other measurements. The cutting points are predominantly in the lower part but can also be found in the mid-section and upper part of the Lorenz curve.

Table 1: Intersections in the General Lorenz Curves by pairs of years

	Number of Intersections	Reference Points
1990-1995	2	0.000
		0.515
		0.000
		0.000
1995-2000	4	0.005
		0.008
		0.001
		0.004
		0.004
		0.007
2000-2005	6	0.019
		0.120
		0.557
1990-2000	3	0.693
		0.793
1990-2005	1	
		0.406
		0.000
		0.000
		0.005
1995-2005	5	0.010
		0.320

Source: drawn up by the authors based on IEA data (2012)
Note: the reference points are the cumulative proportion population

[4] The Annex reproduces the comparisons of the general Lorenz curves by pairs of years which shows the intersections more clearly.

In these circumstances, therefore, the abbreviated welfare indices take on a particular relevance, allowing the distributions to be ordered aggregately, subject in each case to their fundamental properties. Thus Table 2 reproduces the results obtained for the total greenhouse gases and their main components, based on five synthetic welfare indices, with the aim of observing different distributive sensitivities and equations of the welfare functions. Thus the Sen and Kakwani indices are based on the Gini coefficient and its equity preference. It should be remembered that this index is particularly sensitive to the observations (countries) situated around the distribution mode. Meanwhile, in order to observe other options in relation to the equity preference, three Atkinson indices have been take which reflect different inequality aversions; i.e. a low aversion (sensitivity parameter equal to 0.5 or A(0.5), medium aversion (A[1]) and high aversion (A[2]))[5]. In fact, A(1) is an index that is normally equivalent to the Theil index (Theil, 1967) with a sensitivity parameter equal to zero[6].

Given that the indices themselves are not comparable in scale, the interest stems from analysing their evolution over time. If one focuses initially on the total greenhouse gases, environmental welfare would typically have worsened, if 1995 is compared with 2005. Indeed, the decrease would have been concentrated in the final years, i.e. 2000-2005. It can be seen that the Atkinson index with a high inequality aversion would have produced, in contrast, an improvement in welfare. These results would indicate a slight improvement in the lower part of the distribution and is, in fact, consistent with the existence of cutting points in the general Lorenz curve, as seen earlier.

In any event, this aggregate evolution includes a significant heterogeneity of patterns in the different components. Indeed, while in the case of CO_2, the main

[5] For example, Duro (2012) used A(0.5) and A(2) for the analysis of the international distribution of environmental indices. White (2007) used a wider spectrum of Atkinson indices for his analysis of the international distribution of the Ecological Footprint, with sensitivity parameter figures ranging from 0.2 to 3.

[6] Gasparini and Sosa (2001), for example, used similar indices for analysing aggregate welfare in terms of income in Argentina over the period of 1980-1998.

greenhouse gas, the decrease in welfare is evident and unanimous, even for A(2), for methane and nitrous oxide there would have been, in general terms, an improvement in the aggregate welfare.

Table 2: Synthetic Environmental Welfare Indices by GHG Types, 1990-2005

	Sen-type	Kakwani type	A(0.5) type	A (1) type	A (2) type
Total GHG					
1990	0.1901	0.2283	1.0989	0.2258	0.1430
1995	0.1858	0.2221	1.0740	0.2251	0.1518
2000	0.1903	0.2255	1.0915	0.2308	0.1581
2005	0.1680	0.2043	0.9910	0.2077	0.1457
CO2					
1990	0.3333	0.5977	2.4406	0.3978	0.1963
1995	0.3091	0.5565	2.2750	0.3820	0.2067
2000	0.3059	0.5247	2.2027	0.3814	0.2131
2005	0.2621	0.4486	1.8991	0.3295	0.1938
CH4					
1990	0.7881	0.8468	4.0120	0.9300	0.7678
1995	0.8410	0.9019	4.2763	0.9971	0.8422
2000	0.9134	0.9736	4.5957	1.0771	0.9160
2005	0.8791	0.9461	4.5013	1.0487	0.8821
N20					
1990	2.1498	2.4216	11.6368	2.5575	1.8716
1995	2.1808	2.4183	11.6261	2.6159	2.0206
2000	2.2933	2.5198	12.1004	2.7574	2.1981
2005	2.2378	2.4823	11.9786	2.7197	2.1754

Source: drawn up by the authors based on IEA data (2012)

In any event, given the bi-parametric dependence of the welfare measurements, i.e. the equity (or inequality) and the mean, and their general multiplicative equation, the growth of the indices could be decomposed in terms of both factors based on the use of the logarithmic approach. For this purpose, Table 3 reproduces the results of this decomposition for the different indices and the total greenhouse gases, in the first place. If the whole period is taken, environmental welfare would be situated between a drop of 8.3% and an increase of 1.8%. In this respect, what stands out, as mentioned earlier, is the disparity outlined by A(2). With the exception of this last case, for the rest of the welfare measurements the decline would be associated critically with the world mean effect and hence with the increase in global greenhouse gas emissions. In the case of A(2), the improvement in welfare is due to the equity effect, from the improvement in welfare associated with the lower part of the distribution, equivalent to the reduction of emissions per capita of the countries with a higher level. Whatever the case, the result of the decline in welfare is concentrated in the five-year period of 2000-2005 and in this case the result is unanimous for all indices, including the most equity-sensitive, with the mean effect playing a prominent role. However, it can be seen how, in the five-year period of 1995-2000, welfare would have increased, though not by a great deal, but now with the distributive factor playing a greater role.

Table 3: Dynamics of Distributive Environmental Welfare Indices for GHG, 1990-2005

	Sen-type	**Kakwani type**	**A(0.5) type**	**A (1) type**	**A (2) type**
1990-1995					
World Mean	-3.13%	-3.13%	-3.13%	-3.13%	-1.25%
Equity	0.85%	0.36%	0.84%	2.84%	7.22%
Welfare	*-2.28%*	*-2.77%*	*-2.29%*	*-0.29%*	*5.97%*
1995-2000					
World Mean	0.90%	0.90%	0.90%	0.90%	0.90%
Equity	1.48%	0.64%	0.72%	1.60%	3.17%
Welfare	*2.38%*	*1.53%*	*1.62%*	*2.50%*	*4.07%*
2000-2005					
World Mean	-8.01%	-8.01%	-8.01%	-8.01%	-8.01%
Equity	0.00%	-1.87%	-1.66%	-2.55%	-0.18%
Welfare	*-12.45%*	*-9.87%*	*-9.66%*	*-10.56%*	*-8.19%*
1990-2005					
World Mean	-10.24%	-10.24%	-10.24%	-10.24%	-10.24%
Equity	-2.11%	-0.87%	-0.10%	1.89%	12.10%
Welfare	*-12.35%*	*-11.11%*	*-10.34%*	*-8.35%*	*1.85%*

Source: drawn up by the authors based on IEA data (2012)

A detailed analysis has also been given for CO_2 (Table 4). In this case, the evolution in the associated environmental welfare is much worse than in the case of global greenhouse gases. Except for A(2), in all the others cases the decreases are between 19% and 27%. Once again, this evolution is due to the mean factor and its decline. Indeed, the distribution factor would have tended to improve welfare. This improvement is so highly rated by A(2) that, to a large extent, it alleviates the negative effect of the mean. Meanwhile, another interesting point in this respect is the contradiction in the evolutionary patterns of the mean factor and the equity factor. Indeed, it can be seen that while typically the mean effect reduces the aggregate welfare, the equity effect improves it. This contrast is very noticeable in the case of A(2). Amongst other implications, this result would make it advisable to exercise caution when evaluating, in welfare terms, the analysis of international equity of CO_2 emissions per capita.

Table 4: Dynamics of Distributive Environmental Welfare Index for CO_2, 1990-2005

	Sen-type	**Kakwani type**	**A(0.5) type**	**A (1) type**	**A (2) type**
1990-1995					
World Mean	-7.06%	-7.06%	-7.06%	-7.06%	0.24%
Equity	-0.49%	-0.10%	0.03%	3.02%	4.96%
Welfare	*-7.54%*	*-7.15%*	*-7.03%*	*-4.04%*	*5.21%*
1995-2000					
World Mean	-7.15%	-7.15%	-7.15%	-7.15%	-7.15%
Equity	6.13%	1.27%	3.92%	6.99%	10.15%
Welfare	*-1.01%*	*-5.87%*	*-3.23%*	*-0.16%*	*3.00%*
2000-2005					
World Mean	-15.72%	-15.72%	-15.72%	-15.72%	-15.72%
Equity	0.00%	0.05%	0.89%	1.08%	6.24%
Welfare	*-15.47%*	*-15.66%*	*-14.83%*	*-14.63%*	*-9.47%*
1990-2005					
World Mean	-29.92%	-29.92%	-29.92%	-29.92%	-29.92%
Equity	5.90%	1.23%	4.83%	11.09%	28.66%
Welfare	*-24.02%*	*-28.69%*	*-25.09%*	*-18.83%*	*-1.26%*

Source: drawn up by the authors based on IEA data (2012)

Tables 5 and 6 show the decomposition of the dynamic of international environmental welfare associated with methane and nitrous oxide for the period under analysis. In both cases, the welfare would have increased unanimously, irrespective of the index under consideration, and in contrast to the case of CO_2. Similarly, by sub-periods, both cases show a general decline in welfare in recent years, i.e. 2000-2005. In relation to the explanatory parameters, there are differences. Starting with methane, the increase in associated environmental welfare would be attributed essentially to the mean effect and, therefore, a reduction in the level of global pollutants. This is at a general level and in most of the sub-periods. However, this is not the case of the last few years, where the decrease in welfare has had the significant effect of the worsening in international equity. Meanwhile, with respect to international environmental welfare associated with nitrous oxide, welfare also increased generally, but in this case it would typically be attributed to the equity effect.

Table 5: Dynamics of the Distributive Environmental Welfare Index for CH4, 1990-2005

	Sen-type	Kakwani type	A(0.5) type	A (1) type	A (2) type
1990-1995					
World Mean	6.05%	6.05%	6.05%	6.05%	-1.28%
Equity	0.45%	0.26%	0.33%	0.91%	10.52%
Welfare	*6.50%*	*6.31%*	*6.38%*	*6.96%*	*9.25%*
1995-2000					
World Mean	6.73%	6.73%	6.73%	6.73%	6.73%
Equity	1.53%	0.91%	0.47%	0.98%	1.67%
Welfare	8.26%	7.64%	7.20%	7.72%	8.41%
2000-2005					
World Mean	-1.45%	-1.45%	-1.45%	-1.45%	-1.45%
Equity	0.00%	-1.41%	-0.63%	-1.22%	-2.32%
Welfare	*-3.84%*	*-2.86%*	*-2.08%*	*-2.67%*	*-3.77%*
1990-2005					
World Mean	11.33%	11.33%	11.33%	11.33%	11.33%
Equity	-0.41%	-0.24%	0.18%	0.68%	2.55%
Welfare	*10.93%*	*11.10%*	*11.51%*	*12.01%*	*13.88%*

Source: drawn up by the authors based on IEA data (2012)

Table 6: Dynamics of the Distributive Environmental Welfare Index for N2O, 1990-2005

	Sen-type	Kakwani type	A(0.5) type	A (1) type	A (2) type
1990-1995					
World Mean	-1.77%	-1.77%	-1.77%	-1.77%	-6.68%
Equity	3.20%	1.63%	1.68%	4.03%	14.34%
Welfare	*1.43%*	*-0.14%*	*-0.09%*	*2.26%*	*7.66%*
1995-2000					
World Mean	3.07%	3.07%	3.07%	3.07%	3.07%
Equity	1.96%	1.04%	0.92%	2.19%	5.35%
Welfare	*5.03%*	*4.11%*	*4.00%*	*5.27%*	*8.42%*
2000-2005					
World Mean	-0.43%	-0.43%	-0.43%	-0.43%	-0.43%
Equity	0.00%	-1.07%	-0.58%	-0.95%	-0.61%
Welfare	*-2.45%*	*-1.50%*	*-1.01%*	*-1.38%*	*-1.04%*
1990-2005					
World Mean	0.87%	0.87%	0.87%	0.87%	0.87%
Equity	3.14%	1.60%	2.02%	5.27%	14.17%
Welfare	*4.01%*	*2.47%*	*2.89%*	*6.15%*	*15.04%*

Source: drawn up by the authors based on IEA data (2012)

4. Concluding remarks

Studies on international environmental distribution have typically, as a whole, refrained from considering the effects of world mean figures. In this respect, for example, in terms of international greenhouse gas emissions, analyses have focused on distributive terms when analysing the equity between countries, without taking into account the social repercussions associated with global emissions. In particular, the typical approach has been to interpret lower inequality in terms of world welfare without evaluating the joint role played by the distributive mean. Thus when one international emission distribution is better than another one (i.e. it dominates in the Lorenz sense) it may be that it reflects higher global emissions, in which case the translation of this superiority to a welfare dominance is ambiguous. In this respect, if one wishes to combine the analysis of equity with that of the mean figure, it would be necessary to use an instrument that undertakes a joint analysis. Specifically, social welfare functions are a useful analytic framework, with particular reference to two derivative instruments: general Lorenz curves (Shorrocks, 1983) and abbreviated welfare indices (Sen, 1976; Kakwani, 1986; and Atkinson, 1970). In the first case, this entails re-scaling the traditional Lorenz curves, taking into account the distributive mean. In the second case, it would entail deriving synthetic welfare measurements, following in the wake of the inequality measurement approach, by means of different assumptions about welfare functions which would allow the role of distributive equity and the mean figure, as explanatory parameters, to be evaluated.

This paper proposes to adapt this welfare approach to the analysis of the international distribution of greenhouse gas emissions and their main components (CO2, CH4 and NO). To make this adaptation, it proposed to define, as a basic unit of environmental welfare in each country, the inverse of its pollution level. To implement this empirically, five aggregate welfare indices were used with the aim of exploring the effects of different perceptions of welfare and, in particular, to examine different equity-preferences. The analysis was conducted for the period of 1990-2005 with a highly representative sample of the world situation. The main results obtained are as follows:

Firstly, the general Lorenz curves intersect each other. Therefore, there is no dominance in this respect and consequently it is necessary to use synthetic welfare indices to obtain an order, subject to the characteristics of the indices used.

Secondly, the use of various abbreviated welfare indices to analyse the international distribution of total greenhouse gas emissions would show that, typically, world welfare would have decreased, especially in the last few years of the period under examination, i.e. 2000 to 2005.

Thirdly, this decline would essentially be attributed to the mean effect and hence to the increase in global pollution levels.

Fourthly, whatever the case, if welfare indices are used that are very sensitive to changes in the lower part of the distribution (i.e. based on Atkinson indices with high inequality aversion parameters) and hence related to countries with a higher level of pollution per capita, the result is reversed. Welfare would have improved and the main explanation for this would be the equity factor.

In fifth place, this result would be magnified if the analysis is detailed by the main greenhouse gas, i.e. CO_2. In this case, the welfare would have worsened to a large extent, and would even have worsened in the case of the most progressive indices in the Atkinson family. The mean effect would be particularly significant in most of the cases, but would increase the relevance of the equity factor with regard to the global results mentioned earlier. Moreover, in this case there are clearly disparate performances between the roles of the mean factor and the equity factor.

In sixth place, in contrast to the results associated with the international analysis of CO_2 levels per capita, the welfare associated with emissions of methane and nitrous oxide would have improved unanimously, with the mean effect predominating in the former and equity effect being significant in the latter.

It is our view that the above results contain a series of interesting implications. Firstly, the typical worsening of world environmental welfare over these years, at least with respect to the total greenhouses gases, and CO_2 in particular, would underline the need to implement measures to correct them, with a particular emphasis on reducing the overall amount. In this respect, this reduction should be compatible with an improvement in international equity and, therefore, with an approach to per capita levels; secondly, the specific results obtained in the analysis on CO_2 emissions per capita, for example, reveals the need to use caution when establishing implications in terms of welfare based on the unilateral analysis of international equity or the world mean figure, given the contradiction in patterns that can emerge.

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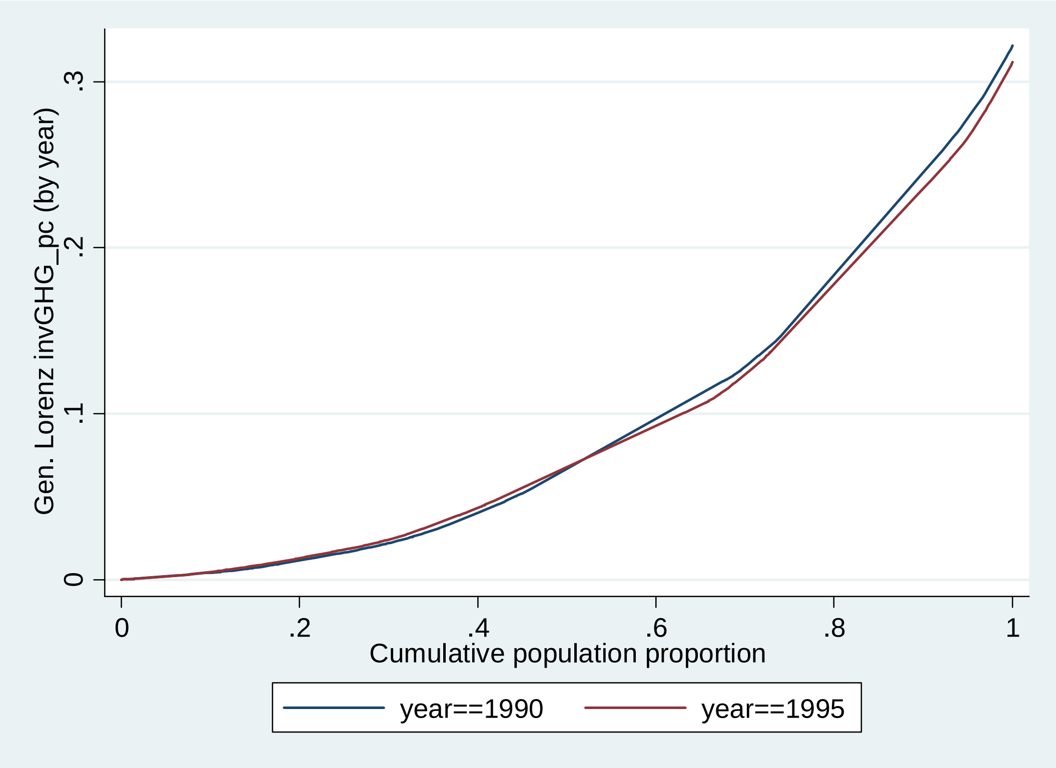
ANNEX

Figure A.1: Comparing Lorenz-Generalized curves, 1990-1995



Source: drawn up by the authors based on IEA data (2012)

Figure A.2. Comparing Lorenz-Generalized curves, 1990-2000

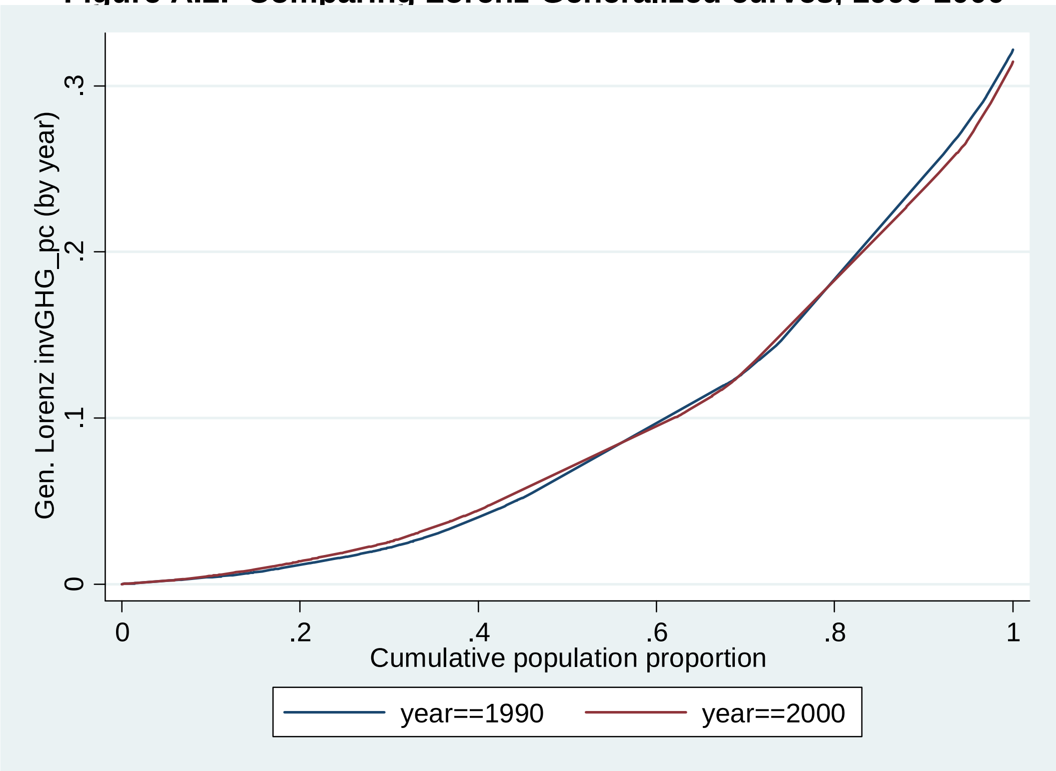
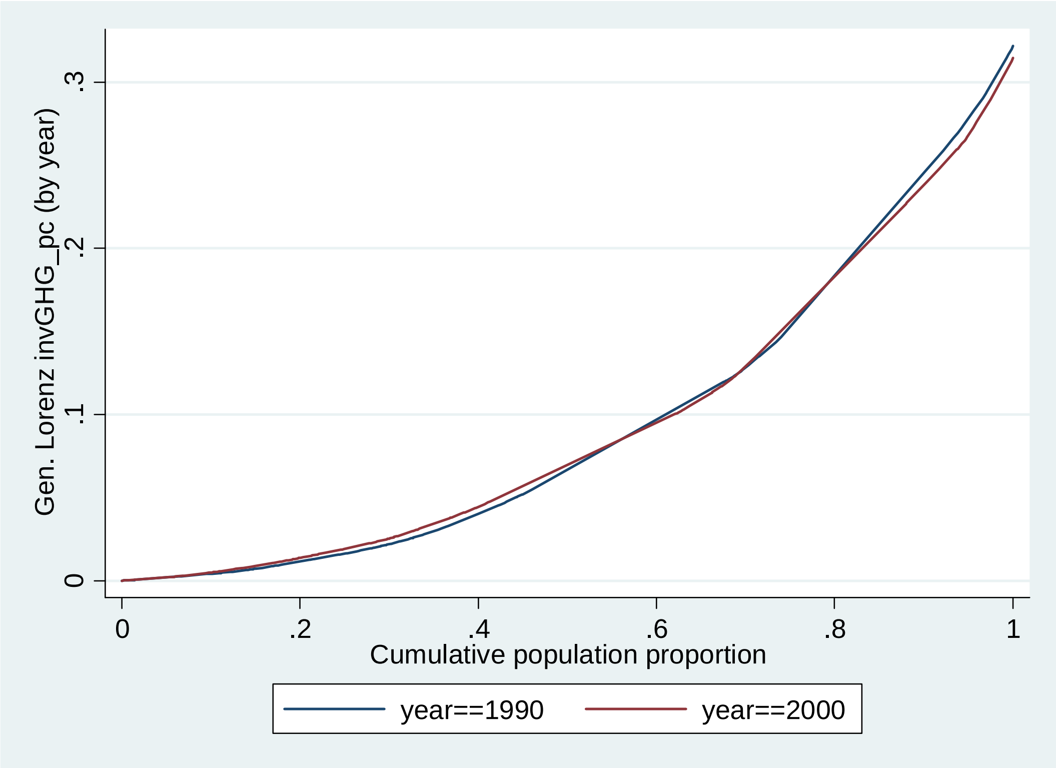


Figure A.3. Comparing Lorenz-Generalized curves, 1990-2000



Source: drawn up by the authors based on IEA data (2012)

Figure A.4. Comparing Lorenz-Generalized curves, 1990-2005

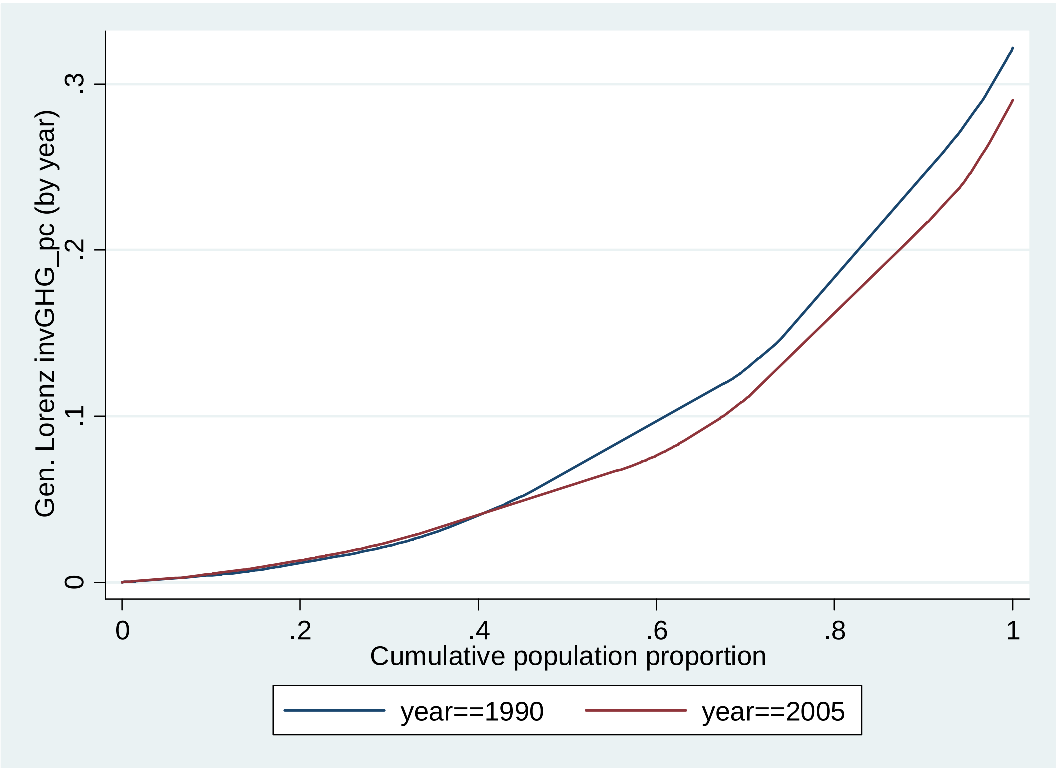
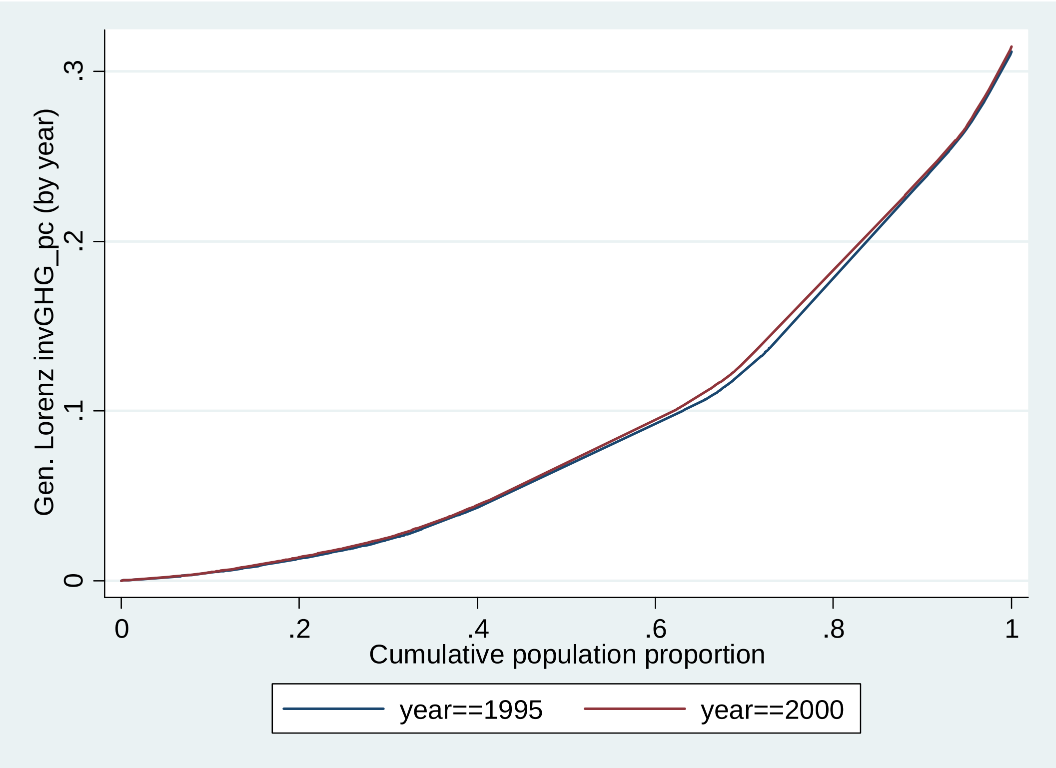


Figure A.5. Comparing Lorenz-Generalized curves, 1995-2000



Source: drawn up by the authors based on IEA data (2012)

Figure A.6. Comparing Lorenz-Generalized curves, 1995-2005

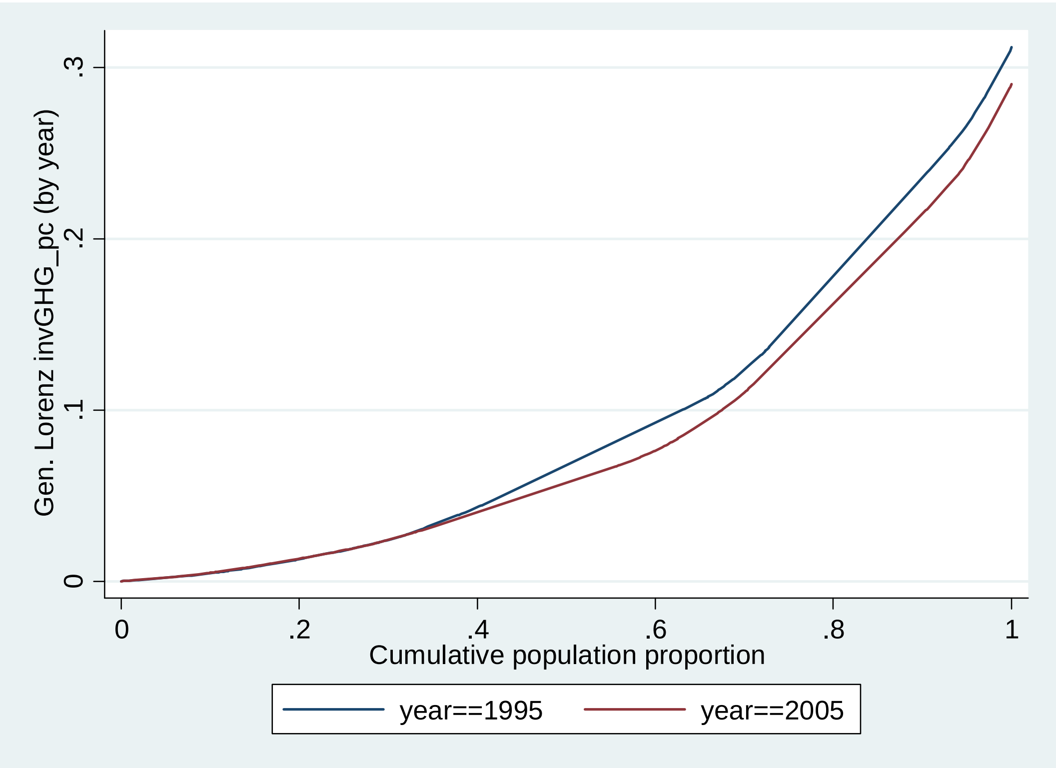
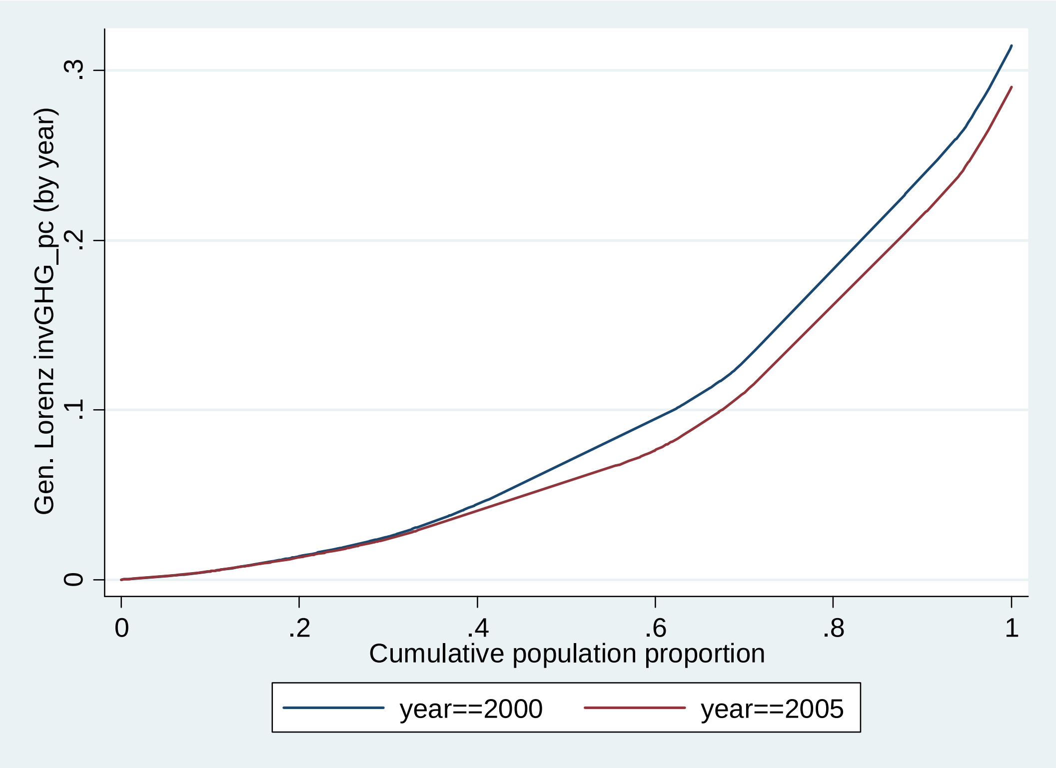


Figure A.7. Comparing Lorenz-Generalized curves, 2000-2005



Source: drawn up by the authors based on IEA data (2012)