WPS2084

POLICY RESEARCH WORKING PAPER 2084

Future Inequality in Carbon Dioxide Emissions and the Projected Impact of Abatement Proposals

Mark T. Heil
Quentin T. Wodon

Under business-as-usual projections to the year 2100, inequality in per capita carbon emissions is likely to decline — but slowly. Targeted reductions should be effective in reducing not only total emissions but emissions inequality.

Summary findings

Heil and Wodon analyze inequality in future carbon emissions using a group decomposition of the Gini index.

Business-as-usual projections to the year 2100 for 135 countries show inequality in per capita emissions declining, but slowly.

They also measure the impact on emissions levels and inequality of the Kyoto Protocol and other abatement proposals for Annex II (non-Eastern European high income) countries in 2010, focusing on the their gap-narrowing and reranking effects.

Per capita emissions of Annex II and non-Annex II countries will probably not be substantially reranked unless the Annex II countries reduce their emissions by at least half (from 1990 levels) and emissions from non-Annex II countries continue growing unabated.

Produced by the Policy Research Dissemination Center

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Projected Impact of Abatement Proposals

Mark T. Heil and Quentin T. Wodon[1]

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1.   **Introduction**

In discussions of global climate change, the level of world greenhouse gas emissions remains the

paramount issue to most analysts, and this is justified given their dominant role in driving the

phenomenon. Interest wanes significantly when the analysis is disaggregated by only a single level, that

is, when distributional issues across countries are raised. To date inequality in greenhouse gas emissions

across countries has received very limited analytical attention. Yet, in order to win the participation of as

many nations as possible in the United Nations climate change accord, which stipulates country-specific

emissions reduction targets, nations must perceive that the agreement is equitable (Paterson and Grubb

1996, Rowlands 1995). This is far from given. The world's leading greenhouse gas emitter, the U.S.,

has insisted on the "meaningful participation" of developing countries in curbing emissions. In contrast,

the developing countries through the Group of 77 (G-77) and joined by China, have consistently rejected

U.S. calls for considering near term emission cuts, refusing even to open discussions on the notion at

recent international meetings. The Third Conference of Parties (COP3) under the UN Framework

Convention on Climate Change (UNFCCC) adopted the Kyoto Protocol, which expressly excludes

developing countries from near term emissions reductions while legally obligating developed countries to

curb their emissions. However, its full ratification, and hence, implementation remain in grave doubt. A

major obstacle to ratification remains the issue of equity between developed and developing countries.

The Fourth Conference of Parties (COP4) in November 1998 made some headway toward a blueprint for

implementing the Kyoto Protocol, but it achieved little to resolve the divisions between North and South.

In order to address the disparities in contributions toward global warming between developed

and developing nations, it is useful to consider national patterns of greenhouse gas emissions. It is

known that the industrialized countries have emitted the lion's share of greenhouse gases in the past.

However, it is also documented that the share of emissions from developing countries is growing rapidly.

Does this mean that the developing nations will "naturally catch up" in emissions with developed

countries and therefore policies addressing international distribution are not required? Or is convergence

in emissions a very distant possibility that should not preclude the implementation of near term proposals to decrease not only emissions but also emissions inequality? Several analysts have suggested that equal per capita emissions ought to guide future allocation of emissions entitlements (Bertram 1992, Engelman 1994). If redistribution seems warranted, are the Kyoto Protocol or pre-Kyoto abatement proposals effective in reducing emissions inequality apart from their impact on the levels of emissions? Can they be considered as equitable?

To address these issues, this paper uses country-level per capita carbon emissions scenarios to the year 2100 and various decompositions of the Gini index of per capita emissions. The Gini index is particularly well suited to a distributional analysis of carbon emissions because it is associated with relative deprivation theory in which deprivation depends on the position of each country relative to other countries (Yitzhaki 1983), a concern at work in negotiations on reduction targets. Section 2 presents the carbon emissions model and its results. Two central features of the model are long term convergence in per capita GDP and the diminishing marginal propensity to emit (MPE) per capita—the inverted-U hypothesis. These features yield a decreasing emissions inequality over time, which is analyzed in more detail in section 3 using a group decomposition of the Gini index. Section 4 is devoted to an analysis of the impact on the level and inequality of emissions of various abatement proposals for high income countries, with a focus on the gap-narrowing and reranking effects of these proposals. Section 5 concludes the paper.

2.   Business-as-Usual Emissions Scenarios

2.1.   The model

Assessing the impact of policy proposals on the future level of carbon emissions[2] and on the inequality in emissions requires first obtaining business-as-usual country-level projections of per capita

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[2]This paper refers to emissions of carbon dioxide (CO_2) in units of carbon, defined as the weight of the carbon content in carbon dioxide. Carbon units may be converted to carbon dioxide by multiplying by 44/12.

emissions. The model presented in this section was developed by Heil and Selden (1998), following

Holtz-Eakin and Selden (1995) in predicting per capita gross domestic product (GDP) and using the

projections to develop business-as-usual scenarios of per capita emissions.[3] Emissions are modeled as a

quadratic function of GDP (the cubic term in levels was not significant).[4] Data for carbon dioxide

emissions (1951-92) come from the sixth release of the DOE NDP-030 data set of the U.S. Oak Ridge

National Laboratory (Boden, Marland, and Andres 1995). These data include all major sources of

anthropogenic carbon emissions, except those from land-use changes which are not sufficiently

developed to be included in this study.[5] PPP-adjusted GDP figures (1951-92) are provided by the Penn

World Tables Mark 5.6 (Summers and Heston 1991). The resulting uneven panel includes 135 countries

(4491 observations) representing nearly 90 percent of world population and three-fourths of carbon

emissions from fossil fuel use and cement manufacture.[6] Denoting per capita emissions (in kgs) by p_{it}

and per capita PPP-adjusted GDP by y_{it}, the estimated emissions model is (standard errors in

parentheses):

$$p_{it} = 57.64 + 131.42\, y_{it} - 1.82\, y_{it}^2 + a_i + d_t \qquad (1)$$
$$\phantom{p_{it} = 5}(12.18) \quad (7.07) \quad (0.35)$$

$$R^2 = 0.84 \qquad n = 4491$$

where a_i are fixed country effects and d_t fixed year effects (see Heil and Selden 1998 for estimation

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[3] See Schmalensee, Stoker, and Judson (1998) for an alternative model for predicting carbon emissions based on GDP.

[4] The model used here for distribution analysis is the baseline quadratic in levels model. The quadratic in logarithms model yields considerably less convergence in per capita emissions over the forecasting period, but the authors believe the levels model more accurately represents future trajectories (Heil and Selden 1998).

[5] The omission of land-use emissions alters both the emissions totals and distributions. In general, the lower income countries currently have higher rates of emissions from land-use (such as from deforestation), which means their overall emissions appear relatively lower than they actually are. The omission of land-use emissions thereby inflates emissions inequality to a degree.

[6] The sample omits the former Soviet Union and Eastern Europe, as Heil and Selden believed their centrally-planned economies to be poor representatives of likely future economic systems, and hence, future emissions patterns. Omission of these high-emitters causes emissions projections to be lower than if the countries were included (the impact on inequality is uncertain).

details). The fixed year effects account for influences (such as world fuel prices) not fully captured by GDP and affecting all countries equally in a given year. The fixed country effects are time-invariant parameters representing the unique characteristics of countries (such as climatic factors) that affect emissions independently of GDP. F-tests report that a_i are jointly significantly different from zero, as are the d_t. The parameter estimates imply a diminishing MPE relationship between per capita emissions and per capita GDP. The turning point and subsequent downturn in per capita emissions occurs at currently out-of-sample levels of per capita income (around \$36,000), but these levels are reached by developed countries during the planning horizon. As will be seen later, the diminishing MPE has profound distributional implications for the future.

Future emissions trajectories by country are predicted by incorporating GDP forecasts and population projections into (1). For per capita GDP projections, also following Holtz-Eakin and Selden (1995), a univariate time-series was fitted on the historic data. The GDP model implies convergence in growth rates in the very long run.[7] Population projections are provided by the World Bank (1994).

2.2.   *Global emissions*

Figure 1 shows the predicted path of global carbon emissions, population (left scale), and gross world product (right scale) to 2100 obtained by summing the country-level projections.[8] Global emissions grow to more than double their 1992 levels by 2050, and to slightly less than four-fold by 2100, in line with the Intergovernmental Panel on Climate Change IS92a reference scenario projections (IPCC 1992). In 1993, emissions and population are roughly equal, with a worldwide emissions average of one metric ton per person per year. By 2100, global per capita emissions more than double. These global business-as-usual emissions exceed the cumulative limits for stabilization of CO_2 concentrations at

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[7] Convergence, the notion that economic growth rates and/or real GDP levels per capita will tend to equalize across countries, was borne of the Solow growth model and remains an unresolved topic of debate in economics. See for example, Islam (1995) for a review of previous work and some recent estimates.

[8] These figures are scaled-up so they represent the world, not merely the sample of 135 countries.

any level below 1000 parts per million, a near-quadrupling of the pre-industrial level.[9] Thus, without intervention for abatement, the carbon emissions driving climate change will continue rising so that the severity of climatic, ecological, and social impacts will surpass those generally discussed in the context of a doubling of CO_2 concentrations. This confirms the necessity of enacting a policy of reducing emissions from their predicted trajectories if climate change is to be mitigated.

Although the level of global emissions is likely to rise over time, the inequality in per capita emissions is likely to recede. The model includes two factors that drive emissions inequality downward. First, the decreasing MPE as income increases implied by the negative coefficient of y_{it}^2 in (1) tends to reduce emissions of very high income countries. Second the income convergence implied by the GDP projections enables low income countries to grow faster and progressively gain ground on higher income countries. How quickly does emissions convergence proceed? Figure 2 provides the answer. While business-as-usual per capita mean emissions rise steadily, inequality in per capita emissions as measured by the Gini index decreases slowly, albeit faster than income inequality because of the diminishing MPE.

2.3. Emissions by groups of countries

Section 3 uses a group decomposition of the Gini index to analyze the contribution of groups of countries to emissions inequality. In order to understand the forces underlying future inequality trends, it is important to analyze the baseline distribution at the start of the period.

Table 1 summarizes the state of affairs by income group in the first year (1993) and highlights the prevailing disparities in carbon emissions between groups of nations.[10] Although more than three-quarters of the world's population reside in the two lower income groups, these countries produce less than one-third of gross world product and a slightly smaller share of global carbon emissions. On a per

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[9]Cumulative emissions and corresponding atmospheric concentrations are provided by IPCC (1996).

[10]Income groups correspond to those of the World Bank (1995), but are adjusted in order to convert from GDP at market exchange rates to GDP at purchasing power parity. Countries are held in one and only one group throughout the period 1993-2100, that of their income level in 1993.

capita basis, the high income group's inhabitants possess twelve times the GDP of low income and lower-middle income residents. Moreover, high income individuals generate ten times the carbon emissions on average of those in low income and lower-middle income countries. This inequality is reflected in the high overall Ginis of 0.557 for per capita income and 0.607 for per capita carbon emissions (starting values shown in Figure 2).

Figure 3 shows the differences in emissions levels between groups tend to diminish over time. This is largely a result of the diminishing MPE property of the model. As noted earlier, per capita emissions rise with income growth at lower income levels, peak at about $36,000 income per capita, and descend at higher income levels. Hence, the high income group's emissions rise to about 4.5 tons per capita in 2040, then steadily decline over the last 60 years. The upper-middle income group's per capita emissions rise until 2080, then decline. In contrast, the lower-middle and low income groups do not reach their per capita emissions peaks by 2100. The lower-middle group's emissions per person grow more rapidly than those of the low income group as a result of faster income growth in lower-middle countries. Per capita emissions of the upper-middle and lower-middle groups come together in 2100, and all groups converge in the long run. Figure 4 presents another interesting result. The ratio of per capita emissions to income measures the emissions intensity of GDP. The lower the ratio, the more energy efficient and the cleaner the economic system. All income groups advance toward lower emissions intensity of production because of the diminishing MPE, but the two higher income groups have the steepest downward slopes, in part because they possess more advanced technology to restrain emissions.

Figure 5 shows the changes in (absolute, not per capita) emissions shares by income group. The trend toward per capita convergence shown in the previous figure masks the large differences in population growth rates between groups that spur dramatic changes in total emissions by group. Most notably, the share of overall emissions represented by the high income group drops from 0.62 to 0.14 during the period. The bulk of the high income group's loss is accounted for by the low income group's gain, which climbs from about one-fifth to over half of global carbon emissions. The lower-middle

group's share triples to one-fourth while that of the upper-middle group remains relatively stable at less than one-tenth of the global total. The shift in emissions shares by group explains why high income countries are concerned about future emissions from low income nations. It also highlights the reason participation of developing countries is considered essential for a successful global climate change treaty.

3.   Group Decomposition of Emissions Inequality

To analyze in more detail why inequality in emissions gradually declines over time, a group decomposition of the Gini index proposed by Yitzhaki and Lerman (1991) can be used. This method was used by Heil and Wodon (1997) to examine the historic evolution of per capita carbon emissions inequality across countries.[11] The decomposition suggests the critical factor is the reduction of inequality *between* groups of countries rather than *within* groups. Dropping the "it" subscripts for simplicity, denote by p per capita emissions, by F the country rank in the cumulative distribution of per capita emissions (F is 0 for the lowest emitting country and 1 for the highest emitting country), and by F_N its rank in the cumulative distribution of all countries except those of its own income group. If $cov_k(x, y)$ is the covariance between x and y over the members of group k, and p_k is mean emissions for countries in group k, the Gini index G_k and the stratification index Q_k of group k are defined as:

$$G_k = 2cov_k(p, F)/p_k \qquad (2)$$

$$Q_k = cov_k[p, (F - F_N)]/cov_k(p, F) \qquad (3)$$

The interpretation of the Gini index is well known. The stratification index measures the overlap between groups in the per capita levels of emissions. When $Q_k=1$, no country in groups other than k has emissions that fall between the emissions of two countries in group k, and group k forms a perfect stratum. When $Q_k = -1$, the countries in group k have emissions levels at the two extremes of the

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[11]See also Wodon and Heil (1999).

distribution (two perfect strata), and all the other countries fall in between. When $Q_k = 0$ for all k, the groups completely overlap each other. The Gini index can be decomposed into three components as follows:

$$G \; = \; \Sigma_k S_k G_k \; + \; \Sigma_k S_k G_k Q_k (H_k - 1) \; + \; 2 \, cov(p_k, \, F_k)/p_w \quad (4)$$

where F_k is the mean rank of countries in group k among all countries, H_k is the population share of countries in group k, S_k is the emissions share of countries in group k, and p_w is the mean per capita emissions level in the world as a whole. The first term on the right side of (4) represents within group inequality (the weighted sum of the within group Ginis with emissions shares as weights). The second term, accounting for stratification, is typically negative because the stratification indices Q_k tend to be positive (population shares H_k are smaller than one). The third term accounts for between group inequality and is a direct extension for groups of the Gini index (2).

Figure 6 illustrates the decline in the Gini index over time is almost fully due to the fall of the between group component of the decomposition. Until about 2030, the between groups component remains relatively high because most high income countries have not yet reached the level of GDP at which per capita emissions turn downward and low income countries' GDPs remain low. Throughout the first 50 years, the between group component accounts for 60 percent or more of total inequality. This implies that during that period, emissions reductions targeted to the higher income groups would be effective in reducing both the level and the inequality of emissions. In 2100 by contrast, the between group component accounts for only 27 percent of the Gini. Note also the decrease (in absolute value) of the stratification component of the decomposition in Figure 6. In 1993, stratification indices (Q_k) for the four groups from lowest to highest income are 0.407, 0.497, 0.878, and 0.987, indicating that the top two groups form almost perfect strata. As per capita emissions decrease (increase) in the high (low) income group in the latter half of the forecasting period, its stratification index Q_k shrinks as well, driving the

stratification component of the decomposition towards zero.

Annual per capita emissions are thus likely to gradually become more equally distributed over time. What about cumulative per capita emissions? Historical responsibility for the enhanced greenhouse effect has been a contentious topic in climate treaty discussions. Since carbon dioxide influences equilibrium concentrations in the atmosphere for roughly 100 years, the large contributions of the developed countries will continue affecting the climate system until the end of the forecasting period. Is convergence in cumulative emissions attained during the next century? Table 2 compares the Gini and its components for annual emissions in 1993 and 2100, and for cumulative emissions over the entire period. When cumulative emissions are examined, the downward trend in inequality weakens, with a Gini of 0.425, and a between group component accounting for more than half the inequality in cumulative emissions, nearly the proportion in 1993. In per capita terms, the higher income countries' cumulative emissions will continue to dominate those of lower income groups throughout the next century, and their contribution to climate change will remain well out of proportion to their populations.

4. The Kyoto Protocol and Other Abatement Proposals

4.1. Target reductions for Annex II countries

The need for public policy to curtail global greenhouse gas emissions if climate change is to be mitigated is widely acknowledged.[12] Recent experience in developing a global emissions reduction policy at COP3, COP4, and their preparatory meetings highlights the centrality of North-South distribution issues.[13] How should the burden of emissions reduction be shared? Should reductions be made, say, by reducing all nations' emissions by equal proportions (no redistribution), or by some distinctly targeted plan (involving redistribution)? The large between group component of the Gini

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[12]The IPCC's First Assessment Report noted that an immediate reduction of 60-80 percent of current carbon emissions would be necessary to stabilize atmospheric concentrations at their 1990 levels (IPCC 1990).

[13]For example, Welsch (1993) applied the Gini index to examine the inequality effects of alternative emissions scenarios for a sample of countries.

decomposition shown in the preceding section suggests that reductions limited to higher income countries should be effective in lowering both the level of emissions and the inequality in per capita emissions.[14] Not surprisingly, most pre-COP3 abatement proposals, such as those presented at the March 1997 session of the Ad-hoc Group on the Berlin Mandate (AGBM), involve redistribution in emissions, chiefly by requesting Annex I or II (the high income nations, see list of countries in the appendix) countries to reduce their emissions by some target percentage by early next century while non-Annex I or II countries continue growing unabated. Not withstanding the U.S. call for developing country participation, none of the official proposals on the table in Kyoto set emissions reduction targets for developing countries.[15] The report of the AGBM does not state the originator of the proposals, but it is well known that, say, proposal 1 which requests a 20 percent reduction of anthropogenic emissions of Annex I countries is favored by the Alliance of Small Island States. All proposals refer to percentage reductions relative to 1990 absolute (not per capita) emissions levels.[16] Proposals differ according to their target date (in most cases 2010), target reduction, and/or determination mechanism (some proposals impose higher reductions at future dates for countries not meeting earlier reduction targets).

Table 3 presents the impact that the Kyoto Protocol and various other target reduction proposals for Annex II countries—the countries with both high levels of emissions and the financial means to reduce them—would have on the level and inequality in emissions in 2010.[17] The business-as-usual figures come from the emissions model. Figures for the target reductions were obtained by using the

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[14]This conclusion is confirmed when applying the group decomposition to historical data as well. Heil and Wodon (1997) show that half of overall per capita carbon emissions inequality across 111 nations 1960-90 is accounted for by just two income groups.

[15]The 1995 Berlin Mandate noted that developing countries should not be held to emission limitations in the near term. However, in November 1998 at COP4, for the first time two non-Annex I parties (Argentina and Kazakhstan) agreed to enact voluntary emissions restrictions in the near term.

[16]This is not to be confused with reductions relative to projected business-as-usual (in the absence of policy) emissions in 2010. Given expected economic and population growth, any emissions limit would appear to be a greater reduction if it were expressed relative to business-as-usual projections in 2010 rather than in relation to 1990 levels.

[17]The U.S. proposal and the Kyoto Protocol use a flexible target date of 2008-2012. This paper uses 2010 as a target date for consistency with other proposals, with a negligible impact on the Gini outcomes.

projected emissions for non-Annex II countries, and imposing the target emissions reductions for each Annex II country. Note that if population increases in an Annex II country, its per capita emissions must decrease by more than the target reduction since the target is expressed in the country's total emissions, not per capita emissions. In terms of climatic effects, the key unit of analysis is global emission totals (column 1), obtained by multiplying per capita emissions by population across all countries in the sample, and scaling up to reflect global totals. Carbon emissions, regardless of geographic origin, have equal effects on atmospheric concentrations, and all emissions contribute to the total. For distributional analysis, the relevant unit of analysis is, as before, per capita emissions (mean in column 2 and Gini in column 3).

Table 3 shows that business-as-usual mean per capita emissions will rise by 2010, but that emissions inequality will decline modestly (as shown in Figure 2). Although these proposals with reductions ranging from 0 to 20 percent (by Annex I or II) cannot constrain global emissions in 2010 to their 1990 level, in large part because of population growth, they do reduce emissions inequality somewhat.

4.2. Gap-narrowing and reranking effects of target reductions

When imposing target reductions to groups of countries, the distributional objective is typically to reduce the gaps in per capita emissions levels between countries, not to change the ranks or relative positions of countries in terms of their per capita emissions. To provide an analogy, in the context of income and progressive taxation, tax schemes are not intended to impose a burden on high income individuals so great that after taxes, their net income falls below the net income of those with lower gross incomes. To analyze the gap-narrowing effect (holding ranks constant) and the reranking effect (holding per capita emissions constant) of abatement proposals for Annex II countries, a decomposition provided by Lerman and Yitzhaki (1995) can be used. Denote the business-as-usual emissions Gini by G_B and the Gini after implementation of the abatement proposal by G_A. If $s = p/p_w$, the ratio of a country's per capita

emissions to the world average, the change in the Gini can be decomposed as the sum of two components:

$$G_B - G_A = 2\text{cov}(s_B - s_A, F_A) + 2\text{cov}(s_B, F_B - F_A) \qquad (5)$$

The first component on the right hand side of (5) is the gap-narrowing effect, and the second component is the reranking effects. The last two columns of Table 3 give the results of the decomposition. Because Annex II countries have very high relative emissions levels, reducing their emissions by any amount less than 50 percent compared to 1990 levels induces little reranking. Reductions beyond that threshold, however, implies much greater reranking. For a reduction of 70 percent in Annex II, 40 percent of the decrease in the Gini is due to reranking. For a reduction of 90 percent, all of the gain is due to reranking. The implication of this analysis is that as long as the reduction required of Annex II countries does not exceed 50 percent in 2010, (far greater than any proposed reduction) there need not be much concern about reranking. The average reduction for Annex II countries specified in the Kyoto Protocol is 5.2 percent, an amount that has some bearing on overall emissions inequality, but no reranking effects.

Rather than imposing uniform percentage reduction targets across all Annex II countries, it is possible to set differential targets for individual countries while reaching an overall target for a group. The Kyoto Protocol takes this approach by stipulating anywhere from a 10 percent increase (Iceland) to an 8 percent cut (several countries) in emissions (relative to 1990) for each of the Annex I countries to achieve the overall 5.2 percent reduction.[18] This differentiation may allow greater consideration of both efficiency (relative costs of reducing) and equity (who must reduce and by how much). Table 3 shows that the Kyoto agreement results in less per capita emissions inequality than does a uniform reduction of

[18]A complete listing of emissions targets by country for the Kyoto Protocol and the for European Union proposal is given in a footnote to Table 3.

the same amount. Given the relatively small emissions reduction, there is little impact on gap-narrowing and reranking. The European Union (EU) abatement proposal announced in March 1997 also used flexible targets by country (within the Union) to achieve a 15 percent emissions cut for the EU. Germany would reduce its emissions by 25 percent, while Portugal, a less developed economy, could increase its emissions by 40 percent. In addition to a lower Gini, the EU proposal entailed less reranking than a uniform 15 percent reduction by all EU countries. In the future, coordinated actions among other groups of countries could help in reducing both the levels and inequality in emissions, and presumably at a lower cost.

4.3.   Implementation alternatives and quasi-emissions

The reduction targets discussed above do not stipulate *how* the targets should be achieved. Apart from real emissions reductions obtained through, say, clean air and energy efficiency regulation in Annex II countries, policy tools such as tradeable emissions permits (TEPs) and joint implementation (JI) may be used.[19] Under a TEP system, countries with emissions above their target can buy TEPs from countries whose emissions fall below their target. Under JI, a high income (investor) country provides financial and/or technical resources to a low income (host) country in order to reduce emissions in the latter. The investor country is partially or fully credited with the emissions offset due to its investment (Kuik, Peters, and Schrijver 1994).[20] The Kyoto Protocol envisions using variations of both mechanisms in order to achieve emissions cuts at a lower cost than if all reductions had to be made domestically.

The working assumption behind both JI and TEPs is that, despite the lower per capita emissions in developing countries, often the marginal cost of abatement is smaller than in developed nations. This is due primarily to the fact that environmental regulation and the oil price shocks of the 1970s prompted

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[19]Both a TEP system and a JI system (through the Clean Development Mechanism) were set up in principle at the COP3.

[20]JI projects may be carried out by firms or municipal government collaboration, not necessarily by national governments. JI projects are underway in numerous countries, but their emission offsets are not formally credited to investors under this current pilot phase.

developed countries to substantially improve energy efficiency through enhanced technologies and conservation. In contrast, the developing countries' regulation generally has not been as stringent, and oil prices had less impact on their less fossil fuel intensive production systems. Therefore, opportunities for easily improved energy efficiency have been largely exhausted in developed countries, while opportunities for low cost improvements remain unexploited in developing countries.

Consider a scenario from the transportation sector that establishes conditions conducive to a JI agreement. Transport in countries at low income levels takes place through predominantly non-motorized (and carbon-free) forms such as walking, bicycling, rickshaws, and animal-drawn vehicles. At slightly higher incomes, a proportion of commuters converts to using the cheapest motorized private transport available, scooters or motorcycles, which generate relatively high carbon emissions per passenger kilometer traveled. Public transportation systems tend to be modest in scope. When middle income levels are attained, fewer passengers use non-motorized transport and a substantial fraction shifts from motorcycles to automobiles. Public transport includes standard buses and micro-buses. These vehicles generally burn less cleanly than those in high income countries due to the older (or nonexistent) abatement technology, the lack of stringent emissions standards (which permit highly polluting vehicles such as those with two-stroke engines), and poor operating conditions (such as chronic traffic congestion) that reduce fuel efficiency and raise emissions. At this point, carbon emissions per capita from transport in middle income nations may exceed those in wealthier countries, a condition ripe for a JI agreement.[21] The Netherlands are currently funding a JI project involving fuel conversion in Hungary. The idea is to transfer the technical knowledge needed to convert Hungary's diesel fuel buses to run on compressed natural gas. The project is small (5 buses only), which is typical of JI projects so far, but it has been

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[21] Although high income countries are marked by much greater private vehicle ownership rates, usage varies widely. In Australia and the U.S., average passenger kilometers traveled rates are high, largely due to spatial dispersion and relatively weak public transport infrastructures. In contrast, the high income Asian and European countries, marked by greater population densities and efficient public transport systems, have considerably lower private vehicle usage. But overall, transport sector carbon emissions per capita in high income countries tends to level off and may even be reduced. For example, per capita car use in Kuala Lumpur fell well below that of Boston and Los Angeles, but exceeded that of London and Paris in 1990 (Kenworthy et. al 1997).

estimated that if all 3,000-4,000 public buses in the major Hungarian cities were converted, 6.4 kilotons of emissions per year would be abated (JIQ 1996).

The Gini analysis and decompositions used in this paper have been applied to projected real emissions only. However, given the likelihood of some form of TEPs and JI in the future, it may be thought the analysis becomes uninteresting. On the contrary, by defining quasi-emissions as real emissions minus TEPs purchased and minus JI carbon offset credits, the inequality in per capita quasi-emissions may be analyzed readily.[22] This would enable the inequality impacts of various trading schemes to be assessed and compared against inequality in real emissions. Since it is likely that developed countries would buy TEPs and fund JI projects in developing countries, it is expected that inequality in quasi-emissions would exceed that in real emissions.

4. Conclusion

Since the UN Conference on Environment and Development in 1992, the international community has devoted significant resources to assessing the threat of global climate change and forging a legally binding treaty to reduce emissions of greenhouse gases. The effort has been painstaking and the progress halting at times, but the complex process involving 166 formal parties has inched forward. In December 1997, the process was boosted by the adoption of the Kyoto Protocol at COP3, which mandates that 38 developed countries reduce six greenhouse gases by an average of 5.2 percent relative to 1990 levels by 2008-2012.

Despite that achievement, ratification and implementation of the Kyoto Protocol remains in doubt. And the recent COP4 made only limited gains toward cementing its implementation. The distribution of greenhouse gas emissions is a critical component of the equity issues that may influence the ultimate success or failure of the UN climate convention process. If per capita emissions equalize naturally through income convergence and improved energy use at higher levels of GDP, redistributive

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[22]See Heil and Wodon (1997) for details on quasi-emissions.

(or compensatory) interventions may appear unnecessary. Using a model for projecting emissions and a group decomposition of the Gini index, this paper has shown that long-run convergence in per capita emissions may be indeed likely, but that it occurs slowly. Moreover, a few countries are historically responsible for creating and aggravating much of the problem. When cumulative per capita emissions are considered, the case for addressing emissions inequality through distributional or compensatory policies become even more compelling.

The major pre-Kyoto proposals for emissions reduction required differential reductions by groups of countries (United Nations 1992, United Nations 1997). Although the definition of these groups is not strictly tied to income, in practice, Annex II countries belong to the high income group. The large between group component of the decomposition conducted in the paper suggests that targeted reductions should be effective not only in reducing overall emissions but also emissions inequality, and this may be an important determinant of its success. This was confirmed using a range of proposals for Annex II countries in reference to targets to be reached by 2010. It was also shown that the proposals and the Kyoto Protocol itself have very limited reranking effects, so that most of the reduction in the emissions Gini is achieved through narrowing the gaps between high and low emitting countries. This should allay concerns among members of the U.S. Congress and the Clinton Administration that reductions by only Annex II countries would impose an unfair burden on the U.S. Finally, the distributional analysis could be extended to include tradeable permits, joint implementation, or other mechanisms used to achieve target reductions.

Appendix

<u>List of Annex II countries</u>

Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States

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Table 1. Summary emissions statistics, 1993 for 135 nations

Income Group	Low income	Lower-middle	Upper-middle	High income	Total
Countries	48	40	17	30	135
Population	2,925	886	285	813	4,909
Population share	0.596	0.181	0.058	0.166	1.000
GDP	3,716	2,559	1,870	12,293	20,437
GDP share	0.182	0.125	0.091	0.601	1.000
Emissions	978	370	383	2,773	4,504
Emissions share	0.217	0.082	0.085	0.616	1.000
Mean p.c. emissions	0.334	0.417	1.347	3.410	0.918
Mean p.c. GDP	1,270	2,887	6,571	15,118	4,163
Mean p.c. emissions/ Mean p.c. GDP	0.260	0.145	0.205	0.226	0.221

Source: Author's calculations using PWT56 and ORNL.
Note: This table is based on 135 nations and is not scaled up to represent the whole world.
Units: Population in millions. GDP in billions of PPP-adjusted 1985 U.S. dollars.
Emissions in millions of metric tons. Per capita emissions in metric tons. Per capita GDP in units.

Table 2. Yearly and cumulative emissions decomposition for 135 nations

	Cumulative 1993-2100	Annual 1993	Annual 2100
Within group component	0.186	0.264	0.176
Stratification component	-0.098	-0.155	-0.044
Between group component	0.338	0.498	0.109
Overall Gini	0.425	0.607	0.241

Source: Authors' computations from ORNL and PWT56. Numbers may not add up due to rounding.
Note: This table is based on 135 nations and is not scaled up to represent the whole world.

Table 3. Annex II abatement proposals, emissions levels and inequality for 135 nations

	Global emissions	Per capita emissions	Per capita emissions Gini	Change due to gap-narrowing	Change due to reranking
1990 benchmark	5.701	0.902	0.613	-	-
2010 projections					
Business-as-usual	8.308	0.983	0.586	-	-
0% reduction	7.066	0.836	0.535	0.051	0.001
5.2% reduction	6.884	0.815	0.525	0.060	0.001
5.2% reduction Kyoto	-	-	0.523	0.062	0.001
10% reduction	6.676	0.790	0.517	0.066	0.003
15 % reduction	6.560	0.776	0.510	0.071	0.005
15% reduction EU	-	-	0.508	0.074	0.004
20% reduction	6.320	0.748	0.498	0.084	0.005
30% reduction	5.963	0.706	0.477	0.102	0.008
50% reduction	5.250	0.621	0.428	0.138	0.021
70% reduction	4.537	0.537	0.376	0.127	0.084
90% reduction	3.829	0.453	0.375	-0.286	0.497

Source: Authors' computations from ORNL and PWT56. Numbers may not add up due to rounding.

Notes: Global emissions totals are scaled up to represent the world. All other figures are based on the sample of 135 nations only. Per capita emissions are affected by the omission of the former Soviet Union and Eastern Europe. Except where otherwise specified, all percentage reductions are uniform for Annex II countries only.

The Kyoto Protocol specifies the following reductions compared to 1990 levels: Australia +8%, Austria -8%, Belgium -8%, Bulgaria -8%, Canada -6%, Croatia -5%, Czech Republic -8%, Denmark -8%, Estonia -8%, Finland -8%, France -8%, Germany -8%, Greece -8%, Hungary -6%, Iceland +10%, Ireland -8%, Italy -8%, Japan -6%, Latvia -8%, Liechtenstein -8%, Lithuania -8%, Luxembourg -8%, Monaco -8%, Netherlands -8%, New Zealand 0%, Norway +1%, Poland -6%, Portugal -8%, Romania -8%, Russian Federation 0%, Slovakia -8%, Slovenia -8%, Spain -8%, Sweden -8%, Switzerland -8%, Ukraine 0%, United Kingdom -8%, United States -7%.

The EU COP3 proposal (not adopted) for EU countries is as follows: Belgium -10%, Denmark -25%, Germany -25%, Greece +30%, Spain +17%, France 0%, Ireland +15%, Italy -7%, Luxembourg -30%, Netherlands -10%, Austria -25%, Portugal +40%, Finland 0%, Sweden +5%, United Kingdom -10%.

Both versions of the 5.2% emissions cut and both versions of the 15% reduction yield equivalent global and per capita emissions although our computations resulted in very slight differences due to negligible data variations.

Units: Global emissions in metric gigatons. Per capita emissions in metric tons.

Figure 1. Global Carbon Emissions, Income, and Population Projections 1993-2100

Legend:
- World CO2 emissions
- World population
- Gross world product

Left axis: CO2 in gigatons of carbon / Population in billions
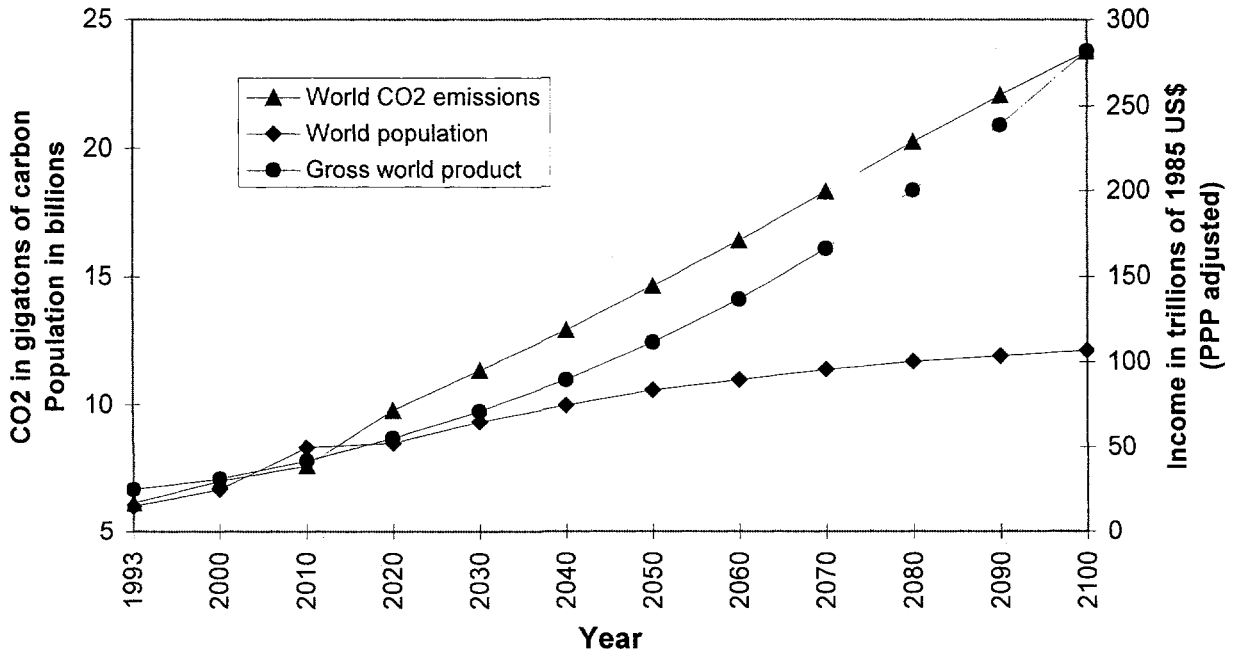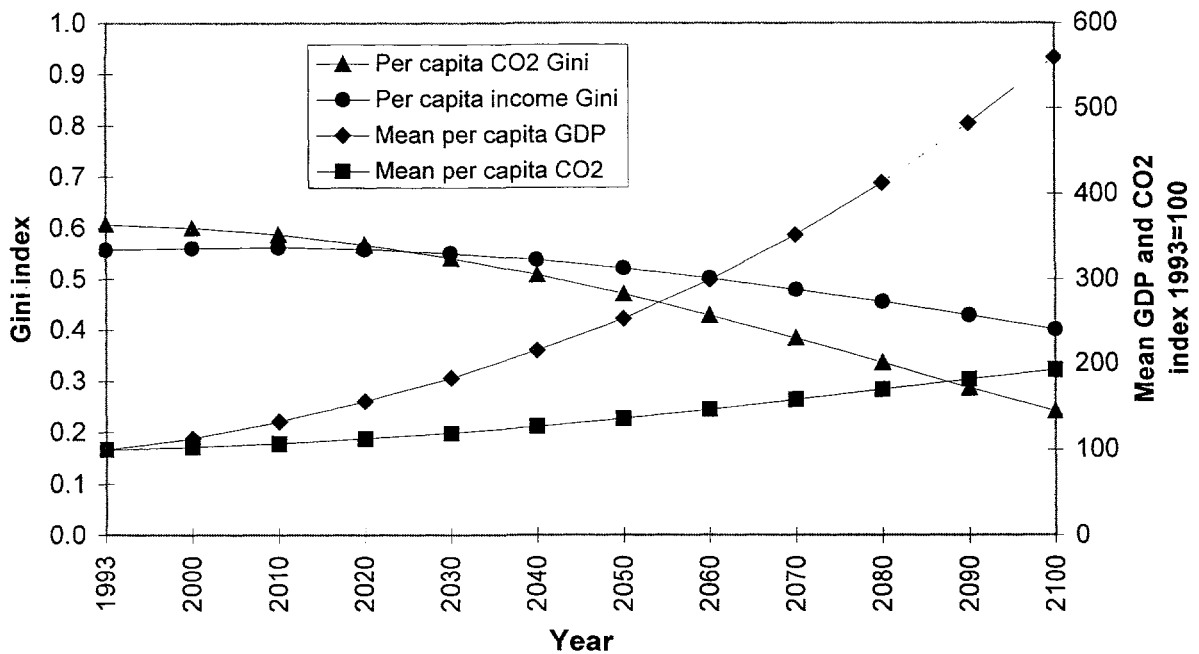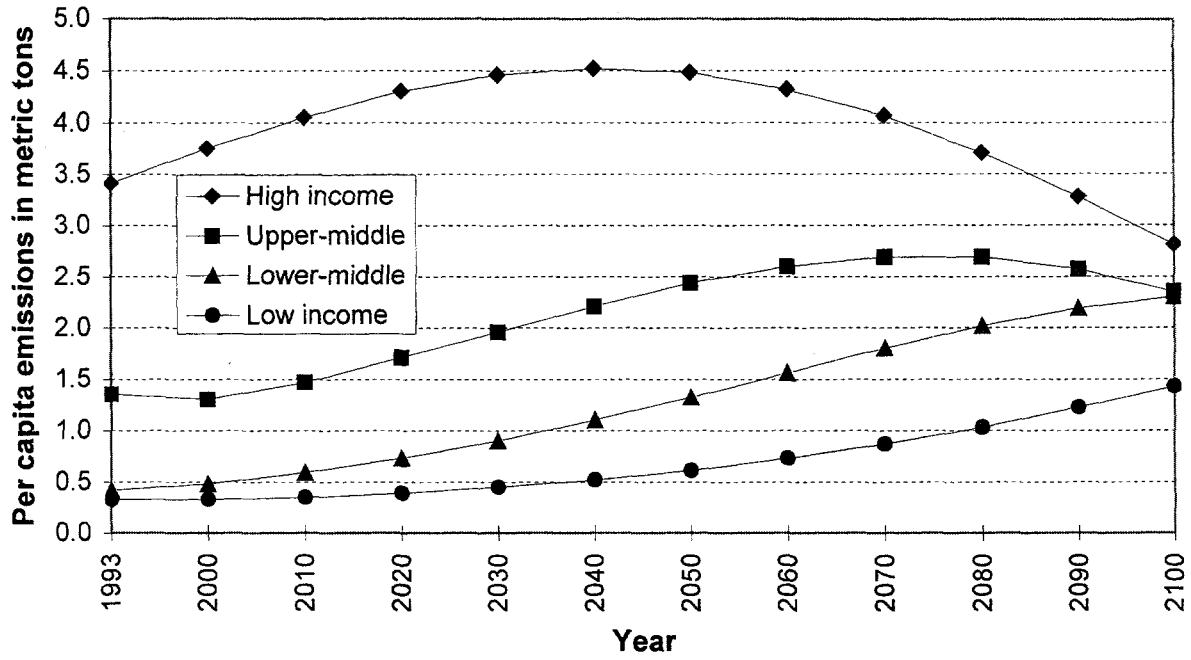Right axis: Income in trillions of 1985 US$ (PPP adjusted)
X-axis: Year

Figure 2. Carbon Emissions and Income: Levels and Inequality 1993-2100

Legend:
- Per capita CO2 Gini
- Per capita income Gini
- Mean per capita GDP
- Mean per capita CO2

Left axis: Gini index
Right axis: Mean GDP and CO2 index 1993=100
X-axis: Year

Figure 3. Projected Carbon Emissions by Income Group 1993-2100
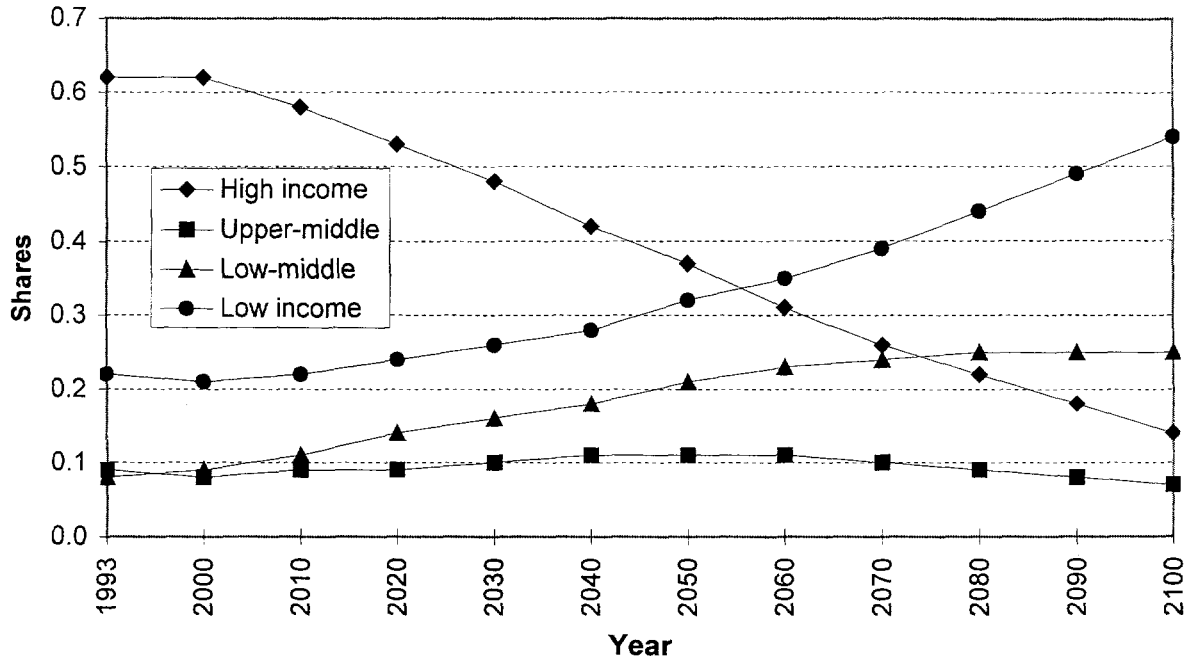

Per capita emissions in metric tons

- High income
- Upper-middle
- Lower-middle
- Low income

Year

Figure 4. Projected Carbon/GDP Ratios by Income Group 1993-2100

Per capita emissions/per capita GDP

- Low income
- Low-middle
- Upper-middle
- High income

Year
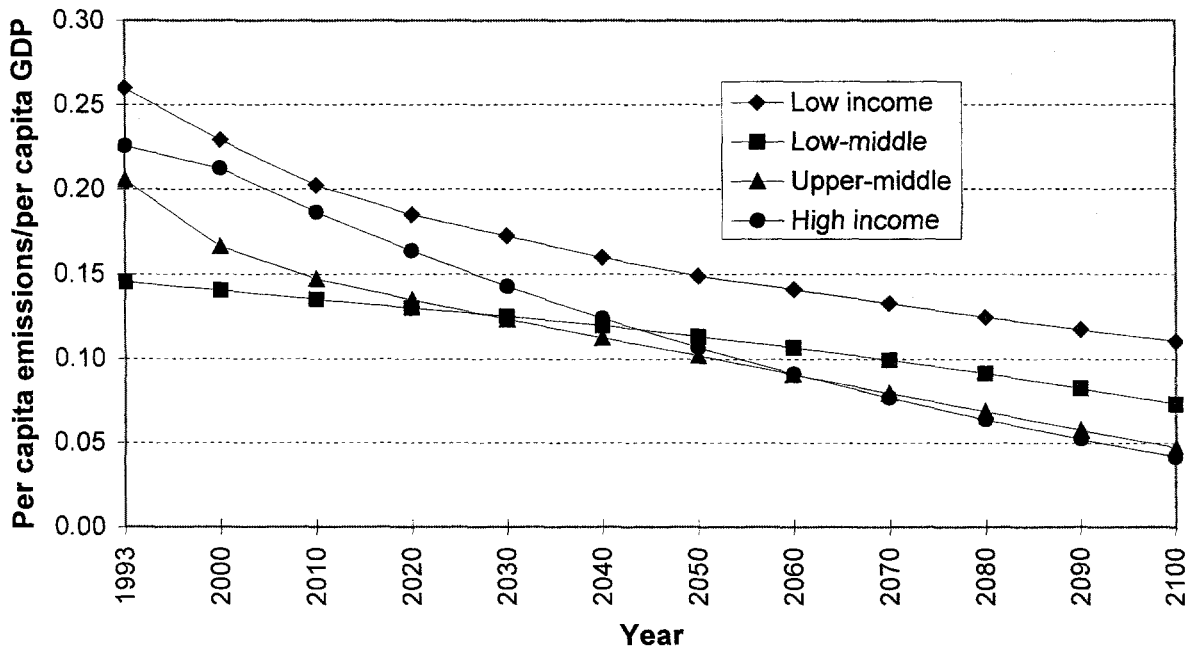
Figure 5. Projected Emissions Shares by Income Group 1993-2100

Figure 6. Group Decomposition of Emissions Forecasts 1993-2100
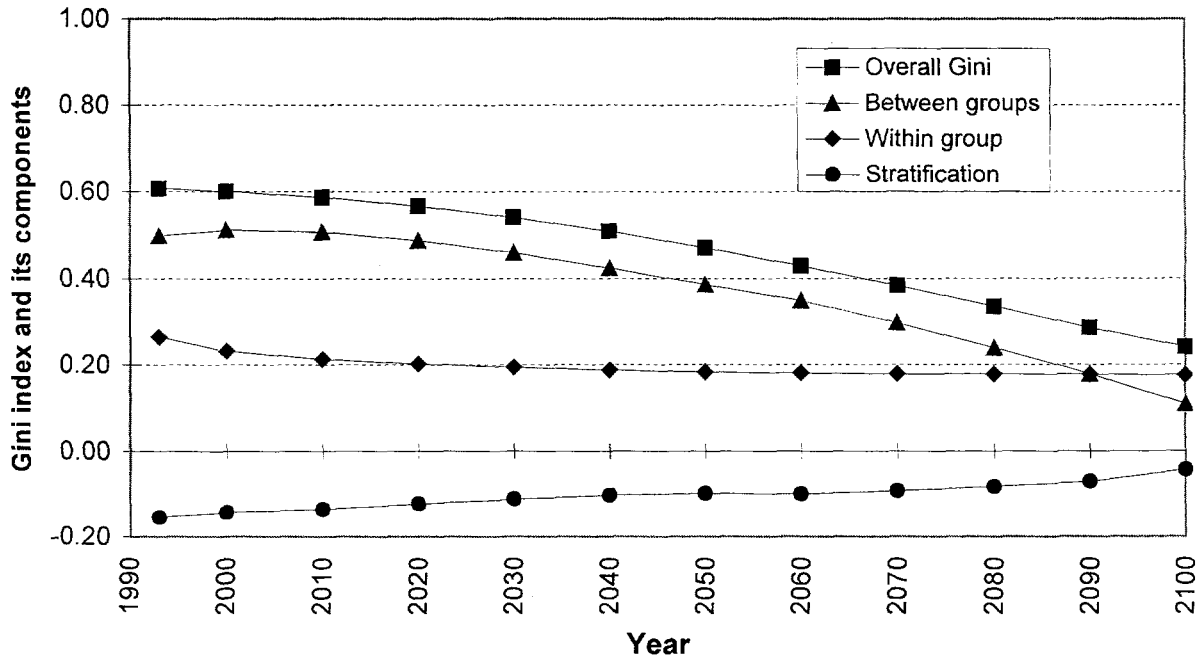
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