Divergence in Per Capita Carbon Dioxide Emissions[1]

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November 10, 2004, Comments Welcome

Abstract

Understanding the distribution of per capita carbon dioxide emissions is important in considering the design of and incentives for participation in international climate change proposals. I evaluate historic international and U.S. states emissions distributions and forecast future distributions to assess whether per capita emissions have been converging or will converge. I find little evidence of emissions convergence with an international data set over 1960-2000. Since this may reflect the lack of income convergence, I constructed a novel data set of U.S. state-level carbon dioxide emissions to assess emissions convergence for a set of advanced economies that have experienced income convergence. I find a stark divergence in per capita carbon dioxide among the states over 1960-1999. Forecasts based on a Markov chain transition matrix framework provide little evidence of future emissions convergence, and in some cases, divergence may occur in the near term. The paper concludes with a review of the shortcomings of reduced form parametric models (environmental Kuznets curve regressions) and structural models in characterizing future emissions distributions.

November 10, 2004, Comments Welcome

Divergence in Per Capita Carbon Dioxide Emissions

1. Introduction

Long-term emissions forecasts of carbon dioxide are critical inputs both to assessing the potential impacts of climate change and to evaluating the cost of emissions abatement. Such forecasts have been undertaken with structural models (e.g., through the Intergovernmental Panel on Climate Change and the Stanford Energy Modeling Forum) and reduced-form models (e.g., Holtz-Eakin and Selden 1995, Schmalensee et al. 1998, and Heil and Selden 2001). Presentations of these forecasts focus on the time path of global emissions, with little attention paid to the emissions distribution. To address the issue of the geographic distribution of carbon dioxide emissions, this paper focuses on two questions: (1) Have per capita emissions been converging in the past? and (2) Should we expect per capita emissions to converge in the future?

While the geographic distribution of greenhouse gas emissions does not influence the climatic impact of those emissions, the distribution of per capita emissions may affect the political economy of negotiating multilateral climate change agreements in two ways. First, countries with lower per capita emissions (i.e., developing countries) may expect countries with higher per capita emissions (i.e., industrialized countries) to undertake more effort to mitigate climate change. For example, the Framework Convention on Climate Change and the Kyoto Protocol established emissions goals and commitments for industrialized countries, but no emissions obligations for developing countries. This allocation of effort may reflect industrialized countries' larger contribution to climate change (a "responsibility" notion of equity) or their greater resources (an "ability to pay" notion), but both of these can be proxied by a country's per capita emissions given both the persistence in emissions over time and the correlation between economic development and emissions.[2] China's response to a proposed process for developing country emissions obligations at the 1997 Kyoto Conference summarizes many developing countries' views on this issue: "In the developed world, only two people ride in a car, and yet you want us to give up riding on a bus."[3]

Second, in lieu of negotiating *ad hoc* emissions obligations periodically (as in the current multilateral process), some have suggested explicit rules to assign emissions rights or obligations that would encourage developing country participation, such as a per capita emissions allocation scheme. In a per capita emissions regime, an aggregate quantity of greenhouse gas emissions would be set and this aggregate would be allocated to all (participating) countries on a per capita basis. The Indian Environment Minister advocated for such an approach at the 1997 Kyoto Conference: "Per capita basis is the most important criteria for deciding the rights to environmental space. This is a direct measure of human welfare."[4] Allocating emissions rights on a per capita basis also enjoyed the support of China and the Africa Group in 1997.

A review of 40+ proposed climate change policies by non-governmental organizations and academics revealed that more than one-quarter of the proposals included a per capita emissions allocation (Bodansky 2004). For several examples, refer to Baer et al. (2000), Gupta and Bhandari (1999), and Meyer (2000).[5]

A per capita scheme would allocate emissions rights in a vastly different way than the current emissions distribution, which reflects variations in development, climate, and land use, energy, and environmental policies, etc. The distribution of rents implicit in a per capita scheme,

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[2] The correlation between the natural logarithm of per capita income and the natural logarithm of per capita carbon dioxide emissions is 0.87 for a sample of 88 countries over the 1960-2000 period. Refer to section 2.1 for a description of this sample. All analyses in this paper focus on fossil fuel-based carbon dioxide emissions.

[3] Reported in: Climate Action Network. 1997. ECO: Climate Negotiations Newsletter 18(6). December 6, 1997. Internet: http://www.climatenetwork.org/eco/c3_6_tactics.html.

[4] Refer to Internet: www.indianembassy.org/policy/Environment/soz.htm.

[5] Rose et al. (1998) and Manne and Richels (1999) evaluate, but do not advocate for, per capita CO_2 allocation rules.

given current emissions, would not likely elicit developed countries' support. If emissions converge over time, then this concern may be less important.[6] If per capita emissions do not converge, a per capita emissions allocation would result in substantial resource transfers, through international emissions trading or the relocation of emissions-intensive economic activity.

To illustrate the potential impacts of a per capita emissions allocation, consider a hypothetical emissions policy among the U.S. states. Suppose that the U.S. Government proceeded with implementing the Kyoto Protocol and decided to allocate its emissions rights to the states either through a per capita allocation (based on each state's share of 1999 U.S. population) or a historical proportional allocation (based on each state's share of 1999 U.S. CO_2 emissions, also known as "grandfathering").[7] The differences in these two allocation schemes would be significant: the average state would receive an allocation under the per capita scheme that differs by 40 percent from the grandfathering allocation. Since CO_2 emissions rights prices could range from tens to hundreds of dollars per ton of carbon (Weyant and Hill 1999), tens of billions of dollars in annual rents would be at stake with this hypothetical allocation. The differences in per capita and grandfathering schemes would be much more pronounced among countries, which have greater cross-section dispersion in per capita emissions than the states.

The lack of emissions convergence may make it less likely that developing countries would agree to emissions abatement obligations. Efforts to broaden participation of developing countries through a per capita allocation rule may not garner the support of developed countries in the absence of emissions convergence. Informing the policy debate on these issues requires a more detailed examination of the distributional dynamics of greenhouse gas emissions.

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[6] While there is little evidence of economic convergence among developed and developing countries to date, many long-term emissions forecasts reflect at least some income convergence (see IPCC 2000).

[7] Refer to section 2.2 for an overview of the U.S. states carbon dioxide data constructed for this paper.

In this paper, I show that historical carbon dioxide emissions reveal little evidence of convergence for a large international data set. I then focus on the U.S. states, for which I constructed a novel carbon dioxide emissions data set. Understanding the historical emissions distributions of a set of advanced economies that have achieved economic convergence may cast some light on possible future emissions distributions of countries as they move towards more advanced stages of economic development. In the case of the U.S. states, I find a striking *divergence* in per capita carbon dioxide emissions over the 1960-1999 period. The lack of convergence in the historical data is also evident in forecasts of future distributions based on non-parametric transition matrix analysis. The long-run steady state international and U.S. states distributions have thick tails, and are less compact than current distributions. Forecasts of future dispersion measures reveal very little convergence relative to current distributions. The forecasts section of the paper concludes with a discussion of the shortcomings of current reduced-form parametric analysis (environmental Kuznets curve regressions) and structural models.

The next section introduces the data used in this paper. The third section presents the international and U.S. states historical analyses. The fourth section focuses on forecasting future distributions of carbon dioxide emissions. The final section concludes the paper.

2. International and U.S. States Emissions and Income Data

2.1 International Data, 1960-2000

The data on fossil-fuel-based carbon dioxide (CO_2) emissions are from Marland et al. (2003). All statistical analyses are conducted with a balanced panel of 88 countries over the 1960-2000 period. Countries with total CO_2 emissions less than 1 million tons of carbon equivalent in 2000 or with missing observations during 1960-2000 were excluded from the sample. For countries that changed borders over time, country aggregates were constructed: USSR observations were constructed from the 15 former Soviet republics and Czechoslovakia observations were constructed from the Czech Republic and Slovakia for the 1990s, and Germany observations were constructed from East Germany and West Germany for the 1960-1990 period. The 88 countries in the sample represent 92 percent of global CO_2 emissions associated with fossil fuel combustion. The income per capita data are from the real chain-weighted GDP per capita (rgdpch) series in the Penn World Table 6.1 (Heston et al. 2002).[8]

2.2 State-Level Data, 1960-1999

Since long-term CO_2 emissions data sets do not exist for the U.S. states, I have constructed state-level emissions estimates based on fossil fuel combustion data (refer to Lutter 2000 and Marland et al. 2003 for similar applications of this approach). The Energy Information Administration (2001b) has compiled state-level energy consumption by fuel type and sector for the 1960-1999 period. I converted energy consumption to CO_2 emissions using national sector- and fuel-specific emissions factors provided in EIA (2001a; Appendix B).[9]

As a check on the plausibility of this construction, I aggregated these state-level CO_2 emissions values to yield annual national estimates and compared these to the Marland et al. estimates for U.S. emissions. Over the 1960-1999 period, my constructed U.S. values differ on

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[8] The 88 countries are: Algeria, Angola, Argentina, Australia, Austria, Belgium, Bulgaria, Bahrain, Bolivia, Brazil, Canada, Chile, China, Cote d'Ivoire, Cameroon, Colombia, Costa Rica, Cuba, Cyprus, Czechoslovakia, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Ethiopia, Finland, France, Germany, Ghana, Greece, Guatemala, Hong Kong, Honduras, Hungary, Indonesia, India, Ireland, Iran, Iraq, Israel, Italy, Jamaica, Jordan, Japan, Kenya, Kuwait, Lebanon, Luxembourg, Morocco, Mexico, Mongolia, Myanmar, Nigeria, Nicaragua, Netherlands, Norway, New Zealand, Panama, Peru, Philippines, Poland, Puerto Rico, Portugal, Qatar, Romania, Saudi Arabia, Singapore, South Africa, South Korea, Spain, Sri Lanka, Sudan, Sweden, Switzerland, Syria, Thailand, Trinidad and Tobago, Tunisia, Turkey, Taiwan, United Kingdom, Uruguay, United Arab Emirates, United States of America, United Soviet Socialist Republics, Venezuela, Yugoslavia.

[9] All statistical analyses presented in this paper exclude Alaska, Hawaii, and Washington, DC.

average 1.7 percent from the Marland et al. estimates (1.0 percent standard deviation). The maximum annual differential between the data sets is 3.8 percent. A comparison with EIA (2001a) CO_2 emissions estimates for the United States yields very similar results. While some states likely have measurement error in excess of 1.7 percent, this comparison illustrates the plausibility of the energy-based construction of state carbon dioxide emissions.

These carbon dioxide estimates reflect all within-state fossil fuel combustion emissions. They represent emissions associated with producing all goods and services in a given state, so they can also be denoted *production*-based CO_2 emissions. In the presence of interstate trade, the emissions intensity of a state's production may differ from the intensity of this state's consumption. To explore this distinction, a second carbon dioxide emissions data set was constructed to account for the trade in electricity among the U.S. states. To modify the carbon dioxide emissions data set, I first calculated the annual average carbon-intensity of each state's electricity sector. For a state that is a net exporter of electricity in a given year, the carbon emissions associated with the exported electricity (reflecting the state's average electricity carbon intensity) are deducted from that state's total emissions for that year. For a net importer, that state's emissions are augmented based on the average carbon intensity of the imported electricity. Since this modified measure reflects post-trade emissions and attempts to approximate for *consumption*-based emissions, as opposed to the production-based or standard measure of emissions, I refer to it as consumption-based CO_2 throughout the analysis.[10]

The income variable used in these analyses is the state personal income series provided by the Bureau of Economic Analysis (2000).[11] These data have been used in a variety of papers,

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[10] Ideally, a complete consumption-based measure of carbon dioxide would also reflect the emissions intensity in all traded goods and services. Unfortunately, such interstate trade data are not collected.

[11] These values were converted to constant year (1999) dollars based on the national CPI-Urban deflator (CEA 2001, Table B60).

including those on economic growth and the environmental Kuznets curve (e.g., Barro and Sala-i-Martin 1992, List and Gallet 1999, and Millimet et al. 2003). The Bureau of Economic Analysis also provides the annual state population data used to construct all per capita estimates.

3. Evaluation of Historical Data

To address the question of whether per capita CO_2 emissions have been converging, I first assess the trends with the international dataset and then evaluate the trends in the U.S. states dataset. To characterize historic emissions distributions, I have evaluated the data for cross-sectional convergence and time series (stochastic) convergence. To assess cross-sectional convergence, I first investigate σ-convergence, or dispersion, by estimating the standard deviation of the natural logarithm of per capita CO_2.[12] If this measure of dispersion declines over time, then per capita emissions are converging in a σ-sense (Barro and Sala-i-Martin 1995).

To complement the assessment of σ-convergence, which is based on a summary measure of the cross-section, I present distributions of per capita emissions over time to illustrate emissions trends. Understanding the change in the complete distributions over time can further illuminate the intra-distributional dynamics that may not be captured by a summary statistic of a distribution (σ-convergence) or time series regressions (stochastic convergence). For these illustrations, a country's (state's) per capita emissions are expressed as the ratio of its emissions per capita to the world (national) average for that year. This presentation of the estimated distributions also sets the stage for the non-parametric distributional forecasting in section 4.

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[12] By employing the standard deviation of the natural logarithm of emissions per capita, in lieu of the standard deviation of per capita emissions, this measure of dispersion can decline only if the growth rate of economies with lower per capita levels exceeds the growth rate of economies with higher per capita levels. Likewise, the measure of dispersion can only increase if the growth rate of economies with higher per capita levels exceeds the rate for those with lower per capita levels.

I have also estimated the 20th and 80th percentiles and associated 80-20 interquantile ranges for the emissions per capita relative to the world (and national) average for three-year periods around the turn of each decade in my data.[13] I employed least (minimum) absolute deviations estimators to construct these percentiles and interquantile ranges, and the estimated variance-covariance matrices were based on bootstrapping with 1,000 replications. These estimates allow for an explicit evaluation of whether the spread in the distribution changes over time through tests comparing the estimated magnitudes of the interquantile ranges.[14]

To assess stochastic convergence, I test for whether relative emissions per capita are separate random walks with drift. If per capita emissions are converging in a stochastic sense, the shocks to emissions are temporary and the data are stationary over time. If a unit root characterizes the emissions time series, however, then shocks are permanent and emissions are not converging. Carlino and Mills (1993) have employed these tests for unit roots to evaluate income convergence among the U.S. states and List (1999) has done the same for assessing regional convergence in per capita NO_X and SO_2 emissions. Following the preceding literature (and using List's notation), I analyze the log of the ratio of per capita emissions for one country (state) to the world (U.S.) average. Specifically, I model the log of an economy's relative emissions per capita (RE_{it}) as a function of a time-invariant equilibrium differential (RE_i^{eq}) and time- and economy-specific deviations from that differential (u_{it}):[15]

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[13] For the international data sets, I evaluated 1960-1962, 1969-1971, 1979-1981, 1989-1991, and 1998-2000. For the U.S. states data sets, I evaluated the same periods, except for 1997-1999 for the last time period. Using only one year for each decade (e.g., 1960, 1970, 1980, 1990, 2000) yields very similar point estimates but larger estimated standard errors.

[14] To evaluate the hypothesis that the 80-20 interquantile range has not changed over time, I jointly estimate the interquantile ranges for each pair under consideration (e.g., 1960-1962 and 1998-2000). A standard F-test is employed to test for whether the estimated ranges are statistically different.

[15] We should not expect complete emissions convergence, but instead an equilibrium differential, among any set of economies because of variations in climates and associated energy demand, as well as variations in the composition of economic activity. See Aldy (2004) for evidence that per capita emissions vary with heating and cooling demand and historic energy endowments for the U.S. states.

(1) $$RE_{it} = RE_i^{eq} + u_{it}$$

where u_{it} is the stochastic process represented by:

(2) $$u_{it} = c_{i0} + \varepsilon_{it}$$

and c_{i0} represents the initial deviation from the equilibrium differential. As in Carlino and Mills and List, I substitute (2) into (1) which yields our stochastic convergence equation:

(3) $$RE_{it} = \mu_i + \varepsilon_{it}$$

and $\mu_i = RE_i^{eq} + c_{i0}$. If the deviations from the long-run equilibrium differential, ε_{it}, are temporary, then the economies are converging in a stochastic sense. To test for whether these disturbances are temporary, I expanded equation (3) to include a linear time trend and conducted economy-specific augmented Dickey-Fuller tests for unit roots. A second set of tests were also undertaken in which I allowed for one endogenously determined break in the time trend based on the Perron and Vogelsang (1992) innovation outlier trend break model. I chose the lag structure for these tests on an economy-specific basis using the Akaike Information Criterion.

3.1 Evaluation of International Data

Figure 1 depicts the dispersion in the log of per capita CO_2 and the log of per capita income for the international data set sample over the 1960-2000 period. Not surprisingly, this figure shows the lack of convergence, and some divergence in recent years, of income per capita. The dispersion in CO_2 emissions has remained remarkably constant over the past 40 years or so, but it is slightly higher in 2000 than in 1960.

In addition to a single summary statistic, such as the dispersion measure, I constructed distributions of per capita CO_2 emissions. Following the work by Quah (1993) and Kremer et al. (2001) on incomes, I have constructed the ratio of per CO_2 dioxide emissions to the world average. I then placed each country into one of five categories: less than 1/4 of the world average, between 1/4 and 1/2 of the world average, between 1/2 of and the world average, between the world average and twice the world average, and more than twice the world average.

Figure 2 displays the histograms based on these five categories for 1960, 1980, and 2000. Two phenomena are very clear in these histograms. First, the tails are thick. A majority of countries have per capita CO_2 emissions that are a factor of two away from the world average (less than ½ of world average and greater than twice the world average). In 1960, 70 percent of all countries in the sample were a factor of two away from the world average, with modest improvement to 62 percent in 1980 but then back up to 66 percent in 2000.

Second, there appears to be some evidence of a twin peaks phenomenon in the CO_2 emissions data, which may parallel some of the evidence of twin peaks in income per capita (Quah 1993, 1997; cf. Jones 1997 and Kremer et al. 2001). In 1960, the density of the distribution was monotonically decreasing in relative per capita CO_2 emissions. The densest category, less than ¼ of the world average, had more than double the number of countries in the one to two times the world average category in 1960. By 2000, these two categories had virtually the same number of countries. This may suggest that an emissions analog to the twin peaks in incomes phenomenon could characterize these data.

Estimates of the 20th and 80th percentiles of the distribution of emissions per capita relative to the world average also show emissions divergence (Table 1). While the emissions per capita of a country at the 20th percentile increased from less than 10 percent of the world average in 1960 to more than one-quarter the world average in 2000, the emissions per capita of a country at the 80th percentile has increased even more relative to the world average, from 1.7 times the world average in 1960 to 2.3 times the world average in 2000. The 80-20 interquantile range increased substantially between 1960 and 1980, from 1.62 to 2.16, before falling to 2.02 by 2000. These larger spreads between the 20th and 80th percentiles of the relative emissions per capita distributions in 1980 and 2000 are statistically different from the 1960 80-20 range at the 10 percent level. The forty percent of countries at the ends of the relative emissions per capita distribution are farther apart now than they were in 1960. The same holds for the twenty percent of countries in the bottom and top 10 percent of the distribution: estimates of the 10th and 90th percentiles (not presented) show a monotonically increasing interquantile range over time, although the estimates are insufficiently precise to statistically discern the ranges.

Tests for stochastic convergence confirm broadly the conclusion from the assessment of dispersion that countries' carbon dioxide emissions per capita are not converging. For only twelve of 88 countries do the test statistics from either the augmented Dickey-Fuller tests or the Perron-Vogelsang innovation outlier trend break model suggest rejecting the null hypothesis of unit root at the 5 percent critical level. Nearly seven out of eight countries in this sample have carbon dioxide emissions time series that appear to suffer from shocks that are permanent and may preclude convergence.[16]

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[16] Strazicich and List (2003) find that per capita carbon dioxide emissions are converging among OECD countries based on a panel unit root test for the 1960-1997 period. This may suggest that per capita emissions would converge, conditional on economic convergence, an issue explored explicitly in the following sub-section on the U.S. states.

3.2 Evaluation of U.S. States Data

Figure 3 illustrates quite starkly a divergence in per capita emissions over the 1960-1999 period for the U.S. states. This trend is all the more striking considering that per capita incomes among the states continue to converge (following a century-plus trend, see Barro and Sala-i-Martin 1992). The dispersion in consumption-based carbon CO_2 also increases with time, but to a much lesser extent than the standard or production-based emissions time series. This indicates that trade in electricity, which has increased in total and as a share of electricity generated over this time period, may be responsible for part of the divergence in per capita emissions.

Figure 4 presents distributions of state level per capita emissions relative to the national average. I adjusted the categories to better reflect the states data, so the first three categories are less than 1/2 of the national average, between 1/2 and 3/4 of the national average, and between 3/4 of and the national average. As in the international data, the tails become thicker with time. In 1960, only 2 states had per capita emissions that were less than half the national average and no states had per capita emissions more than twice the national average. By 1999, 18 percent of the states were in either the lowest or highest categories.

Table 2 presents the estimated 20th and 80th percentiles of the emissions per capita relative to the national average distributions. A state at the 20th percentile of the production-based emissions distribution has experienced modest variations in its relative emissions per capita between about three-fifths and two-thirds of the national average over the 1960-1999 period. In contrast, a state at the 80th percentile has experienced growth in its production-based emissions per capita relative to the national average from 1.28 times the national average in 1960 to about 1.47 times the national average in 1999. This resulted in a widening in the 80-20 interquantile range for production-based emissions from 0.57 in 1970 to 0.93 in 1990 before shrinking slightly to 0.84 in 1999. The larger spread in the 80-20 range for 1990 is statistically distinct from the 1960 and 1970 interquantile ranges at the 2 and 1 percent critical levels, respectively. The 1999 interquantile range is statistically different from the 1970 range at the 8 percent level. Analyses of the 90-10 interquantile range (not presented) reveal similar trends: the range increases monotonically starting in 1970, and the 1999 90-10 range is some 40 percent larger than the 1970 90-10 range. These estimates, however, are not sufficiently precise to support a conclusion that these estimated ranges are statistically different.

While the production-based CO_2 distributions experience an increasing spread in their 80-20 interquantile ranges over time, the consumption-based CO_2 estimated 80-20 interquantile ranges are quite stable over time (Table 2). The 20th and 80th percentile estimates experience only very modest changes over time: the 20th percentile estimates range from 0.65-0.68 and the 80th percentile estimates range from 1.19-1.26 over the 1960-1999 period. These result in an 80-20 range that experiences very little variation over this time period, from 0.53-0.58, and the 1990 and 1999 ranges are virtually identical to the 1960 range. The 90-10 spread (not presented) does increase some over time, but these interquantile range estimates cannot be statistically discerned.

The wedge between consumption-based CO_2 and production-based CO_2 may reflect the effects of local air quality regulation and economic trade. Henderson (1996) has shown that concentrations of regulated air pollutants have decreased in areas failing to meet national ambient air quality standards (non-attainment areas) but increased in those complying with these standards (attainment areas). Since non-attainment areas are generally more densely populated than attainment areas, this shift in emissions-intensive economic activity has relocated production to more sparsely populated areas. Given the correlation between carbon dioxide emissions and regulated air pollutants (fossil fuel combustion is the primary source of emissions for most air pollutants), higher CO_2 emissions in sparsely populated areas coupled with lower CO_2 emissions in densely populated areas could explain this divergence in per capita emissions. With minimal barriers to interstate trade, relocating emissions-intensive production to other states should not substantially affect a state's consumption. The low population density of the highest per capita carbon dioxide states[17], the increasing role of emissions-intensive interstate electricity trade,[18] and the high correlations between carbon dioxide and sulfur dioxide and nitrogen oxides emissions[19] all suggest that this mechanism could explain at least part of the emissions divergence.

An evaluation of stochastic convergence for the states likewise reveals little evidence of convergence. Virtually every state's emissions time series is characterized by a trend break (occurring between the late 1960s and late 1970s). Even while accounting for the trend break, we could not reject the hypothesis of a unit root in the emissions time series for any state. Shocks to relative emissions appear to be permanent, and the states are not converging in a stochastic sense.

I find, at best, limited evidence of convergence among countries. The lack of emissions convergence among countries may reflect the current absence of convergence in per capita income. For the U.S. states, despite economic convergence, I find a consistent trend towards divergence in per capita CO_2. The distribution of emissions has evolved over time revealing increasing density in both the lower and upper tails. The next section will investigate whether such trends may continue into the future.

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[17] The five (ten) states with the highest per capita carbon dioxide emissions in 1999 had a population density equal to less than one-fifth (one-third) the national average.

[18] Interstate electricity trade has been increasing over the past 40+ years. Nearly one-quarter of all electricity-related CO_2 emissions in 1999 for the 26 net exporting states were associated with electricity exports.

[19] The primary source of all three pollutants is the combustion of fossil fuels.

4. Forecasting Future Emissions Distributions

To address the question of future emissions distributions, I consider three approaches. First, I present results from a Markov chain transition matrix analysis, a non-parametric method employed in the economic growth literature to evaluate income distributions. Second, I discuss reduced-form parametric environmental Kuznets curve (EKC) regressions and note the shortcomings in using a fitted EKC to characterize future emissions distributions. Third, I review the results from structural models used to forecast emissions for the IPCC's 2000 *Special Report on Emissions Scenarios* and characterize the implicit emissions distributions in these forecasts.

4.1 Markov Chain Transition Matrices

Quah (1993) applied the transition matrix framework to evaluate the distribution of per capita incomes. Following Quah, this framework effectively maps today's distribution (F_t) of per capita CO_2 emissions into tomorrow's distribution (F_{t+1}):

$$F_{t+1} = M \cdot F_t \tag{4}$$

The mapping operator, M, can be assumed to follow any process, but as in Quah and Kremer et al. (2001), I assume a first-order Markov process with time-invariant transition probabilities. Iterating this expression T times yields:

$$F_{t+T} = M^{T} \cdot F_t \tag{5}$$

As T becomes large and if $F_{t+T} = F_{t+T-1}$, this expression can illustrate the long-run (ergodic) distribution of per capita carbon dioxide emissions.

As in Quah and Kremer et al., I have discretized the data following the five categories of emissions per capita relative to the world average (and to the national average for the U.S. states) described in section 3. I then calculated the one-year transitions from one category to another to construct the transition matrices presented in Tables 3 and 6. The transition probabilities in these tables represent the mapping operator that is applied to the distribution in the last year of the data sets (2000 for the international data and 1999 for the U.S. states data) to estimate the future distribution for each data set.

The benefit of this approach is that it imposes little structure on the data (other than in the construction of the five discrete categories and the first-order Markov assumption), so the data can reveal without substantial constraint their evolution over time. There are, however, several downsides of this approach. First, while it may characterize future distributions, we still need to conduct further analysis to understand why the distribution of emissions evolves as it does. Further, while not addressed in previous papers, one may be concerned that the drivers of distributional dynamics in 2000 may be different than in the 1960s or 1970s. To explore this point, I assess and compare the ergodic distributions derived from transition probabilities based on a variety of time periods, from 1960-2000 to 1990-2000 samples. Finally, by using information on historical distributional dynamics to forecast future distributions, significant changes from past experience in policies or technologies (e.g., new CO_2 regulations, breakthroughs in renewable energy) may not be well represented by this approach.

4.1.1 Transition Matrices for the International Data

Table 3 presents the transition matrix based on the 1960-2000 international sample and its ergodic distribution. As in the papers by Quah and Kremer et al. on the dynamics of income distributions, there is considerable persistence evident in the high probabilities along the diagonal. For example, a country in the lowest category (per capita emissions less than ¼ of the world average) has a 97.5 percent probability of remaining in that category next year and a 2.5 percent probability of moving up one category. If that country does move up to the next category, then in the following year, it has a 9.0 percent probability of moving up to the third category, a 7.2 percent probability of returning to the lowest category, and an 83.8 percent probability of remaining in the second category. The triple diagonal condition noted in the literature on income distributions effectively holds here: transition probabilities off of the three main diagonals are zero. This implies that countries do not experience a more than doubling or less than halving of per capita emissions from one year to the next.

The long-run distribution of per capita emissions, represented by the estimated ergodic distribution, shows that nearly 60 percent of all countries would be expected to have less than half of the world's average per capita emissions. Fewer than one out of three countries would have per capita emissions within a factor of two of the world average. Indeed, the bottom of the ergodic distribution is thicker than in historical distributions (see Figure 2), suggesting further divergence in emissions. To explore the sensitivity of using one-year data, I have also constructed five-year averages for this sample (not presented here). The estimated ergodic distribution is even thicker in the lowest two categories with the five-year average transition matrix.

The choice of time period from which to draw observations to construct the transition matrix does appear to influence the estimated ergodic distribution. Table 4 shows the ergodic distributions for transition matrices based on time periods starting in 1960, 1970, 1980, and 1990 and all ending in 2000. For the 1960-2000 sample, the first-order Markov transition matrix framework treats a transition in 1961 the same as one in 1999 for forecasting future distributions, although it is reasonable that the underlying economic, technological, and institutional factors influencing transitions change over time. Estimating ergodic distributions with shorter panels effectively weights the early observations in our sample with a zero and maintains equal unit weights on observations remaining in the shorter panels. After the 1970s, the bottom of the emissions distribution appears to be thinner in the ergodic distributions, and in the one-decade sample, the ergodic distribution reveals the twin peaks characteristic evident in the year 2000 in Figure 2. While this sensitivity analysis raises questions about the appropriate length of a panel to construct transition matrices, none of these estimated ergodic distributions display meaningful convergence in per capita emissions.

To test the sensitivity of constructing these five categories relative to the world average, I have also conducted these transition matrix analyses with five categories of per capita emissions relative to the U.S. average: less than 1/16, 1/16-1/8, 1/8-1/4, 1/4-1/2, and greater than 1/2 of U.S. per capita emissions (see Jones 1997 for incomes per capita relative to the U.S. average). I find even more pronounced evidence of the twin peaks phenomenon in per capita CO_2, especially in the shorter panels-based ergodic distributions (see Table 5). Note that in the ergodic distribution estimated from the 1990-2000 transitions, the two largest categories are the tails, with nearly two-thirds of all countries with either less than 1/16 the U.S. emissions or more than 1/2 of the U.S. emissions.

While the estimated ergodic distributions characterize the long-run steady state distribution of emissions, the transition is also of interest. Figure 5 presents the estimated dispersion measure over the next 100 years based on the transitions underlying the ergodic distributions summarized in Table 4.[20] While the 1960-2000 and 1970-2000 transition matrices suggest some convergence over the next 100 years, the shorter and more recent panels show continued divergence over the next 50 or so years, followed by some modest convergence back to current levels of dispersion.

4.1.2 Transition Matrices for the U.S. States Data

Table 6 presents the transition matrix for the U.S. states over the 1960-1999 period and the estimated ergodic distribution. As in section 3.2, the categories for the U.S. states differ from the international data categories by starting with the first category of less than 1/2 of the national average per capita emissions. The transition matrix still satisfies the triple diagonal condition and the high probabilities along the main diagonal illustrate even greater persistence than in the international data.

The ergodic distribution based on the 1960-1999 transitions appears to be more compact than the 1999 distribution of emissions, but less compact than in 1960 (compare with Figure 4). The evolution of the emissions distribution over the 1960-2000 period is evident in the estimated ergodic distributions with shorter panels (see Table 7). The ergodic distribution associated with the 1990-1999 transition matrix actually has thicker tails than the 1999 distribution, suggesting that emissions may continue to diverge if the more recent dynamics better explain future distributions.

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[20] Each country in a category in a given year was assigned the averaged relative CO_2 per capita for that category.

I also evaluated the ergodic distributions for consumption-based carbon dioxide per capita and income per capita. Table 8 shows that the consumption-based distribution is slightly more compact than the standard carbon dioxide per capita distribution. The income per capita ergodic distribution is a much more compact distribution. This further illustrates that the dynamics underlying the distribution of incomes may differ from the dynamics underlying the distribution of emissions.

4.2 Environmental Kuznets Curve Analysis

The environmental Kuznets curve attempts to characterize pollution (in this case, per capita CO_2 emissions) as an inverted-U function of per capita income. Some have suggested that finding an inverted-U environmental Kuznets curve is a test of cross-sectional convergence (e.g., List 1999). While this may be the case in the long-term (assuming convergence in incomes), the environmental Kuznets curve income-emissions relationship cannot unambiguously support emissions convergence or divergence during the transition to a long-term steady state.[21]

A brief graphical analysis illustrates that the environmental Kuznets curve yields ambiguous conclusions about convergence during the transition to the steady-state. Consider a scenario in which incomes converge. In each graph in Figure 6, suppose that A corresponds to a representative developing country and that B corresponds to a representative developed country. Times t and T represent the beginning and ending of the time period under consideration. A

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[21] An empirical environmental Kuznets curve may even fail to yield long-term emissions convergence if the estimated shape of the curve reflects only transitory phenomena. For example, the inverted-U shape may reflect changes in production associated with a country's stage of development (Arrow et al. 1995). A decrease in pollution in one economy may simply represent a shift in the polluting production activity to another economy, which would then experience an increase in pollution. This could follow the development path from agriculture (low income) to heavy industry (middle income) to services (high income). Since agriculture tends to be less energy-intensive (carbon-intensive) than heavy industry, which is also more energy-intensive (carbon-intensive) than services, this development path could result in an environmental Kuznets curve for carbon dioxide. Note, however, that the inverted-U would only be temporary, since *every* economy cannot specialize in services and export its heavy industry to other economies. Refer to Aldy (2004) that presents some evidence in support of this hypothesis.

determination of emissions σ-convergence would reflect the relative within-time frame differences among the countries ($|CO2_{At} - CO2_{Bt}|$ versus $|CO2_{AT} - CO2_{BT}|$).

Suppose that at the beginning of the time period, developing and developed countries have identical per capita emissions, but different income levels (Figure 6a). With an inverted-U environmental Kuznets curve, income convergence implies emissions divergence. Per capita emissions for developing countries would initially increase but then decrease by the end of the period ($A_t \rightarrow A_T$), while developed countries' emissions would decrease throughout the period ($B_t \rightarrow B_T$), and fall to a greater extent than the net effect of developing countries' emissions. Per capita emissions dispersion increases over the time period ($|CO2_{At} - CO2_{Bt}| < |CO2_{AT} - CO2_{BT}|$).

Suppose in the second case that developing countries' per capita emissions are greater than developed countries' emissions (Figure 6b). With the environmental Kuznets curve relationship and these starting points, income convergence could imply emissions convergence or divergence depending on the length of the time period under consideration. For the longer t to T time period, developing countries' per capita emissions decline to a greater extent over the time period than do developed countries' emissions resulting in a decline in emissions dispersion over the time period ($|CO2_{At} - CO2_{Bt}| > |CO2_{AT} - CO2_{BT}|$). For the shorter t to t+1 time period, the countries with higher emissions per capita would experience positive growth in emissions ($A_t \rightarrow A_{t+1}$) while those with lower emissions per capita would experience negative growth ($B_t \rightarrow B_{t+1}$), resulting in an increase in dispersion over time in per capita emissions.

The third case most resembles the current state of the world with developed countries' per capita CO_2 emissions levels exceeding the levels of developing countries (Figure 6c). Income convergence and the environmental Kuznets curve again can imply emissions convergence or divergence. Emissions convergence could occur in both the short- and long-run, but divergence could characterize the medium-term. In the emissions convergence subcases (t to t+1 and t to T periods), reduced emissions dispersion occurs over time ($|CO2_{At} - CO2_{Bt}| > |CO2_{AT} - CO2_{BT}|$ and $|CO2_{At} - CO2_{Bt}| > |CO2_{At+1} - CO2_{Bt+1}|$). Note, however, that while emissions dispersion is less at the end of the time period (T) than at the beginning of the period, it is greater than at the end of the short time period (t+1): $|CO2_{AT} - CO2_{BT}| > |CO2_{At+1} - CO2_{Bt+1}|$. This reveals the increase in dispersion that occurs in the medium term as developing countries experience a substantial increase in per capita emissions ($A_{t+1} \rightarrow A_{t+2}$) while developed countries experience a modest decrease in per capita emissions ($B_{t+1} \rightarrow B_{t+2}$).

The fourth case with income convergence employs a non-inverted-U income-emissions relationship (Figure 6d). In this case, emissions are assumed to always grow with income, but at a declining rate. Note, however, that per capita emissions never fall with rising incomes in this case. This case, like the third case, best reflects the current state of the world with developed countries' per capita emissions exceeding developing countries' emissions. With this income-emissions relationship, income convergence implies unambiguously emissions convergence.

The first three cases illustrate the ambiguous implications of the environmental Kuznets curve on emissions convergence even in the presence of income convergence. These results would commend the use of extreme caution in extrapolating any emissions convergence implications from standard environmental Kuznets curve analyses. Moreover, the combination of emissions divergence and convergence in some cases should raise questions about the appropriate timing of implementing any per capita emissions allocation policies. The fourth case illustrates quite clearly a relationship between income convergence and emissions convergence, although at the expense of the inverted-U income-emissions relationship.

4.3 Structural Model Emissions Forecasts from IPCC 2000

The IPCC published long-term emissions forecasts in 1992 and 2000 (Leggett et al. 1992 and IPCC 2000) and these have been widely used and evaluated in the policy-making and academic communities. These long-term forecasts likely serve as the basis for decision-makers' expectations about future levels of emissions. The forecasts have served as inputs to global circulation models (e.g., Houghton et al. 2001) and long-term energy-economic models (e.g., the Stanford Energy Modeling Forum's EMF-14 exercise). Both the 1992 and 2000 emissions forecasts reports present emissions and population data in terms of four aggregated regions: the OECD (member countries as of 1990), the Soviet Union and Eastern Europe, Asia, and the rest of the world (primarily Africa and Latin America). It is important to recognize that the IPCC's reports do not present any statistics or figures characterizing the distribution of emissions, but they do provide some necessary information to construct measures of dispersion.

The IPCC forecast in the central emissions scenario of its 1992 report (IS92a) revealed that dispersion in CO_2 emissions per capita would decline by about 20 percent between 1990 and 2025 and by nearly 45 percent between 1990 and 2100. Building on this earlier work, the IPCC employed six long-term models to develop 40 long-term emissions scenarios for its 2000 report. For the IPCC's A1 scenario (a "central" marker scenario), per capita CO_2 emissions converge among the four regions in all 6 models (Figure 7). In several models, the dispersion coefficient falls by at least a factor of three in this scenario over the 1990-2100 period.

This convergence in the structural models may be a result of regional aggregation of the data. Figure 7 also presents the historical dispersion in CO_2 per capita for countries (as in Figure 1) and for these four regions. The convergence among regional aggregates is evident in the historical data, but this obviously masks the lack of convergence over the same time period with the country-level data set. While more disaggregated structural models exist (including those that participated in the 2000 IPCC effort), they may not have sufficient geographic detail, especially of developing countries, to adequately replicate the historical distribution of emissions or to characterize future emissions distributions.

6. Conclusions

As decision-makers continue to debate policies to mitigate climate change, they will benefit from information about future distributions of CO_2 and other greenhouse gas emissions. Understanding future levels of emissions (and associated atmospheric concentrations, climate impacts, etc.) can help decision-makers determine the appropriate magnitude of emissions abatement effort and understanding future distributions of emissions can help decision-makers allocate abatement obligations, or emissions rights. The lack of focus on emissions distributions in the existing literature and the continued interests in designing policies to increase participation by both key developed and key developing countries suggests that an analysis of past emissions distributions and forecasts of future distributions are merited. This paper makes an initial effort in describing both past and future distributions of per capita CO_2 emissions.

An analysis of an international panel for the 1960-2000 period shows little evidence of convergence in per capita CO_2 emissions based on a measure of dispersion, the distribution of emissions over time, and tests for stochastic convergence. Since this may reflect the absence of income convergence, I then focused on a set of economies that have been converging in incomes, the U.S. states. I find that CO_2 per capita has been diverging among the U.S. states over the 1960-1999 period. This increase in dispersion, while still evident, is weaker after accounting for the trade in electricity to better approximate consumption-based CO_2 emissions.

Forecasts of long-run emissions distributions using a transition matrix framework provide little evidence of emissions convergence in the future. Estimated ergodic distributions do appear to be sensitive to choice of time period when constructing transition probabilities, but all variations revealed no signs of future convergence. The distributions of emissions appear to be more dispersed than income distributions (presented in Quah 1993, Kremer et al. 2001, and in Table 8).

The other means of forecasting future emissions may not adequately characterize emissions distributions. Empirical environmental Kuznets curve regressions may not appropriately estimate long-run emissions distributions, especially if factors such as trade in energy-intensive goods are important, as appears to be the case in work on the U.S. states. Moreover, simply estimating an inverted-U emissions-income relationship does not unambiguously imply emissions convergence or divergence, at least during the transition to the steady state. Structural models, by focusing on aggregated regions, may not have sufficient geographic detail to represent the international emissions distribution well.

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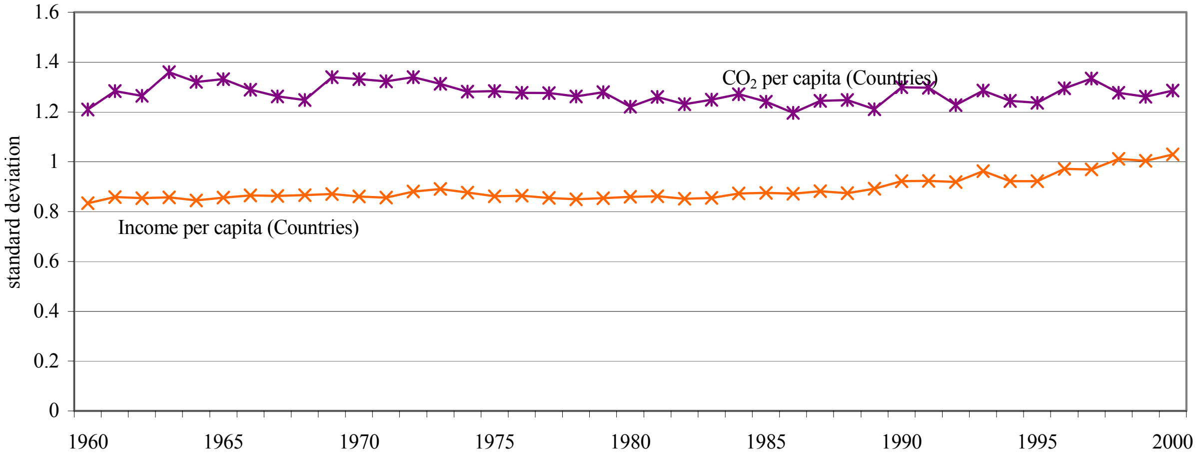
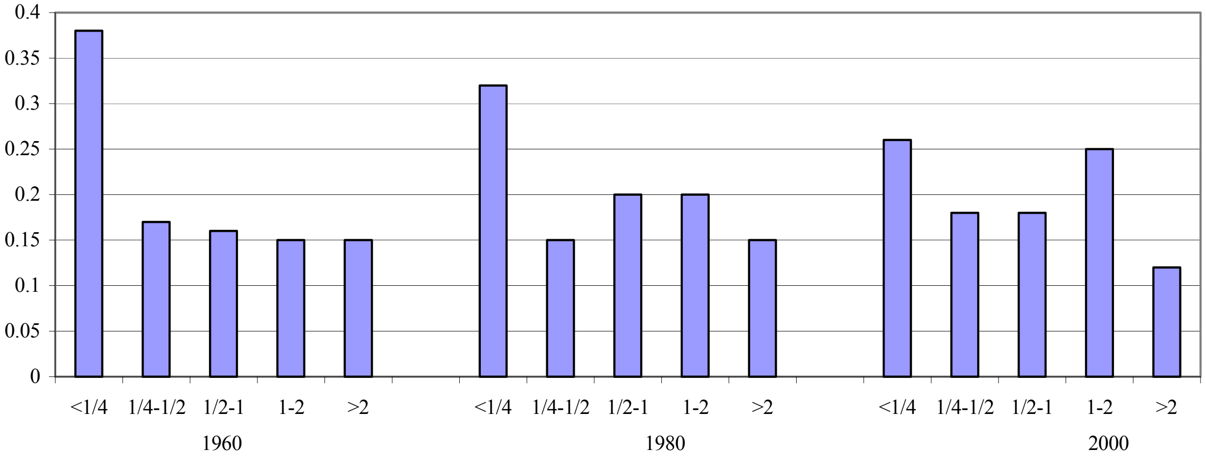
Figure 1. Dispersion in Per Capita Incomes and Carbon Dioxide Emissions, 1960-2000



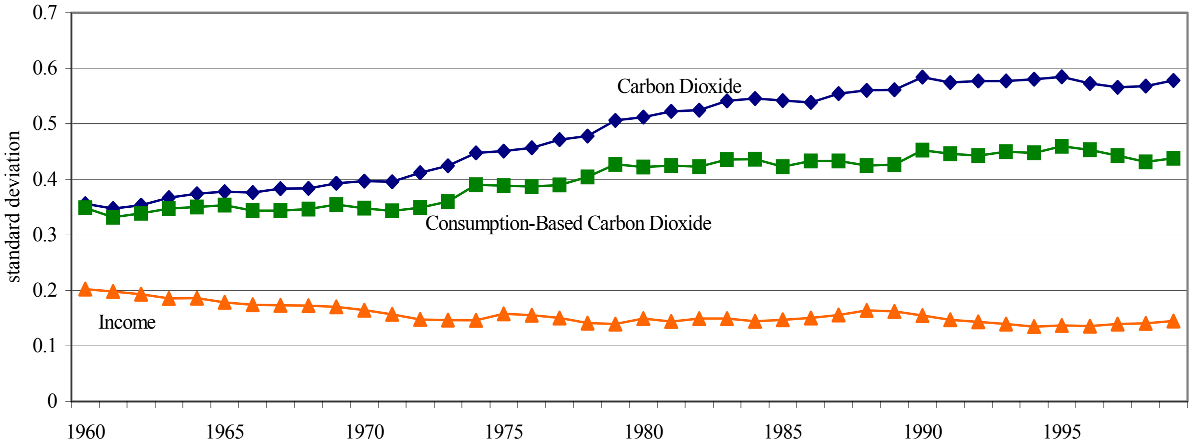
Notes. Represents the standard deviation of the natural logarithm of carbon dioxide emissions per capita and the standard deviation of the natural logarithm of income per capita. Carbon dioxide emissions data are from Marland et al. (2003) and income per capita data are from Heston et al. (2002; rgdpch series). Based on a balanced sample of 88 countries (refer footnote 7 for the complete list of countries in the sample).

Figure 2. Distribution of Countries by CO$_2$ per Capita (Relative to World Average)



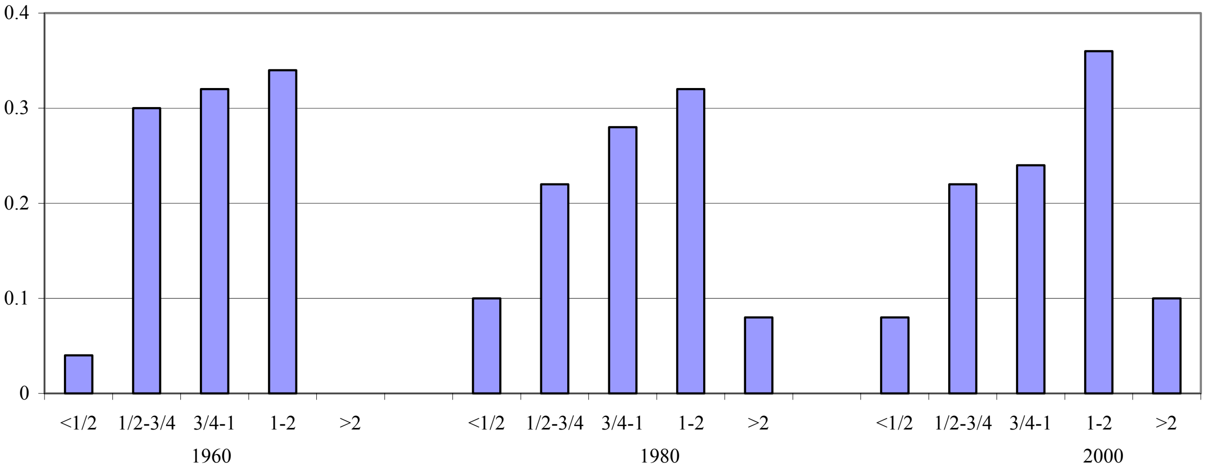
Notes. Annual world average carbon dioxide per capita estimated for the 88-country sample used in this paper. Carbon dioxide emissions data are from Marland et al. (2003).

Figure 3. Dispersion Among the U.S. States in Carbon Dioxide Emissions
and Income Per Capita, 1960-1999



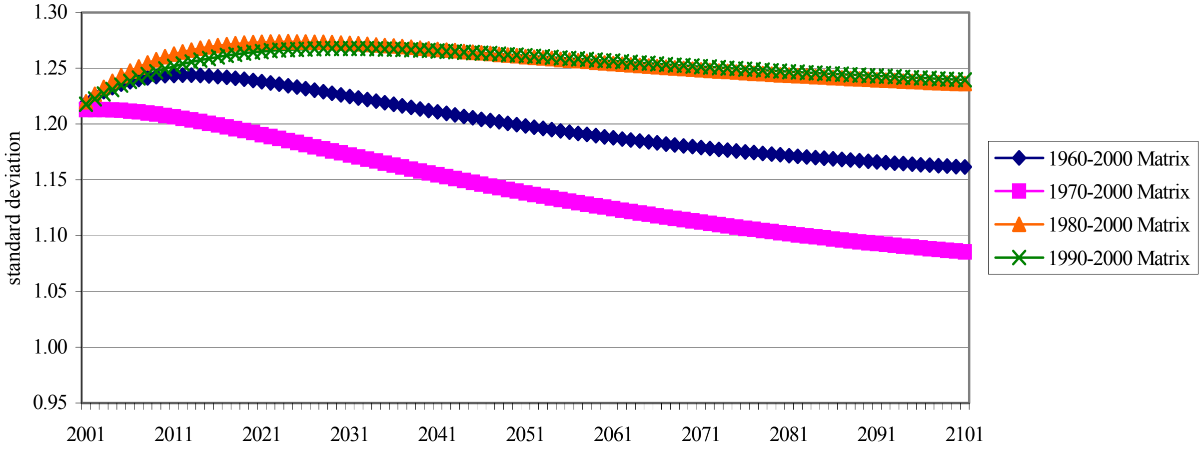
Notes. Represents the standard deviation of the natural logarithm of carbon dioxide emissions per capita and the standard deviation of the natural logarithm of income per capita. Carbon dioxide emissions data are constructed by author from energy consumption data in EIA (2001a) and income per capita data are from BEA (2000).

Figure 4. Distribution of States by CO_2 per Capita (Relative to U.S. Average)



Notes. Annual national average carbon dioxide per capita estimated for the 48-state sample used in this paper. Carbon dioxide emissions data are constructed by author from energy consumption data in EIA (2001a).

Figure 5. Transition Path for Measure of Carbon Dioxide Per Capita Dispersion, Based on Various Transition Matrices, 2001-2101



Notes. Represents the standard deviation of the natural logarithm of carbon dioxide emissions per capita forecasts based on Markov transition matrix analyses of the 88-country world sample. Carbon dioxide emissions data are from Marland et al. (2003).

Figure 6(a). Illustration of Environmental Kuznets Curve (I)

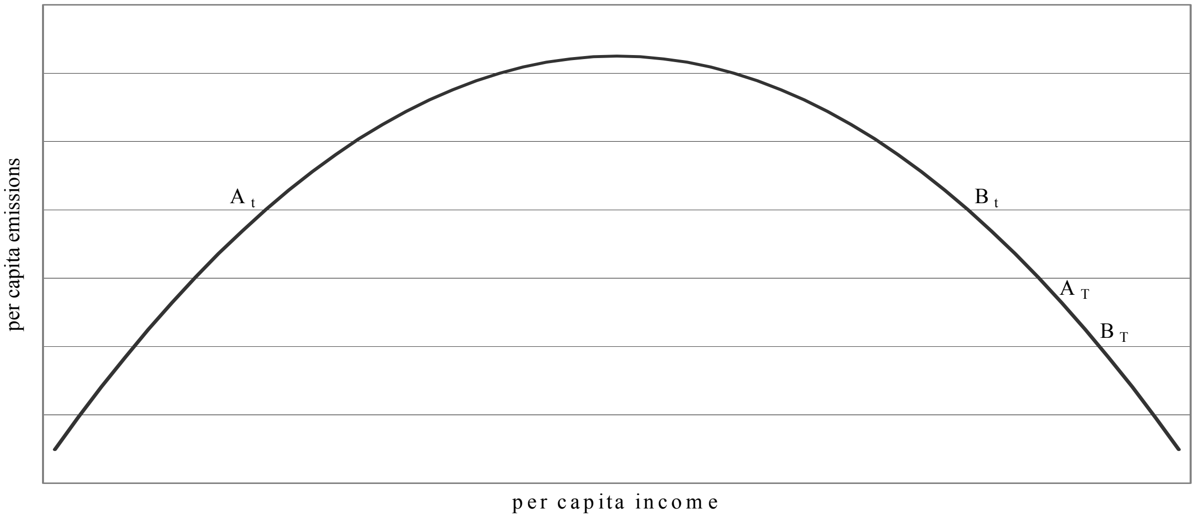


Figure 6(b). Illustration of Environmental Kuznets Curve (II)

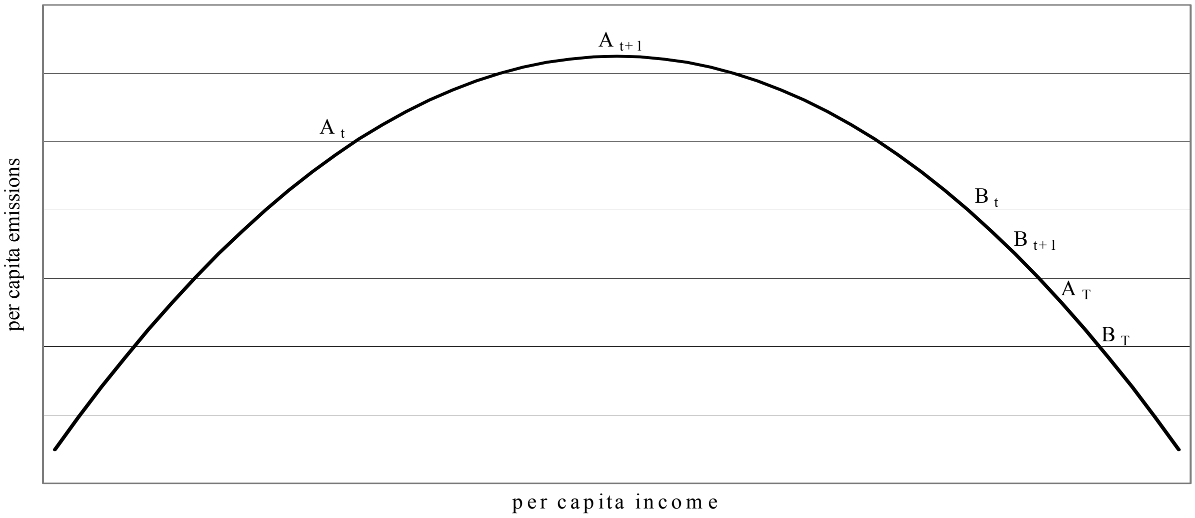


Figure 6(c). Illustration of Environmental Kuznets Curve (III)

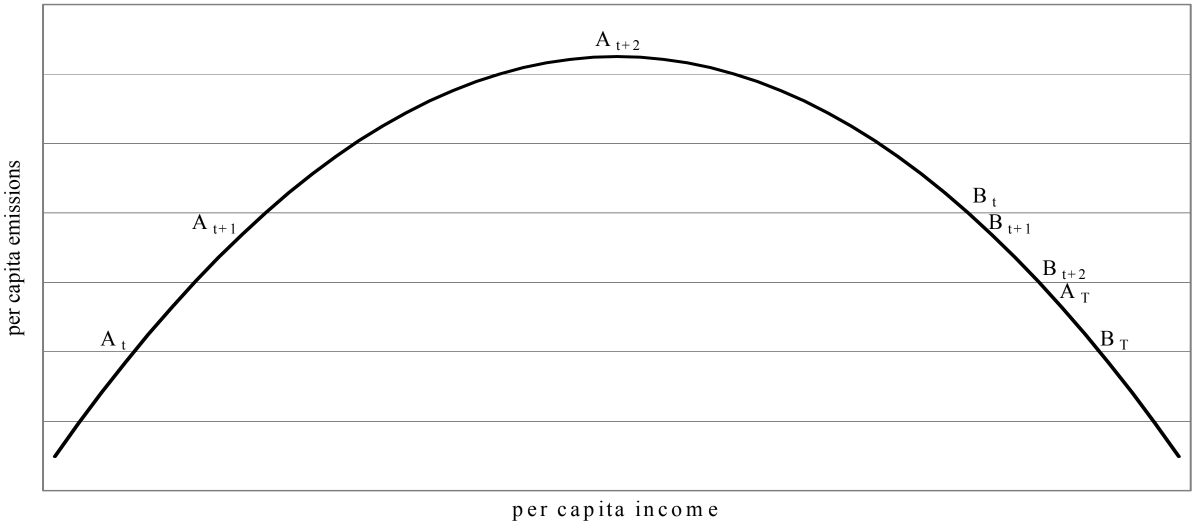


Figure 6(d). Illustration of Environmental Kuznets Curve (IV)

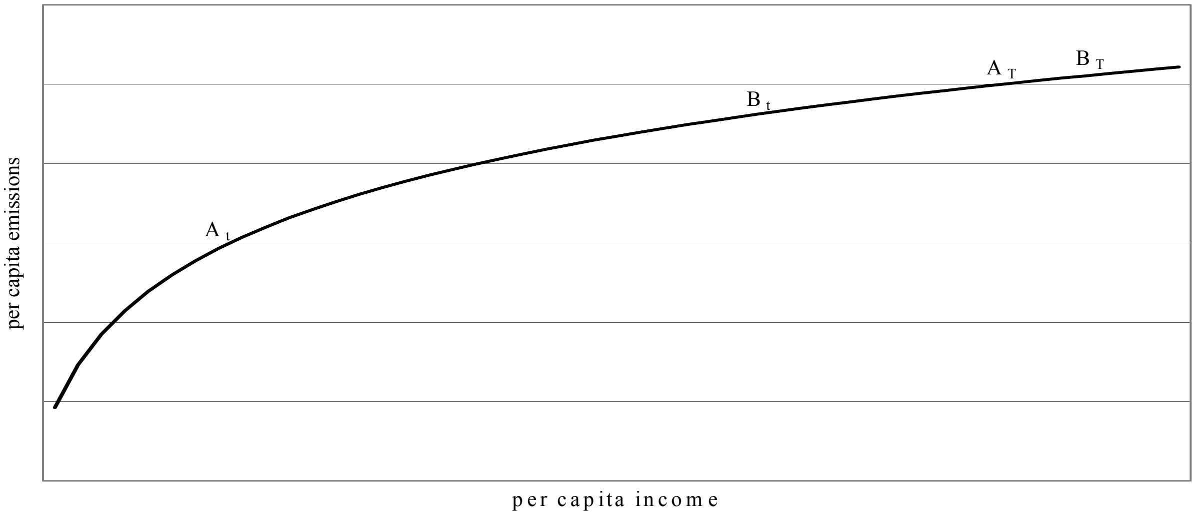
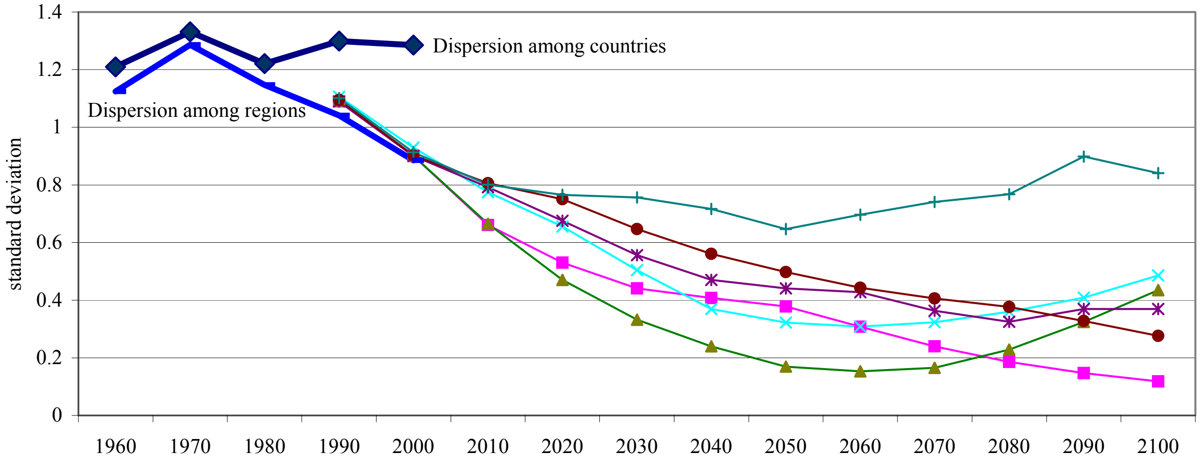


Figure 7. Historical Dispersion in Per Capita Carbon Dioxide and
Forecast Dispersion by 6 IPCC Models (A1 Scenario)



Notes. Represents the standard deviation of the natural logarithm of carbon dioxide emissions per capita for 88 countries (1960-2000) and four regions – OECD-90, Soviet Union and Eastern Europe, Asia, and rest of the world – for 1960-2000 and for 1990-2100 emissions forecasts of the IPCC's A1 scenario with six long-term energy-economic models (IPCC 2000).

Table 1. Estimated 20th, 80th Percentiles, and 80-20 Interquantile Range, World Relative CO_2 per Capita Distribution, 1960-2000

	1960-1962		1961-1971		1979-1981		1989-1991		1998-2000	
Percentile of distribution	20th	80th	20th	80th	20th	80th	20th	80th	20th	80th
CO_2 per capita (relative to world average)	0.089 (0.0086)	1.71 (0.19)	0.15 (0.012)	2.05 (0.19)	0.18 (0.028)	2.34 (0.20)	0.20 (0.037)	2.15 (0.20)	0.27 (0.048)	2.29 (0.11)
CO_2 per capita Interquantile Range	1.62 (0.22)		1.90 (0.17)		2.16 (0.23)†		1.95 (0.15)		2.02 (0.10)†	

Notes. † indicates that F-tests comparing the estimated interquantile ranges for the 1960 period and the 1980 (2000) period rejects the null that the ranges are identical at the 8 (10) percent level for carbon dioxide and. Tests are based on estimating interquantile ranges for pairs of time periods. Bootstrapped standard errors based on 1,000 replications presented in parentheses.

Table 2. Estimated 20th, 80th Percentiles, and 80-20 Interquantile Range, U.S. States Relative CO_2 per Capita Distribution, 1960-1999

	1960-1962		1961-1971		1979-1981		1989-1991		1997-1999	
Percentile of distribution	20th	80th	20th	80th	20th	80th	20th	80th	20th	80th
CO_2 per capita (relative to national average)	0.68 (0.021)	1.28 (0.11)	0.68 (0.026)	1.25 (0.093)	0.66 (0.042)	1.34 (0.071)	0.59 (0.042)	1.52 (0.11)	0.63 (0.045)	1.47 (0.12)
CO_2 per capita Interquantile Range	0.60 (0.074)		0.57 (0.086)		0.67 (0.073)		0.93 (0.11)†‡		0.84 (0.13)‡	
Consumption CO_2 per capita (relative to national average)	0.67 (0.016)	1.26 (0.083)	0.68 (0.037)	1.21 (0.059)	0.65 (0.045)	1.19 (0.054)	0.68 (0.047)	1.26 (0.095)	0.68 (0.049)	1.24 (0.095)
Consumption CO_2 Interquantile Range	0.58 (0.090)		0.53 (0.053)		0.54 (0.077)		0.58 (0.064)		0.57 (0.064)	

Notes. † (‡) indicates that an F-test comparing the estimated interquantile ranges for the 1960 (1970) period and the 1990 (1990, 1999) period rejects the null that the ranges are identical at the 2 (1, 8) percent level. Tests are based on estimating interquantile ranges for pairs of time periods. Bootstrapped standard errors based on 1,000 replications presented in parentheses.

Table 3. Estimates of Transition Matrix and Ergodic Distribution, World CO_2 Emissions Per Capita, 1960-2000

	Upper Endpoint (Ratio of National CO_2 Emissions Per Capita to World CO_2 Emissions Per Capita)				
(Number)	0.25	0.50	1.00	2.00	∞
1189	0.975	0.025	0	0	0
526	0.072	0.838	0.090	0	$0^{\dagger}$
615	$0^{\dagger}$	0.090	0.843	0.067	$0^{\dagger}$
762	$0^{\dagger}$	0	0.062	0.891	0.042
428	0	0	$0^{\dagger}$	0.070	0.930
Ergodic	0.44	0.15	0.15	0.16	0.10

Notes: Constructed by author with data from Marland et al. (2003). † These five cells actually have non-zero transition probabilities representing a total of 6 observations, but reflect atypical emissions shocks in energy producing countries in the 1960s, with the exception of Kuwait following the 1990-1991 Gulf War. The non-zero probabilities for these cells were used in estimating the ergodic distribution presented in the last row of this table.

Table 4. Estimated Ergodic Distributions Based on Various Time Periods, World CO_2 Emissions Per Capita

	Upper Endpoint (Ratio of National CO_2 Emissions Per Capita to World CO_2 Emissions Per Capita)				
Time Period	0.25	0.50	1.00	2.00	∞
1960-2000	0.44	0.15	0.15	0.16	0.10
1970-2000	0.52	0.14	0.14	0.13	0.07
1980-2000	0.38	0.14	0.18	0.18	0.12
1990-2000	0.39	0.13	0.17	0.19	0.12

Notes: Constructed by author with data from Marland et al. (2003).

Table 5. Estimated Ergodic Distributions Based on Various Time Periods, World CO_2 Emissions Per Capita

	Upper Endpoint (Ratio of National CO_2 Emissions Per Capita to U.S. CO_2 Emissions Per Capita)				
Time Period	0.0625	0.125	0.25	0.50	∞
1960-2000	0.67	0.15	0.07	0.06	0.04
1970-2000	0.62	0.14	0.08	0.09	0.07
1980-2000	0.44	0.12	0.11	0.14	0.17
1990-2000	0.41	0.08	0.10	0.15	0.25

Notes: Constructed by author with data from Marland et al. (2003).

Table 6. Estimates of Transition Matrix and Ergodic Distribution, U.S. States CO_2 Emissions Per Capita, 1960-1999

	Upper Endpoint (Ratio of State CO_2 Emissions Per Capita to U.S. CO_2 Emissions Per Capita)				
(Number)	0.50	0.75	1.00	2.00	∞
127	0.882	0.118	0	0	0
464	0.028	0.918	0.054	0	0
560	0	0.048	0.909	0.043	0
659	0	0	0.046	0.951	0.003
140	0	0	0	0.050	0.950
Ergodic	0.07	0.29	0.32	0.30	0.02

Notes: Constructed by author with carbon dioxide emissions data constructed from energy consumption data in EIA (2001a).

Table 7. Estimated Ergodic Distributions Based on Various Time Periods, U.S. States CO_2 Emissions Per Capita

	Upper Endpoint (Ratio of State CO_2 Emissions Per Capita to U.S. CO_2 Emissions Per Capita)				
Time Period	0.50	0.75	1.00	2.00	∞
1960-1999	0.07	0.29	0.32	0.30	0.02
1970-1999	0.07	0.26	0.33	0.31	0.03
1980-1999	0.12	0.26	0.27	0.31	0.04
1990-1999	0.11	0.22	0.24	0.34	0.10

Notes: Constructed by author with carbon dioxide emissions data constructed from energy consumption data in EIA (2001a).

Table 8. Estimated Ergodic Distributions, U.S. States CO_2 Emissions Per Capita, Consumption-Based CO_2 Emissions Per Capita, Income Per Capita

	Upper Endpoint (Ratio of State Value Per Capita to U.S. Value Per Capita)				
	0.50	0.75	1.00	2.00	∞
CO_2 per capita	0.07	0.29	0.32	0.30	0.02
Consumption-Based CO_2 per capita	0.05	0.30	0.39	0.26	0.01
Income per capita	0	0.10	0.55	0.34	0

Notes: Constructed by author with carbon dioxide emissions data constructed from energy consumption data in EIA (2001a) and income data from BEA (2000).