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Joseph E. Aldy
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An Environmental Kuznets Curve Analysis of U.S. State-Level Carbon Dioxide Emissions

JOSEPH E. ALDY

Most environmental Kuznets curve (EKC) theories do not apply to carbon dioxide (CO₂)—an unregulated, invisible, odorless gas with no direct human health effects. This analysis addresses the hypothesis that the income-CO₂ relationship reflects changes in the composition of an economy as it develops and the associated role of trade in an emissions-intensive good (e.g., electricity). To test this hypothesis, I use a novel data set of 1960 to 1999 state-level CO₂ emissions to estimate pretrade (production-based) CO₂ EKCs and posttrade (consumption-based) CO₂ EKCs. Based on the first EKC analysis of CO₂ emissions in the United States, I find that consumption-based EKCs peak at significantly higher incomes than production-based EKCs, suggesting that emissions-intensive trade drives, at least in part, the income-emissions relationship. I have also investigated the robustness of the estimated income-CO₂ relationship through a variety of specifications. Estimated EKCs appear to vary by state, and the estimated income-emissions relationships could be spurious for some states with nonstationary income and emissions data. Finally, I find that cold winters, warm summers, and historic coal endowments are positively associated with states’ CO₂ emissions.

Keywords: environmental Kuznets curve; greenhouse gas emissions; electricity trade; cubic spline

Empirical researchers have characterized the relationship between economic development and environmental pollution with the environ-

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AUTHOR’S NOTE: Correspondence concerning this article should be addressed to Joseph E. Aldy, Department of Economics, Littauer Center, Room 200, Cambridge, Massachusetts 02138; e-mail: aldy@fas.harvard.edu.

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mental Kuznets curve (EKC)—pollution follows an inverted-U shape with respect to per capita income. The application of EKC analyses to greenhouse gas emissions such as carbon dioxide (CO₂) has raised several important questions. First, some empirical studies have estimated an inverted-U shape of per capita CO₂ emissions with respect to per capita income but with a peak in this function occurring well outside the range of incomes in the studies’ samples. Because these studies often rely on restrictive regression specifications (i.e., quadratic income), these results do not unequivocally support an inverted U for per capita CO₂ emissions. Moreover, recent empirical analyses have challenged the robustness of estimated EKC relationships (Harbaugh, Levinson, & Wilson, 2002; Millimet, List, & Stengos, 2003; Perman & Stern, 2003).

Second, some studies have suggested that the inverted U reflects an economy’s changing structure as it develops: Economies are characterized by agriculture at low incomes, move to more emissions-intensive manufacturing at middle incomes, and then transition to less emissions-intensive services at high incomes. Trade in emissions-intensive goods facilitates this specialization. The downward slope of the inverted U estimated for higher incomes may reflect the combination of a transition from manufacturing to services and an increase in imports of emissions-intensive manufactured goods. Because all economies cannot import emissions-intensive goods, failing to account for these trade effects could bias downward, long-term emissions forecasts.

This article addresses these two questions and makes several additional contributions to the EKC literature and related policy debates. First, by using a novel data set constructed by the author of state-level CO₂ emissions for the 1960 to 1999 period, this article presents the first panel-based EKC analysis for CO₂ emissions in the United States. Second, by focusing on the United States—a set of economies that have achieved advanced stages of economic development—this analysis provides better evidence of whether per capita emissions actually do fall at high-income levels. Third, with a state’s dataset, the empirical analysis investigates explicitly the effects of emissions-intensive trade (specifically electricity trade) on the income-CO₂ relationship. Fourth, this research evaluates other determinants of CO₂ emissions such as energy endowments and the variation in winter and summer climates across the country. Finally, by employing a variety of econometric methods, this article assesses the robustness of the income-emissions relationship.

The empirical results based on standard EKC specifications illustrate that per capita CO₂ emissions may follow an inverted U-pattern with respect to per capita income for the United States during the 1960 to 1999 period. The estimated peak in the EKC does occur at incomes that fall
within the sample range. The estimated EKCs, however, are sensitive to a number of modifications to the analysis. First, as an explicit test of the effect of trade in emissions-intensive goods, I have estimated pre-electricity and post-electricity trade EKC regressions. I find that consumption-based CO₂ per capita (posttrade) EKCs have peaks at much higher incomes than the standard (production-based or pretrade) CO₂ per capita measure. Furthermore, consumption-based CO₂ emissions appear to remain much higher at high incomes than production-based CO₂ based on more flexible regression specifications. This suggests that individuals in high-income states do not consume less carbon-intensive goods than those in lower income states but that they consume more imported carbon-intensive goods, and lower income states may be net exporters of carbon-intensive goods. Second, I assess whether the income-emissions relationship is the same across the states. Tests of heterogeneous slopes models show that this relationship varies across the states. Third, an evaluation of the time-series properties of the state-level data suggests that some estimated relationships could be spurious and that less than one in five states follow an inverted-U EKC for which one could reject the possibility of a spurious relationship. Finally, I find that states’ cold-winter and warm-summer weather and historic coal endowments are positively associated with states’ per capita CO₂ emissions.

By characterizing the income-CO₂ relationship for the United States, this analysis can also help inform our understanding of greenhouse-gas emissions in an international context. First, illustrating the economic dynamics of per capita CO₂ for high-income states provides evidence of what may occur for countries as they achieve advanced stages of development. Second, the potential role of trade in emissions-intensive goods (e.g., electricity) in the income-CO₂ relationship may be valuable for other regions of the world that may share similar characteristics to the United States. For example, the European Union—with converging incomes, policies, and institutions and substantial cross-border trade in emissions-intensive goods and energy—may follow similar production- and consumption-based CO₂ trends as the United States. Third, if trade in emissions-intensive goods is as important in the international context as for the United States, then this work suggests that studies that attempt to forecast CO₂ emissions may produce biased results without attempts to correct for trade.

The next section briefly reviews several key hypotheses of the EKC literature as it relates to greenhouse-gas emissions. The third section provides an overview of the data used in this article, including the novel state-level CO₂ emissions data set constructed by the author. The fourth section describes the empirical methods and presents the results of the analysis. The final section concludes.
Hypotheses of EKC Related to Greenhouse-Gas Emissions

A variety of theories have been posited to motivate the empirical work of the EKC (see Arrow et al., 1995; Selden & Song, 1994; Stern, 1998). First, environmental quality may be income elastic. As individuals enjoy greater incomes, they demand better environmental quality either through markets or regulatory policies. Second, and related to this first point, is the increasing role of democracy with economic development. Because emissions of many environmental pollutants reflect missing markets, government institutions are necessary to address them. More responsive democracy may be necessary to translate individual demand for environmental quality into policies that restrict pollution. In contrast to air or water pollution, which can have immediate, identifiable local health effects, CO₂ emissions are locally innocuous and only impact the global environment during the long term. Moreover, per capita, CO₂ emissions have no local impacts and reflect, at best, an indirect measure of the impact on the global environment. It is not clear that either of these phenomena would explain the per capita CO₂ EKC.2,3

Third, the inverted-U shape may reflect changes in production associated with an economy’s stage of development and a wedge between the emissions-intensity of production and the intensity of consumption (Arrow et al., 1995; Rothman, 1998). For example, 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 second economy would then export pollution-intensive goods to the first economy. This could follow the development path from agriculture (low income) to heavy industry (middle income) to services (high income). Because 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 EKC for CO₂. Note, however, that the inverted U would only be temporary because every economy cannot specialize in services and export its heavy industry to other economies.

Although a variety of theories may explain the shape of the EKC for many local air pollutants, the development-induced changes in produc-

2. Andreoni and Levinson (2001) also illustrated how increasing returns to pollution abatement could yield an inverted-U income-pollution relationship. Because no state or federal regulatory authorities implemented policies to control carbon dioxide (CO₂) emissions during the 1960 to 1999 period, this hypothesis is probably not relevant to CO₂ emissions.

3. Given the high correlation between CO₂ emissions and sulfur dioxide and nitrogen oxides emissions (fossil fuel combustion is the primary source of all three types of pollutants), an inverted-U income-CO₂ shape could arise as a byproduct of an inverted-U income-SO₂ or income-NOₓ relationship.
tion coupled with trade story seems most plausible for CO$_2$. An empirical test of this theory could attempt to discern the production of carbon-based goods from the consumption of these goods. Modifying measures of CO$_2$ emissions to reflect the location of consumption and comparing these with the standard measures that reflect location of production could allow for an assessment of whether the inverted-U shape of per capita emissions with income simply reflects shifts in production or substantial changes in the carbon-intensity of consumption at higher income levels.

Several articles have attempted to test for this production-location hypothesis in an international context by simply expanding the set of regressors to include measures of trade and manufacturing intensity. For example, Harbaugh et al. (2002), in an analysis of sulfur dioxide concentrations and other pollutants, included a measure of trade intensity, which nearly doubles the income at which the estimated EKC peaks. Suri and Chapman (1998) investigated energy use per capita and compared EKC regressions with and without a number of such controls: the ratio of manufacturing exports to domestic manufactured production, the ratio of manufacturing imports to domestic manufactured production, and the ratio of total manufacturing value-added to GDP. For the Suri and Chapman analysis, without these controls for trade the estimated EKC peaked at about U.S. $55,000 (1985 dollars). Including these additional variables resulted in a peak of nearly U.S. $144,000. In contrast, Cole (2003) included measures of trade intensity in EKC regressions of SO$_2$, NO$_x$, and CO$_2$ and found that these tended to have a minor impact on the estimated peaks in these EKCs. Frankel and Rose (2002) have also investigated the role of trade and economic growth on environmental quality, and they find in-sample EKC peaks for SO$_2$ and NO$_x$ concentrations when accounting for the trade share of GDP. It is interesting to note that Frankel and Rose estimated an always-increasing EKC for CO$_2$ per capita when controlling for trade.$^{4,5}$

Although some articles suggested that accounting for trade generally may increase the income at which EKCs peak, caution should be exercised when considering this approach. Some researchers have noted previously that as a reduced-form framework, EKC regressions should not include regressors that may be endogenous to the income variables or the economic growth process more generally (Heil & Selden, 2001; Holtz-Eakin & Selden, 1995). It may not be appropriate to include the trade share of output or the economy’s manufacturing intensity as

4. Refer to Antweiler, Copeland, and Taylor (2001) for a more detailed evaluation of the determinants of sulfur dioxide emissions that focuses on disaggregating the impacts of trade on the environment through scale, technique, and composition effects.

5. Perman and Stern (2003) also noted a concern that the estimated income-emissions relationships could be spurious, at least in the case of sulfur dioxide. I address this issue explicitly in the Methods and Results section.
regressors and then estimate the income at the EKC peak from the regression’s income variables holding everything else, including trade and manufacturing variables, constant (as is typically done in the literature). Because manufacturing intensity and trade intensity are likely to be systematically related to the economic growth process, constructing the EKC peak only from the income variables would result in a biased estimate because it omits the information in the manufacturing and trade variables that may explain, in part, the relationship between development and emissions. The approach in this article is to modify the measure of emissions directly to reflect trade aims to circumvent this potential bias.

**Emissions and Income Data**

**CO₂ EMISSIONS DATA**

Because long-term CO₂ emissions data sets do not exist for the United States, I have constructed state-level emissions estimates based on fossil-fuel combustion data (refer to Lutter, 2000, and Marland, Boden, & Andres, 2003, for similar applications of this approach). The Energy Information Administration (EIA; 2001b) has compiled state-level energy consumption by fuel type and sector for the 1960 to 1999 period. I converted energy consumption by sector-specific fuel type to CO₂ emissions using U.S. emissions factors provided in EIA (2001a, Appendix B).

As one test of the plausibility of this construction, I aggregated these state-level CO₂ emissions values to yield annual national estimates and compared these to the Marland et al. (2003) estimates for U.S. emissions. During the 1960 to 1999 period, my constructed U.S. values differ, on average, 1.7% from the Marland et al. estimates (1.0% standard deviation). The maximum annual differential between the data sets is 3.8%. A comparison with EIA (2001a) CO₂ emissions estimates for the United States during this time period yields very similar results. Although some states likely have measurement error in excess of 1.7%, this comparison

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6. CO₂ emissions are expressed in terms of tons of carbon in this article.
7. Subsequent to the initial drafting of this article, the Carbon Dioxide Information Analysis Center (CDIAC) released a state-level CO₂ data set for the 1960 to 2001 period (Blasing, Marland, & Broniak, 2004). This CDIAC data set includes standard (production-based) CO₂ emissions and CO₂ emissions per capita from fossil fuel combustion but not a postelectricity trade (consumption-based) emissions measure. I have replicated the ordinary least squares (OLS) specifications for the production-based CO₂ measure in Table 2 and in Figure 1 with the CDIAC data set and found that the estimated environmental Kuznets curves (EKCs) are very similar between the CDIAC and my data sets. A comparison of these results is available from the author on request.
illustrates the plausibility of the energy-based construction of state CO₂ emissions developed for this article.

These CO₂ estimates reflect all within-state fossil-fuel combustion emissions. They represent emissions associated with producing all goods and services in a given state so we can also denote them production-based CO₂ 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 CO₂ emissions data set was constructed to account for interstate electricity trade. To modify the CO₂ 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 electricity imports.8 Because this modified measure reflects posttrade 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 CO₂ throughout this analysis.9,10

8. This average intensity of imports is a national average; it reflects the average intensity of electricity generation for all states that export electricity in that year. Although the carbon-intensity of the marginal power source for electricity would be preferable, it is difficult to determine what constitutes the marginal source in each state. Simply assuming the fuel type of the most recent plant(s) to come on line may be misleading because this approach may characterize hydropower dams or nuclear power plants as the marginal fuel source. For example, lack of economic water resources may make replication of a dam within a state difficult. The long construction and licensing process for nuclear power plants (and the fact that zero nuclear facility license applications were submitted in the second half of my sample period) complicates consideration of nuclear power as a marginal power source.

9. Ideally, a complete consumption-based measure of CO₂ would also reflect the emissions intensity in all traded goods and services. Unfortunately, such interstate trade data are not collected.

10. If states that export electricity are disproportionately importers of energy-intensive goods, then this consumption-based measure could yield misleading results about the role of trade. To investigate this proposition, I evaluated petroleum and coal products, paper, primary metals, stone, glass, and clay, and chemicals—the five most energy-intensive two-digit Standard Industrial Classification manufacturing industries, according to the U.S. Energy Information Administration. There is a weak positive correlation between concentration in an energy-intensive industry (i.e., the state’s share of income from economic activity in this industry relative to the national average) and electricity exports for three of these five categories, but the correlation coefficients do not exceed 0.06. For the other two, there is a weak negative correlation but, again, the magnitudes of the correlation coefficients are small (–0.09 and –0.18). This provides little evidence that states substitute the production of one emissions-intensive good (e.g., electricity) with the production of other emissions-intensive goods.
STATE INCOME AND POPULATION DATA

The income variables used in the statistical analyses represent state personal-income data provided by the Bureau of Economic Analysis (2000).\textsuperscript{11} These data have been used in a variety of economic analyses, including articles on economic growth and the EKC (e.g., Barro & Sala-i-Martin, 1992; List & Gallet, 1999; Millimet et al., 2003).\textsuperscript{12} The Bureau of Economic Analysis also provides annual state-level population estimates. These population values were used to construct all per capita estimates.

CLIMATE DATA

Previous research has shown that weather fluctuations can cause short-term shocks to energy demand that influence CO\textsubscript{2} emissions (Considine, 2000; EIA, 2001a). The National Oceanic and Atmospheric Administration (NOAA) has developed so-called heating degree days (HDD) and cooling degree days (CDD) metrics to characterize the effects of high summer temperatures and low winter temperatures on energy demand. Annual data for state HDD and CDD were compiled from Heim, Garvin, and Nicodemus (1993a, 1993b) and NOAA (1999, 2001).

ENERGY ENDOWMENT DATA

The energy endowment variable reflects a state’s coal endowment. To focus on the persistent effects of historic coal production on the industrial composition and associated emissions in a state, I focus on lagged coal production (10-year lag). The historic coal-production data reflect state-level production of all types of coal. These data were compiled and provided by the U.S. EIA (R. Bonskowski, personal communication, March 19, 2002) and measure coal in thousands of short tons.

\textsuperscript{11} These values were converted to 1999 dollars based on the national CPI-Urban deflator (Council of Economic Advisers, 2001, Table B60).

\textsuperscript{12} Previous studies based on international data sets have typically used per capita gross domestic product (e.g., the rgdpch series in the Penn World Table). The Bureau of Economic Analysis has estimated the analogous state-level measure, gross state product, for the states only since 1977; in contrast, state personal income per capita series date to 1929. Gross state product measures the sum of value added for all industries in a given state, whereas personal income measures state residents’ income from wages and salaries, dividends, interest, other returns to capital, and net government transfers. If one believes that per capita emissions should vary with per capita income, as opposed to per capita output, then the personal income measure is superior to gross state product. If this is not the case, then using personal income in lieu of output would introduce some, presumably modest, measurement error in the regression models.
DESCRIPTIVE STATISTICS

The variables used in the regression analyses presented below are summarized in Table 1. The state-level data for the 1960 to 1999 period reveal substantial variation in the per capita CO₂ emissions data and per capita income data. State average per capita CO₂ emissions is about 5.75 tons. Within a given year, the ratio of maximum to minimum per capita CO₂ varies from about four in the 1960s to the high teens during the past several decades.¹³ This variation in per capita emissions is not too dissimilar from the variation evident in international data sets: The ratio of U.S. per capita emissions to India per capita emissions in 1999 is almost identical to the ratio of the maximum to the minimum per capita emissions among the states in that year. Per capita incomes vary by about a factor of two in any given year and by a factor of more than five during the entire 40-year sample. Incomes at the beginning of the sample ranged between about U.S. $7,000 and U.S. $16,500, which is about on par with current middle-income developing countries (e.g., Venezuela or Brazil) and lower income OECD countries (e.g., the Czech Republic or South Korea) in purchasing-power parity terms.

Methods and Results

ESTIMATION STRATEGY

To estimate the EKC for state-level CO₂ emissions per capita, I employed four econometric approaches with a panel of 48 states during the 1960 to 1999 period.¹⁴ The general regression specification takes the following form:

\[ \ln(\text{CO}_2)_{it} = \ln(y_{it}) \beta + \gamma X_{it} + \alpha_i + \tau_t + \epsilon_{it} \]

where \( \text{CO}_2_{it} \) represents per capita CO₂ emissions in state \( i \) in year \( t \), \( y_{it} \) represents per capita income, \( X \) represents the vector of other explanatory variables (\( \ln \text{CDD}, \ln \text{HDD}, \) and coal production), \( \beta \) and \( \gamma \) are vectors of parameters to be estimated, \( \alpha_i \) and \( \tau_t \) are state and year fixed effects, \( \epsilon_{it} \) is the error term that is characterized by a strict exogeneity assumption:

¹³. The increasing dispersion in per capita CO₂ emissions throughout time is evident for the entire sample of states, and not just the outlying annual minimums and maximums in the sample. Refer to Aldy (2004) for further details.

¹⁴. Alaska and Hawaii have been omitted from this analysis because cooling degree day and heating degree day data are not available for these states.
In the first set of regressions, the income function is specified as quadratic, following Grossman and Krueger (1995), Holtz-Eakin and Selden (1995), and Heil and Selden (2001). These specifications were estimated by ordinary least squares (OLS) and a feasible generalized least squares (FGLS) approach that corrects for cross-sectional heteroskedasticity and incorporates a one-lag autoregressive error structure. For the OLS regressions, I report both robust standard errors and standard errors corrected for within-group heteroskedasticity (the errors have been clus-

\[ \mathbb{E}[r_t \mid \mathbf{X}_t, \mathbf{Z}_t^{1999}] = 0 \]

and \( \mathbf{Z}_t \) represents the vector of all regressors.\(^{15}\)

In the first set of regressions, the income function is specified as quadratic, following Grossman and Krueger (1995), Holtz-Eakin and Selden (1995), and Heil and Selden (2001). These specifications were estimated by ordinary least squares (OLS) and a feasible generalized least squares (FGLS) approach that corrects for cross-sectional heteroskedasticity and incorporates a one-lag autoregressive error structure.\(^{16}\) For the OLS regressions, I report both robust standard errors and standard errors corrected for within-group heteroskedasticity (the errors have been clus-

\(^{15}\) F tests of the inclusion of state and year fixed effects for a variety of specifications all reject the null hypothesis that the coefficient estimates of these effects equal zero.

\(^{16}\) Breusch-Pagan tests indicate that the residuals are heteroskedastic (test statistics range from 3,468 to 3,973 for the production-based \( \text{CO}_2 \) regressions and 1965 to 1993 for the consumption-based \( \text{CO}_2 \) regressions). Wald tests of the null hypothesis of no serial correlation in the panel yield \( F \) statistics ranging from 107 to 256 for a variety of specifications, recommending rejection of the null.
tered by state). The robust standard errors correct for cross-sectional heteroskedasticity but assume independence in the residuals in the time-series dimension, whereas the clustered standard errors allow for state-specific arbitrary serial correlation but assume independence across states.

In the second set of regressions, I characterize income by a cubic spline function, a more flexible variant of the piecewise linear spline approach used in Schmalensee, Stoker, and Judson (1998). The cubic spline ensures that the estimated EKC is smooth (twice everywhere differentiable) by fitting cubic functions of income in between analyst-chosen points or knots in the distribution of the data. For example, one could choose nine knots in the data, one at each decile in the income distribution, and fit cubic functions specific to each decile but constrained to be smooth at every knot. I experimented with a variety of specifications, including 2 to as many as 11 knots in the cubic spline function. The results presented below are robust to setting the distance between knots based on quantiles of the data or based on an equal interknot distance rule.

Third, I have made the regression specification more flexible by allowing the slope parameters ($\beta$'s) to vary by state, following List and Gallet’s (1999) EKC analysis of state NO$_X$ and SO$_2$ emissions. This approach allows for an explicit test for whether the inverted-U income-emissions shape is common across all economies or whether this relationship is economy-specific. I find evidence of the latter.

Fourth, based on the evidence that the EKC shape is state-specific, I conduct analyses on the 48 separate time series. This facilitates an investigation of state-specific relationships and an evaluation of the time-series properties of the data. I find that the emissions and income data are stochastically trending and that these two time series are cointegrated for only nine states. I conduct dynamic ordinary least squares (DOLS; Stock & Watson, 1993) for these states and compare the results with state-specific OLS.

The estimation strategy allows for an examination of two important issues typically not addressed in the EKC literature. First, I have undertaken a number of regressions with a modified measure of per capita CO$_2$ emissions that reflects the effects of trade on emissions. The standard, production-based measure of CO$_2$ emissions may not best characterize the carbon-intensity of a state or region’s standard of living. Consider a hypothetical world with two regions: Region 1 specializes in carbon-intensive goods, and Region 2 specializes in carbon-lean goods. Suppose that Region 1 exports its carbon-intensive goods to Region 2, and Region 2 exports its carbon-lean goods to Region 1. This standard approach to estimating CO$_2$ emissions reflects a region’s carbon-intensity of production, and Region 1 would have higher emissions than Region 2, ceteris paribus. The carbon-intensity of consumption, however, would
vary from the production carbon-intensity because trade allows the import of carbon-intensive goods in Region 2 (and the import of carbon-lean goods in Region 1). If one assigned CO₂ emissions to the region in which the good associated with those emissions is consumed, then estimates of Region 1’s emissions would fall, whereas Region 2’s emissions would increase. Modifying the measure of CO₂ emissions to reflect electricity trade is a first step toward employing a true consumption-based CO₂ measure. The analyses with this modified measure can serve to illustrate whether the failure to account for trade yields a distinctly different income-emissions relationship and test for the production-shifting hypothesis of the EKC.

Second, I have included a number of control variables in addition to per capita income that would reasonably be expected to influence per capita CO₂ emissions. This analysis can quantitatively assess questions such as do warm weather regions have lower per capita emissions than cold weather regions and do historical energy endowments influence current per capita emissions? To address these questions, I have included the following variables in a subset of the regressions reported below: annual measures of weather-related heating and cooling demand and lagged (10-year) coal production by state. Colder winter states and hotter summer states would be expected to have higher per capita emissions resulting from greater heating demand (winter) and cooling demand (summer). Historic energy endowments would be expected to influence per capita emissions by a combination of high transportation costs and geographic specialization. In the former case, a state may exploit its local energy resources because the high cost of shipping fuels or transmitting electricity makes it uneconomic to do otherwise. In the latter case, even the decline in transportation costs throughout time may not substantially alter a region’s fuel mix because years of capital investments have already been made geared toward that region’s historic fuel mix (see Krugman, 1991). The coal-endowment variable would be expected to be positively associated with per capita emissions.

REGRESSION RESULTS

Quadratic Income Specifications

Table 2, Columns 1 to 4, presents the results for the quadratic income specifications with the standard (production-based) CO₂ per capita emissions measure as the dependent variable. All specifications reveal the typical inverted-U shape in income—the linear term is positive, and the squared term is negative. The income variables in all specifications are statistically significant at the 1% level. The coefficient estimates of 15.06 and −0.78 on the log income per capita and its square in Column 1 yield an EKC that peaks at an income of U.S. $14,708 (refer to the last row of Table 2). In the OLS specifications, all of the additional control vari-
**Table 2**
Regression Results for Quadratic Income Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>(1) OLS ln(CO$_2$) Production</th>
<th>(2) OLS ln(CO$_2$) Production</th>
<th>(3) FGLS ln(CO$_2$) Production</th>
<th>(4) FGLS ln(CO$_2$) Production</th>
<th>(5) OLS ln(CO$_2$) Consumption</th>
<th>(6) OLS ln(CO$_2$) Consumption</th>
<th>(7) FGLS ln(CO$_2$) Consumption</th>
<th>(8) FGLS ln(CO$_2$) Consumption</th>
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<tbody>
<tr>
<td>Dependent</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>ln(y)</td>
<td>15.06 (0.76)***</td>
<td>13.85 (0.77)***</td>
<td>8.34 (0.26)***</td>
<td>8.45 (0.31)***</td>
<td>8.12 (0.66)***</td>
<td>7.14 (0.66)***</td>
<td>6.23 (0.22)***</td>
<td>6.13 (0.16)***</td>
</tr>
<tr>
<td>ln(y)$^2$</td>
<td>-0.78 (0.040)***</td>
<td>-0.72 (0.041)***</td>
<td>-0.43 (0.013)***</td>
<td>-0.43 (0.016)***</td>
<td>-0.41 (0.035)***</td>
<td>-0.35 (0.035)***</td>
<td>-0.31 (0.011)***</td>
<td>-0.31 (0.0085)***</td>
</tr>
<tr>
<td>ln(CDD)</td>
<td>-0.022 (0.024)</td>
<td>-0.022 (0.018)</td>
<td>0.0082 (0.0015)***</td>
<td>-0.0032 (0.018)</td>
<td>-0.0032 (0.016)</td>
<td>-0.0032 (0.0093)***</td>
<td>0.0086 (0.0093)***</td>
<td>0.0086 (0.0093)***</td>
</tr>
<tr>
<td>ln(HDD)</td>
<td>-0.080 (0.047)*</td>
<td>-0.059 (0.0034)**</td>
<td>0.078 (0.036)**</td>
<td>-0.078 (0.016)</td>
<td>0.078 (0.036)**</td>
<td>0.078 (0.020)**</td>
<td>0.056 (0.020)**</td>
<td>0.056 (0.020)**</td>
</tr>
<tr>
<td>Coal production</td>
<td>1.67 × 10$^{-6}$</td>
<td>1.50 × 10$^{-5}$</td>
<td>1.45 × 10$^{-5}$</td>
<td>1.45 × 10$^{-5}$</td>
<td>2.44 × 10$^{-5}$</td>
<td>2.44 × 10$^{-5}$</td>
<td>9.27 × 10$^{-7}$</td>
<td>9.27 × 10$^{-7}$</td>
</tr>
<tr>
<td>Income at emissions peak (in 1999 dollars)</td>
<td>14,708 (801)</td>
<td>15,295 (900)</td>
<td>16,449 (336)</td>
<td>16,840 (354)</td>
<td>20,389 (1,717)</td>
<td>23,870 (2,556)</td>
<td>22,072 (481)</td>
<td>21,491 (428)</td>
</tr>
</tbody>
</table>

Note: OLS = ordinary least squares; FGLS = feasible generalized least squares; CO$_2$$_{cons}$ = consumption-based carbon dioxide. N = 1,920. Robust standard errors are presented in parentheses and robust standard errors clustered by state are in brackets for OLS specifications. Standard errors are corrected for first-order serial correlation and for heteroskedasticity for FGLS specifications. All regressions include state and year fixed effects.

*p < .10. **p < .05. ***p < .01.
ables have the expected signs, although the weather variables are marginally statistically significant at best. In the FGLS specifications, all explanatory variables have their expected signs and all are statistically significant at the 1% level. The quadratic income specifications in Columns 1 to 4 yield income-emissions relationships with similar incomes at emissions peaks ranging from U.S. $14,708 to U.S. $16,840.

To assess whether the nonincome controls are associated with CO₂ emissions, I have conducted F tests of the hypothesis that the X vector variables—ln(CDD), ln(HDD), and lagged coal production—equal zero. The F statistic for the comparison of the specifications (Columns 1 and 2) is 42. Including these additional controls has little impact, however, on the estimated peak in the EKC. As the bottom row of Table 2 illustrates, the incomes associated with the maximum of the EKC are fairly similar between specifications that only vary in terms of the inclusion of the X vector of variables (U.S. $14,708 versus U.S. $15,295 in Columns 1 and 2; U.S. $20,389 versus U.S. $23,870 in Columns 5 and 6).

To place some of these estimated coefficients in context, consider their implications for expected per capita emissions across the states based on their 1999 values. North Dakota, with the most HDD in 1999, would have approximately 1.2 tons per capita higher emissions than Florida, with the fewest HDD, ceteris paribus. The variation in emissions associated with CDD is negligible. Wyoming, with the most coal production in 1989 (the lagged value for 1999), would be expected to have about 2 tons per capita more emissions than states that do not produce coal.

Table 2, Columns 5 to 8, presents the regression results for the quadratic income specifications with the consumption-based CO₂ per capita dependent variable. Similar to the results with the production-based CO₂ variable, these specifications all reveal an inverted-U in income, and all income variables are statistically significant at the 1% level. In the OLS specifications, all explanatory variables have their expected signs and are statistically significant at the 1% level, with the exception of the weather variables. The income coefficient estimates of 8.12 and −0.41 in

17. The per capita income at the maximum of the EKCs can be represented by

\[ y = \exp \left( \frac{-\hat{\beta}_1}{2\hat{\beta}_2} \right) \]

where \( \hat{\beta}_1 \) is the coefficient estimate for the log income per capita variable and \( \hat{\beta}_2 \) is the coefficient estimate for its square. Technically, this expression is distributed Cauchy, not normal, but estimates of the empirical distribution indicate that the normal can serve as a good approximation of this expression's distribution.

18. All comparisons are based on the coefficient estimates presented in Table 2, Column 2 (OLS, full set of control variables).

19. Refer to Neumayer (2002) for a cross-country comparison of similar nonincome determinants of CO₂ emissions.

20. F tests regarding the inclusion of the X vector of variables were also conducted for the consumption-based specifications. Based on an F statistic of 37, I reject the null hypothesis that the X vector coefficients are equal to zero.
Column 5 yield an estimated income at the peak of the consumption-based EKC function of U.S. $20,389. The consumption-based EKCs have incomes at emissions peak ranging from U.S. $20,389 to U.S. $23,870. In the FGLS specifications, all explanatory variables have their expected signs and are statistically significant at the 1% level.

The per capita incomes associated with the EKC peaks are higher for the consumption-based CO₂ emissions specifications than for the standard CO₂ emissions specifications. This indicates that higher income states may experience a decline in per capita CO₂ emissions not because individuals consume less carbon-based goods in those states than before but because they consume carbon-based goods (in this case, electricity) produced in lower income states. These differences in the income levels associated with EKC peaks between the two specifications are not inconsequential. The per capita incomes associated with the peak of the consumption-based CO₂ emissions EKC range up to 56% higher than the incomes associated with the production-based CO₂ emissions specification.

The differences between the production- and consumption-based CO₂ EKCs are statistically significant. To statistically evaluate the properties of the income-emissions relationships for the production- and consumption-based measures in an integrated regression framework, I undertook multivariate least squares regressions in which the dependent variables vector includes production- and consumption-based CO₂ per capita:

\[
\ln(CO_{it}^{\text{prod}}) = \beta_1^{\text{prod}} \ln y_i + \beta_2^{\text{prod}} (\ln y_i)^2 + \alpha_i^{\text{prod}} + \tau_i^{\text{prod}} + \epsilon_i^{\text{prod}} \\
\ln(CO_{it}^{\text{cons}}) = \beta_1^{\text{cons}} \ln y_i + \beta_2^{\text{cons}} (\ln y_i)^2 + \alpha_i^{\text{cons}} + \tau_i^{\text{cons}} + \epsilon_i^{\text{cons}}
\]

This two-equation system allows for correlation in the errors across the two equations and a robust estimated variance-covariance matrix.\textsuperscript{21} Table 3 shows the results of F tests applied to two specifications of this system: one with and one without the X vector of controls. These tests evaluate two hypotheses:

Equality of Parameter Estimates: \( H_0^{\text{prod}}: \beta_k^{\text{prod}} = \beta_k^{\text{cons}} \) for \( k = 1, 2 \), and

Equality of Estimated EKC Peaks: \( H_0: \exp \left[ -\frac{\hat{\beta}_1^{\text{prod}}}{2\hat{\beta}_2^{\text{prod}}} \right] = \exp \left[ -\frac{\hat{\beta}_1^{\text{cons}}}{2\hat{\beta}_2^{\text{cons}}} \right] \)

With F statistics of 87 and 113 for the first hypothesis and 41 and 48 for the second hypothesis, these results strongly recommend rejecting

\textsuperscript{21} This system of two equations is an application of Zellner’s seemingly unrelated regressions model.
the null hypotheses. The differences in the magnitudes of the estimated production- and consumption-based CO₂ EKC peaks are economically and statistically significant. Employing the standard, production-based CO₂ EKC for long-term emissions forecasts could result in a substantially different forecast for the United States than using the consumption-based curve because per capita emissions would continue to increase for a longer period of time with the latter function.²²

Cubic Spline Income Specifications

As an alternative to quadratic income specifications, a cubic spline function of income can also characterize the emissions-income relationship. Employing a cubic spline specification allows for a second approach to investigate the potential effects of emissions-intensive trade on estimation of the CO₂ per capita EKC and to begin assessing the robustness of the EKC estimates. As Schmalensee et al. (1998) noted, a spline specification is more flexible than power functions and may better describe the EKC relationship. I have conducted a series of OLS regressions with the cubic spline function divided into as few as 2 and as many as 11 knots for both the production- and consumption-based measures of emissions and including state- and year-fixed effects.²³ Based on F tests evaluated at a 5% significance level, I could reject specifications with fewer than 8 knots for the production-based regressions and those with fewer than 10 knots for the consumption-based regressions. Figure

<table>
<thead>
<tr>
<th>Specification</th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>State and year effects</td>
<td>OLS</td>
<td>OLS</td>
</tr>
<tr>
<td>X vector</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>(F) statistic, (H₀¹)</td>
<td>112.54</td>
<td>86.70</td>
</tr>
<tr>
<td>(F) statistic, (H₀²)</td>
<td>47.50</td>
<td>40.52</td>
</tr>
</tbody>
</table>

Note: CO₂cons = consumption-based carbon dioxide. \(N = 1,920\). Based on multivariate regressions in which the dependent variables vector includes ln(CO₂) and ln(CO₂cons).

22. Note again that this consumption-based measure of CO₂ emissions only reflects interstate electricity trade. Accounting for interstate trade in other goods and services and for international trade may well affect the estimated consumption-based EKC.

Figure 1: Production- and Consumption-Based Carbon Dioxide Environmental Kuznets Curves From Cubic Spline Regressions

1 presents the estimated EKCs for the production- and consumption-based measures based on 10-knot cubic spline specifications.24

Figure 1 shows a striking divergence in the income-emissions relationship between the production- and consumption-based measures at higher incomes. The two relationships track each other quite closely for the U.S. $7,000 to U.S. $14,000 range, at which point the consumption-based measure crosses the production-based measure and remains at relatively high levels (between about 5.5 and slightly more than 6.0 tons per person) through the rest of the sample range for income. In contrast, the production-based EKC declines substantially with increasing per capita income. At the maximum income level in the sample (about U.S.

24. For consistency between the two emissions measures, I have presented the estimated EKCs based on the same specification. The production-based 8-knot EKC yields a virtually identical (and statistically indistinguishable) shape as the 10-knot version.
$39,000), the production-based EKC has a per capita emissions level (3.1 tons per capita) that is just slightly more than half of its peak (5.7 tons per person, occurring at about U.S. $16,000). The consumption-based EKC, however, has a per capita emissions level (5.5 tons per capita) that is about 90% of the value associated with its peak (6.1 tons per person, occurring at about U.S. $20,500). Per capita carbon emissions with the consumption-based measure are up to 75% greater than the production-based carbon emissions measure at high incomes. Although the results from the cubic spline specifications confirm the quadratic income results that emissions peak at higher incomes with the consumption-based measure, these estimated EKCs also show that per capita emissions decline at a much more gradual rate after peaking on a consumption basis than on a production basis. The consumption-based results could be more consistent with a peak and plateau shape than the more typical inverted-U EKC shape.

Heterogeneous Slopes Specifications

The previous two sets of results, and the vast majority of the empirical EKC literature, assume that all economies follow a common income-emissions relationship. Although the typical EKC (panel) regression only allows economies' emissions to vary in terms of level (fixed) effects, following List and Gallet (1999), I have relaxed the assumption of common slope terms (β's) for all states by allowing these parameters to vary by state. I have conducted regressions with both the production-based CO2 and consumption-based CO2 measures specified as functions of state-specific quadratic income, state-fixed effects, and year-fixed effects. This heterogeneous slopes model provides a third approach both for assessing the hypothesis that emissions-intensive trade affects the estimated EKC and for determining the robustness of the earlier results.

Table 4 presents summary statistics of these two regressions. Most states follow an inverted-U shape for the production-based CO2 measure, although fewer of the states have such a relationship for consumption-based CO2 per capita. Forty states have a statistically significant estimated EKC peak (and all estimates fall within their states' respective income range) for standard CO2 per capita, and 37 states do for consumption-based CO2 per capita. The median EKC peak income for the consumption-based measure is about 15% greater than the median production-based measure.

This more general model that allows for heterogeneity in the slope coefficients yields results that question the typical assumption of common parameter estimates for all states. I evaluated the following two hypotheses:
Equality of Parameter Estimates:

\[ H^0_{K} \beta_k = \beta_k \text{ for } k = 1, 2, \text{ and for all } i = 2, \ldots, 48, \]

Equality of Estimated EKC Peaks:

\[ H^0_i \exp \left( -\frac{\beta_{1i}}{2\beta_{2i}} \right) = \exp \left( -\frac{\beta_{1i}}{2\beta_{2i}} \right) \text{ for all } i = 2, \ldots, 48. \]

F tests of the equality of the income parameters reject the hypothesis of a common income-emissions relationship among the states. Likewise, tests of equality of the estimated EKC peaks also recommend rejecting the hypothesis that the states can be characterized by one EKC function (refer to the last two rows of Table 4). These results are consistent with the findings of List and Gallet (1999) for SO2 and NOX EKCs for the United States. Recent research by Brock and Taylor (2004) provided some insights into economy-specific EKCs. State-specific EKC analyses may be appropriate in light of this finding, which motivates the time-series analyses in the next section.

State-Specific Time-Series Specifications

State-specific EKC regressions can provide several checks to the preceding analyses. First, every state has income-per-capita observations on both the upward and downward sloping regions of the emissions-income inverted-U function estimated with the production-based CO2 per capita measure in Table 2. If this reduced-form relationship estimated from a panel is robust, it should be evident individually among these states. Second, the analysis with heterogeneous slopes indicates that the relationship may not be identical for all economies. A better understanding of which economies experience such trends in emissions

<table>
<thead>
<tr>
<th>Summary Statistics for the Heterogeneous Slopes Regression Models</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dependent Variable</strong></td>
</tr>
<tr>
<td>Number of states with inverted-U income-emissions relationship</td>
</tr>
<tr>
<td>Number of states with statistically significant estimated EKC peaks</td>
</tr>
<tr>
<td>Median EKC peak for states with inverted-U relationships</td>
</tr>
<tr>
<td>( F ) statistic, ( H^0_0 )</td>
</tr>
<tr>
<td>( F ) statistic, ( H^0_1 )</td>
</tr>
</tbody>
</table>

Note: \( CO_{2, \text{cons}} \) = consumption-based carbon dioxide; EKC = environmental Kuznets curve. Regressions are specified as state-specific quadratic income and include state and year fixed effects. These regressions are estimated with robust standard errors.
as their incomes grow could further inform the theory that motivates the empirical work. Third, several articles in this literature have questioned the empirical methods that fail to account for possible stochastic trends in emissions and income data (see Perman & Stern, 2003; Stern, 2004). Focusing on state-specific time series will allow for an explicit investigation of these properties for the state-level data.

Before undertaking state-specific regressions, I conducted several time-series tests of the income and emissions data. First, I tested for whether the state-specific natural logarithm of per capita income and natural logarithm of per capita CO₂ emissions time series are nonstationary (stochastically trending) with the Elliott, Rothenberg, and Stock (1996) generalized least squares (GLS) version of the Dickey-Fuller test. As a test with higher power than the augmented Dickey-Fuller test, this GLS version is more likely to reject the null hypothesis of a unit root against the alternative of a stationary distribution when the root is close to but less than one. For only one state do the data suggest rejecting the null of a unit root at the 5% significance level for the log per capita income time series and only four additional states at the 10% significance level. Likewise, I reject the null for only one state for the log per capita carbon emissions time series at the 5% level and for only two states at the 10% level. To determine if the data are integrated of order one, I conducted the same tests on the first differences in log per capita emissions and incomes. For all but one state, the tests recommend rejecting the null hypothesis of a unit root for the changes. The state-specific log per capita income and emissions data appear to be integrated of order-one time series. This suggests the need to evaluate whether the state-specific time series are cointegrated to determine if the reduced-form EKC regression analyses are actually spurious.²⁵

If the per capita emissions and income time series for a given state share a common stochastic trend (are cointegrated), then regression analysis can still be conducted to estimate consistent parameters on the income variables. Because the cointegration vector is not known, I made a preliminary estimate of the cointegration vector and tested for whether the emissions, income, and income-squared variables share a common trend with the Engle-Granger Augmented Dickey-Fuller test (EG-ADF; Engle & Granger, 1987). First, I conducted an OLS regression for each state of the natural logarithm of per capita emissions on the natural logarithm of per capita income and the square of the natural logarithm of per capita income. Second, I constructed the predicted residuals from these regressions and tested these for a unit root with an augmented Dickey-Fuller test. If the data reject the hypothesis of a unit root, then the esti-

²⁵ I estimated EKC regressions in first differences, with both the full panel and state-specific time series. Virtually every regression yielded statistically insignificant coefficient estimates for the income variables.
mated cointegrating vector (the parameter estimates on the income variables) yields a stationary relationship between the emissions and income variables. Following Stock (1994), I used the Akaike Information Criterion to determine the lag structure of the second-stage test of the residuals.

The results of the cointegration tests showed that few states have cointegrated data. Using a 10% critical level cutoff, I could reject the hypothesis of a unit autoregressive root for the residual for 9 (11) of 48 states for the production-based (consumption-based) analyses.26 This suggests that the income-emissions relationship estimated through OLS could be spurious for many states and may also be in a panel context (see Perman & Stern, 2003, for similar findings for an international EKC analysis of sulfur dioxide emissions).

To provide consistent estimates of the parameters and their associated standard errors for the states with cointegrated data, I estimated state-specific dynamic ordinary least squares (DOLS) regressions following Stock and Watson (1993):

\[
\ln(CO_{jt}) = \alpha_j + \beta Y_j + \sum_{j=p}^{r} \delta Y_{t-j} + \epsilon_i
\]

where \(Y_j\) represents the natural logarithm of income per capita and its square, \(\Delta Y_{t-j}\) represents lags, leads, and current values of the changes in the two income variables, \(p\) represents the number of lags/leads (assumed to be 2 in this analysis), and \(\beta\) and \(\delta\) are parameter vectors to be estimated. The \(t\) statistics constructed from DOLS are based on Newey-West standard errors (I have assumed a two-period lag structure). The \(\beta\) parameter vector can be considered the long-run effect of the income variables on the emissions variable (assuming that the income variables are exogenous). I compare these with OLS regressions of the natural logarithm of emissions on a constant, the natural logarithm of income per capita and its square, with Newey-West standard errors assuming a two-period autocorrelation structure. Appendix Tables 1 and 2 present all DOLS regression results, even for states with data that do not reject the null of no cointegration in the EG-ADF tests, and all OLS regression results.

Thirty-two states have inverted-U EKCs that have estimated peaks that are statistically different from zero (\(p < .05\)) and within their sample income range. The consumption-based state-specific OLS results show even more evidence of an inverted-U income-emissions relationship: 38

26. Supplemental data may be found online at http://jed.sagepub.com/content/vol14/issue1/.
states have statistically significant EKC estimated peaks in their sample income ranges.

Although the estimated state-specific EKC peaks are similar for production- and consumption-based CO₂ measures for many states, a pattern is evident in these comparisons. States that have tended to be electricity exporters more frequently during the sample period have higher production-based EKC peaks than consumption-based EKC peaks. In contrast, the states that tended to be electricity importers have higher consumption-based EKC peaks than production-based EKC peaks. Both of these findings are consistent with the view that trade in emissions-intensive goods can influence estimated income-emissions relationships.

These results are supportive of the earlier reported regressions, although caution should be exercised because of the stochastic trends characterizing the per capita income and emissions time series for many states. For the production-based CO₂ results (in Appendix Table 1), only 8 of 48 states are characterized by both cointegrated time series and inverted-U income-emissions relationships with statistically significant \( p < .05 \) estimated peaks. Another 19 states have an inverted-U shape with a statistically significant in-sample emissions peak from the DOLS specifications, but because of the cointegration tests, one cannot rule out a spurious regression and inconsistent variance estimates. For the consumption-based CO₂ results (in Appendix Table 2), only 7 states are characterized by both cointegrated time series and inverted-U income-emissions relationships with statistically significant \( p < .05 \) estimated peaks. Another 26 states have an inverted-U shape with a statistically significant in-sample emissions peak but could not be described as having cointegrated data. If the null of no cointegration could be rejected for every state, the evidence from the DOLS models would suggest that no more than two thirds of the states have an inverted-U income-emissions relationship in either consumption-based or production-based CO₂ emissions.

Conclusions

This article provides the first panel-based evaluation of a per capita CO₂ emissions EKC for the United States with a novel data set on CO₂ emissions constructed by the author. By focusing on the role of emissions-intensive trade, this analysis evaluates an important CO₂ EKC hypothesis, but the estimated inverted-U income-emissions relationships vary across several specifications.

The only theory of the EKC that appears plausible for per capita CO₂ emissions focuses on the shifts in energy-intensive production associ-
ated with various stages of economic development. In a global context, all economies cannot someday converge to a low carbon-intensity, advanced stage of development characterized by specialization in services and imports of carbon-intensive goods from other economies. This certainly questions whether the inverted-U income-emissions shape is permanent or only reflects the presumably temporary variation in economic development across the world. Although the previous literature has attempted to address this issue by including broad measures of trade as additional regressors, this article makes a contribution by explicitly adjusting CO₂ emissions based on the emissions intensity of net electricity trade. The empirical evaluation in Section 4 provides evidence in support of this theory as the estimated EKCs for consumption-based CO₂ have peaks at higher incomes than standard or production-based CO₂ EKCs and the postpeak shapes of these two types of EKCs also diverge. Although the production-based CO₂ EKC follows a standard inverted-U shape in the more flexible specifications, the consumption-based CO₂ EKC follows a peak and plateau shape.

The empirical work also calls into question the robustness of the inverted-U shape of the per capita CO₂ EKC. The consumption-based EKC appears to have higher peaks and much higher postpeak emissions than production-based EKCs. Tests for common slope parameters suggest that the states do not follow a common income-emissions relationship. The state-specific time series regressions show that some of the estimated reduced-form regressions may be spurious, and few states have cointegrated data that yield a statistically significant inverted-U EKC. The regression results also show that per capita emissions do reflect variations in state climatic conditions as well as the impact of historic energy endowments.

Finally, the empirical work also highlights several issues that merit consideration in subsequent EKC research. Accounting for a limited amount of trade (in this case, electricity trade) has important implications for the shape of the EKC. Testing for this effect in international data, perhaps with data on trade in goods and services, could further assess whether the income-emissions relationship derives primarily from shifts in production. Including trade effects (consumption-based measure) casts some doubt whether per capita emissions fall appreciably with income during any part of the sample, despite the advanced stage of development characterizing the data. If this pattern holds for international data, it could have important implications for forecasting long-term CO₂ emissions. Finally, the state-specific time series results confirm concerns raised in Perman and Stern (2003) that failure to account for potential stochastic trends in the data may yield misleading results. Continued work applying time-series methods to evaluate the robustness of estimated EKCs would be worthwhile.
References


Joseph E. Aldy is a doctoral candidate at Harvard University where his research focuses on environmental and public economics. He served on the staff of the President’s Council of Economic Advisers from 1997 to 2000 where he worked on the development and analysis of domestic and international climate change policies.