Overview

This paper investigates the existence of an environmental Kuznets curve (EKC) for carbon dioxide emissions and the underlying role of alternative (particularly low-carbon) fuels being employed in the production of electricity. The EKC poses an inverse-U relationship between income and pollution, where society initially pollutes more as income increases before reaching a maximum (at a certain income level) and then decreasing the level of pollution at higher income levels. As electricity production is generally responsible for a large share of carbon emissions, the fuel mix plays an important role in determining a nation’s total emissions. The hypothesis has two parts: First, that countries with higher levels of per-capita income show a declining trend (or at least a levelling off) in carbon emissions and, second, that this levelling off or decline in emissions is due in part to fuel switching in the nation’s power generation sector. Thus, it is expected that higher income levels correspond with a larger share of power generation from low-carbon fuels (such as natural gas) and non-thermal/renewable fuels (such as hydropower and wind). The study asks: to what extent does the electricity generation fuel mix play a role underlying existing evidence of an EKC relationship for carbon emissions in industrialized nations? Additionally, if no evidence of a relationship is found, the study attempts to ascertain the theoretical conditions which are necessary for such a relationship to arise.

The paper begins with a review of relevant theory from the EKC literature and develops its own specific model that can be applied to the electricity generation sector. The empirical analysis uses panel data from the International Energy Agency and the World Bank for countries belonging to the Organization for Economic Co-operation and Development (OECD) from 1960-2009 (where available).

Methods

There are several papers which explore the theoretical conditions by which an EKC relationship is possible from the consumer side, in particular Stokey (1998), who assumes that initially full production is achieved by using the dirtiest possible input and that only after government regulation do producers begin using cleaner production processes. Similar to Stokey (1998), this study shows that fuel switching is the primary means by which the electricity producer achieves less CO\textsubscript{2} emissions. After some type of government regulation (e.g. carbon tax, production subsidy, etc.), cost minimizing firms may instead prefer other cheaper inputs which emit less CO\textsubscript{2} in their consumption (such as natural gas or hydropower).

This paper develops a theoretical model, following the framework set forth in Hanley et al. (2007), which investigates the effect of a tax on emissions and the elasticity of substitution between carbon-intensive and carbon-neutral inputs. Using a constant elasticity of substitution (CES) production function and defining emissions \( e = h(x_1) = \beta x_1 \) where \( x_1 \) is the carbon-intensive input, the electricity producer minimizes costs by solving the Lagrangian:

\[
\mathcal{L} = p_1 x_1 + p_2 x_2 + t(\beta x_1) + \lambda \left[ Y^\rho - \left( a_1 x_1^\rho + a_2 x_2^\rho \right) \right],
\]

where \( p_1 \) and \( p_2 \) are the prices of inputs \( x_1 \) and \( x_2 \), \( t \) is a tax on emissions, and \( Y \) is a given level of output. The parameter \( \rho \) is related to the elasticity of substitution \( \sigma \), such that \( \rho = 1 - 1/\sigma \). The conditional factor demands can be derived as:

\[
x_1^* = Y \left[ \alpha_1^\sigma (p_1 + t\beta)^{1-\sigma} + \alpha_2^\sigma p_2^{1-\sigma} \right]^{\sigma/(1-\sigma)} \left[ \frac{\alpha_1}{[p_1+t\beta]} \right]^\sigma \] \quad \text{and}
\]
\[
x_2^* = Y \left[ \alpha_1^\sigma (p_1 + t\beta)^{1-\sigma} + \alpha_2^\sigma p_2^{1-\sigma} \right]^{\sigma/(1-\sigma)} \left( \frac{\alpha_2}{p_2} \right)^\sigma.
\]

Thus, the optimal level of emissions is equal to:
\[ e^* = \beta Y \left[ a_1^\alpha (p_1 + t\beta)^{1-\alpha} + a_2^\alpha p_2^{1-\alpha} \right]^{\alpha/(1-\alpha)} \left( \frac{a_1}{p_1 + t\beta} \right)^\alpha. \]

This emissions level is analyzed for changes in the tax rate and the elasticity of substitution, all else equal.

The next part of the paper uses panel methods to empirically estimate CO\textsubscript{2} emissions from the OECD countries from 1960-2009. The basic model follows the reduced-form:

\[ \ln e_{it} = \alpha + \beta_1 \ln y_{it} + \beta_2 \left( \ln y_{it}^2 \right) + \sum_{j=1}^n \gamma_j x_{jt} + \phi Z_{it} + a_{it} + u_{it}, \]

where \( e \) is CO\textsubscript{2} emissions (in country \( i \) in year \( t \)), \( y \) is per-capita GDP, \( x_j \) is generation fuel \( j \), \( Z \) is a vector of control variables (such as population, indicator variables for natural endowments, etc.), and \( a \) and \( u \) are error terms. For the fuel variables accounted for by \( x_j \), several fuels are used including coal, natural gas, hydropower, nuclear, renewables, and others. In a closely related model which better resembles the theoretical model laid out above, these variables are also consolidated into two groups depending upon the carbon-intensity of the fuel. There are several estimations of these models, namely those using fixed and random effects, and the necessary tests (such as the Hausman test for endogeneity) are performed.

**Results**

Preliminary results confirm that there is an EKC for CO\textsubscript{2} emissions for the OECD countries (the coefficient on \( y^2 \) is negative and significant at the .001 significance level). In addition, the fuel variables are highly significant in predicting CO\textsubscript{2} emissions and, for the most part, have the expected signs (that is, there is a positive and significant coefficient for coal and natural gas and a negative and significant coefficient for nuclear and renewables). Interestingly, however, hydropower has a positive coefficient, though it should be stressed that these results are preliminary. Furthermore, changes in the emissions tax and elasticity of substitution behave in the expected manner, with the impact of the tax varying widely for differences in the elasticity of substitution (which also depends on the relative price). The results confirm the intuitive reasoning that at very low elasticities, even relatively high tax rates have a meager impact on alleviating CO\textsubscript{2} emissions (and vice-versa).

**Conclusions**

The theoretical model shows that an environmental Kuznets curve is possible for CO\textsubscript{2} emissions if electricity generators switch from the carbon-intensive fuel to a low-carbon one. The initial results confirm the existence of an EKC for CO\textsubscript{2} for the OECD countries and suggest that this is at least partially due to fuel switching the power generation sectors of the various countries. This study has potentially important implications for policymakers in that it makes inferences into the necessary conditions for achieving carbon downturns and also suggests which policies may be effective in achieving the desired result.

**Selected References**


