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Explaining the relationship between CO_2 emissions and national income—The role of energy consumption

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Abstract

I estimate a simultaneous equation system in which GDP and CO_2 emissions are jointly determined. I find that including energy consumption in the regression implies a negative relationship between income and CO_2 emissions, which is contrary to previous findings.

Keywords: CO_2 emissions; Environmental Kuznets Curve; Energy consumption; Kyoto Protocol; OECD

JEL classification: Q25

1. Introduction

At low-income levels we might see a positive relation between national income and pollution, and at high levels of income a negative relation between the two variables. This inverted U-shaped relation is known as the Environmental Kuznets Curve (EKC). Studies show that the EKC describes the relation between income and several local pollutants such as sulfur dioxide, suspended particulate matter, nitrogen oxide and water pollutants.

The connection between a country's national income and the level of pollution it experiences is weaker or even negligible for global pollutants such as CO_2. Due to free-rider problem, increased

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income would not induce greater attempts to control emissions. The production effect would remain, but without the offsetting income effect we would observe a positive relation between income and emissions. Some studies, such as Holtz-Eakin and Selden (1995) and Shafik (1994), provide empirical evidence of a monotonically increasing relation between carbon emissions and income. Martinez-Zarzoso and Bengochea-Morancho (2004) find that CO_2 emissions tend to decline when income increases up to a certain level, and then there would be an increase of emissions at higher incomes.

Most of previous estimates of the EKC treat the level of income as exogenous. However, if income and pollution are jointly determined–as theory suggests–OLS parameter estimates of the environmental Kuznets curve will be biased, as Stern et al. (1996) note. I am interested in examining this possible bias by jointly estimating income and emissions.

Other factors in addition to income may be important in determining a country's level of CO_2 emissions. Two countries with similar levels of technology and factor endowments may have significantly different industrial structures as a result of past investment decisions. Their aggregate capital levels may be similar, but differences in the composition of capital may lead to differences in the opportunity cost of reducing emissions. A regression of emissions on income, without controlling for the difference in industrial structure, may lead to misspecification bias. The challenge, of course, is to improve the specification.

I estimate a system of simultaneous equations, in which national income and CO_2 emissions are endogenously determined by country-specific characteristics including levels of capital, labor and technology. This system approach takes into account the endogeneity of GDP, thereby reducing bias. When I include an additional regressor–energy consumption–to account for structural differences across economies, I find a negative relation between income and CO_2 emissions, contrary to previous research.

2. The model

I estimate a two-equation system using 1975–1990 panel data for 24 OECD countries. For the first equation I assume that GDP and CO_2 emissions are joint products, produced by country-specific factors: capital, labor and technology. I refer to this equation as the revenue function.

To conserve notation I suppress time and country subscripts in describing the model. The joint production function is

$$F(Y,E) = G(C,K,L,T,\text{pop}),$$

where Y=GDP (measured in constant 1987 US\$); E=industrial CO_2 emissions (in kt, i.e. thousands of metric tons); C is a country-specific dummy; K=physical capital stock (in constant 1987 US\$); L=labor force; T=patent applications (a proxy for technology); pop=country population. I invert the relation $F(\,)$= $G(\,)$ to obtain the revenue function: $Y=f(C,K,L,T,\text{pop},E)$, which represents the feasible trade-off between income and emissions, for given levels of the other variables. I divide all variables (except the dummy) by pop to obtain per capita variables, and estimate a log–linear relation.

The estimation equation for the revenue function is

$$y_{is} = c_i + \alpha_1 k_{is} + \alpha_2 l_{is} + \alpha_3 t_{is} + \alpha_4 e_{is} + \varepsilon_{1is}. \quad \text{(Revenue function)}$$

Lower case variables y, k, l, t and e are logarithm of the per capita of the corresponding upper case variables, c_i is the country-specific dummy, ε_{1is} the error associated with country i in period s. The

Table 1
3SLQ estimates

Variable	Model I	Model II
	Coefficient (*t*-ratio)	Coefficient (*t*-ratio)
The Revenue Equation		
ln (*K* per capita)	0.3242 (1.779)	0.5096 (20.142)
ln (*L* per capita)	−0.3182 (−0.5141)	0.2646 (8.7759)
ln (*T* per capita)	0.1408 (1.5764)	0.0653 (9.0234)
ln (*E* per capita)	0.7968 (1.1972)	0.1315 (5.1702)
Constant	10.4580 (2.0544)	5.3316 (14.6250)
The Emissions Equation		
ln (*Y* per capita)	1.0072 (160.93)	−0.1992 (−5.1650)
Square ln (*Y* per capita)	−1.0072 (−3.0985)	−0.0016 (−3.1318)
ln (*N* per capita)		1.1654 (31.398)
Constant	−14.0630 (−394.04)	3.3053 (5.9721)

parameters $\alpha_j (j=1,2,3,4)$ are to be estimated. I view Y and E as endogenous and I treat K, L, T and pop as exogenous. I include the country dummy to account for country-specific variables such as arable land and cultural factors.

I refer to the second equation as the emissions function. In principle, the emissions function should include variables which proxy political constraints (e.g., membership in environmental groups, relative income of workers in "dirty" industries). Much of this kind of information is not available for my sample. In an effort to improve the specification of the emissions function and maintain identification, I include commercial energy use (kt of oil equivalent), N, as a regressor in the emissions function. I view N as a proxy for the structure of the economy. Although energy consumption (like most variables) is not genuinely exogenous, it does seem like a reasonable proxy for those variables that affect a country's ability to reduce emissions. Energy consumption and emissions are highly correlated, but it is possible to reduce one without reducing the other. By switching technologies (e.g. from coal-fired to gas-fired power generation) an economy can consume the same amount of energy while producing fewer emissions. I am interested in whether richer economies are more likely to make such a switch,for a given level of energy-dependence.

I estimate a log–linear specification of the emissions function:

$$e_{is} = d + \beta_1 y_{is} + \beta_2 y_{is}^2 + \beta_3 n_{is} + \varepsilon_{2is}, \quad \text{(Emissions function)}$$

where the variable n_{is} is the log of per capita energy consumption in country i, year s; d is a constant, and ε_{2is} is the error term.

I jointly estimate both revenue and emissions functions using three stage least squares (3SLQ) to account for the correlation between the errors ε_{1is} and ε_{2is}, in addition to the endogeneity of the explanatory variables. In order to illustrate the role of energy consumption, I estimate two versions of the emissions function: using regressors y and y^2 only (in Model I), and then including n (in Model II). Table 1 reports the estimation results. The estimation of revenue equation implies Model II is superior to Model I because the estimates of revenue equation in Model I are less reasonable than that in Model II.[1]

[1] For example, the elasticity of GDP with respect to labor,α_2, is negative in Model 1.

In Model I, although the coefficient of y^2 is statistically significant, its magnitude is small. The turning point of the graphs of e against y is (vastly) higher than GDP in my sample.

Thus, in the model where n is excluded, emissions are monotonically increasing with GDP over the range in my sample. This result is in agreement with Holtz-Eakin and Selden (1995) and Shafik (1994). When n is included in Model II, the coefficient of y in the emissions equation turns out to be negative, contrary to previous findings. This interesting result implies that CO_2 emissions will decrease with income if economic structure is held to be constant.

This contrasting result is consistent with two quite different interpretations. If per capita energy consumption is chiefly determined by income, then I should treat n as endogenous. In this case, the interesting relation is between e and y, allowing n to vary endogenously. This view–which appears to be the conventional wisdom–implies that CO_2 emissions are likely to increase with income. However, if I think that per capita energy consumption is partly the result of the structure of the economy (e.g. the relative importance of manufacturing and services), then it becomes interesting to consider the relation between e and y, holding n fixed. This view implies that CO_2 emissions are likely to fall with income. For a given level of per capita energy consumption, higher income is associated with cleaner technology and lower emissions.

3. Conclusion

Earlier studies show that national income and CO_2 emissions are positively related. They treat the level of income as exogenous and do not take economic structure into account. To examine the possible bias in the previous studies, I estimate a simultaneous equation system in which GDP and CO_2 emissions are jointly determined. I also include energy consumption in the emissions function to account for structural differences across economies. I find that including energy consumption in the regression implies a negative relation between income and CO_2 emissions, which is contrary to previous findings.

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