Environment and Development Economics 2 (1997): 505–515

Income and environmental R&D: empirical evidence from OECD countries*

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ABSTRACT: This paper extends previous empirical studies of the environmental Kuznets curve by examining the role of rising incomes in promoting development of new technologies directed toward environmental improvements. The main result, based on an analysis of data from 19 OECD countries for the period 1980–94, shows that the income elasticity of public research and development funding for environmental protection is positive, and may be close to unity. This finding suggests that emissions of at least some pollutants may decline with income after a threshold level of income is reached. However, this should be interpreted cautiously in light of: (1) the small size of public research and development funding relative to overall spending on environmental protection, (2) the ability of a country to substitute between public and private research and development expenditures, as well as among alternative policy instruments, and (3) the possibility that public research and development funding may be a form of industrial subsidy in some countries.

1. Introduction

Whether economic growth and environmental protection are compatible policy goals has become one of the most hotly debated topics among social and natural scientists interested in resource and environmental management. Alternative views on this matter have been expressed in the recent literature on the environmental Kuznets curve (EKC). The EKC suggests that in industrializing nations with low levels of per capita income, increased emissions of certain pollutants may result when the scale of

* We thank the STIR Foundation at Wageningen Agricultural University and the University of Wyoming College of Business for partial financial support and Edward Barbier, Charles Perrings, John List, Stef Proost, Jason Shogren, and three anonymous reviewers for helpful comments on a previous version of this manuscript.

economic activity expands. However, after per capita income reaches a threshold level, further economic growth may bring about environmental improvements through, for example:

- declining population growth rates;
- shifts in the composition of output favouring production and consumption of less pollution-intensive goods;
- increased imports of pollution-intensive goods;
- environmental policy as a consequence of, *inter alia*, better education, the establishment of government agencies aimed at pollution control and development of technologies aimed at reducing emissions.

Hettige *et al.* (1992), Selden and Song (1994), Shafik (1994), Holtz-Eakin and Selden (1995) and Grossman and Krueger (1996) present empirical evidence suggesting that this inverted-U relationship holds between per capita income and environmental degradation, at least for some pollutants. Numerous cautions and qualifications concerning the interpretation of these results have been issued by Arrow *et al.* (1995), various contributors to the Policy Forum in the inaugural issue of *Environment and Development Economics* (see, for example, Daly, 1996), as well as by other prominent contributors to the recent literature including Stern, Common, and Barbier (1996) and McConnell (1996).

The main result of this paper, which analyses data from 19 OECD countries for the period 1980–94, is that the income elasticity of public research and development funding for environmental protection is positive and may be approximately equal to unity. This finding is of interest primarily because:

- Previous empirical studies of the EKC focus on the overall linkage between per capita income and environmental degradation, rather than on the role of individual underlying components, such as research and technology development.
- It may help explain why the EKC appears to be negatively sloped for some pollutants in countries that are relatively industrialized.

In particular, if demand for environmental quality is income elastic, then environmental research and development may be expected to increase with income as well. Moreover, research is frequently an important first step in identifying causes and remedies of environmental problems and in many situations is a prerequisite for the introduction of environmental policy. In this regard, public research and development expenditures are crucial because the approaches to environmental problems at this level are mainly of a basic scientific nature and this type of research is primarily financed through government sources. Also, public spending on environmental research and development can be a catalyst for private spending on development of cleaner technologies. Although research conducted in the private sector is often quite applied, with specific commercial objectives, extensive use may still be made of basic scientific research results. In consequence, both basic and applied research are vital for developing inventions and innovations aimed at improving environmental quality (Folmer and Hutton, 1989).

Additionally, empirical results presented concerning the income elasticity of public research and development funding are of interest in at least two interrelated contexts outside the immediate scope of the EKC literature. First, public and private research and development conducted in OECD countries may, in the long run, have a positive impact on the environmental problems faced by industrializing nations because knowledge generated may be transferable internationally through publications, exchanges of personnel, or international sales of abatement equipment. For example, there are dozens of environmental journals published in industrialized countries, but read in all parts of the world. In any case, the ultimate impact of public research and development expenditures on environmental protection is likely to be larger than those measured in the home country. Second, income elasticities reported below may be larger than expected based on examining income elasticities for specific environmental goods considered in contingent valuation studies (e.g., Loehman *et al*., 1979; Alberini *et al*., 1994; Kristrom and Riera, 1996), although they may not be entirely consistent with conjectures of Borcherding and Deacon (1972), Pearce (1980) and Baumol and Oates (1988), who suggest that environmental quality may be a superior good.

The remainder of this paper is divided into three sections. Section 2 presents the empirical model, describes the data, and discusses econometric issues. Section 3 presents empirical results. Implications and conclusions are drawn out in Section 4.

2. Model, data, and econometric issues

The empirical model applied focuses on the relationship between real per capita public (government) research and development budget appropriations, aimed at protecting the environment from degradation (PRD), and real gross domestic product per capita (GDP). Data were obtained from OECD countries over the period 1980–94 (OECD, 1989, 1991, 1993, 1995). Although this data set contains no observations on industrializing countries, results reported here may be indicative of future developments in those countries when they reach income levels that are within the range spanned by the OECD. As indicated in *Environmental Data* (OECD, 1993, p. 299), PRD includes funds for the study of:

- origins and causes of pollution;
- diffusion and transformation of pollutants in the environment;
- effects of pollution on man and the environment.

Additionally, the data include research on ‘end-of-line’ pollution controls, but exclude research on production process changes that result in generation of less pollution.

It is important to emphasize that the PRD variable should not be confused with spending on protection or abatement. The latter can be achieved with little or no spending on either public or private research and development. This situation might arise if a country seeking to invest in abatement or prevention imported equipment from another country, rather than developing the technology itself. Also, public sector spending for research and development on environmentally friendly technology need not necessarily lead to spending on environmental protection. This type of expenditure could simply be part of a high-tech economy's effort to boost its competitiveness in the international market for abatement and prevention equipment.

Table 1 shows means of PRD and GDP for the 19 countries considered in this study. Attention is restricted to this subset of OECD countries because data on PRD are unavailable for most years during the 1980–94 time period for Iceland, New Zealand, Switzerland, Turkey, Yugoslavia and Luxembourg.[1] As shown in Table 1, missing data on PRD is a lesser problem for the remaining OECD countries. Also, note that available data for Germany pertain to West Germany for the period 1980–90 and to a unified Germany for 1991–94. For each country, PRD is measured as nominal expenditures converted to 1991 US dollars at prevailing purchasing power parities. GDP for each country is correspondingly measured in thousands of US dollars at prevailing purchasing power parities. Use of purchasing power parities for international comparisons has the advantage that it better reflects command over purchase of goods and services than would use of exchange rates.[2]

Table 1. *Gross domestic product per capita (GDP) and public research and development expenditures for environmental protection per capita (PRD): descriptive statistics*

		Sample mean	
Country	*Available time series*	*GDP ($000) Mean*	*PRD Mean*
Canada	1980–92	18.39	1.89
USA	1980–94	21.60	1.58
Australia	1980–94	15.50	2.60
Austria	1980–94	15.79	1.09
Belgium	1980–94	15.61	2.01
Denmark	1980–94	16.35	2.10
Finland	1980–94	14.73	1.49
France	1980–93	16.70	1.49
Germany	1980–93	16.90	5.17
Greece	1980–93	8.99	0.77
Ireland	1980–93	10.05	0.36
Italy	1980–93	15.31	2.25
Norway	1980–93	15.64	2.93
Spain	1980–94	11.13	0.97
Sweden	1980–93	15.87	3.49
United Kingdom	1980–93	14.43	2.11
The Netherlands	1984–94	15.54	4.99
Portugal	1986–93	9.67	1.72
Japan	1985–94	17.46	0.29

[1] Measures of PRD are available for Iceland only for the years 1983–86, 1991–96, for New Zealand only for the years 1989–93, for Switzerland only for the years 1981, 1986, 1988–91. No data are available on PRD for Turkey, Yugoslavia, and Luxembourg.

[2] In research on health care expenditures, Parkin *et al.* (1987) demonstrate that use of purchasing power parity measures is important when attempting to distinguish between normal and superior goods, a related question to that considered here.

Values of PRD indicate that public research and development represents a relatively small fraction of what countries spend on environmental improvements. For example, Rutledge and Leonard (1992) estimate that in 1990, the USA spent about $99 billion on all aspects of pollution control and abatement, of which about $3.3 billion was allocated to research and development (both public and private). Multiplying the figure in Table 1 for the USA (1.58) by that country's 1990 population yields a value for public research and development expenditures of $400 million, which is about 12 per cent of total research and development expenditures. Despite its relatively small share of pollution control and abatement expenditures, however, the relationship between PRDs still is important to analyse for the general reasons outlined in the introduction.

The empirical model to be estimated is:

$$PRD_{jt} = \alpha + \beta GDP_{jt} + u_{jt} \tag{1}$$

where subscripts j and t denote country and time period and u is a disturbance term. A positive relationship between PRD and GDP supports the notion that as incomes rise, governments in industrialized countries make investments to expand their pollution control capital stocks, defined to include information and technical know-how for coping with pollution problems. This relationship between investment and income is similar to that found in a Solow growth model, in which savings are a constant proportion of output, but would not be automatically expected based on a more general Ramsey growth model.

Two additional features of equation (1) warrant further explanation. First, this equation contains only one explanatory variable, GDP. Explanatory variables that may be endogenously related to the growth process have been excluded in order to focus more directly on total effects of GDP on PRD. Examples of such variables that have been explicitly considered in related studies include composition of output (Grossman *et al.*, 1994), institutional framework (Congleton, 1992), degree of openness to trade (Lopez, 1992 and Rauscher, 1992). Holtz-Eakin and Selden (1995) suggest that further examples along these lines might include government regulations, taxes, and extent of urbanization. Second, estimation of equation (1) envisions use of time-series observations on each country in the data set. The implication here is that exogenous country-specific factors, such as extent of reliance on public research and development expenditures as an environmental policy tool, resource endowment and climate, and slowly changing demographic variables, such as population density, which may reflect the degree of environmental degradation and/or public pressure for environmental protection, need not be explicitly modelled. Instead, their net effects on PRD can be controlled using the panel structure of the data set. Net effects of time-specific factors, such as changing global economic conditions or concern for the environment, can be treated in corresponding fashion. In estimating equation (1), the opportunity to exploit this aspect of the data set is important because individual country- and time-specific effects would be difficult both to exhaustively enumerate and to measure.

Econometric estimates of equation (1) are obtained for both random effects and fixed effects models of panel data (a good discussion of panel data estimation methods may be found in Hsiao, 1986). Both estimation approaches control for unmeasured heterogeneity between countries and over time, such as those just discussed, that would remain uncontrolled if least squares was applied either to the pooled data or to a single cross-section. Generalized least squares (GLS) estimates (of the random effects model) treat unmeasured characteristics as a component of the error term, economize on degrees of freedom and yield coefficients that are not conditioned on unmeasured country and time effects. Least-squares-dummy-variable (LSDV) estimates of the fixed-effects model, in contrast, treat unmeasured country and time effects as shifts in the constant term. Hence, estimates of the marginal effect of GDP on PRD are conditioned on the unmeasured characteristics. Also, the GLS estimator is consistent under the null hypothesis of no correlation between country and time effects and GDP, but is biased and inconsistent otherwise. On the other hand, the LSDV estimator remains consistent whether or not this correlation exists, but is inefficient because it neglects variation between countries. In consequence, Hausman (1978) tests of the null hypothesis of zero correlation between GDP and the country and time effects are performed when comparing GLS and LSDV estimates. Finally, the problem of first-order serial correlation (AR(1)) is investigated and corrected estimates are provided.

3. Empirical results

Table 2 presents estimates of equation (1) based on alternative specifications and estimation methods using the unbalanced panel of data (i.e., time series of differing lengths for some countries) described above. In all specifications presented, both PRD and GDP are measured in levels. In preliminary regressions, quadratic and cubic terms in GDP were included in equation (1), but coefficients of these variables were never significantly

Table 2. *Empirical estimates of equation (1): selected results (t-statistics shown in parentheses beneath coefficient estimates)*

	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
Explanatory variable	*OLS*	*LSDV country*	*GLS country*	*LSDV country & time*	*GLS time & country*	*LSDV–AUTO country*	*GLS–AUTO country*
Constant	−0.145	—	−0.937	−4.043	−0.101	—	0.630
	(−0.345)		(−1.616)	−(3.129)	(−0.146)		(0.744)
GDP	0.146	0.209	0.200	−0.131	0.143	0.098	0.103
	(5.503)	(5.991)	(6.073)	(−1.536)	(3.471)	(1.677)	(2.034)
Summary statistics							
R^2	0.105	0.787	0.091	0.823	0.105	0.574	0.530
n	259	259	259	259	259	259	259
r	0.84	0.53	0.56	0.58	0.56	0.15	0.15
Hausman	—	—	0.63	—	13.45	—	0.04
LM	—	—	777.35	—	778.16	—	723.73

different from zero. Double-log versions of this equation also were estimated and will be discussed momentarily.

Column (1) of Table 2 shows the outcome of regressing PRD on GDP using ordinary least squares (OLS) while ignoring the panel structure of the data. The coefficient of GDP is positive (0.146) and different from zero at conventional levels of significance. The coefficient of determination is 0.105. However, heterogeneity among countries and over time is left uncontrolled and first-order serial correlation appears to be a problem as the AR(1) coefficient is $r = 0.84$.

Columns (2) and (3) present LSDV and GLS results that control for heterogeneity between countries. Coefficients of GDP are highly significant and approximately equal (0.209 using LSDV and 0.200 using GLS). These results highlight the importance of controlling for unmeasured country-specific effects. In the column (2) regression, coefficients of the country dummy variables are jointly significant at less than the 1 per cent level ($F(18,239) = 42.51$), whereas in the column (3) regression, the LM statistic of 777.35, distributed as chi-square with one degree of freedom, indicates that the country-specific variance component is significant at less than the 1 per cent level (Greene, 1997, p. 628–629). Also, the Hausman statistic of 0.63 presented in column (4), distributed as chi-square with one degree of freedom, suggests that the null hypothesis of consistency of the GLS estimator (i.e., orthogonality between the random country effects and GDP) is not rejected. Values of r, the AR(1) coefficient, suggest that first-order autocorrelation still may be a problem in both the column (2) and column (3) regressions.

Columns (4) and (5) show the outcome of controlling for both country- and time-specific heterogeneity in the same regression. In the fixed effects case (column (4)), this extension yields a negative coefficient of GDP that is insignificant at the 10 per cent level ($p = 0.126$). This result, of course, indicates that after conditioning on both country and time effects, GDP has no effect on PRD. This interpretation, however, may be questioned from at least three perspectives. First, serial correlation remains a problem as suggested by the reported value of $r = 0.58$. Second, regressions of GDP on both country and time dummies yields a coefficient of determination of 0.97, whereas corresponding regressions of GDP on country and time dummies alone yield values of R^2 of 0.85 and 0.11, respectively. This outcome, together with results presented in columns (2) and (3) of Table 2, suggests that a multicollinearity problem arises from interactions between GDP and the two sets of dummy variables, thus making it difficult to isolate the independent contribution of GDP in explaining variation in PRD (see Greene, 1997, pp. 420–421 for a related example on use of auxiliary regressions to identify multicollinearity). Third, the column (5) regression, estimated by GLS, yields a highly significant and positive coefficient of GDP of 0.143. The Hausman statistic for this equation (13.45), which is significantly different from zero at the 1 per cent level, may well be attributable to high multicollinearity pertaining to the fixed-effects estimates.

Regressions corrected for first-order serial correlation, presented in columns (6) and (7), were estimated using a two-step generalized least-squares procedure under the assumption that the AR(1) parameter is the same for all countries. As shown, estimates presented pertain to one-way fixed- and random-effects cases. Corrections for autocorrelation turn out to be computationally difficult in two-way models in which the panel is unbalanced. In both equations, the estimated coefficient of GDP is positive and significantly different from zero at least at the 10 per cent level using a one-tailed test. Also, the two estimates are roughly equal (about 0.10) and the Hausman statistic is very small and insignificant. Hence, the hypothesis that the individual effects are uncorrelated with GDP is not rejected. Moreover, the first-order serial correlation coefficient is $r = 0.15$, indicating that the transformation applied is effective in reducing the autocorrelation problem present in the earlier regressions.

A simple approach to summarizing estimates in Table 2 is to compute elasticities of PRD with respect to GDP. These values, which are shown in row 1 of Table 3, were evaluated at the overall sample average of GDP (15.12) and PRD (2.06) for each of the Table 2 regressions. Standard errors of these elasticity estimates, shown in parentheses, were obtained using an approximation to the standard error of a function of a random variable discussed by Greene (1997, p. 360). As shown, the column (5) regression, which controls for random country and time effects, yields an elasticity estimate of 1.07; whereas the column (6) and (7) regressions, which control for unmeasured country effects and first-order autocorrelation, yield corresponding estimates of around 0.75. The null hypothesis that the true value of the elasticity of PRD with respect to GDP equals unity cannot be rejected at conventional significance levels in any of the three equations. Additionally, these three elasticity estimates may be preferred to the larger numerical values obtained from the column (2) and (3) regressions, which control only for country-specific effects, as well as the value generated by the multicollinearity-plagued column (4) regression.

To analyse the GDP elasticity of PRD further, equation (1) was re-estimated in two ways. First, by dividing the sample roughly in half into high- and low-income subsamples and then re-estimating the specifications shown in Table 2, an attempt was made to determine whether this elasticity varies systematically with income. This analysis yielded no clear-cut results as the resulting estimates turned out to be quite sensitive to both the method of estimation (LSDV vs. GLS) and the way in which the sample was split. Just how countries near the sample median of GDP are

Table 3. *Elasticity estimates of PRD with respect to GDP (standard errors in parentheses)*

	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
Functional form	*OLS*	*LSDV country*	*GLS country*	*LSDV country & time*	*GLS country & time*	*LSDV-AUTO country*	*GLS-AUTO country*
Linear	1.07	1.51	1.47	−0.96	1.07	0.72	0.76
	(0.19)	(0.26)	(0.24)	(0.62)	(0.30)	(0.43)	(0.37)
Log	1.64	2.28	2.16	0.16	1.91	1.30	1.26
	(0.20)	(0.29)	(0.27)	(0.69)	(0.32)	(0.48)	(0.41)

assigned to the high- and low-income subsamples or whether they are dropped from the analysis entirely greatly affects whether the estimated GDP elasticity of PRD is larger for high-income countries than for low-income countries. Results of this analysis are not presented here, but instead can be made available to interested readers on request.

Second, equation (1) was re-estimated in double-log form for each of the specifications shown in Table 2. Resulting elasticities of PRD with respect to GDP are presented in Row 2 of Table 3. As shown, elasticities obtained from the double-log form of equation (1) are uniformly larger than those obtained from the linear specification. For example, in the column (5) regression, the elasticity estimate is 1.91, which exceeds unity by about three standard errors. Elasticity estimates, however, fall to about 1.30 in the Column (6) and (7) regressions which control for unmeasured country effects and autocorrelation. These two elasticity estimates are not different from unity at conventional levels of significance. Thus, a possible conclusion from both the linear and log-linear estimates presented Table 3 is that the GDP elasticity of PRD is approximately equal to unity.

4. Implications and conclusions

The empirical analysis of OECD data presented in this paper supports the notion that publicly supported research and development aimed at environmental improvements increases with income. This outcome suggests that emissions of at least some pollutants might decline with income after a threshold level of income is reached. Additionally, the elasticity estimates reported here are larger by a factor of two or three than might be expected based on income elasticity estimates of willingness to pay for specific environmental improvements obtained in certain contingent valuation and hedonic price studies (e.g., Loehman *et al.*, 1979; Alberini *et al.*, 1994; Kristrom and Riera, 1996). This comparison indicates that government spending on environmental improvements may be more responsive to income changes than is individual willingness to pay. Moreover, it is consistent with the idea that public agencies can take a broader view of benefits of environmental improvements than can individuals.

Two qualifications, however, are in order. First, income elasticities presented in this paper actually are reduced-form coefficients that involve the marginal cost of pollution control as well as the income elasticity of demand for pollution control. Second, as demonstrated by Flores and Carson (1997), elasticities of willingness to pay with respect to income will generally be less than conventionally conceived income elasticities. Nevertheless, these relatively optimistic conclusions concerning the link between economic growth and environmental quality should, however, be treated cautiously in light of the numerous general limitations of environmental Kuznets curve analysis as well as the specific limitations of this study including:

- the small size of public research and development funding to address problems of environmental degradation in comparison to total spending on environmental protection;
- the possibility that in some countries, public research and development

expenditures for environmental protection may be a form of industrial subsidy;

- the possibility that countries may substitute research and development for other environmental policy instruments as per capita income grows.

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