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ANALYSIS

Air quality and economic growth: an empirical study

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Abstract

In the present empirical study, we have observed an inverse (and sometimes U-shaped) relationship between environmental degradation and per capita real income as opposed to the inverted U-shaped environmental Kuznets curve (EKC) found in many earlier studies. It was felt that a possible explanation of the observed pattern of relationship might be sought in the dynamics of the process of economic growth experienced by the countries concerned. Thus, e.g. economic development may strengthen the market mechanism as a result of which the economy may gradually shift from non-market to marketed energy resources that are less polluting. This phenomenon may show up in the form of an inverse relationship, as mentioned above. Also, due to the global technical progress the production techniques available to the countries all over the world are becoming more and more capital intensive and at the same time less polluting. This may mean that, given the income level, the pollution level decreases as the capital intensity of an economy rises. In the present study, it is indeed observed that as capital intensity increases the level of suspended particulate matter (spm) in the atmosphere decreases. Per capita real income is also found to be inversely related to spm partially, but the interaction effect of per capita income and capital-intensity on spm is observed to be positive. This suggests that, given the level of per capita income (capital intensity), a more capital intensive production technique (a higher per capita income level) would cause less pollution. For spm a surprising result is also obtained, i.e. a U-turn is observed at a very high level of per capita real income (i.e. ~ US$12 500 at 1985 US prices). This is possibly indicative of the fact that there are technological limits to industrial pollution control such that beyond a threshold level of income further rise in income cannot be achieved without environmental degradation. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Environmental degradation; U-turn; Capital intensity; Sectoral composition of GDP; Technological limitation

1. Introduction

Worldwide deterioration of environmental quality made many feel concerned about the issue

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and a sizeable literature on the pollution–income growth relationship has grown in the recent period. The World Development Report (World Bank, 1992) presents cross-sectional evidences on the relationship between different indicators of environmental quality and per capita national income across countries. Other studies (e.g. Selden and Song, 1994; Shafik, 1994; Grossman and Krueger, 1995; Holtz-Eakin and Selden, 1995; Carson et al., 1997; McConnell, 1997; Moomaw and Unruh, 1997; de Bruyn et al., 1998; Rothman, 1998; Suri and Chapman, 1998) have found an inverted U-shaped relationship between environmental degradation and income. The common point of all these papers is the assertion that the environmental quality deteriorates initially and then improves as an economy develops. This inverted U-shaped relationship between environmental deterioration and economic growth has been called the environmental Kuznets curve (EKC). An explanation of the EKC has been pursued on many lines. Two major explanations are as follows: (i) use of environment as a major source of inputs and a pool for waste assimilation increases at the initial stage of economic growth, but as a country grows richer, structural changes take place which result in greater environment protection; and (ii) viewed as a consumption good, the status of environmental quality changes from a luxury to a necessary good as an economy develops. Phenomena like structural economic change and transition, technological improvements and rise in public spending on environmental R&D with rising per capita income level are considered to be important in determining the nature of the relationship between economic growth and environmental quality. Grossman and Krueger (1995), using cross-country city level data on environmental quality, found support for the EKC hypothesis with peaks at a relatively early stage of development.[1] However, no such peak was observed for the heavier particles. Shafik (1994) also estimated the turning point for suspended particulate matter (spm) to be at per capita GDP US$3280. Selden and Song (1994) used aggregate emission data (rather than the data on concentration of pollutant in the atmosphere as used in many studies, including the present one) and estimated peaks for air pollutants at per capita GDP levels greater than US$8000. The results of Cole et al. (1997) tend to suggest that meaningful EKC's exist only for local air pollutants. Vincent (1997) analysed the relationship between pollution and income level using time series data for Malaysia. His results, which contradict the findings obtained from the cross-country panel data, were thought to reflect the consequences of non-environmental policy decision. Carson et al. (1997) also obtained inverse relationship between per capita income and emissions for seven major types of air pollutant in 50 US states. Further, they observed greater variability of per capita emissions for the lower income states (which possibly suggests that the individual US states follow widely divergent development paths). Kaufmann et al. (1998) found a U-shaped relation between income and atmospheric concentration of SO_2, and an inverted U-shaped relation between spatial intensity of economic activity and SO_2 concentration. Socio-political conditions (Panayotou, 1997; Torras and Boyce, 1998) are also found to have significant effects on environmental quality. Thus, while a faster economic growth may involve a higher environmental cost, a better institutional set up characterised by good governance, credible property rights, defined political rights, literacy, regulations, etc. can create strong public awareness against environmental degradation and help protect the environment. Rothman (1998), Suri and Chapman (1998) tried to explain the EKC phenomenon in terms of trade and consumption pattern differences of the developing and the developed countries. Their observation is as follows: Manufacturing industries (which are often more polluting) concentrate mostly in the less developed countries, whereas the high-tech industries (which are far less polluting) concentrate in the rich already industrialised countries due to the nature of the established pattern of international trade. Therefore, the rising portion of the EKC could be due to the

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[1] Namely, for lighter particles (i.e. smoke) and sulphar dioxide (SO_2) the observed peak corresponded to per capita GDP level of US$6151 and 4053, respectively. It may be noted that the per capita GDP values reported here and elsewhere in this paper are measured at 1985 US prices.

concentration of manufacturing industrial activities in the developing countries and the declining portion of the EKC could be due to the concentration of less polluting high-tech industries in the developed world. Finally, household preferences and demand for environmental quality are also regarded as possible explanatory factors for the EKC phenomenon (Komen et al., 1997; McConnell, 1997). As the demand for environmental quality is income elastic, a strong private and social demand for a high quality environment in the developed countries would induce considerable private and public expenditures on environmental protection. Thus, whereas the rising portion of the EKC may be a manifestation of the substitution relationship between the demands for material consumption and environmental quality, the declining portion of the EKC may result as the substitution relationship turns to one of complementarity between the two kinds of demand.

The present paper re-examines the EKC hypothesis of an inverted U-shaped relationship between environmental degradation and economic growth using the World Bank cross-country panel data on environment and per capita real GDP for the period 1979–90. Two different measures of environmental quality, i.e. spm and SO_2 have been used here.[2] An inverse relationship between the levels of air pollutant and per capita real GDP is observed. In the case of spm, a significant U-turn at a reasonably high per capita income level is found. This may be due to the fact that as income rises, the countries become more energy intensive.[3] Recognising the possibility that the environmental quality of a country may, in addition to real per capita GDP, depend on the production technology, here we have attempted to examine if, in addition to the per capita GDP level, the production technique (i.e. capital–labour ratio) and the sectoral composition of GDP have any effect on pollution level.[4] We have also examined the relationship between pollution level and economic growth rate. The present paper is organised as follows: Section 2 briefly explains the nature of data used, the regression set up used in the study and the regression results are described in Section 3, and finally, Section 4 concludes the paper.

2. Description of the data

The basic air pollution data on spm and SO_2 used in the present study were obtained from World Development Report (World Bank, 1992). This report gives city-wise annual data on mean atmospheric concentration (μg per cubic meter) of spm and SO_2 separately for three time periods (i.e. 1979–82, 1983–86 and 1987–90) for 33 countries classified into low, middle and high income groups. For each city in the sample, the data relate to the level of pollution either at the city centre or at the neighbourhood suburb. Further, the sites from where data were recorded in a city centre/suburb were classified as residential, commercial or industrial, as the case might be. The countries covered in the low income group were China, Egypt, Ghana, India, Indonesia and Pakistan; those covered in the middle income group include Brazil, Chile, Greece, Iran, Malaysia, Philippines, Poland, Portugal, Thailand, Venezuela and Yugoslavia, and finally, the high income group includes Australia, Belgium, Canada, Denmark, Finland, Germany, Hong Kong, Ireland, Israel, Italy, Japan, the Netherlands, New Zealand, Spain, the UK and the USA. For the purpose of the present analysis, we have calculated country-wise annual mean concentration of spm and SO_2 separately for residential and commercial centres for each of the three time periods mentioned above. The data thus constructed relate to 42 cities for spm and 39 cities for SO_2 in 26 countries.

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[2] See World Development Report (World Bank, 1992), Table A.5, p. 199.

[3] Using World Bank data (1986) on energy consumption per capita (kg of oil equivalent) for high and low income countries, the average propensity to consume for energy is estimated to be 0.446 kg/US$ for high income countries (i.e. USA, UK, Canada, Finland, Norway, Netherlands, Japan, Germany, France) and 0.367 kg/US$ for low income countries (i.e. Indonesia, Malaysia, Thailand, Philippines, Panama, Paraguay, Uruguay, Brazil, Morocco).

[4] The major determinants of environmental quality are specified to be resource endowment, income and technology. See Shafik (1994), Agras and Chapman (1999).

Table 1
Distribution of sample by PCGDP level

Group[a]	Low PCGDP	Middle PCGDP	High PCGDP	All
spm				
No. of countries	4	7	15	26
No. of cities	11	8	23	42
SO_2				
No. of countries	4	7	15	26
No. of cities	10	8	21	39

[a] As per World Bank guideline.

As regards the country-wise per capita income data, we have used the Summers and Heston country-wise real per capita GDP (measured at a common set of international prices) available from the Penn World Tables (Summers and Heston, 1988, 1991). It should be mentioned that the Summers and Heston real GDP data are available up to 1988, whereas the country-wise data on air pollution are available up to 1990. For the years 1989 and 1990, we have used the World Bank's country-wise data on nominal per capita GDP after dividing these by the ratio of the Summers and Heston GDP data and the corresponding World Bank (1988) data in order to index-link the World Bank data for 1989 and 1990[5] (World Bank, 1989, 1990). Since the pollution data are available city-wise for individual countries, ideally we should have some measure of city-wise per capita income. However, such income data being unavailable, we have used the real per capita GDP of the country (to which a specific city belongs) as a proxy for the per capita income of a city. Thus, for all the cities belonging to a country, the same country level per capita income has been used. As the city-wise pollution data are available separately for three time periods as already mentioned, we have used the average of yearly per capita incomes for a specific time-period as the measure of per capita income of that time period. Thus, the data set we have used in the present study is essentially of the nature of a panel data consisting of 42 cities in 26 countries and three time-periods.[6] Note that of the 26 countries represented in our data set, 15 belong to the high-income group. Thus, the present data set has a somewhat biased representation of countries with high income. Table 1 presents a two-way summary of the distribution of the countries and the cities by per capita income level (PCGDP) and pollutant type.

In our empirical analysis reported in this paper we have tried to explain the level of pollution in terms of production technique (as reflected by the capital–labour ratio for the economy as a whole) and sectoral composition of GDP of individual countries, in addition to PCGDP. Country-wise capital–labour ratios have been calculated on the basis of country-wise data on gross capital and employed labour force available in the United Nations National Income Accounts Statistics (1990) and ILO's Yearbook of Labour Statistics, respectively. Finally, country-wise data on sectoral composition of GDP have been obtained from the World Bank reports.

3. The regression set up and the results

As already mentioned, the primary focus of the present study is on the relationship between ambient air quality and real PCGDP. To examine the nature of this basic relationship, a number of alternative functional forms of the regression model have been tried, i.e.

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[5] Also see footnote 5 in Grossman and Krueger (1995).

[6] To be precise, for spm we have data for 42 cities in 26 countries, where as for SO_2 data for 39 cities in 26 countries.

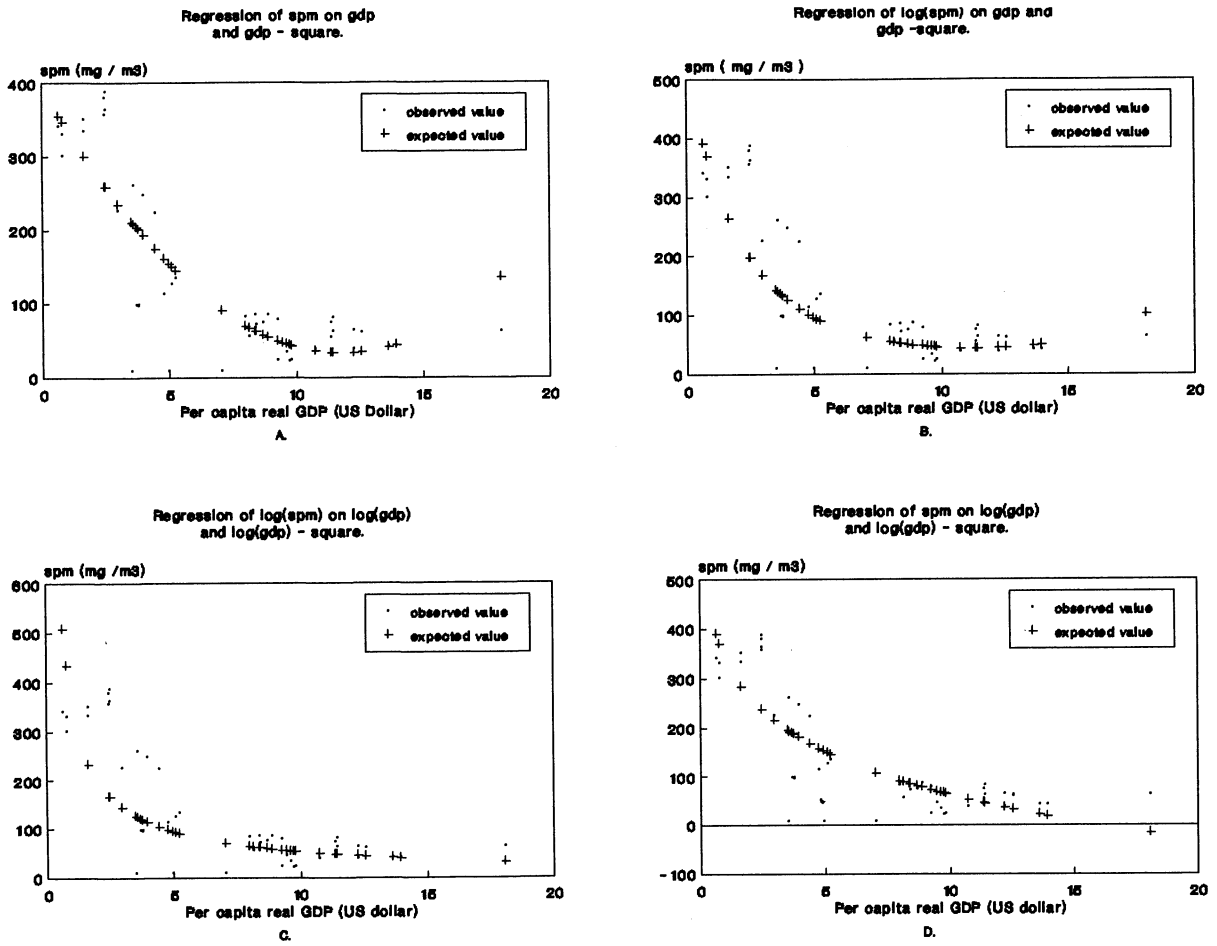

Fig. 1. Relationship between PCGDP and spm.

$$y_{it} = \beta_0 + \beta_1 x_{it} + \beta_2 x_{it}^2 \qquad (1)$$

$$y_{it} = \beta_0 + \beta_1 \ln x_{it} + \beta_2 (\ln x_{it})^2 \qquad (2)$$

$$\ln y_{it} = \beta_0 + \beta_1 x_{it} + \beta_2 x_{it}^2 \qquad (3)$$

$$\ln y_{it} = \beta_0 + \beta_1 \ln x_{it} + \beta_2 (\ln x_{it})^2 \qquad (4)$$

where y_{it} and x_{it} denote levels of air pollutant and real PCGDP for ith country at tth time period, respectively. These equations have been estimated for spm and SO_2 separately for residential and commercial locations at the three different time periods and also for the two types of locations combined and the three time periods combined.

The correlation coefficient between spm and real PCGDP was found to be negative and large separately for each data set and also for the combined data sets. The smallest absolute value of this correlation is 0.79 (see Table 3). This finding contradicts the EKC hypothesis. However, such contradictory empirical results have been obtained earlier also. Grossman and Krueger (1993) and Torras and Boyce (1998) (and also Grossman and Krueger, 1995) reported results not supporting the EKC hypothesis for ambient spm and heavier particles, respectively.[7] This is confirmed if we look at the scatter diagrams, all of

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[7] Grossman and Krueger (1995), however, did not find a minimum point of the estimated curve for heavy particles.

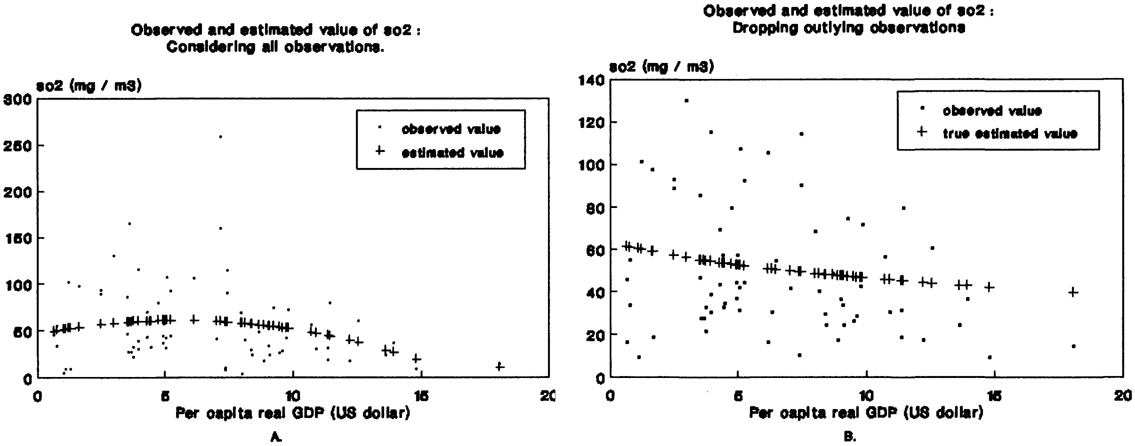

Fig. 2. Relationship between PCGDP and SO_2.

Table 2
Distribution of countries by the level of PCGDP corresponding to turning point of EKC

Pollutants	Group	US\$0–3000	US\$3000–6000	US\$6000–8000	US\$8000 and more
spm	*c*	6	7	1	20
	r	8	2	0	4
	All	14	9	1	24
SO_2	*c*	8	14	7	20
	r	5	10	2	3
	All	13	24	9	23

which show the same decreasing pattern (see Fig. 1). A possible explanation of this may be the fact that the present data set contains observations relating to mostly developed countries (which may have crossed the so-called turning point of the EKC). Table 2, which gives the distribution of countries by selected level of PCGDP (assumed to correspond to the possible turning point of the EKC), may corroborate this. Thus, e.g. if the level of PCGDP corresponding to the turning point of the EKC for spm is taken to be US\$8000, there 20 out of the 34 sample observations would belong to the declining portion of an inverted U-shaped EKC for spm.

As a part of the preliminary data analysis, we examined the summary statistics relating to the pollution data (i.e. mean and variance and correlation coefficient with PCGDP). These are reported in Table 3. It may be noted in this Table that the average spm level for residential areas is higher than that for commercial areas, but the mean PCGDP level is higher for commercial areas than that for residential areas. This is possibly because of the fact that the residential areas in the present data set are mostly located in the less developed and developing countries.

Tables 4–6 present our regression results for spm. The scatter diagrams in Fig. 1A suggest that the shape of the underlying relationship between PCGDP and spm is U-shaped. The ordinary least squares (OLS) estimates of corresponding quadratic relationship between PCGDP and spm for different periods and areas are reported in Table 4. All these results show a negative value of β_1 and a positive value of β_2, both of which are statistically significant.[8] Thus, for spm our results

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[8] β_1 and β_2 are the coefficients of Eq. (1).

Table 3
Summary statistics of the suspended particulate matter for different groups and their combinations[a]

Group	Variables	Mean	Variance	Correlation	No. of countries
c_1	spm	127.97	12 448	−0.91	14
	GDP	7034.6			
c_2	spm	133.57	13 572	−0.90	13
	GDP	7537.7			
c_3	spm	141.15	15 554	−0.87	7
	GDP	10226			
c	spm	132.82	12 692	−0.82	34
	GDP	7884.1			
r_1	spm	186.17	16 453	−0.87	6
	GDP	4960.8			
r_2	spm	187.67	18 966	−0.84	6
	GDP	5484.3			
r	spm	194.99	17 252	−0.79	14
	GDP	4912.1			
All	spm	150.96	14 499	−0.82	48
	GDP	7017.2			

[a] Note: c_t is the group of countries with data from commercial areas of cities at time t, r_r is the same from residential areas.

Table 4
Groupwise results of OLS regression for spm data[a]

Group	Estimated coefficients of explanatory variable			R^2 (df)	$\sqrt{\Sigma e^2/n}$	$\Sigma\lvert e\rvert/n$	Turning points
	Intercept	x	x^2				
c_1	419.43***	−0.073***	0.36×10^{-5}***	0.93 (11)	32.30	25.37	10 033
	(14.15)	(−6.54)	(4.08)				
c_2	437.00***	−0.067***	0.29×10^{-5}**	0.89 (10)	41.31	27.70	11 538
	(10.4)	(−4.81)	(2.91)				
c_3	466.76***	−0.065**	0.25×10^{-5}**	0.91 (4)	44.13	26.70	13 238
	(7.38)	(−3.75)	(2.79)				
c	418.68***	−0.060***	0.24×10^{-5}***	0.89 (31)	38.17	29.78	12 618
	(20.6)	(−11.57)	(7.84)				
r_1	382.06***	−0.090*	0.5×10^{-5}	0.89 (3)	55.50	28.42	8374
	(6.72)	(−2.48)	(1.9)				
r_2	375.59**	−0.067	0.33×10^{-5}	0.76 (3)	87.16	44.92	10 225
	(3.75)	(−1.22)	(0.84)				
r	371.37***	−0.070**	0.37×10^{-5}*	0.80 (11)	61.93	39.60	9529
	(8.13)	(−2.74)	(1.9)				
All	382.07***	−0.055***	0.22×10^{-5}***	0.81 (45)	52.89	37.92	12 500
	(19.37)	(−9.11)	(5.75)				

[a] Note: figures in parentheses are the t-ratios. Pollution is measured in mg/m^3. Income is measured in terms of 1985 US dollars.
* Coefficient estimate is significantly different from zero at 10%.
** Coefficient estimate is significantly different from zero at 5%.
*** Coefficient estimate is significantly different from zero at 1% level.

Table 5
OLS AND LAE regression results of spm on PCGDP for different forms separately for commercial and residential areas[a]

Class	OLS and LAE	Estimated coefficients of explanatory variable					R^2 (df)	Turning points
		Intercept	x	x^2	P_1	P_2		
c	OLS	418.68***	−0.06***	0.24×10^{-5}***			0.89 (31)	12 618
		(20.62)	(−11.57)	(7.84)				
	LAE	373.17	−0.053	0.21×10^{-5}			0.87	12 604
	OLS	430.42***	−0.058***	0.22×10^{-5}***	−27.24	−12.22	0.90 (29)	13 122
		(18.66)	(−10.17)	(6.31)	(−1.31)	(−0.59)		
	LAE	405.59	−0.05	0.17×10^{-5}	−34.07	−25.44	0.89	14 504
r	OLS	371.37***	−0.07**	0.37×10^{-5}*			0.80 (11)	9529
		(8.13)	(−2.74)	(1.94)				
	OLS	374.43***	−0.07**	0.37×10^{-5}	−6.94		0.80 (10)	9559
		(7.32)	(−2.56)	(1.8)	(−0.18)			
	OLS	395.02***	−0.079**	0.42×10^{-5}	−31.63	0.005	0.81 (9)	9524
		(6.06)	(−2.44)	(1.8)	(−0.53)	(0.55)		
All	OLS	382.07***	−.055***	0.22×10^{-5}***			0.81 (45)	12 500
		(19.37)	(−9.11)	(5.75)				
	LAE	368.75	−0.052	0.2×10^{-5}			0.81	12 667
	OLS	387.77***	−.054***	0.21×10^{-5}***	−16.67		0.82 (44)	12 717
		(18.98)	(−8.88)	(5.47)	(−1.05)			
	OLS	395.77***	−.053***	0.2×10^{-5}***	−27.13	−14.25	0.82 (43)	12 998
		(16.28)	(−8.26)	(4.9)	(−1.17)	(0.62)		

[a] Note: figures in parentheses are the t-ratios. Pollution is measured in mg/m^3. Income is measured in terms of 1985 US dollars
* Coefficient estimate is significantly different from zero at 10% level.
** Coefficient estimate is significantly different from zero at 5% and level.
*** Coefficient estimate is significantly different from zero at and 1% level.

suggest a U-shaped relationship between spm and PCGDP, which implies that beyond a certain level of PCGDP (~ US$12 500), a further rise of PCGDP can be achieved at the cost of environmental degradation. [9] Clearly, this result contradicts the usual EKC hypothesis, but supports some earlier findings. For example, Kaufmann et al. (1998)[10] found U-shaped relationship between income and atmospheric concentration of SO_2 with a turning point around the PCGDP level of US$12 000; Sengupta (1997) noted that beyond the per capita income US$15 300, the environmental base (particularly carbon emissions) relinks with economic growth[11]; and Shafik (1994), Grossman and Krueger (1995) obtained upward rising curves by fitting cubic relationships.

It may be mentioned that our OLS diagnostics indicated presence of heteroscedasticity in the present data set. We therefore re-estimated all the

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[9] An alternative measurement also reveals the same result. Instead of PCGDP, we took Gross City Product Per Capita (GCPPC) from World Resources 1998–99 (World Resources Institution et al., 1998). Using GCPPC and spm (mg/m^3) for the year 1993, we found the same result, i.e. U-shaped relationship between spm and GCPPC. This later data set covered 22 cities across the world. The estimated relationship is: $\text{spm} = 215.4$ $(7.5) - 0.01906(\text{GCPPC})$ $(-2.755) + 0.416 \times 10^{-6}$ $(\text{GCPCDP})^2$ (2.001). and the coefficients of GCPPC and square of GCPPC are significant at 5 and 10% level, respectively. In case of SO_2, after removing an outlier, we obtained negatively sloped linear relationship. See Sukla and Parikh (1992).

[10] See Kaufmann et al. (1998), pp. 214–215.

[11] See Sengupta (1997), p. 215.

Table 6
OLS regression results of spm on GDP and different dummy variables for different groups and their combination[a]

Group	Estimated coefficient of explanatory variable										R^2 (df)	$\bar{R}^2$
	Intercept	X	P_1	P_2	Z_1	Z_2	d_1	d_2	W_1	W_2		
c	318.4***	−0.018***	23.65	23.64	−0.012**	−0.01*					0.81 (28)	0.78
	(7.54)	(−4.68)	(0.45)	(o.43)	(−2.24)	(−1.77)						
	311.5***	−0.02***					−32.36				0.73 (31)	0.71
	(14.06)	(−5.82)					(−1.08)					
	356.2***	−0.03***					−209.4***		0.02***		0.82 (30)	0.80
	(16.5)	(−7.87)					(−4.07)		(3.92)			
	418.7***	−0.051***						−320***		0.047***	0.91 (30)	0.90
	(18.35)	(−7.38)						(−8.19)		(6.29)		
r	474.3**	−0.07*	−262.67	−227.5	0.054	0.053					0.51 (8)	0.21
	(2.7)	(−1.92)	(−1.3)	(−1.118)	(1.4)	(1.39)						
	340.2***	−0.0004					−282.7***				0.93 (11)	0.92
	(16.67)	(−0.14)					(−9.37)					
	281.5***	0.037*					−218.08***		−0.04*		0.95 (10)	0.93
	(7.77)	(1.84)					(−4.97)		(1.88)			
	377.9***	−0.057***						−296**		0.05**	0.68 (10)	0.59
	(6.4)	(−3.437)						(−2.96)		(2.92)		
All	288.1***	−0.017***	12.6	7.28	−0.008	−0.006					0.60 (42)	0.56
	(6.16)	(−3.47)	(0.21)	(0.12)	(−1.21)	(−0.83)						
	297.2***	−0.014***					−107.42***				0.69 (45)	0.67
	(15.3)	(−4.57)					(−4.12)					
	363.8***	−0.031***					−273.26***		0.03***		0.83 (44)	0.82
	(20.15)	(−8.62)					(−8.2)		(6.13)			
	406.8***	−0.054***						−317***		0.05***	0.81 (44)	0.80
	(16.23)	(−7.3)						(−7.39)		(6.28)		

[a] Note: pollution is measured in mg/m^3. Income is measured in terms of 1985 US dollars. Figures in parentheses are the t-ratios.

* Coefficient estimate is significantly different from zero at 10% level.

** Coefficient estimate is significantly different from zero at 5% level.

*** Coefficient estimate is significantly different from zero at 1% level.

Table 7
OLS and LAE regression results of SO_2 on GDP[a]

Group	OLS and LAE	Estimated coefficient of explanatory variable						R^2 (df)	$\sqrt{\Sigma e^2/n}$	$\Sigma\lvert e\rvert/n$
		Intercept	x	x^2	P_1	P_2	c			
c	OLS	78.53***	−0.0039***					0.220 (47)	27.96	22.86
		(9.4)	(−3.65)							
	OLS	71.6***	−0.0038***		7.06	7.75		0.230 (45)	28.42	23.06
		(5.49)	(−3.43)		(0.61)	(0.67)				
	LAE	62.43	−0.0028					0.130	30.39	22.45
	OLS	80.64***	−0.0047	0.5×10^{-7}				0.220 (46)	28.25	22.72
		(6.3)	(−1.35)	(0.22)						
	LAE	81.9	−0.0063	0.14×10^{-7}				0.200	35.41	32.95
r	OLS	48.93***	0.0005					0.003 (18)	31.98	24.8
		(3.76)	(0.245)							
	OLS	50.72**	−0.00025	0.6×10^{-7}				0.004 (17)	32.89	24.65
		(2.17)	(−0.03)	(0.09)						
All	OLS	68.7***	−0.0027***					0.100 (67)	29.63	24.65
		(9.75)	(−2.79)							
	OLS	59.15***	−0.0028***		5.9	9.86	4.95	0.122 (64)	29.99	24.65
		(5.14)	(−2.735)		(0.58)	(0.98)	(0.6)			
	LAE	56.09	−0.0023						32.88	23.25
	OLS	66.99***	−0.002	-0.4×10^{-7}	6.07	10.02		0.100 (64)	29.84	24.65
		(6.15)	(−0.65)	(−0.207)	(0.57)	(0.95)				
	OLS	59.5***	−0.003	0.13×10^{-7}			4.98	0.123 (65)	30.23	24.37
		(4.54)	(−0.88)	(0.06)			(0.6)			
	LAE	54.05	−0.002	-0.2×10^{-7}					28.31	23.24

[a] Note: pollution (SO_2) is measured in mg/m^3. Income is measured in terms of 1985 US dollars. Figures in parentheses are the t-ratios. Two and three asterisks indicate that estimated coefficient are statistically significant at 1 and 5% level, respectively.

regression specifications using the least absolute error (LAE) method.[12] The estimated LAE and OLS results are presented in Table 5. As is to be expected, the estimated LAE results are similar to the corresponding OLS results. Perhaps the most interesting findings for spm again are the U-shaped relationship with rather high PCGDP values corresponding to the turning point (vide last columns of Tables 4 and 5). This is in contrast to the results of Selden and Song (1994), Grossman and Krueger (1995), who observed a turning point for spm around PCGDP levels of US$8000 and 5000, respectively. To be precise, our turning point estimates for spm vary between US$9500 and 14 000.

Table 5 presents the estimated OLS and LAE results for commercial, residential areas separately and also for the combined data for the two types of areas. So far as these estimates are concerned, it should be noted that the OLS and the corresponding LAE estimates are broadly similar, both in terms of goodness of fit and magnitude of the estimated parameters (however, unique LAE estimate could not be obtained in specific cases). A closer look at Table 5 may suggest the following results. First, the values of R^2 and the PCGDP corresponding to the turning point for residential areas are smaller than those estimated for commercial areas. Next, while the estimated coefficients of PCGDP (i.e. β_1) are negative and those of square of PCGDP (i.e. β_2) are positive in all the cases, the estimated β_2 coefficients for residential areas are not highly significant. Thus, statistically speaking, the U-shape of the Pollution–PCGDP relationship is weaker for the data

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[12] In econometric theory, LAE estimates are regarded as robust estimates. See Judge et al. (1985), 2nd edn., Ch. 20 for the LAE estimation method and the properties of the LAE estimator.

relating to the residential areas, but is rather strong for the data relating to the commercial areas. The estimated values of PCGDP corresponding to the turning point are estimated to be ~ US$9500 and 12 500 for residential and commercial areas, respectively.[13] Interestingly, the high-income countries observed to lie beyond the turning point in the present exercise included the USA, Canada, Japan, Finland and Germany. One might seek an explanation of difference in the results for the two types of areas in terms of how the relative density of population in these two types of areas changes with economic growth.

In the next part of the exercise an attempt was made to have a causal explanation of the observed U-shaped/inverse pollution–PCGDP relationships. A priori, one should expect the pollution level in an economy to depend not only on the level of PCGDP, but also on the sectoral composition of GDP, how the PCGDP level is being achieved, and the time rate of growth of PC GDP. The sectoral composition is important, because, *ceteris paribus*, an economy with a larger industrial production is likely to have more pollution. The nature of the production technique used may be relevant, because often a more capital-intensive production technique is likely to be more non-human, energy-intensive and hence more polluting. Finally, the rate of growth of PCGDP may be a determining factor since, *ceteris paribus*, a faster growth may commonly be achieved by exercising the softer option of using more polluting production practices. In other words, a strong urge to grow faster, given the level of PCGDP, may induce a less developed economy to adopt a less clean production technique. Coming to the possible partial effect of production technique (as represented by the capital–labour ratio) of an economy, say, it may be argued that between two countries with the same level of PCGDP, one having a greater concern for pollution would have a higher capital–labour ratio, if a cleaner technology is more capital intensive.[14] Thus, we tried to examine the validity of the following hypotheses (i) the marginal change in pollution level with respect to PCGDP is increasing in the rate of growth of PCGDP and decreasing in time; and (ii) the marginal change in pollution level with respect to PCGDP is decreasing in both the capital–labour ratio and the sectoral composition of GDP. To examine the possible partial effects of production technique and sectoral composition of GDP on pollution, the following regression set up was used:

$$y_{it} = \beta_0 + \beta_1 x_{it} + \gamma_1 p_1 + \gamma_2 p_2 + \delta_1 z_1 + \delta_2 z_2 + \eta_1 d_1 + \eta_2 d_2 + \theta_1 w_1 + \theta_2 w_2 + e_{it} \quad (5)$$

where y_{it} and x_{it} are as already defined; p_j is the dummy variable representing time period (i.e. $p_1 = 1$ for the period 1979–1982 and zero otherwise, $p_2 = 1$ for period the 1983–1986 and zero otherwise); d_1 is the dummy variable for capital intensity (i.e. $d_1 = 1$ for a country having capital–labour ratio greater than or equal to 1 and zero otherwise); d_2 is the dummy variable for share of non-agricultural sector in GDP (i.e. $d_2 = 1$ for a country for which the non-agricultural sector accounts for 90% or more of GDP and zero otherwise); $z_j = x^*p_j$, $j = 1, 2$ are the income–time period interaction terms; $w_1 = x^*d_1$ is the income–capital intensity interaction term; $w_2 = x^*d_2$ is the income-share of non-agricultural sector interaction term; and e_{it} is the equation disturbance term.

Let us first discuss the results relating to the effects of capital intensity and sectoral composition of GDP on the pollution level. Table 6 presents these results for spm. So far as the level of spm (i.e. the intercept term of the regression of

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[13] These figures are higher than those found in the studies of Shafik and Banerjee (World Development Report 1992); Selden and Song (1994), Shafik (1994), Grossman and Krueger (1995). Kaufmann et al. (1998), on the other hand, found a U-turn for the atmospheric concentration of SO_2 at PCGDP level ~ US$12 000. Grossman and Krueger (1995) also observed an upswing of the pollution level at about a PCGDP level of US$16 000. However, because there were only two observations beyond these levels, existence of such a reverse upswing at high level of PCGDP was not claimed.

[14] A cleaner industrial technology would frequently be more expensive and hence more capital intensive because of the technical sophistications involved — take, e.g. the catalytic converters used to reduce lead emission from automobiles. There may, however, be innovation leading to less polluting and at the same time less expensive production techniques, but such innovation is infrequent.

Table 8
Estimated coefficients of Eq. (6)

	Estimated coefficients of explanatory variable						R^2 (df)	$\bar{R}^2$
	Intercept	x	x^2	g	g^2	$x*g$		
Estimates	365.3	-0.05374	2.49×10^{-6}	-4.086	1.2207	-0.0011	0.85 (42)	0.84
t-ratio	(16.86)	(-8.09)	(4.82)	(-0.84)	(2.8)	(-2.507)		

spm level on PCGDP) is concerned, in none of the equations the coefficients of the time dummy variables were statistically significant, implying thereby that the level of spm did not shift perceptibly over time. As regards the effect of capital intensity on the spm level (i.e. the intercept dummies for this variable), this was observed to be negative and highly significant for the data relating to the residential areas and the combined data, but non-significant for the data relating to the commercial areas. A similar significant negative level effect of the sectoral composition variable was also observed for all the three data sets.

Let us next describe the results showing how the marginal change in pollution in response to a change in the level of PCGDP (i.e. the slope term of the regression of spm level on PCGDP) are affected by the time dummy, capital intensity and the sectoral composition variables. These are given by the estimated values of the parameters associated with the interaction terms of PCGDP and these variables (i.e. the values of the parameters δ_1 and δ_2 measuring the effect of interaction between time and PCGDP, θ_1 measuring the effect of interaction between capital intensity and PCGDP, and θ_2 measuring the effect of interaction between sectoral composition of GDP and PCGDP, respectively, in Eq. (5)). The interaction effect between time and PCGDP is negative and significant only for the data relating to the commercial areas. This implies that compared to 1979–82 in latter periods the decrease in pollution in response to a marginal increase in PCGDP was greater. Next, the interaction effect between capital intensity and PCGDP is positive and highly significant for the data relating to the commercial areas and also for the combined data. For the data relating to the residential areas this effect is, however, negative and significant at 10% level. The positive interaction effect suggests that, *ceteris paribus*, a country with a higher capital intensity would have a lower, but flatter, pollution–PCGDP curve compared to one with a lower capital intensity.

Finally, the interaction effect between sectoral composition of GDP and PCGDP was estimated to positive and significant for all the three data sets. This, together with the fact that the coefficient of the corresponding intercept dummy is negative and significant, suggests that, *ceteris paribus*, more industrialised countries have a lower, but flatter, pollution–PCGDP curve.

In this context it may be mentioned that for all the data sets the goodness of fit of the quadratic pollution–PCGDP equation is more or less similar to those of the corresponding regression equation in which PCGDP, capital intensity (sectoral composition of GDP) and interaction between PCGDP and capital intensity (sectoral composition of GDP) are used as separate regressors. This possibly means that in association with PCGDP structural factors like production technique and sectoral composition may help explain observed changes in pollution level over time or across region. In other words, the quadratic term on the r.h.s. of Eq. (1) is in fact replaced by $(\gamma_1 p_1 + \gamma_2 p_2 + \delta_1 z_1 + \delta_2 z_2 + \eta_1 d_1 + \eta_2 d_2 + \theta_1 w_1 + \theta_2 w_2)$ to yield Eq. (5), because a priori rate of change of marginal pollution due to PCGDP level may be due to the total effects of technology, sectoral composition of GDP, time and their interaction with income level.

Next, to examine the partial effect of growth rate of PCGDP on pollution the following regression set up was used :

$$y_{it} = \beta_0 + \beta_1 x_{it} + \beta_2 x_{it}^2 + \alpha_1 g_{it} + \alpha_2 g_{it}^2 + \psi(x_{it} * g_{it}) + e_{it} \qquad (6)$$

where y_{it}, x_{it} and e_{it} are as already defined and g_{it} denotes the rate of growth of PCGDP for the ith country at time t. It should be mentioned that for each individual country in the sample average growth rate of PCGDP for the three sub-periods, i.e. 1979–82, 1983–86 and 1987–90, were computed so that the value of g_{it} would be the average growth rate for the period to which the year t belonged.

The regression equation specified above was estimated for the combined data set alone. The estimated equation is presented in Table 8. As may be seen from the Table 8, the overall fit of the regression equation is fairly satisfactory. The estimated coefficients, except the one associated with the growth rate variable g_{it}, are all statistically significant. The quadratic form of this relationship suggests that, given a rate of growth, the pollution–PCGDP relationship is inverse or even U-shaped. On the other hand, given a PCGDP level, the quadratic pollution–growth relationship suggests a U-shaped relationship between the two variables. To be more specific, at a relatively high level of PCGDP the level of pollution falls initially as the rate of growth rises from a negative level towards zero, and subsequently rises when the rate of growth crosses a threshold level. At a relatively low level of PCGDP, however, pollution increases much faster with growth beyond a threshold level. A diagrammatic representation of the estimated pollution–PCGDP–growth equation is presented in Fig. 3.

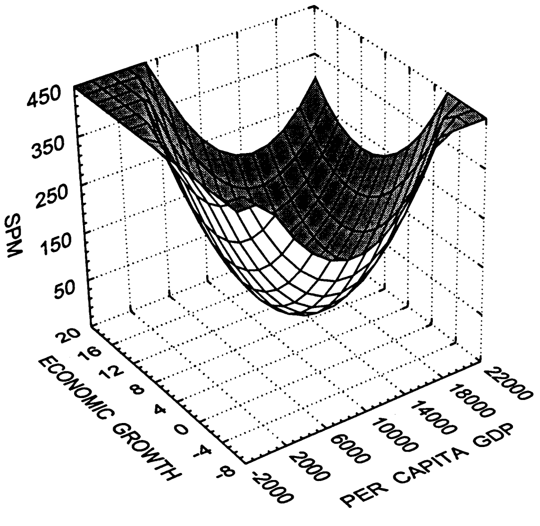

Fig. 3. Spm level vs. per capita GDP and economic growth.

The results of the analysis of our SO_2 pollution data are summarised in Table 7. Compared with the analysis of the spm data, fewer interesting findings are obtained in this case. To be precise, while the correlation coefficients between SO_2 and PCGDP were observed to be negative for data sets relating to commercial areas, the corresponding correlation coefficients for residential areas were observed to be positive. This may be due to the fact that the data set for residential areas included data for only three developed countries, i.e. USA, Canada and the New Zealand, whereas the data set for commercial areas covered, in addition to these three countries, a number of other developed countries. Examination of the scatter diagrams suggested wide variation of the SO_2 level at low level of PCGDP which gradually narrowed down as the PCGDP level increased. Further probe suggested presence of some outliers (i.e. data relating to Iran and Italy) in the data set, which were dropped in subsequent analyses.[15] Removal of these outliers resulted in a linear relationship with a negative slope (not an inverted U-shaped relationship) between SO_2 level and PCGDP (see Fig. 2B). These results thus suggest absence of any clear relationship between the level of SO_2 and PCGDP for data relating to the residential areas. A possible explanation of the observed relationship for commercial areas could be that the extent and the quality of automobile emission improved considerably with rise in PCGDP.[16] In addition, the type of fuel used for domestic and commercial purposes in low income developing countries might contribute to the relatively high level of atmospheric SO_2 in them. With economic growth a transitional force strengthens the market mechanism and as a result the econ-

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[15] The data for Iran was unusual possibly because of the Iraq–Iran war during 1977–88, whereas Italy experienced a series of volcanic eruptions during the early 1980s.

[16] See, e.g. Kahn (1998).

omy gradually shifts from non-commercial to commercial energy resources. There may also be another reason, i.e. high income countries tend to spend more on defensive expenditure, enforce a stricter environmental regulation and use cleaner technology which others cannot afford.

4. Conclusion

The basic objective of the present study was to re-examine the hypothesis of EKC using cross-country time series data on two air pollutants, i.e. spm and SO_2. Our results do not support the EKC hypothesis. In contrast, for SO_2 we obtained an inverse relationship with PCGDP, while for spm a U-shaped, rather than an inverted U-shaped, relationship with PCGDP is observed with an upward turn of the curve around a PCGDP level of US$12 500, which represents a rather high level of material consumption. To the extent the level of currently available technology is unable to ensure sustainability of such a high consumption level, a further rise of PCGDP beyond the threshold level can support consumption only at the cost of a slow but steady deterioration of the environmental quality.

To explain the observed pollution–PCGDP relationship, three economic variables other than PCGDP were brought into the analysis i.e., the economy-level capital intensity, the sectoral composition of GDP, and the rate of growth of GDP. It was thought that, given the PCGDP level of an economy, these three aspects would determine the exact nature of relationship that might exist between pollution and income level. In other words, it is not only the level of income but also the characteristics of an economy which together determine the rate of environmental degradation that an economy will experience as it moves along the trajectory of development. Although the way these variables have been used in the present study leaves scope for improvement, their inclusion does give meaningful and statistically significant results so far as the explanation of the phenomenon of pollution is concerned. Briefly, our results suggest that the partial effect of capital intensity on pollution is generally negative (which may not be unreasonable, if the trend of technological progress is such that more capital-intensive techniques are more environment-friendly and vice versa). The observed negative partial effect of the sectoral composition variable on pollution perhaps suggests that, given the PCGDP level, the more industrialised an economy is, the lower and flatter would be its pollution–PCGDP curve. Finally, PCGDP and the rate of growth variable seem to be jointly important in explaining observed pollution level of an economy.

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