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Testing for environmental Kuznets curves within a developing country

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ABSTRACT: Previous studies of the association between pollution and income have tended to analyse cross-sectional or panel data for a sample of developing and developed countries. This paper presents an analysis for a single country, Malaysia. This south-east Asian country has more, and probably better, data on environmental quality than perhaps any other developing country. I find that pollution–income relationships from the cross-country studies fail to predict accurately trends in air and water pollution in Malaysia. In particular, none of six pollution-income relationships estimated using a panel data set for Malaysian states has the hypothesized 'environmental Kuznets curve' form. Although these results are inconsistent with the predictions of the cross-country relationships, they make sense in the Malaysian context. Perhaps most important, their interpretation confirms the importance of policy decisions in determining environmental outcomes.

Introduction

Previous studies of the association between pollution and income have tended to analyse cross-sectional or panel data for a sample of developing and developed countries (Grossman and Krueger, 1991; Shafik and Bandyopadhyay, 1992; Panayotou, 1993, 1995; Selden and Song, 1994).[1] Owing to the short length of historical data series on pollution, which generally do not extend back in time to the period when today's developed countries were still developing, the data sets typically contain little or no overlap between the observations from developing and developed countries. Virtually all the low-income observations come from developing countries, while all the high-income observations come from developed countries.

This lack of overlap leaves the studies' findings open to the criticism that they may be no more than statistical artifacts. Specifically, 'environmental Kuznets curves' (inverted U-shaped relationships; EKCs) may simply reflect the juxtaposition of a positive relationship between pollution and income in developing countries with a fundamentally different, negative one in developed countries, not a single relationship that applies to both categories of countries.

The obvious alternative empirical approach is to analyse the relationship

[1] See Stern *et al.* (1996) for a review of these studies.

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between pollution and income over time in an individual country. This approach has advantages for interpreting statistical results. Most authors argue that EKCs, if they exist, reflect in part (and possibly primarily) environmental policy responses as countries approach and then pass income thresholds. That is, EKCs are not unique environment-development paths that countries automatically follow (Arrow *et al*., 1995). Yet, aside from a few efforts to include policy variables in the cross-country regressions (for example, Grossman and Krueger included a communist/non-communist dummy variable), the cross-country studies shed little light on the impact of policy decisions on pollution levels as incomes rise.

This paper presents an analysis of the pollution–income relationship in a single country, Malaysia. To my knowledge, this is the first such analysis for a developing country.[2] Malaysia has more, and probably better, data on environmental quality than perhaps any other developing country. It established its first air and water quality monitoring stations in the mid-1970s. By the early 1990s, its air monitoring system included several dozen stations spanning all the major urban areas in the country, as well as selected suburban and rural areas, and its water monitoring system included stations in all the country's river basins. It therefore offers a rich data set of nearly two decades of readings on ambient air and water pollution concentrations.

Malaysia's economy has been one of the fastest-growing in the world since the 1970s. Per capita income doubled in less than a generation as the country transformed itself from an exporter of rubber, tin, palm oil, tropical timber, and other primary commodities to an exporter of a sophisticated array of manufactured goods. Malaysia's rapid growth means that Malaysian income data contain ample variation over time, which is obviously necessary for statistical analysis. The data also vary within the country, as growth has not been equally rapid in all 13 states of the Malaysian federation. Coupled with the facts that (i) the income data overlap between states, (ii) the borders of most states are determined by ridges that separate major water basins and to a certain extent air basins, (iii) the states share essentially the same pollution policies,[3] and (iv) those policies vary across pollutants, this income variation makes the 13 Malaysian states a nearly ideal sample for analysing interactions among pollution, income, and policies.

The analysis in the paper proceeds along two lines. First, for both air and water pollution, I compare aggregate data on Malaysian pollution trends with corresponding predictions from the cross-country studies. This is a quick and dirty way to check how well the Malaysian experience matches the studies' findings. Then, using a panel data set containing observations across states from the late 1970s into the early 1990s, I estimate pollution–income relationships specific to Malaysia for one air pollutant, total

[2] One reviewer commented that similar studies have been done for the United States and the European Union. I am not familiar with these studies.

[3] In contrast, natural resource policies vary considerably across states.

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suspended particulates (TSP),[4] and five water-quality parameters: biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen, pH and suspended solids. I interpret the results in light of characteristics of the Malaysian economy and Malaysian environmental policies, finding that they confirm the importance of policy decisions in determining environmental outcomes.

Air pollution and income

Emissions and per capita national income

Data on ambient air quality from the monitoring system mentioned above are more extensive in Malaysia than data on air pollution emissions. Since 1987, however, the Malaysian Department of Environment (DOE) has estimated annual emissions of five pollutants: particulates, sulphur oxides (SO_x), nitrogen oxides NO_x, carbon monoxide (CO), and hydrocarbons (DOE, 1992).[5] These estimates are at the national level, not the state level. Examining these estimates before analysing the monitoring data on TSP is useful, as emissions are the principal determinant of ambient quality.[6]

The DOE constructs emissions estimates by multiplying data on consumption of polluting inputs (e.g., fossil fuels) times factors that predict the quantity of emissions per unit of input. Table 1 shows the DOE's estimates for four of the five pollutants (excluding hydrocarbons) by major source categories. Although total emissions fluctuated substantially during 1987–91, they tended to be higher at the end of the period than at the beginning, except in the case of SO_x.

These trends can be compared with predictions from Selden and Song (1994), the most comprehensive cross-country study of air pollution emissions and income.[7] Selden and Song regressed national estimates of per capita emissions of particulates, SO_x,[8] NO_x, and CO on three categories of variables:

[4] The Malaysian Department of Environment and the Malaysian Meteorological Service also collect a limited amount of data on dust fallout and its chemical composition (e.g., lead content) and on PM_{10}. In its 1991 annual *Environmental Quality Report* (DOE, 1992), the Department of Environment announced plans to begin monitoring ambient concentrations of SO_2 and other gaseous pollutants.

[5] The report of the Klang Valley Environmental Improvement Project, which was funded by the Asian Development Bank, contained partial estimates of emissions of these pollutants in the Klang Valley during 1985 (Government of Malaysia and Asian Development Bank, 1987).

[6] TSP concentrations are also affected by pollution that drifts into the country from neighbouring countries. In recent years, forest fires in Indonesia have been an important cause of particulate pollution along the west coast of Peninsular Malaysia.

[7] Panayotou (1993, 1995) also analysed per capita air pollution emissions. He analysed fewer pollutants (three, not four) and used less data (his sample was a cross-section, not a panel).

[8] Selden and Song state that they analysed SO_2, not SO_x. However, technical notes in their data source, World Resources Institute (1990), indicate that the data pertain to SO_2 for some countries and SO_x for others.

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Table 1. *Principal sources of air pollution emissions in Malaysia (1000 metric tonnes)*

		Source				
			Stationary			
Pollutant	*Year*	*Mobile*	*Power plants*	*Other*[a]	*Open burning*	*Total*
Particulates	1987	3	1	10	6	21
	1988	3	2	33	4	43
	1989	4	2	23	7	36
	1990	5	3	26	14	48
	1991	4	3	24	32	62
SO_x	1987	3	195	54	0	252
	1988	3	182	63	0	248
	1989	3	30	34	0	68
	1990	3	31	42	0	77
	1991	4	32	37	2	75
NO_x	1987	36	42	26	1	105
	1988	36	37	24	2	98
	1989	29	38	24	1	92
	1990	43	40	29	1	114
	1991	47	38	29	4	119
CO	1987	506	0	5	30	541
	1988	476	0	3	22	501
	1989	511	2	2	7	522
	1990	551	3	8	12	575
	1991	596	1	6	33	636

Note: [a] Industrial fuel, industrial processes, households. No data on industrial processes in 1987.
Source: DOE (1992)

- per capita GDP, measured in purchasing power parity (PPP) terms and raised to the first, second, and third powers;
- national population density;
- dummy variables for period of time (the data were three-year means for 1973–75, 1979–81, and 1982–84).

The number of countries ranged from 15 to 30, depending on the pollutant and the time period.

Selden and Song found statistically significant relationships between per capita emissions and per capita GDP for all pollutants except CO. The relationships for the other three pollutants all had inverted-U shapes,[9] with turning points in the vicinity of US$10,000. This figure is comparable to the dividing line between upper-middle-income and high-income countries in 1988, approximately US$9,400 in PPP terms (1985 price levels; see Summers and Heston, 1991, and World Bank, 1992). It is well above Malaysia's per capita GDP in PPP terms during the 1987–91 period (US$4,727 in 1988, according to Summers and Heston, 1991). Selden and Song's results therefore imply that air pollution emissions in Malaysia should have been rising during 1987–91.

[9] Statistical tests rejected the significance of per capita GDP cubed.

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Table 2. *Actual and predicted per capita air pollution emissions (kg)*

	Actual[a]		*Predicted*[b]
Pollutant	*1987*	*1991*	*1991*
Particulates	1.3	3.4	10.5
SO_x	15.3	4.1	29.5
NO_x	6.4	6.5	12.1
CO	32.8	34.9	39.6

Notes: [a] Calculated by dividing estimates of total emissions in DOE (1992) by national population.
[b] Calculated by inserting estimates of Malaysian per capita GDP into relationships estimated by Selden and Song (1994).

Table 2 shows that per capita emissions did indeed rise between 1987 and 1991 for all pollutants except SO_x. The increases were much smaller than those predicted by Selden and Song's estimated relationships, however. I calculated the predicted values by first calibrating Selden and Song's estimated relationships to 1987 Malaysian data (so the relationships predicted 1987 per capita emissions perfectly) and then inserting 1991 data into the calibrated relationships. The relative degree of overprediction of the 1991 values was greatest for SO_x (a factor of seven), followed by particulates and then NO_x.

The immediate reason the cross-country relationship for SO_x failed to get even the direction of change right is evident from Table 1: emissions by power plants fell sharply. In turn, this reflects a non-environmental policy decision by the Malaysian government linked to the country's geological good fortune. Malaysia discovered substantial reserves of natural gas in the 1970s and 1980s. In the mid-1980s it decided to reduce dependence on imported fuel oil by converting power plants to natural gas. Had it not discovered natural gas, or had it decided to export all the gas it produced instead of raising consumption by domestic power plants, emissions of SO_x would not have declined as sharply as they did, if at all. Geology and a desire for energy independence, not rising income and associated environmental policy responses, were responsible for the decline in SO_x emissions.

Ambient quality and per capita state income

The Malaysian data series on emissions were too short for an econometric analysis of the pollution–income relationship. The data on ambient air quality were much more abundant. The Malaysian Meteorological Service (MMS) began collecting data on TSP in 1977 from two monitoring stations. By 1991, it had established an additional 13 stations. The DOE established its own system of TSP monitoring stations in 1985. By 1991, it had established 32 additional ones. For the analysis in this paper, the MMS and the DOE provided data on mean annual readings through 1991 for all stations except five of the DOE stations. The sample included at least one station in all states except Kelantan and Perlis.

Both Grossman and Krueger (1991) and Shafik and Bandyopadhyay (1992) investigated the pollution–income relationship for TSP. Grossman

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and Krueger's sample included urban areas in 29 countries during 1977–88. They used annual median or 95th-percentile (peak) concentrations of TSP concentrations as the dependent variables in their regressions, and per capita GDP (raised to the first, second and third powers), urban population density and several other variables as independent variables. Their per capita GDP estimates were in PPP terms. Shafik and Bandyopadhyay's approach was similar, differing mainly in that their data set was larger and their list of independent variables excluded population density.

Grossman and Krueger found that both median and 95th-percentile concentrations of TSP were related to per capita GDP at an extremely high level of statistical significance, though not in an EKC fashion. Median concentrations declined continually as per capita GDP rose.[10] The results for 95th-percentile concentrations were quite similar. On the other hand, Shafik and Bandyopadhyay found that the relationship was given by an EKC. The turning point was US$3,280 (PPP terms, 1985 international prices). This is well below the 1988 PPP estimate of Malaysian per capita GDP cited above. Both studies therefore imply that TSP concentrations should have been falling in Malaysia by the late 1980s.

As a first, exploratory approach, I tested this prediction by calculating the annual mean reading across a subsample of monitoring stations consisting of the 21 stations with readings for at least five consecutive years. I limited the subsample to these stations to reduce the potential bias associated with new monitoring stations being located in areas that were, on average, either more or less polluted than areas with existing stations. Contrary to the prediction of the cross-country studies, annual mean readings were substantially higher during the second half of the period, rising from 45.6–69.7 $\mu g/m^3$ during 1977–84 to 63.7-93.4 $\mu g/m^3$ during 1985–91.

There is reason to believe that this approach is not entirely free of potential biases, however. Thirteen of the 21 stations were established after 1984, and nine of the 13 were located in industrial, commercial, or traffic areas, which tend to be more polluted than residential and rural areas. This was a higher proportion than for the eight stations established during 1977–84.

In light of this, as a next step I estimated the relationship between TSP concentration and income using data from all the stations, not just those with at least five consecutive years of readings. I hypothesized that TSP concentration was related to an intercept that varied across monitoring stations and a term given by the product of population density and per capita pollution impact. The intercept was intended to capture non-anthropogenic sources of variation in TSP concentrations across monitoring stations (e.g., climate, topography). The product of population density and per capita pollution impact is, by definition, the total contribution of anthropogenic sources to pollution on a unit area basis.

[10] This finding was not very robust. When Grossman and Krueger changed the specification from random effects to fixed effects (see Table 5 in their paper), they obtained the opposite result: TSP levels rose continuously with income. As discussed below, this matches our findings for the fixed-effects model in Malaysia.

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I measured population density by the value in the administrative district (county) where a monitoring station was located. I defined per capita pollution impact as a function of a constant, per capita GDP in the state where the station was located (income data were not available for administrative districts) and a time trend (year). The constant was intended to capture per capita impacts invariant to income and time. Per capita GDP was raised to the first through third powers and expressed in 1978 Malaysian ringgit (1 RM ≅ US$0.40). The time trend was a proxy for changes in per capita impacts over time due to factors not necessarily correlated with income (e.g., policy changes).

The estimated model was therefore:

$$Q_{it} = \beta_{0i} + P_{it} \times (\beta_P + \beta_Y Y_{it} + \beta_{YY} Y_{it}^2 + \beta_{YYY} Y_{it}^3 + \beta_t t) + \epsilon_{it},$$

which can be rewritten as:

$$Q_{it} = \beta_{0i} + \beta_P P_{it} + \beta_Y P_{it} Y_{it} + \beta_{YY} P_{it} Y_{it}^2 + \beta_{YYY} P_{it} Y_{it}^3 + \beta_t P_{it} t + \epsilon_{it},$$

where Q is TSP concentration, i indicates monitoring station/administrative district/state (depending on the variable), t indicates year, Y is state-level per capita GDP, and P is district-level population density. Note that, according to this model, population density on its own can affect air quality (if β_P is statistically significant), while per capita GDP cannot. This makes sense, for if there are no people, there are no anthropogenic sources of pollution.

I estimated both fixed-effects and random-effects specifications of the model. This affected the definition of the β_{0i}s: deterministic for fixed-effects, stochastic for random-effects (see Chapter 13 in Judge *et al*., 1985). I used the Hausman χ^2 test (5 per cent significance level) to decide between the specifications.[11] The fixed-effects specification turned out to be the preferred one. This is not surprising, given the evidence that monitoring stations established after 1984 tended to be located more in urban areas, where population density (one of the explanatory variables) was higher, instead of randomly. Table 3 shows results for this model.

The cubic version had the best statistical properties. All coefficients in it were statistically significant at the 5 per cent level. Figure 1 shows the relationship between TSP concentration and per capita GDP according to this model, with population density and year set equal to their mean values in the sample.[12] The curve has neither the continually declining form estimated by Grossman and Krueger nor the inverted-U shape estimated by Shafik and Bandyopadhyay. It rises continually, although its slope does diminish up to an inflection point at RM 6,300. Thereafter, however, it gets steeper. If there is a turning point for TSP concentration in

[11] The null hypothesis in this test is that the random effects are uncorrelated with the explanatory variables, in which case coefficient estimates from the random-effects model are unbiased and inefficient. Rejection of the null hypothesis suggests that the random-effects estimates are biased. Fixed-effects estimates will still be unbiased in that case, although possibly inefficient.

[12] The relationship is plotted only up to an income of RM 8,000, because the highest income in the sample was RM 7,553 (for Kuala Lumpur/Selangor, in 1991).

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Table 3. *Regression results for TSP (fixed-effects specification)*

	Cubic	*Quadratic*	*Linear*
Coefficient estimates[a]			
Intercept[b]			
Population density	+1609	+1398	+682
	(462)***	(0.0359)***	(388)*
Population density ×	+0.0248	+0.00674	+0.00171
(per capita GDP)	(0.00824)***	(0.00182)***	(0.000376)***
Population density ×	-0.365×10^{-5}	-0.352×10^{-6}	
(per capita GDP)^2	(0.147×10^{-5})**	(0.125×10^{-6})***	
Population density ×	$+0.194 \times 10^{-9}$		
(per capita GDP)^3	(0.864×10^{-10})**		
Population density ×	−0.835	−0.715	−0.349
year	(0.234)***	(0.230)***	(0.194)*
R^2	0.176	0.153	0.116
Number of observations	232	232	232
Hausman χ^2 statistic[c]	21.9 (5)	25.2 (4)	16.5 (3)

Notes: [a] Standard errors are in parentheses under the coefficient estimates.
*** = estimate is significantly different from zero at the 1 per cent level;
** = estimate is significantly different from zero at the 5 per cent level;
* = estimate is significantly different from zero at the 10 per cent level.
[b] Varied across monitoring stations.
[c] Degrees of freedom are in parentheses.

Malaysia, it appears to be at a much higher level than Shafik and Bandyopadhyay predicted. Their turning point, US$3,280 at 1985 international prices, is equivalent to only RM 2,689 at 1978 Malaysian prices.[13]

Although the curve depicted in Figure 1 is the opposite of what Grossman and Krueger found in a cross-country context, it is consistent with the increase in per capita particulate emissions that occurred at the national level during 1987–91 (see Table 2). It is plausible in the Malaysian context in other ways as well. Agriculture tends to be a more important sector of the Malaysian economy in lower-income states. In those states, open burning during land conversion and replanting of tree crops has historically been a major source of particulate pollution. (These sources are not included in the estimates for 'Open burning' in Table 1, which include only municipal and industrial burning.) In higher-income states, industrial processing and the burning of industrial and municipal wastes are more important. The curve probably shows that the rate of increase in TSP concentration temporarily diminishes as agricultural expansion slows down, but it then accelerates as emissions related to manufacturing and waste disposal rise.

Results for variables other than income are also plausible. The net impact of population density on TSP concentration was positive,[14] which is what one would expect if, as is the case, household activities like cooking

[13] For 1988, the ratio of Malaysia's per capita GDP in purchasing power parity terms (US dollars at 1985 international prices) to its per capita GDP in ringgit (at 1978 Malaysian prices) was 1.22.

[14] This statement is based on analysis of statistically significant coefficients, evaluated at sample means for income and the time trend.

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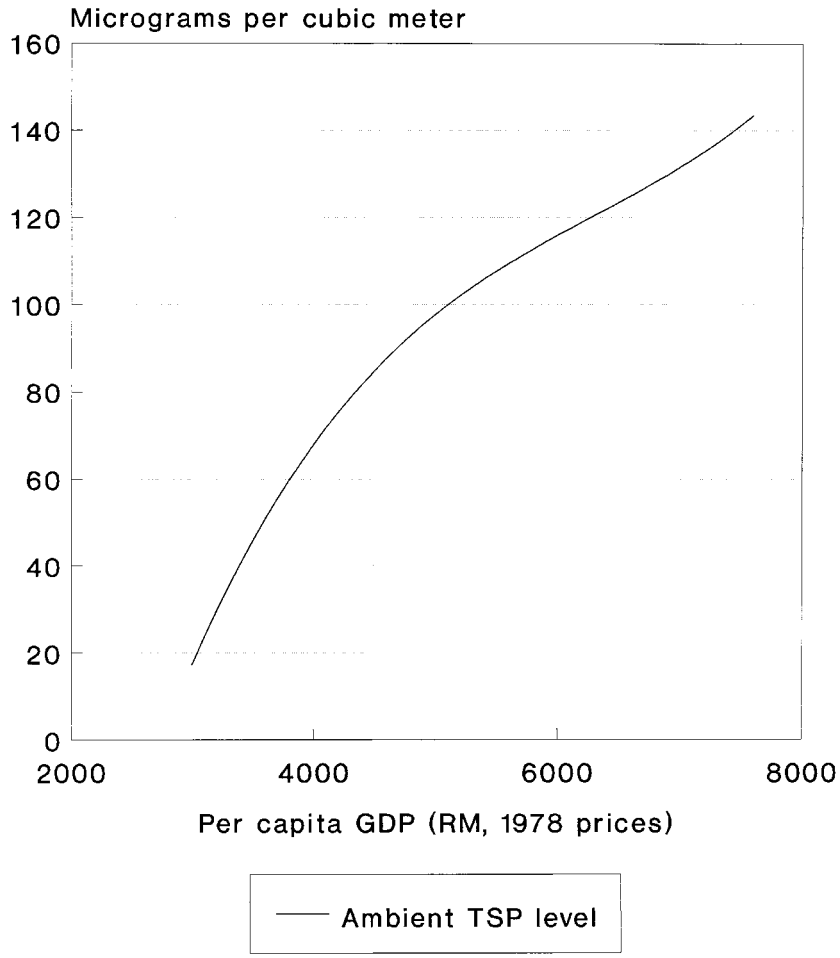


Figure 1. *Estimated TSP-income relationship in Malaysia*

and heating, rubbish disposal and transportation are important sources of particulate emissions (Table 1). The statistically significant, negative coefficient on the interaction term involving population density and year indicates that the simple passage of time exerted downward pressure on TSP concentrations through a reduction in the per capita pollution impact. This result mirrors the statistically significant, negative residual trends in Grossman and Krueger's and Shafik and Bandyopadhyay's regressions.[15] The explanation probably relates to increasingly effective enforcement of air-pollution regulations. Relevant regulations include the 1977 Motor Vehicle (Control of Smoke and Gas Emissions) Rules, which contained

[15] It does not mirror them perfectly, as the trend variables in Grossman and Krueger's and Shafik and Bandyopadhyay's regressions were independent of population density.

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provisions related to black smoke emissions from diesel-powered vehicles, and the 1978 Environmental Quality (Clean Air) Regulations, which contained provisions related to the open burning of rubbish and the emission of dark smoke from industrial premises. Enforcement of these regulations was tightened up in the latter half of the 1980s after the country experienced severe 'haze episodes' in the densely populated, highly industrialized Klang Valley.

As the monotonically increasing relationship in Figure 1 shows, however, this regulatory response was not sufficient to generate an EKC result. Indeed, the Malaysian government's commitment to heavy industry, in particular to the establishment of a local automobile industry, has dampened its enthusiasm for stronger measures to reduce air pollution. Its failure to take stronger action to reduce particulate emissions has led to significant increases in mortality rates among urban dwellers, due to exposure to TSP concentrations far above World Health Organization guidelines (Vincent, Rozali and Associates, 1997).

Water pollution and income

Compared to the case of air pollutants, there is less correspondence between the water pollutants analysed by the cross-country studies and the water pollutants monitored in Malaysia. Shafik and Bandyopadhyay analysed two indicators of river water quality: dissolved oxygen concentration and faecal coliform count. They found that neither followed an EKC. The former worsened continually (oxygen concentration diminished) as per capita GDP rose. The estimated relationship for faecal coliform had an inverted-U shape for incomes up to US$11,400, with a turning point of just US$1,375 (these values are in PPP terms, at 1985 international prices). For incomes above US$11,400, however, the relationship turned upward. Malaysia's per capita GDP passed the US$1,375 turning point well before the 1970s, and even today it is far below the US$11,400 turning point. On the basis of the Shafik and Bandyopadhyay study, one would therefore expect both dissolved oxygen concentration and faecal coliform count to have declined in Malaysia since the 1970s, with the decline in the former indicating worsening environmental quality and the decline in the latter indicating environmental improvement.

Unfortunately, data on these two parameters are not readily available in Malaysia. Data on related parameters are, however. The DOE established its first water-quality monitoring stations in 1978. By 1991, it had expanded the system to include 555 monitoring stations in 87 river basins throughout the country. At each station, it measures the levels of as many as 52 water-quality parameters (DOE, 1992, Appendix 4.7).[16] It is most concerned about the five listed in the introduction: BOD, COD, ammoniacal nitrogen, pH and suspended solids. BOD and COD tend to be negatively correlated with dissolved oxygen concentration, while ammoniacal nitrogen tends to be

[16] The Malaysian Drainage and Irrigation Department also has a system of river monitoring stations. Most of the stations monitor streamflow, but more than 50 in Peninsular Malaysia also monitor suspended sediment levels. I did not analyse these data because they are very incomplete.

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positively, though often poorly, correlated with faecal coliform count, as it reflects contamination by not only human sewage but also fertilizer runoff and runoff from livestock operations. To the extent these correlations hold in Malaysia, the results of Shafik and Bandyopadhyay's study imply that BOD and COD concentrations should have risen in Malaysia during 1987–91, while concentrations of ammoniacal nitrogen should have declined.

As a first approach, I tested these predictions by examining trends in the mean annual concentrations of these parameters pooled across river basins. The DOE provided data on mean annual concentrations in all 47 major river basins in Peninsular Malaysia during 1978–91. Hence, the analysis reflected conditions in just the 11 states in Peninsular Malaysia (the other two states, Sabah and Sarawak, are on the island of Borneo). For most river basins, the data covered all or nearly all of the period. For this reason, mean concentrations across river basins are unlikely to suffer the sorts of biases affecting the national mean TSP value.

Results (not shown) can be summarized as follows. As predicted, COD concentration rose, but only in the second half of the period. It actually declined in the first half. BOD concentration also declined in the first half, but it was more or less stable thereafter. Concentration of ammoniacal nitrogen showed no apparent trend. The relationship between water pollution and income in Malaysia is therefore not consistent with the predictions of the cross-country study.

Of course, aggregate values might disguise important differences within the country. I therefore also estimated relationships analogous to those for TSP, including ones for pH and suspended solids, as well as for the other three parameters. In contrast to the TSP analysis, I defined population density at the state level instead of the district level, because water pollution could be a consequence of household activities in upstream districts. Most rivers in Peninsular Malaysia pass through more than one district but not more than one state.

Table 4 presents estimation results for the 'best' model for each parameter,[17] which in no case was the quadratic or cubic version.[18] The random-effects specification was preferred for all parameters except suspended solids. The general superiority of random effects is not surprising: the DOE sited water monitoring stations with the aim of comprehensive coverage of all river basins (roughly speaking, a stratified random sampling approach), not coverage biased toward areas thought to be suffering more severe pollution problems (as in the case of air monitoring stations established after 1984). Coefficients on terms involving per capita GDP were statistically significant at a minimum level of 10 per cent for only two parameters, ammoniacal nitrogen and pH. For neither was the pollution–income relationship an EKC, as the linear model gave the best results in terms of coefficient significance. The relationship was positive in both cases: higher income was associated with higher concentrations of ammoniacal nitrogen and higher pH values (more alkaline water).

[17] Full estimation results are available upon request.

[18] Differences in number of observations are due to missing data (no or unreliable recordings), which were most numerous for pH.

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Table 4. *Preferred regression results for water-quality parameters (fixed-effects specification for suspended solids; random-effects specification for all others)*

	BOD	*COD*	*Ammoniacal nitrogen*	*pH*	*Suspended solids*
Coefficient estimates[a]					
Intercept	+2.74 (0.914)***	+69.8 (13.3)***	+0.740 (0.284)***	+6.23 (0.0673)***	—[c]
Population density	+162 (59.2)***	+365 (1070)	+27.3 (16.4)*	−0.348 (7.12)	−22740 (5904)***
Population density × (per capita GDP)	+0.000169 (0.000172)	+0.00105 (0.00293)	+0.000161 (0.484×10^{-4})***	+0.318 × 10^{-4} (0.166×10^{-4})*	+0.00635 (0.00858)
Population density × year	−0.0814 (0.0301)***	−0.187 (0.543)	−0.0140 (0.00834)*	+0.000103 (0.00362)	+11.1 (2.91)***
R^2	0.018	0.002	0.034	0.190	0.059
Number of observations	542	541	542	443	541
Hausman χ^2 statistic[b]	2.69 (3)	1.58 (3)	0.67 (3)	3.93 (3)	28.4 (3)

Notes: [a] Standard errors are in parentheses under the coefficient estimates.
*** = estimate is significantly different from zero at the 1 per cent level;
** = estimate is significantly different from zero at the 5 per cent level;
* = estimate is significantly different from zero at the 10 per cent level.
[b] Degrees of freedom are in parentheses.

Urbanization and industrialization, which have been correlated with rising income in Malaysia, probably explain the relationship for ammoniacal nitrogen, as the expansion of municipal and industrial sewage treatment capacity did not keep pace. The government did not announce a major project to upgrade and expand the country's sewage system until 1992. These same factors probably explain the positive relationship for pH, as nitrogenous wastes tend to be alkaline when dissolved in water.

The lack of a significant relationship between either BOD or COD and per capita GDP probably reflects the fact that a single industry, palm-oil processing, was the dominant industrial source of pollutants responsible for BOD and COD during most of the period. The contribution of this industry to BOD and COD loads greatly exceeded its contribution to overall economic activity, so it is not surprising that per capita GDP had little explanatory power in the regressions.

The lack of a relationship for suspended solids is more surprising. Soil erosion due to land clearing for agriculture is commonly thought to be the major source of sediment loads in Malaysian rivers. This would lead one to expect the relationship between suspended solids and income to be an EKC, as land clearing in Malaysia has risen and then fallen with income as the structure of the economy has shifted from small-scale traditional agriculture to large-scale commercial agriculture to non-agricultural activities. Indeed, the random-effects specification yielded an EKC, with a turning point at RM 5,700. This value was comparable to the per capita GDP of more industrialized states in 1991. But the results of the Hausman test indicate that the coefficient estimates underlying this relationship are biased.

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The most likely explanation is that, within a given river basin (the fixed-effects estimates reflect only 'within' variation), changes in economic structure also involve rising erosion from urban and industrial development and infrastructure projects, which offsets declining erosion from agricultural land clearing and results in income having no net effect.

Holding income and year constant at the sample means, and including only variables with statistically significant coefficients (at the 10 per cent level or higher), population density had a significant impact on BOD, ammoniacal nitrogen and suspended solids, with higher population densities being associated with worse water quality as measured by BOD and ammoniacal nitrogen and better quality as measured by suspended solids. The impact on ammoniacal nitrogen probably again reflects sewage discharge, which rises with population. This probably also explains the impact on BOD (decomposition of sewage depletes oxygen). The impact on suspended solids probably reflects not so much population growth *per se* as the movement of people out of rural areas and into urban areas, which has accompanied population growth in Malaysia. From the late 1970s onwards, this internal migration led to substantial areas of agricultural land in Peninsular Malaysia being taken out of production (Vincent, Rozali and Associates, 1997) and thus placed at less risk of soil erosion.

The interaction term involving population density and year was significant and negative for BOD and ammoniacal nitrogen, but significant and positive for suspended solids. This implies that water quality as measured by the first two parameters would have improved if per capita GDP and population density had remained constant. Policy-related factors provide obvious explanations in both cases. In 1978, right at the start of the period analysed, the DOE introduced regulations to reduce BOD discharge by crude palm-oil mills, the major source of BOD pollution at that time. These regulations have been spectacularly successful (Vincent, Rozali and Associates, 1997). Regarding ammoniacal nitrogen, despite shortcomings in the country's sewerage system, the percentage of the population without access to any sanitary facility dropped from 10.2 to 6.3 per cent during the 1980s (*Sixth Malaysia Plan 1991–1995*, p. 335), owing to public investments in system expansions.

No similarly notable changes in soil management policies occurred during the period analysed. Hence, it is not surprising that the coefficient on the trend term was not negative for suspended solids. The fact that it was positive rather than zero probably reflects the movement of agriculture and settlement into steeper areas more prone to erosion as remaining land in the lowlands available for development dwindled.[19]

Conclusions

Pollution–income relationships from cross-country studies poorly predict trends in air and water pollution in Malaysia during the period from the late 1970s to the early 1990s. Ambient concentrations of some pollutants predicted to decline actually increased (e.g., TSP and ammoniacal nitrogen), while concentrations of others that were predicted to increase

[19] I thank one of the reviewers for suggesting this explanation.

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actually declined (BOD). Cross-country relationships for air pollution emissions correctly predicted increases for three out of four pollutants (particulates, NO_x, CO), but they greatly overstated the magnitudes of the increases. Moreover, they failed to predict a sharp drop in emissions for a fourth (SO_x). Ambient concentrations did not follow an inverted U-shaped EKC for any of the six air and water pollutants analysed. Income was not significantly associated with some pollutants in any fashion (BOD, COD, suspended solids). When it was (TSP, ammoniacal nitrogen, pH), the association was positive: rising income worsened pollution.

Although these results are inconsistent with the predictions of the cross-country relationships, they make sense in Malaysia. They reflect the characteristics of the processes generating pollution (e.g., industrial or household), the country's natural resource endowments (the natural gas–SO_x link), shifting patterns of population (the link between population density and suspended solids), and, most important, the impacts of environmental policies (e.g., BOD) and non-environmental policies (energy independence and SO_x emissions). The lack of evidence of EKCs in Malaysia does not prove that EKCs do not exist anywhere. It does indicate, however, that policymakers in developing countries should not assume that economic growth will automatically solve air and water pollution problems.

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