Environmental quality is not a luxury good

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We develop a model to show that environmental quality being a normal good implies a negative relation between pollution intensity and income per capita, rather than emissions and income per capita. We propose pollution per unit of manufacturing or industry, rather than pollution per unit of output, as a measure of intensity. We use the proposed measure of intensity to test the hypothesis that a clean environment is a normal good using NOx, SO_2 and $NMVOC$. Our empirical results corroborate the hypothesis.

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1 Introduction

This paper investigates the relationship between income per capita and environmental quality. We develop a simple theoretical model to show that environmental quality being a normal good implies a negative relation between pollution intensity of production and income per capita, rather than total emissions and income per capita. Although the empirical literature on the relationship between these two variables proliferated during the last decade, there is almost no theoretical work on the matter. Copeland and Taylor (2004) is an exception.

The main purpose of this paper is to test the idea that environmental quality is a normal good. While this is an implicit working assumption in many economic papers,[1] arguments in the popular press seem to question the assumption. To the best of our knowledge, we are the first ones to explicitly test the assumption. The question bears on the future of the environment.

Our model is much simpler than Copeland and Taylor's. Because they want to focus on the effects of trade, their model has two goods and two factors of production. Because our main interest is the relationship between income and pollution, we only need one good and one factor of production. The simpler structure means that we need less restrictive assumptions both on production and preferences. The other differentiating feature is that, in their model, endogenous environmental policy is modelled explicitly while, in our case, it is just behind our assumptions.

That environmental quality is a normal economic good means two different things, both of which imply a negative relation between pollution and income per capita. On the one

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[1] Explicit in the case of Copeland and Taylor (2004).

hand, that a clean environment is an ordinary good means that economic agents are willing to spend more on it when its price decreases. According to the new growth theory (Romer 1986, Lucas 1988, etc.), economic growth and technical progress walk hand by hand. It is plausible to think that economic agents in richer countries have access to technological developments that make improving local air quality relatively cheaper. Therefore, agents in rich countries will “consume” proportionately more air quality than agents in poor countries simply because air quality is cheaper for them.

On the other hand, that environmental quality is a normal good means that economic agents are willing to spend more on it when income increases even if prices stay the same. In this case and because of the externalities, individual agents are not usually the ones willing to spend more on a cleaner environment. It is usually society as a whole, through government regulations (taxes, standards, tradable emissions permits, etc.), who is willing to spend more on a cleaner environment. As Grossman and Krueger (1995) state “the strongest link between income and pollution in fact is via an induced policy response”.

The relation between income per capita and environmental quality depends on the scale of pollutant industries and their intensity (also called technique effect, since changes in intensity are due to changes in production techniques).[2] The model posed in section 2 shows that environmental quality being a normal good implies a negative relation between intensity and income per capita but, because of the scale effect, not necessarily between emissions and income per capita: the net effect of economic development on emissions can be positive, negative, or non-monotonic.

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[2] There is also a third factor, the so-called composition effect, not relevant to our model since there exists only one good.

Recent empirical research indicates that the relation between pollution and income per capita is characterized by an inverted U-shaped relation for many pollutants; i.e., environmental quality deteriorates with income at low to middle levels of income and improves with income at middle to high levels of income. This relation is usually called Environmental Kuznets Curve (EKC), mimicking the relation between income inequality and income per capita hypothesized by Kuznets (1955). For example Shafik and Bandyopadhyay (1992) and Shafik (1994) show that the relation between emissions of sulfur dioxide (one of the gases used in this analysis) and income per capita is characterized by such a shape. The shape is corroborated by Grossman and Krueger (1995) and Kaufmann et al. (1998) among others. According to Lomborg (2001), time series for average concentrations of SO_2 in London (1585-1994, p. 165), and Europe (1880-1995, p. 172) show the same shape. The shape is less pronounced for the US (1900-2010, same page).

According to our model, because of the by-product nature of pollution, the correct way to look at the relation between income per capita and a clean environment is to look at the intensity of pollution. We test the hypothesis that a clean environment is a normal good by regressing intensity against income per capita. If environmental quality is in fact a normal good, a negative relationship between pollution intensity and income should lie behind the relation between (total) pollution and income, be this relation positive, negative, or non-monotonic.

We believe that air pollution is mainly a result of manufacturing and other industry, such as electric power generation. Services do not contaminate the air to the same extent. Agriculture contaminates the water, deforests and degrades the soil more than contaminates the air. The changes in sectoral composition associated with economic development mean that the proportion of GDP that value added in manufactures or industry represents increases with income at low levels of income (see, for example, Echevarria 1997). This means that manufactures and industry grow faster than GDP at low levels of income. Thus, pollution grows faster than income partially because manufactures grow faster than income. At high levels of income there is a deceleration in the production of manufactures. The proportion of GDP that value added in manufactures or industry represents starts to decrease with income at high levels of income. This means that manufactures and industry grow slower than GDP at high levels of income. Thus pollution grows slower than income. Cole (2000) shows the changing sectoral composition of income to have the expected result on pollution intensity, as conventionally measured: *ceteris paribus*, pollution intensity increases with income at low levels of income and decreases with income at high levels of income.

Because of the changing sectoral composition of total output, we believe that the usual intensity measure (pollution per unit of output) would be misleading for our purposes: using the usual intensity measure to make comparisons across countries may have the effect of making rich countries, which produce comparatively less manufactures, look "cleaner" than what in fact they are. Therefore, we use a more relevant measure of intensity, pollution per unit of manufacturing or industry, to test the hypothesis that a clean environment is a normal good. In this way we do not need to worry about the sectoral composition of output and its effect on pollution.[3]

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[3] We recognize that consumption-generated pollution is a large part of total pollution. Since the data cannot be decomposed into consumption-generated and production-generated pollution, we also use the usual measure of intensity (pollution per unit of output) to contrast results. Results are basically the same although the elasticities are somewhat smaller.

Our results concerning the relation between pollution per unit of manufacturing and GDP per capita seem to be in striking opposition to Cole's results. However, Cole uses the US intensity per sector—in this way, he calibrates the effect of the sectoral composition, holding techniques constant—while we in fact calculate manufacturing pollution intensity. We allow for both technique and intra-industry composition to change with per capita income yielding a better measure of industry response to regulation, as both technique and intra-industry composition reflect the stringency of regulations.

We test our hypothesis using emissions of sulfur dioxide (SO_2), nitric oxides (NOx) and non-methane volatile organic compounds ($NMVOC$) as a measure of air pollution. When we plot emissions per capita versus income per capita, we find the above mentioned inverted U-shape. However, when we use intensity, we find that pollutant emissions per unit of manufacturing or industry decrease monotonically with increases in income per capita. In all cases we found a strong and significant negative relation between intensity of emissions and income per capita. We conclude that, at any level of income, the richer people are, the more they are willing to invest in a cleaner environment.

The model in this paper applies to any kind of pollution. However, the empirical tests in sections 3 and 4 apply to pollutants which affect local air quality. Nevertheless, Hettige, Mani and Wheeler (2000) find a similar relation between water quality and income per capita: water pollution intensity is negatively correlated with income per capita. Similarly Echevarria and Ho (2000) find carbon dioxide emissions intensity is negatively correlated with income per capita. It should be pointed out that carbon dioxide does not affect local air quality but, as a greenhouse gas which affects the ozone layer, it may affect the global temperature.

Is environmental quality a luxury good? Martínez-Alier (1995) rejects the idea that environmentalism is a wealthy concern or that only rich countries can afford to improve environmental quality. He refers to cases that he deems "environmentalism of the poor." That environmental quality is not a luxury good may mean that countries start implementing environmentally sound practices at lower levels of income; on the other hand, that environmental quality is a luxury good implies that, as countries become richer, progress in this sense is more rapid. Because we are interested in the issue, in sections 3 and 4 we perform the empirical tests in logarithmic form so to be able to gauge the elasticity of air quality. Environmental quality is not a luxury good: the estimated elasticities are all smaller than or close to unity.

2 A preference for environmental quality

We assume that economic agents care about environmental quality, specifically air quality, but they also care about manufactures and other goods. Pollution emissions are a by-product of goods production. For the rest of the section we refer to goods as manufactures, because we believe manufactures to be the main culprit in air pollution, but the model can be read understanding goods in a broader sense and we test both readings of the model.

More specifically emissions equal $i \cdot m$ where i denotes pollution intensity and m denotes amount of manufactures produced.

We use a static model representing a period. At the beginning of the period air quality is given, $\bar{C}$. Air quality is deteriorated by the amount of emissions. Pollution intensity depends negatively on abatement activities. Some types of pollution, as sulfur dioxide and particulates in the air, dissipate very rapidly. In this case, the initial air quality can be assumed to be the same across countries.

We do not differentiate between production factors, talking instead of "resources". For simplicity we assume that both manufacture production and abatement technology are linear; b denotes productivity in manufactures and a denotes productivity in abatement. In this way, and using the rental price of "resources" as the *numéraire,* we can think of $1/b$ and $1/a$ as the prices of manufactures and abatement, respectively.

Ours is a representative agent model and, thus, our results should be understood in per capita terms. The representative agent in our model chooses $\{m, c, i, k_1, k_2\}$ to maximize the following function

$$U(m, c)$$

subject to the following constraints

$$\begin{aligned} m &\leq b \cdot k_1 \\ c &\leq \bar{C} - i \cdot m \\ i &\leq z - a \cdot k_2 \\ k_1 + k_2 &\leq \bar{k} \end{aligned}$$

where c denotes air quality; $\bar{k}$ are the total resources available that can be used in the production of manufactures, k_1, or in pollution abatement, k_2; and z denotes pollution intensity if abatement effort is nil.

Note that the above maximization problem is the one that the social planner solves. Hence, it can also be understood as the problem solved by a "benevolent" government, one that has in mind the representative agent's best interests. Although endogenous policy is not modelled explicitly, as in Copeland and Taylor (2003), is behind our assumptions.

To write everything in terms of scale (manufactures) and intensity of pollution, the problem can be written in the following way

$$\max_{\{m,i\}} U(m, \bar{C} - im)$$

subject to the following constraint

$$\frac{1}{b}m + \frac{1}{a}(z - i) \leq \bar{k}, \tag{1}$$

written in terms of the respective prices of manufactures and abatement.

From the first order conditions, assuming an interior solution and $i \geq 0$, we obtain

$$\frac{U_1(m, \bar{C} - im)}{U_2(m, \bar{C} - im)} = \frac{a}{b}m + i \tag{2}$$

Equations 1 and 2 implicitly determine m and i as functions of the parameters $(a, b, \bar{k}, \bar{C}, z)$. Details are to be found in the appendix A. An increase in resources, $\bar{k}$, has a positive effect on scale/manufactures and a negative effect on pollution intensity. An increase in productivity in the manufacturing sector, b, has exactly the same effects.

An increase in $\bar{C}$, the initial air quality, has a positive effect both in scale and intensity. These effects are to be expected since such an increase is analogous to a fall in the marginal damage of emissions. Conventional cost-benefit approach tells us that a fall in the marginal damage leads to a fall in optimal abatement and, thus, to a higher intensity. Since an increase in initial air quality changes the initial marginal rate of substitution between environmental quality and manufactures, it also leads to more manufacturing production.

An increase in z, the pollution intensity when abatement effort is nil, has a negative effect on scale/manufacturing production and a positive effect in intensity. Again, the negative effect on manufacturing is to be expected since an increase in z changes the initial marginal rate of substitution. This means that there is more abatement effort; however, the increase in abatement effort is not enough to counteract the increase in z. Thus, the net effect of an increase in z on i is positive.

Finally, the increase in abatement productivity, a, decreases pollution intensity. The effect of a on scale/manufactures depends on the proportion of resources devoted to manufacturing and abatement.

Economic growth is due to two things: an increase in capital (an increase in $\bar{k}$ in our model) and an increase in the technology level. Technological progress in our model shows as increases in b and a, the productivity in both sectors. It is plausible to think that, in the same way economic agents in richer countries have access to technological developments that make manufactures cheaper in terms of resource use, they also have access to technological developments that make improving local air quality cheaper. All increases in $\bar{k}$, b and a imply a decrease in i; i.e., we should witness a negative relation between pollution intensity and income per capita.

But the model says that, because of the fact that pollution is a by-product of production, in most cases a decrease in pollution intensity goes hand in hand with an increase in pollution scale. Thus, since pollution emissions are the product of scale and intensity, the net effect of economic development on emissions is non-monotonic. In the model

$$\frac{de}{d\bar{k}} = \frac{di}{d\bar{k}}m + \frac{dm}{d\bar{k}}i \geq 0$$

if

$$\frac{dm}{d\bar{k}}\frac{\bar{k}}{m} \geq -\frac{di}{d\bar{k}}\frac{\bar{k}}{i};$$

i.e., total emissions increase with increases in resources if the resource elasticity of manufacturing is greater than the resource elasticity of intensity. Because of the by-product nature of pollution, these elasticities are not constant. But the fact that emissions increase with resources does not mean that agents do not care about the environment. The correct way of seeing if they do, according to the model, is to look at the relation between income per capita and pollution intensity (pollution per unit of output). By looking at this relation, it becomes clear that, at any level of income, agents in richer countries “consume” proportionately more air quality than agents in poorer countries, both because they are richer and because air quality is cheaper for them. Economic agents in poor countries care and do something about environmental quality, but this may be hidden by scale effects.

3 Methodological issues

As stated above, we firstly decompose the relation between air pollution and income per capita between the scale effect, the technique effect and the manufactures/non-manufactures composition effect by the simple proceedure of using pollution per unit of manufacturing as a measure of air pollution intensity. The units we use are millions of dollars of value added in the sector. Secondly, we regress this measure against income per capita to see if the relation is negative as hypothesized.

According to the model, intensity is a function of $\bar{k}, a, b, \bar{C}$ and z, negative on the first three arguments and positive in the other two. As argued above, the negative effect of the first three parameters should be captured by the effect of income per capita. We assume z (the dirtiest technology) to be the same across countries and levels of income. To control for initial air quality, we look at pollutant concentrations. Since this measure is in fact the opposite of air quality, we expect pollutant concentrations to have a negative effect on pollution intensity. Thus, we are posing that emissions per unit of output of manufacturing are a function of income per capita y and initial concentrations ψ, negative in both arguments, $i = f(y, \psi)$. When pollutants dissipate very rapidly, the initial concentration ψ (as the dirtiest technology) can be assumed to be the same across countries.

Since what we are interested in are elasticity values, we use the following log-linear model:

$$\ln i = b_0 + b_1 \ln y + b_2 \ln \psi + \nu.$$

We use OLS regressions with White heteroskedastic-consistent covariance matrix estimation.

3.1 The data

3.1.1 Air pollutants

Data are taken from the UNEP (2003) and were provided by the Netherlands' Organization for Applied Scientific Research—TNO, and the National Institute of Public Health and the Environment—RIVM. Sulfur dioxide emissions (SO_2), nitric oxides (NOx) and non-methane volatile organic compounds ($NMVOC$) are measured in thousand metric tons. Nitric oxides is the term used to describe the sum of NO, NO_2

and other oxides of nitrogen. Data are for 1990 and 1995 and covers in excess of 250 countries/jurisdictions.

We eliminate "splinter" countries whose population is smaller than one million people. Rather than eliminating oil producers, as it is customary in cross-country studies, and since in our case oil production may have an effect, we identify oil producers with a dummy variable which in most cases turns out to be non-significant.

3.1.2 GDP and income per capita

Gross Domestic Product and per capita income data come from the World Bank's (2002) *World Development Indicators*. Data are measured in millions of constant 1995 US dollars.

3.1.3 Manufactures

Manufacturing comprises clothing and textile; food and beverage industries; machinery and transport equipment; petrochemical and mineral refining; chemical; and other sectors. Industry includes mining; manufacturing; electricity, gas, and water; and construction. Data are measured in millions of constant 1995 US dollars.

We construct the measure of value added in manufactures or industry by multiplying the share of manufacturing or industry in GDP by GDP. Data for manufacturing and industry shares come from World Bank (2002). As some OECD manufacturing shares are missing, we calculate the share of manufacturing using the OECD's (1998) *National Accounts*.

3.1.4 Concentration of NO_2 and SO_2

The World Resources Institute (2003) compiles air quality measures for cities around the world. It does not report data on NOx concentration but it does report data on NO_2 (a subset) concentration. Nitric oxides are generated jointly in high-temperature combustion processes. Thus, we use NO_2 concentration as a proxy for NOx concentration. Data on NO_2 and SO_2 are reported in micrograms per cubic meter for selected years from 1988 to 1995. We use 1995 data. Where these are missing we use the most recent data taken prior to 1995. Some countries report data for more than one city. We use two measures. We either use the economic capital (referred in the tables as SO_2C or NO_2C) or the average weighted concentration using populations of the cities as weights (in the tables as SO_2A or NO_2A).

4 Results

Although the usual EKC uses pollution concentrations, the model in section 2 relates emissions to income per capita. The model is written in per capita terms and, according to it, the relation between (total) emissions per capita and economic development can be positive, negative, or non-monotonic. When we regress tons of emissions in per capita terms versus income per capita we obtain an inverted-U curve, as seen in the enclosed figure.[4] The curves peak between 1995US$ 20,000 and 22,000—the level of income of the Netherlands or Belgium, ranked around 10th in income level terms in 1995.

Sulfur dioxide is one of the gases on which the case for the EKC has been established.

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[4] The figure pools data from 1990 and 1995.

According to Shafik (1994), the curve for SO_2 concentration (not emissions) peaks at around 1985 PPP$ 3,670. While Grossman and Krueger (1995) find a peak similar to Shafik's (1985PPP$ 4,053), Kaufman et al's (1998) show a concentration peak closer to ours: 1985PPP$ 12,000. The case for an inverted U-curve for nitric oxides or volatile organic compounds is not as well established; nevertheless, we find a relation between per capita emissions of these gases and income per capita similar to that of SO_2 per capita emissions and income per capita.

Because we believe the subset Manufacturing to be dirtier than the whole Industry set, we report results concerning emissions per unit of manufacturing in the text while results concerning emissions per unit of industry are relegated to appendix B.

4.1 SO_2 intensity

We run a SUR regression which did not reject the hypothesis of the slope coefficients being the same for 1990 and 1995; therefore, we run a pooled regression introducing a dummy for 1995. Table 1 is our main table for this subsection. The dependant variable is ln of tons of SO_2 per $1,000 of manufacturing output. *Oil* refers to the dummy for oil producing countries; 1995 to the dummy for this year; and R^2 to the adjusted R^2.

The results are much as expected: there is a significant negative correlation between our measure of intensity and income per capita and the elasticity is less than one.

As explained above, since these gases do not really accumulate, concentrations may be assumed to be the same across countries. Nevertheless, we run the regressions. When we introduce measures of concentration we lose most of the observations and the measures of concentration turn out to be non-significant, as expected.[5]

To test for constant elasticity we run another regression with a quadratic term for $\ln y$ which turns out to be non-significant so we can take the elasticity to be the same at all levels of income in this case. Note that, consistent with a constant elasticity, the elasticities implied by the three regressions in Table 1 are similar even though the smaller sample corresponds to richer countries, generally speaking.

TABLE 1

Finally, we use the more standard measure of intensity: in this case the dependant variable is ln of tons of SO_2 per \$1,000 of GDP. Table 2 shows a smaller elasticity and a lower R^2. Consistent with our priors regarding the importance of sectoral composition, for all pollutants results are weaker when we use the more standard measure of intensity.

TABLE 2

4.2 NOx intensity

In this case when we run the regression with a quadratic form the quadratic form turns out to be significant so this is the pooled regression we report for NOx intensity in Table 3.

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[5] The low values of the coefficients may be explained by the facts that concentrations measures refer to one or two cities in the whole country.

TABLE 3

Consistent with the idea of the income elasticity not being constant, and since the world became richer from 1990 to 1995, when we run a SUR regression (Table 4) we cannot reject the coefficients being different ($Wald\ Stat = 1.5889$, $P - value = 0.2075$). Similarly, the elasticity implied for the subsample of richer countries is smaller than the implied elasticity for the whole sample.

TABLE 4

Finally, and as above, we use a more standard measure of intensity—tons per $1,000 of GDP—in Table 5.

TABLE 5

4.3 $NMVOC$ intensity

With volatile organic compounds, as with nitric oxides, when we run a regression with a quadratic form the quadratic form turns out to be significant (Table 6). In this case, we do not have a measure of concentration.

TABLE 6

Once again, and consistent with income elasticity not being constant, when we run a SUR regression (Table 7) we find strong evidence of the coefficients being different

$(Wald\ Stat = 13.394,\ P - value = 0.00025)$.

TABLE 7

The more standard measure of intensity is used in Table 8.

TABLE 8

5 Concluding remarks

The main point of this paper is that environmental quality is a normal good; i.e., its consumption increases as per capita income increases. We develop a model that shows that the assumption that environmental quality is a normal good, coupled with the assumption that pollution is a by-product of production, implies that, although the relation between emissions and income per capita is not necessarily monotonic, the relation between pollution intensity and income per capita is negative. Thus, according to this model, the correct way to test the assumption of environmental quality being a normal good is to look at the relation between intensity and income per capita, rather than at the relation between pollution and income per capita.

We use pollution per unit of manufacturing, rather than pollution per unit of output, as a measure of intensity. When we use pollution per unit of output results are similar but the elasticities are smaller. We test our model using emissions of sulfur dioxide (SO_2), nitric oxides (NOx) and non-methane volatile organic compounds ($NMVOC$). The results reported here corroborate our hypothesis. Our study is consistent with the idea that per capita income growth goes along with environmental quality improvement. Demand for environmental quality rises with income and technological progress at all levels of per capita income. This study finds evidence that pollutant emissions per unit of manufacturing or industry decrease with increases in income per capita.[6]

Is local air quality a luxury good? The answer seems to be no. The income elasticity for $NMVOC$ is close to one while the elasticity for SO_2 is roughly 1/2 and the elasticity for NOx is approximately 0.8. While the income elasticity for SO_2 appears constant the other two income elasticities vary with income.

Although this paper applies to air quality we believe that environmental quality in general is not a luxury good. Hettige, Mani and Wheeler (2000) found a similar relation with water pollution intensity and income per capita. Echevarria and Ho (2000) found a negative relation between carbon dioxide (CO_2) emission intensity and income per capita, even though the relation between carbon emission per capita and per capita income is positive, according to Shafik and Bandyopadhyay (1992) and Shafik (1994). Carbon dioxide does not affect local air quality but it is a greenhouse gas which affects global environment. The income elasticity of CO_2 intensity is much smaller than the income elasticities found in this paper while the income elasticity of water pollution intensity is unitary.

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[6] As stated in the introduction and in section 2, we understand that the decrease in intensity usually occurs as a change in policy.

A Mathematical appendix

We calculate the derivatives using the system of functions implied by equations 1 and 2; i.e.,

$$dy = -\left[\frac{\delta F}{\delta y}\right]^{-1}\frac{\delta F}{\delta x}dx,$$

where F_1 refers to the consolidated FOC and F_2 refers to constraint; $y_1 = m$ and $y_2 = i$; and $x_1 = a$, $x_2 = b$, $x_3 = \bar{k}$, $x_4 = \bar{C}$ and $x_5 = z$.

The determinant of the matrix $\delta F/\delta y$, omitting the arguments of the functions, equals

$$\Delta = -\frac{(U_{11} - iU_{12})\,U_2 - U_1\,(U_{21} - iU_{22})}{(U_2)^2\,a} + \frac{U_{12}U_2 - U_1U_{22}}{(U_2)^2}\frac{m}{b} + \frac{2}{b} > 0.$$

We obtain the following results

$$\frac{dm}{da} = \frac{1}{\Delta}\left[-\frac{m}{ab} + \left(\frac{U_{12}U_2 - U_1U_{22}}{(U_2)^2}m + 1\right)\frac{z-i}{a^2}\right]$$

$$\frac{dm}{db} = \frac{1}{\Delta}\left[\frac{2m}{b^2} + \frac{U_{12}U_2 - U_1U_{22}}{(U_2)^2}\frac{m^2}{b^2}\right] > 0$$

$$\frac{dm}{d\bar{k}} = \frac{1}{\Delta}\left[\frac{U_{12}U_2 - U_1U_{22}}{(U_2)^2}m + 1\right] > 0$$

$$\frac{dm}{d\bar{C}} = \frac{1}{\Delta a}\left[\frac{U_{12}U_2 - U_1U_{22}}{(U_2)^2}\right] > 0$$

$$\frac{dm}{dz} = -\frac{1}{\Delta}\left[\frac{U_{12}U_2 - U_1U_{22}}{(U_2)^2}\frac{m}{a} + \frac{1}{a}\right] < 0$$

$$\frac{di}{da} = \frac{1}{\Delta}\left[-\frac{m}{b^2} + \frac{(U_{11} - iU_{12})\,U_2 - U_1\,(U_{21} - iU_{22})}{(U_2)^2}\frac{z-i}{a^2} - \frac{z-i}{ba}\right] < 0$$

$$\frac{di}{db} = \frac{1}{\Delta}\left[\frac{\left(U_{11} - iU_{12}\right)U_2 - U_1\left(U_{21} - iU_{22}\right)}{\left(U_2\right)^2}\frac{m}{b^2}\right] < 0$$

$$\frac{di}{d\bar{k}} = \frac{1}{\Delta}\left[\frac{\left(U_{11} - iU_{12}\right)U_2 - U_1\left(U_{21} - iU_{22}\right)}{\left(U_2\right)^2} - \frac{a}{b}\right] < 0$$

$$\frac{di}{d\bar{C}} = \frac{1}{\Delta b}\left[\frac{U_{12}U_2 - U_1U_{22}}{\left(U_2\right)^2}\right] > 0$$

$$\frac{di}{dz} = -\frac{1}{\Delta}\left[\frac{\left(U_{11} - iU_{12}\right)U_2 - U_1\left(U_{21} - iU_{22}\right)}{\left(U_2\right)^2 a} - \frac{1}{b}\right] > 0.$$

The signs of all the derivatives are well determined except for the sign of dm/da. We can rewrite it in the following way

$$\begin{aligned} \frac{dm}{da} &= -\frac{m}{ab}\frac{1}{\Delta} + \frac{1}{\Delta}\left(\frac{U_{12}U_2 - U_1U_{22}}{\left(U_2\right)^2}m + 1\right)\frac{z-i}{a^2} = \\ -\frac{m}{ab}\frac{1}{\Delta} + \frac{dm}{d\bar{k}}\frac{z-i}{a^2} &= \frac{1}{a}\left(-k_1\frac{1}{\Delta} + \frac{dm}{d\bar{k}}k_2\right) \end{aligned}$$

where $k_1 = m/b$ or resources devoted to manufacturing and k_2 denotes resources devoted to abatement. Thus, dm/da is positive if

$$\frac{k_1}{k_2} \leq \Delta\frac{dm}{d\bar{k}}$$

and negative otherwise.

B Emissions per unit of industry

B.1 SO_2 intensity

As with emissions per unit of manufacturing, the SUR regression did not reject the hypothesis of the slope coefficients being the same for 1990 and 1995; therefore, we run a pooled regression introducing a dummy for 1995. Table 9 is our main table for this subsection. The dependant variable is ln of tons of SO_2 per $1,000 of industry output. To test for constant elasticity we run another regression with a quadratic term for $\ln y$ which turns out to be non-significant so we can take the elasticity to be the same at all levels of income in this case as well.

TABLE 9

B.2 NOx intensity

In this case when we run the regression with a quadratic form the quadratic form turns out to be significant although when we run a SUR regression we reject the coefficients being different ($Wald\ Stat = 0.0002$, $P - value = 0.9896$). Consistently with the quadratic term being significant, the elasticity implied for the subsample of richer countries is smaller than the implied elasticity for the whole sample.

TABLE 10

B.3 $NMVOC$ intensity

Again, the quadratic form turns out to be significant (Table 11).

TABLE 11

Consistently with income elasticity not being constant, when we run a SUR regression (Table 12) we find strong evidence of the coefficients being different ($Wald$ $Stat = 7.1911$, $P - value = 0.0073$).

TABLE 12

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Table 1

	Constant	$\ln y$	Oil	1995	SO_2A	SO_2C	R^2
Observations	254						
	4.244	-0.542	0.474	-0.012			0.4033
$t-$stat	42.640	-14.680	2.477	-0.092			
Std err	0.100	0.037	0.192	0.129			
Observations	45						
	4.328	-0.682	0.196		0.095		0.5225
$t-$stat	6.545	-5.679	0.598		0.578		
Std err	0.661	0.120	0.328		0.164		
Observations	44						
	3.813	-0.651	0.091			0.239	0.5527
$t-$stat	6.926	-5.781	0.244			1.697	
Std err	0.551	0.113	0.373			0.141	

Table 2

	Constant	$\ln y$	Oil	1995	R^2
Observations	254				
	2.309	-0.391	0.260	-0.054	0.2750
$t-$stat	24.280	-11.360	1.676	-0.438	
Std err	0.095	0.034	0.155	0.123	

Table 3

	Constant	$\ln y$	$(\ln y)^2$	Oil	1995	NO_2A	NO_2C	R^2
Observations	252							
	4.513	-0.915	0.056	0.299	-0.016			0.6850
$t-$stat	42.470	-17.920	2.689	1.804	-0.140			
Std err	0.102	0.051	0.021	0.166	0.111			
Observations	38							
	4.382	-0.319	-0.086	0.240		-0.101		0.7075
$t-$stat	9.079	-2.777	-2.485	2.306		-0.837		
Std err	0.483	0.115	0.035	0.104		0.121		
Observations	38							
	4.305	-0.329	-0.084	0.232			-0.078	0.7061
$t-$stat	0.461	-2.847	-2.424	2.110			-0.709	
Std err	9.330	0.116	0.035	0.110			0.110	

Table 4

	Constant	$\ln y$	Oil	R^2
Observations	119			
1990	4.633	-0.772	0.055	0.6778
$t-$stat	50.870	-16.710	0.172	
Std err	0.091	0.046	0.318	
1995	4.603	-0.753	0.035	0.6927
$t-$stat	52.660	-17.370	0.114	
Std err	0.087	0.043	0.307	

Table 5

	Constant	$\ln y$	$(\ln y)^2$	*Oil*	1995	R^2
Observations	252					
	2.680	-0.677	0.003	0.048	-0.056	0.7120
$t-$stat	33.480	-16.810	0.160	0.422	-0.654	
Std err	0.080	0.040	0.016	0.114	0.085	

Table 6

	Constant	$\ln y$	$(\ln y)^2$	*Oil*	1995	R^2
Observations	254					
	4.990	-1.042	0.080	1.204	-0.002	0.7016
$t-$stat	46.110	-21.570	3.670	4.790	-0.018	
Std err	0.108	0.048	0.022	0.251	0.119	

Table 7

	Constant	$\ln y$	*Oil*	R^2
Observations	120			
1990	5.205	-0.964	0.861	0.7197
$t-$stat	55.160	-21.080	2.643	
Std err	0.093	0.046	0.326	
1995	5.198	-0.913	0.861	0.7091
$t-$stat	56.440	-20.550	2.645	
Std err	0.092	0.044	0.325	

Table 8

	Constant	$\ln y$	$(\ln y)^2$	Oil	1995	R^2
Observations	254					
	3.162	-0.801	0.025	0.950	-0.045	0.7501
$t-$stat	39.400	-23.310	1.536	5.321	-0.519	
Std err	0.080	0.034	0.016	0.179	0.087	

Table 9

	Constant	$\ln y$	Oil	1995	SO_2A	SO_2C	R^2
Observations	265						
	3.727	-0.466	-0.181	-0.054			0.3702
$t-$stat	41.880	-14.240	-1.122	-0.462			
Std err	0.089	0.033	0.161	0.116			
Observations	45						
	3.815	-0.659	-0.070		0.121		0.5164
$t-$stat	6.126	-5.427	-0.220		0.805		
Std err	0.623	0.122	0.316		0.151		
Observations	45						
	3.390	-0.634	-0.160			0.241	0.5374
$t-$stat	5.951	-5.468	-0.471			1.704	
Std err	0.570	0.116	0.340			0.142	

Table 10

	Constant	$\ln y$	$(\ln y)^2$	Oil	1995	NO_2A	NO_2C	R^2
Observations	263							
	3.928	-0.862	0.065	-0.304	-0.026			0.7516
$t-$stat	52.920	-20.600	3.741	-2.427	-0.307			
Std err	0.074	0.042	0.017	0.125	0.086			
Observations	38							
	3.900	-0.340	-0.081	0.045		-0.071		0.7239
$t-$stat	8.722	-3.549	-2.544	0.344		-0.630		
Std err	0.447	0.096	0.032	0.131		0.112		
Observations	38							
	3.899	-0.350	-0.080	0.042			-0.067	0.7239
$t-$stat	9.262	-3.799	-2.533	0.322			-0.667	
Std err	0.421	0.092	0.031	0.130			0.101	

Table 11

	Constant	$\ln y$	$(\ln y)^2$	Oil	1995	R^2
Observations	256					
	4.384	-1.000	0.092	0.616	0.002	0.7868
$t-$stat	58.350	-28.130	5.590	3.550	0.023	
Std err	0.075	0.036	0.016	0.174	0.086	

Table 12

Observations	Constant 129	$\ln y$	Oil	R^2
1990	4.601	-0.904	0.376	0.7750
$t-$stat	67.780	-25.940	1.506	
Std err	0.068	0.035	0.250	
1995	4.580	-0.873	0.423	0.7655
$t-$stat	66.450	-25.260	1.655	
Std err	0.069	0.035	0.255	