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**Pollution and the State:
The Role of the Structure of Government**

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Abstract

Government spending has significant environmental implications. This paper analyzes the effect of the allocation of government spending between public goods broadly defined and private goods or non-social subsidies on air and water pollution. The theoretical model predicts that a reallocation of expenditures from private subsidies to public goods improves environmental quality by reducing production pollution. We estimate an empirical model that shows that such a reallocation causes a significant reduction in air pollutants namely sulfur dioxide and lead and an improvement in water quality measures including dissolved oxygen and biological oxygen demand.

1. Introduction

This article investigates the impact of the composition of government expenditures between public goods, broadly defined, and private goods or non-social subsidies on environmental quality. We develop a model to illustrate the relationship between government spending allocation and the environment and then empirically analyze how the composition of government spending affects air and water pollution. The key distinction between “public goods” and “private goods” expenditures is that the former alleviates the negative effects of market failure, while the latter does not. We broadly define public goods to include subsidies to households (education, health and other social transfers), expenditures in conventional public goods, environmental protection, research and development (R&D), and knowledge diffusion. Government spending in private goods involves direct and indirect government subsidies to firms other than subsidies directly for R&D and environment protection.

Spending in the household sector, mainly through social transfers, education, and health care, tends to alleviate credit market failures which constrain investment in human capital. This may ameliorate the tendency to under-invest in education and other forms of knowledge by households.¹ Other distortions that may be alleviated by spending in public goods include common market failures such as environmental externalities, externalities associated with the generation and diffusion of knowledge and the under provision of “pure” public goods in a market.

In contrast, government-provided private goods such as credit subsidies, energy and other input subsidies, farm programs, government grants to corporations, financial bailouts, and other financial subsidies targeting specific industries or even individual firms often exacerbate the

¹ Credit market failures are prevalent in both developed and developing economies. Grant (2007), for example, shows that about one third of US households face binding credit constraints.

distortions caused by market failure. Government expenditures in private goods tend to substitute rather than complement private investments. Studies have shown that at best these private subsidies are ineffective at promoting private investment.² In addition, expenditures in private goods crowd out spending in public goods given a fiscal budget.

Another distinction between private and public goods is that the former are much more affected by lobbying than the latter (López and Islam, 2008). Apart from causing efficiency losses, the influence of the lobby groups tends to affect the distribution of expenditures in private goods in favor of a small number of wealthy individuals or firms. One consequence of the lobbying process is that expenditures in private goods usually promote capital intensive economic sectors, which have the greatest capacity to effectively lobby governments, as opposed to service sectors which tend to be human capital-intensive. Expenditures in public goods not only disperse more evenly across households, thus allowing human capital investments by credit-constrained poor households, but also tend to promote more human capital-intensive activities which are generally less environmentally demanding.

The reallocation of government spending towards public goods may affect pollution via the proximate factors identified in the literature: scale, composition, income, technique, and growth effects (Antweiler et. al. 2001). As shown by López and Islam (2008), restructuring government expenditures in favor of public goods causes more economic growth inducing a scale effect which, *ceteris paribus*, increases environmental pressures. On the other hand, such a reallocation of government spending for favors human capital intensive activities as opposed to physical capital intensive activities. To the extent that human capital intensive activities tend to be

² Examples include Bregman, Fuss, and Regev (1999) for Israel, Fakin (1995) for Poland, Lee (1996) for Korea, Bergstrom (1998) for Sweden, Estache and Gaspar (1995) for Brazil, Harris (1991) for Ireland

environmentally cleaner than the physical capital intensive activities, a reallocation from private to public goods causes a composition effect that is pro-environment.

The technique effect could also be pro-environment to the extent that more public goods provisions is associated with more R&D and technological diffusion which could also directly or indirectly cause the development and implementation of cleaner technologies. The technique effect is not necessarily related to income growth on a one-to-one basis as assumed by the literature (Antweiler, *et al.* 2001). In fact, the literature often refers to the technique “or” income effect as if they were the same thing. While it is true that sometimes income growth may trigger technique effects, this is not always the case as shown by (López, 2008). Neither is it true that the only source of the technique effect is income growth. We show below that a technique effect can arise from the restructuring of government expenditures, even if we control for per capita income growth.³

We hypothesize that the reallocation of government expenditures from private to public goods will trigger pro-environment composition and technique effects which may overcome the scale effect thus improving environmental quality as measured by a decrease in production pollution, *ceteris paribus*.⁴ We empirically test this hypothesis and find that, in general, increasing the government share of public goods improves both air and water quality indicators. Specifically, there are improvements in sulfur dioxide and lead, for air pollutants, and dissolved oxygen and biological oxygen demand for water pollutants. Since increasing the share of public goods has been demonstrated to also promote economic growth (López and Islam, 2008), such a

³ Moreover, López and Islam, (2008) showed that such a reallocation of government expenditures is not caused by higher income growth; the causality is one way from the structure of public expenditures to growth and not the other way around.

⁴ It must be noted that we focus our analysis on production pollution only and not consumption pollution. The mechanisms by which government expenditure size and composition affect consumption pollution is likely to differ compared to production pollution.

reallocation from private to public goods is win-win – good for the environment and good for growth.

The study of the determinants of pollution has been closely linked to the environmental Kuznets curve. These studies examine a reduced form inverted u-shaped relationship between pollution and per capita income (Grossman and Krueger, 1993). Some extensions involve explicitly considering the role of political and institutional variables in affecting such a relationship (Barret and Graddy, 2000). More recent studies have called into question both the accuracy of the datasets used, the methods of estimation and the robustness of the findings in this literature to changes in specifications (Harbaugh et al. 2002, Deacon and Norman 2004).

Despite the number of studies that have used a variety of specifications to derive the determinants of pollution, we know of only one study that focuses on the role of fiscal policies play on pollution. Bernauer and Koubi (2006) examine the impact of government expenditures on sulfur dioxide (SO₂) only. They find that increasing the level of total government expenditures increases SO₂ concentrations. They only consider the impact of aggregated government expenditures ignoring the potentially vital issue of the structure or composition of government expenditures.

To the best of our knowledge the present study is the first to consider the *composition* of government expenditures on environmental quality using a comprehensive set of air and water quality indicators. The ensuing econometric results consistently show that the composition of public expenditures is important in determining air and water quality. Transferring expenditures from private to public goods can be an effective instrument to improve environmental quality as opposed to increasing total public expenditure alone.

The remainder of this paper is organized as follows: Section 2 formulates the theoretical and empirical model. Section 3 describes the data used in the paper. Section 4 summarizes the results of the empirical analysis. Section 5 concludes the study.

2. Model

2.1 Theoretical Model

The model considers three sectors: one that produces an environmentally clean final good, y_c , the other a dirty final good, y_d , and the third sector produces an intermediate good called human capital or knowledge, h . Human capital is an input in the production of all three sectors. Development of human capital augments labor efficiency measured by hl_i where l_i is labor in the i^{th} sector. Firms also use inputs from government expenditure. The government uses its revenues in spending in productive inputs, g , and the rest is spent on excessive bureaucracy as well as in other forms of inefficient subsidies and waste, x .

To capture the fact that dirty industries are generally more capital intensive than clean industries, we make the assumption that the clean sector's production uses only knowledge, labor, l_c , and the productive government input such that the production function is:

$$(1) \quad y_c = Ahl_c g^\Omega$$

where A is a productivity index and Ω is the input elasticity of productive government inputs on clean good. We assume that $0 < \Omega < 1$ and clean final good is homogeneous of degree one in efficient labor, hl_c .

The dirty sector utilizes quasi-fixed physical capital, k , labor, l_d , knowledge, dirty input creating production pollution, Z , productive government input, g , and government subsidy, x such that the production function is represented as follows:

$$(2) \quad y_d = D(hl_d)^\alpha Z^\beta (x+k)^{1-\alpha-\beta} g^\eta$$

where D is a productivity index, α is the input elasticity of efficient labor, β is the input elasticity of dirty inputs, η is the input elasticity of productive government inputs in producing the dirty good and $1-\alpha-\beta$ is the input elasticity of capital. Note that we assume perfect substitution between physical capital and government subsidies. Production of the dirty good is homogenous of degree one in the private inputs (k, hl_d, Z) . We assume that $\alpha > 0$, $\beta > 0$, $\eta > 0$ and $\alpha + \beta < 1$.

Production of human capital uses labor, l_r , and knowledge and a government-provided input such that the production function can be presented as follows:

$$(3) \quad h = \bar{B}(hl_r)^\varepsilon g^{\bar{\mu}},$$

where ε , $\bar{\mu}$, and \bar{B} are positive parameters. Equation (3) can be rewritten as:

$$(3') \quad h = \bar{B}^{1-\varepsilon} l_r^{\varepsilon} g^{1-\varepsilon \bar{\mu}}$$

We make the assumption that $\varepsilon=1/2$ for the sake of reducing algebraic clutter. This assumption is also convenient because it does not alter the qualitative results and yields a production function for h which is linearly homogenous in private inputs. Equation (3') can be re-written as,

$$(3'') \quad h = B l_r g^\mu$$

where $B \equiv \bar{B}^2$, and $\mu \equiv 2\bar{\mu}$. Thus B can be interpreted as a productivity index, and μ is the input elasticity of the government-provided inputs in producing human capital. We assume that $0 < \mu < 1$. We also assume that the productivity index in the human capital sector is larger than the clean good sector or dirty good sector such that $B > A$ and $B > D$.

The labor market clearing condition implies:

$$(4) \quad \bar{L} = l_c + l_d + l_r$$

Where \bar{L} is the total supply of labor in the economy which is assumed to be fixed, and is normalized to 1.

Assumptions:

(i) Government-provided input. The model assumes that the government-provided productive input affects all sectors of the economy though its productivity differs across sectors. Governments provide a variety of inputs, some public goods and others that target individual sectors. Given the public good component of many government inputs, it is very difficult to allocate them across sectors. In fact, many government inputs such as institutions, infrastructure, health care and others tend to have broad productive effects on many sectors at the same time. For this reason we use one aggregate measure of government input which has different impacts on each sector.

A large portion of the productive government spending comprises expenditures in education, R&D, technological diffusion and health care. The clean final good sector and intermediate human capital sector are mainly comprised of services and high technology industries, which are dependent on communication infrastructure, development and enforcement of property right institutions and incentives provided to R&D. By contrast, the dirty sector is less dependent on public goods, property right institutions and other government inputs than the clean sector and the human capital production sector. For this reason we expect that the elasticity of g in the production of knowledge and clean good is larger than the dirty good. Since we assume that the elasticity effective labor in the clean sector is equal to one, we constrain the elasticity of government-provided input for clean goods and human capital to be equal such that $\mu = \Omega$ (see Appendix 1). Therefore, we assume: $\mu = \Omega > \eta$.

(ii) Labor intensities. We assume that efficient labor, hl_i , has a larger effect on the output of the dirty sector than government inputs: $\alpha > \eta$. This assumption is consistent with the assumptions of $\mu < 1$, and $\Omega < 1$ in the other sectors, which imply that efficient labor also has a higher production elasticity than the government-provided input in these sectors. Given the use of human capital in the production of dirty goods, we also find the $\alpha = \eta/\mu$ which also implies that $\Omega\alpha - \eta = 0$ since $\mu = \Omega$ (see Appendix 1).

Competitive equilibrium

Producers in the dirty sector minimize cost of production by choosing labor and the dirty input, given g , x and k .

$$(5) \quad C(w, \tau, r, k + x, g, y_d) = \min_{l_d, Z} whl_d + \tau Z : \quad D(hl_d)^\alpha Z^\beta (x+k)^{1-\alpha-\beta} g^\eta = y_d,$$

where τ is the unit tax rate on pollution and r is the rental rate of capital. Thus, we have the following first order conditions:

$$(6) \quad \tau = \lambda D\beta (hl_d)^\alpha Z^{\beta-1} (x+k)^{1-\alpha-\beta} g^\eta$$

$$(7) \quad w = \lambda D\alpha h (hl_d)^{\alpha-1} Z^\beta (x+k)^{1-\alpha-\beta} g^\eta$$

$$(8) \quad y_d = D(hl_d)^\alpha Z^\beta (x+k)^{1-\alpha-\beta} g^\eta$$

where λ is the marginal cost of production of dirty output. Solving for Z and hl_d and substituting into the objective function yields the cost function (see Appendix 2),

$$(9) \quad C = D^{-\frac{1}{\alpha+\beta}} (\alpha/\beta)^{\frac{\beta}{\alpha+\beta}} (1+\beta/\alpha) y_d^{\frac{1}{\alpha+\beta}} (x+k)^{\frac{\alpha+\beta-1}{\alpha+\beta}} g^{-\frac{\eta}{\alpha+\beta}} w^{\frac{\alpha}{\alpha+\beta}} \tau^{\frac{\beta}{\alpha+\beta}}.$$

Using Shepherd's Lemma, we derive the input demand for dirty inputs,

$$(10) \quad \frac{\partial C}{\partial \tau} = Z = \phi y_d^{\frac{1}{\alpha+\beta}} (x+k)^{\frac{\alpha+\beta-1}{\alpha+\beta}} g^{-\frac{\eta}{\alpha+\beta}} w^{\frac{\alpha}{\alpha+\beta}} \tau^{-\frac{\alpha}{\alpha+\beta}}$$

where $\phi = D^{-\frac{1}{\alpha+\beta}} (\alpha/\beta)^{-\frac{\alpha}{\alpha+\beta}}$. Here, the direct effects of output and wage rates increases the demand for Z while the direct effect of pollution tax, government expenditure and capital decreases Z .

Logarithmic differentiation of (10) with respect to g yields,

$$(11) \quad \frac{\partial \ln Z}{\partial \ln g} = \frac{\alpha}{\alpha+\beta} \frac{\partial \ln w}{\partial \ln g} + \frac{1}{\alpha+\beta} \frac{\partial \ln y_d}{\partial \ln g} - \frac{\alpha}{\alpha+\beta} \frac{\partial \ln \tau}{\partial \ln g} - \frac{\eta}{\alpha+\beta}.$$

Government expenditure affects the use of dirty inputs through four channels: the direct effect of government expenditure on Z and the indirect effects through wage, output in the dirty industry and pollution tax. To determine the total effect of government expenditure on Z in the general equilibrium model, we derive the impact of g on w in the labor market, the impact of g on y_d using the production possibility frontier and isorevenue line of the economy and the impact of g on τ in the pollution market.

The wage rate can be expressed as the marginal value product of labor in the clean sector:

$$(12) \quad w = Ahg^{\Omega}$$

All three sectors compete for labor. Assuming perfect competition, the marginal value products of all three sectors equalize. Equating the marginal products of labor in the clean and knowledge sectors gives us the following:

$$(13) \quad Ahg^{\Omega} = Bg^{\mu}$$

Since $\mu = \Omega$, we derive a unique equilibrium level of h and w consistent with competitive labor markets:

$$(14) \quad h^* = \frac{B}{A} \quad \text{and}$$

$$(15) \quad w^* = Bg^{\Omega} \quad .$$

Because provision of productive government inputs yields the same percentage change in human capital and clean output, the equilibrium human capital level will only depend on the productivity ratios in both sectors. Since we assume $B > A$, human capital production ensures labor productivity augmentation. Equilibrium wage rate is increasing in government spending since it increases marginal productivity of labor. Thus, logarithmic differentiation of (15) with respect to g yields,

$$(16) \quad \frac{\partial \ln w^*}{\partial \ln g} = \Omega.$$

Government expenditures can also affect output in the dirty sector. We use the production possibility frontier and the isorevenue function to derive the optimal level of dirty output, y_d . To derive the production possibility frontier, we solve for efficient labor of each sector by substituting (14) into (1), (2) and (3") and then substituting labor in each sector into the labor constraint (4). We obtain the following production possibility formulation,

$$(17) \quad \bar{L} = A^{-1}g^{-\mu} + y_c B^{-1}g^{-\Omega} + y_d^\alpha D^{-\frac{1}{\alpha}} (A/B) Z^{-\frac{\beta}{\alpha}} (x+k)^{\frac{\beta+\alpha-1}{\alpha}} g^{-\frac{\eta}{\alpha}}.$$

The corresponding isorevenue equation is,

$$(18) \quad TR = py_d + y_c$$

where TR is total revenue in the economy and p is output price ratio of the dirty good relative to the clean good. To derive the optimal level of output in the dirty sector, we equate the marginal rate of transformation from the production possibility frontier to the output price ratio from the isorevenue equation, i.e. $\frac{\partial y_c}{\partial y_d} = -p$. Using the implicit function theorem on (17), we arrive at

the following condition,

$$(19) \quad \frac{\partial y_c}{\partial y_d} \equiv - \frac{\frac{1}{\alpha} y_d^{\frac{1-\alpha}{\alpha}} D^{-\frac{1}{\alpha}} (A/B) Z^{\frac{\beta}{\alpha}} (x+k)^{\frac{\beta+\alpha-1}{\alpha}} g^{-\frac{\eta}{\alpha}}}{B^{-1} g^{-\Omega}} = -p .$$

Using (19), we solve for y_d ,

$$(20) \quad y_d = \alpha^{\frac{\alpha}{1-\alpha}} p^{\frac{\alpha}{1-\alpha}} D^{\frac{1}{1-\alpha}} A^{-\frac{\alpha}{1-\alpha}} Z^{\frac{\beta}{1-\alpha}} (x+k)^{\frac{1-\beta-\alpha}{1-\alpha}} g^{\frac{\eta-\alpha\Omega}{1-\alpha}} .$$

Logarithmic differentiation of (20) with respect to g and using the condition $\eta - \alpha\Omega = 0$ yields,

$$(21) \quad \frac{\partial \ln y_d}{\partial \ln g} = \frac{\beta}{1-\alpha} \frac{\partial \ln Z}{\partial \ln g} .$$

The impact of g on output in the dirty sector will depend on the effect of g on demand for dirty inputs.

Increasing government productive expenditures may also affect the pollution tax rate. We assume that the government uses a virtual optimal pollution tax as a reference in setting the actual tax. Depending on institutional and social conditions the government may be able to choose a level of τ below the optimal tax rate, τ^* . We first examine how g may affect the optimal pollution tax.

The optimal tax rate is equal to the marginal rate of substitution between income and pollution (López, 1994).

$$(22) \quad \tau^* = \frac{v'(Z)}{u'(c)}$$

where u is the utility from consumption, c , and $v(Z)$ is the disutility from pollution. We assume $v'(Z)$ is positive and linear in Z such that $v'(Z) \equiv \gamma$.⁵ Also, u is increasing and strictly concave, $u'(c) > 0$, $u''(c) < 0$ where we assume the functional form $u = \ln(c)$. Total consumption is equal to total income which can be defined as total factor returns. Thus, $c = (1-t)(wL + rk)$, where t is the

⁵ If $v(Z)$ is strictly convex instead of linear, the ensuing results are reinforced.

income tax rate and total labor, L , is normalized to 1. Given our assumptions, the resulting pollution tax rate is equal to,

$$(23) \quad \tau^* = \gamma(1-t)(w + rk).$$

Logarithmic differentiation of (23) with respect to g yields,

$$(24) \quad \frac{\partial \ln \tau^*}{\partial \ln g} = \frac{\gamma(1-t)w}{\tau} \frac{\partial \ln w}{\partial \ln g}.$$

Since the impact of g on w is constant from (16), we find that τ^* is increasing in g . Here, an increase in g raises income of consumers. In turn, demand for pollution regulation increases resulting in higher levels of pollution taxes.

The total impact of g on Z is derived by substituting (16), (21) and (24) into (11),

$$(25) \quad \frac{\partial \ln Z}{\partial \ln g} = \frac{\alpha\mu}{\alpha+\beta} + \frac{1}{\alpha+\beta} \frac{\beta}{1-\alpha} \frac{\partial \ln Z}{\partial \ln g} - \frac{\alpha}{\alpha+\beta} \left(\frac{\gamma w(1-t)\mu}{\tau} \right) - \frac{\eta}{\alpha+\beta}.$$

We find that the direct effect of g along with the indirect effect through tax regulations and dirty output production is to decrease Z . On the other hand, an increase in g results in an increase in wage which decreases demand for labor in the dirty sector and results in a substitution towards Z . Solving for $\partial \ln Z / \partial \ln g$, the total effect of increasing productive government expenditures, causes pollution to fall, *ceteris paribus*.

$$(26) \quad \frac{\partial \ln Z}{\partial \ln g} = -\frac{1-\alpha}{1-\alpha-\beta} \left(\frac{\gamma(1-t)w\mu}{\tau} \right).$$

Lemma 1. The total effect of increasing productive government expenditures is to lower pollution since the direct effect of productive government expenditure on demand for dirty inputs and the indirect effect through pollution taxes and output of dirty goods outweigh the indirect effect through wages, *ceteris paribus*.

Productive expenditures and wasteful expenditures:

We now examine with more detail the connotation of increasing productive government expenditures on wasteful expenditures. Total revenues generated from taxation are spent by the government on productive inputs, g , and government waste, x :

$$(27) \quad g+x = t(w+rk) + \tau Z .$$

Thus,

$$(28) \quad \frac{dx}{dg} = -1 + t \frac{\partial(w+rk)}{\partial g} + \frac{Z\tau}{g} \left(\frac{\partial \ln Z}{\partial \ln g} + \frac{\partial \ln \tau}{\partial \ln g} \right)$$

An increase in productive government expenditures has a direct and indirect effect on government expenditures in wasteful activities, x . The direct effect is the reduction in wasteful activities x , as indicated by ‘-1’ in equation (27). If we assume total government expenditures are constant, then only the direct effect exists. However, increasing government expenditures in productive inputs may generate higher incomes and raise total government expenditures. Thus the second order effects may further increase government expenditures in productive inputs or in wasteful activities.

Decomposing the Effect of Government Productive Inputs

As in the case of the effects of trade policy analyzed by Antweiler, *et al.* (2001), the effect of changes in productive government inputs on production pollution can be decomposed into scale, composition, and technique effects. The indirect effect of productive government inputs through wages are representative of the scale effect since it relates to total income of the economy while the indirect effect through pollution tax regulations alter the composition of the economy. Technological innovation is measured as the change in pollution intensity per efficient labor.

The Scale Effect

Since productive government spending increases the total income of the economy (that is increases returns to labor and capital), we find total output value increasing including the output

of the dirty good. Thus, the increase in the scale of economic activity caused by higher levels of government spending may increase pollution.

The Composition Effect

To determine the composition effect, we derive the impact of g on output in the dirty and clean sector. Simplifying (21) using (26), we find the total effect of g on production of the dirty good,

$$(21') \quad \frac{\partial \ln y_d}{\partial \ln g} = -\frac{\beta}{1-\alpha-\beta} \left(\frac{\gamma(1-t)w\mu}{\tau} \right) < 0.$$

Thus, g reduces dirty sector output.

To determine the impact of g on y_c , we derive output in the clean sector by substituting output in the dirty sector (20) into the production possibility frontier (17). We find,

$$(29) \quad y_c = \bar{L}B g^\Omega - (B/A) - \theta(x+k)^{\frac{1-\beta-\alpha}{\alpha}} Z^{\frac{\beta}{1-\alpha}},$$

where $\theta = \alpha^{\frac{1}{1-\alpha}} p^{\frac{1}{1-\alpha}} D^{\frac{1}{1-\alpha}} A^{-\frac{\alpha}{1-\alpha}}$. Differentiating the *clean good* production function above with respect to g results in:

$$(30) \quad \frac{\partial \ln y_c}{\partial \ln g} = \frac{1}{y_c} \left[\Omega \bar{L}B g^\Omega - \theta(x+k)^{\frac{1-\beta-\alpha}{\alpha}} \left(\frac{\beta}{1-\alpha} \right) Z^{\frac{\beta}{1-\alpha}} \frac{\partial \ln Z}{\partial \ln g} \right] > 0.$$

Since we derived $\partial \ln Z / \partial \ln g < 0$ from (26), we find that an increase in g will expand output in the clean sector. Lemma 2 summarizes the above results.

Lemma 2. An increase in g alters the composition of the economy towards the clean final good sectors and away from the dirty sector, thus the composition effect of the economy is pollution decreasing.

The Technique Effect

The technique effect refers to the emission intensity per unit of dirty output in the economy. The effect of g on the dirty input-to-output ratio is,

$$(31) \quad \frac{\partial \ln\left(\frac{z}{y_d}\right)}{\partial \ln g} = \frac{\partial \ln Z}{\partial \ln g} - \frac{\partial \ln y_d}{\partial \ln g}.$$

Using (26) and (21'), we simplify (31) as,

$$(31') \quad \frac{\partial \ln\left(\frac{z}{y_d}\right)}{\partial \ln g} = -\left(\frac{\gamma(1-t)w\mu}{\tau}\right) < 0.$$

We find that an increase in g decreases dirty input use as well as output in the dirty sector. Because the elasticity of dirty input to output is less than 1, the decline in dirty input is larger than dirty output with an increase in g . Thus, the technique effect decreases pollution levels.

Lemma 3. Increasing productive government expenditure reduces emissions intensity thus resulting in lower pollution levels through the technique effect.

Combining Lemma 1 through 3 leads to the following the central hypothesis.

The Central Hypothesis: *An exogenous reallocation of government expenditures towards productive instead of wasteful activities reduces production pollution via the composition and technique effects.*

2.2 Empirical Model

We estimate the effect of government expenditure composition on pollution levels by specifying an empirical model that controls various macroeconomic policies as well as proxy measures for the scale effect and technique effect. To derive the empirical model of estimation, we simplify and substitute for various variables in the demand for dirty inputs (10).

First, the actual pollution tax rate τ may deviate from the optimal tax rate τ^* due to political economy factors, P , or the growth rate of GDP, R . More transparent governments are likely to institute pollution regulations close to τ^* . Also, we hypothesize that the growth rate of GDP may have an impact on the ability of regulations to adjust to pollution levels. Countries that grow too

fast may not be able to adjust environmental regulations that control pollution levels. We assume that $\tau = a(P, R)\tau^*$, where $0 < a \leq 1$ is a constant. Next, we assume that the productivity index in the dirty sector is a function of trade policies (T) such that $D=D(T)$. More open economies may adopt more efficient technologies in the dirty sector. Lastly, output prices are dependent on total GDP, Y , such that $p=p(Y)$.

Substituting (20) into (10) along with our assumptions for D , τ , and p , we derive,

$$(32) \quad Z = \omega D(T)^{\frac{1}{1-\alpha-\beta}} p(Y)^{\frac{1}{1-\alpha-\beta}} (x+k) g^{\frac{\eta-\Omega\alpha}{1-\alpha-\beta}} a(P, R)^{\frac{1-\alpha}{1-\alpha-\beta}} c^{\frac{1-\alpha}{1-\alpha-\beta}}$$

where $\varpi = \alpha^{\frac{\alpha}{1-\alpha-\beta}} \beta^{\frac{1-\alpha}{1-\alpha-\beta}} B^{\frac{1-\alpha}{1-\alpha-\beta}} \gamma^{\frac{\alpha-1}{1-\alpha-\beta}}$. If we multiply the right hand side by $G^{\frac{\eta-\Omega\alpha}{1-\alpha-\beta}} / G^{\frac{\eta-\Omega\alpha}{1-\alpha-\beta}}$

where G is total government expenditure we can re-write (32) as,

$$(32') \quad Z = \varpi D(T)^{\frac{1}{1-\alpha-\beta}} p(Y)^{\frac{1}{1-\alpha-\beta}} (x+k) s^{\frac{\eta-\Omega\alpha}{1-\alpha-\beta}} G^{\frac{\eta-\Omega\alpha}{1-\alpha-\beta}} a(P, R)^{\frac{1-\alpha}{1-\alpha-\beta}} c^{\frac{1-\alpha}{1-\alpha-\beta}},$$

where $s=g/G$ is the share of public goods expenditure in total government expenditure. Assuming Cobb-Douglas functions for D , τ , and p and taking logs, we postulate the following empirical relationship:

$$(33) \quad \ln Z_{ict} = \gamma_1 s_{ct} + \gamma_2 P_{ct} + \gamma_3 \ln T_{ct} + \gamma_4 \ln Y_{ct} + \gamma_5 G_{ct} + \gamma_6 R_{ct} + \gamma_7 k_{ct} + \gamma_8 c_{ct} + \chi_i + \zeta_t + \mathcal{G}_{it},$$

where subscript i represents site, c represents country, and t represents time. Thus Z_{ict} is pollution concentration measured from site i in country c at year t ; s_{ct} is the share of public goods expenditure in total government expenditure; R_{ct} is GDP growth rate; c_{ct} is household income per capita; Y_{ct} is total GDP per land area; G_{ct} is government consumption expenditure over GDP; T_{ct} is an index of trade policy openness; k_{ct} is a the share of investment over GDP; P_{ct} is a political economy variable; χ_i is a country effect, ζ_t is the time effect, \mathcal{G}_{it} is a random disturbance with the usual desirable properties, and γ_j ($j=1, \dots, 8$) are parameters.

Several important comments regarding (33) are in order. We use annual dummies, ζ_t , to capture international shocks that may have a common effect on all countries in the sample such as world financial crises and international interest rates. The variable χ_i controls omitted variables as site-fixed or random effects such as climate, land quality and institutions that may affect pollution. We use household income per capita, c , and total GDP per land area, Y , as proxy measures for the technique effect and scale effect, respectively. This implies that the effect of the composition of government expenditure takes into consideration the composition effect since we do not control for it given data limitations.

3. The Data

Water and air quality measures are derived from the Global Environmental Monitoring System (GEMS) dataset which has been the most consistent data source for cross-country pollution.⁶ The air quality measures are currently compiled by the WHO Automated Meteorological Information System (AMIS) program. In this study, we use only the WHO-AMIS updated dataset from 1986 – 1999. We use site level air pollutant concentrations measures for sulfur dioxide (SO₂) and lead since they are main production pollutants from the energy sector and steel and iron manufacturing sector, respectively.⁷ Taking SO₂ as an example, there are about 2156 observations distributed in 120 cities with about 2.5 measurement sites per city per year on average. The total number of countries included in the sample is 38 of which 19 are low and middle income and 19 are considered developed according to the World Bank classification.

⁶ The air quality database is sponsored by the World Health Organization (WHO) and maintained by the Environmental Protection Agency (EPA) while the water quality database is maintained by GEMSWater. The original air quality dataset utilized by Grossman and Krueger (1995) has been updated to GEMS/AIRS resulting in two GEMS datasets which were cleaned and combined by Harbaugh et al. (2002) for the years 1971 to 1992. However, in their study they do not explicitly explain how they combine the data when both datasets have differing observations.

⁷ The National Ambient Air Quality Standard lists six common air pollutants: sulfur dioxide, nitrogen dioxide, lead, ozone, particulate matter and carbon monoxide (EPA, 2007a). Nitrogen dioxide, ozone, particulate matter and carbon monoxide are more likely to be consumption pollutants since they arise from the use of transportation vehicles. Thus, we use only sulfur dioxide and lead.

We use data from GEMS-water for the period 1980-2005 for two water quality measures: dissolved oxygen (DO) and biological oxygen demand (BOD). Dissolved oxygen refers to oxygen freely available in water, vital to fish and other aquatic life and for the prevention of odors. Thus, high DO content indicates better water quality. These data are actual measurement of water quality from various groundwater, wetland, rivers or lakes in fixed sites. Using dissolved oxygen as an example, there are 5020 observations per pollutant distributed in 702 sites. The countries are listed in the appendix.

Government expenditures data is obtained from the Government Financial Statistics database compiled by the IMF and, in some cases, we used data from the Asian Development Bank. Public goods expenditures include expenditures in education, health, social protection, transport, communications, public order and safety, research and development, environment, recreation and culture, and social housing. Table A1 in the appendix presents summary statistics of the data. Data source and descriptions are in Table A2 in the appendix.

4. Results

We present Ordinary Least Squares (OLS), Fixed Effects, Random Effects and Hausman Taylor Random Effects (HTRE) estimates of air and water quality indicators based on the specification in (33).⁸ Fixed Effects and Random Effects models take into consideration the heterogeneous characteristics across countries. The underlying assumption in the Fixed Effects model allows endogeneity in all regressors and individual effects while in the Random Effects Model exogeneity is assumed. Alternatively, we relax the all or nothing choice of endogeneity with regressors by estimating a Hausman Taylor Random Effects (HTRE) model that assumes some

⁸ Several variations of Fixed Effects and Random Effects were estimated including with and without year effects, with and without site characteristics, and with and without political variables. We also estimate One Way Fixed Effects. Results are available upon request.

of the regressors are correlated with the individual effects in the air and water pollutants regressions. We also probe the robustness of our coefficients using different specifications.⁹

The first two columns of Tables 1 through 4 present the coefficient estimates of the determinants of different air pollutants. The goodness-of-fit of the model is satisfactory as shown by the adjusted R-squared and significant coefficients. We correct for any potential autocorrelation and heteroskedasticity by estimating the standard errors of the coefficients using the Huber / White / Sandwich estimator of variance. The Hausman tests rejects the assumption that all regressors are endogenous indicating that Fixed Effects are preferred over Random Effects. However, the Hausman test is in favor of HTRE.

We find a negative and significant effect for the share of public goods on SO₂ and lead concentrations in all specifications. When we take into consideration heterogeneous characteristics across countries, the impact of the share of public goods expenditures in reducing lead concentrations are larger than SO₂ concentrations. The estimates from the HTRE model suggest an elasticity of share of public goods expenditure on pollution in the magnitude of -0.396 and -0.720 for SO₂ and lead, respectively. This implies a 10% reallocation of expenditures from private subsidies to public goods expenditure holding total public expenditure constant, would result in a 4% decrease in SO₂ concentration and 7% decrease in lead concentrations. In contrast, the share of overall government consumption expenditure relative to Gross Domestic Product is smaller and less significant.

The last two columns of Tables 1 through 4 present the results for water quality and water pollutants. For dissolved oxygen (DO) and Biological Oxygen Demand (BOD), the share of government expenditures in public goods is significant and reduces (increases) water pollution

⁹ The results presented in tables 1 through 5 do not change with inclusion of Tax over GDP, and Foreign Direct Investment.

(quality) in all estimations apart from TWFE where the sign is correct but insignificant. Using estimate from HTRE, a 10% reallocation of expenditures from private subsidies to public goods expenditure holding total public expenditure constant, would result in a 0.2% increase in water quality as measured by dissolved oxygen concentration and a 1% decrease in BOD.

Using the estimates from HTRE, we performed a simulation of the effect of changes in the share of public goods on the air and water quality measures. Increasing the share of public goods by one standard deviation (about 27% of the sample mean) reduces SO₂ concentrations by 8% of its standard deviation (11% of the sample mean), lead by 12% of its standard deviation (or 20% of the sample mean), and BOD concentration by 1% of its standard deviation (or 4% of the sample mean) while increasing dissolved oxygen level by about 2% of its standard deviation (or 0.5% of the sample mean) .

The size of the government, as measured by the share of government consumption expenditure in GDP, consistently significantly decreases SO₂ and lead while increasing water quality as measured by DO. This particular result lends some support to theories that governments do provide public goods and correct for externalities instead of adding to market inefficiencies through added bureaucracy and policy distortions. Our results are also in contrast with the empirical findings of Bernauer and Koubi (2006) where they find an increase in government spending by 1% leads to a 1.70% to 2.88% increase in SO₂ concentrations. We find that increasing government expenditure by 1% leads to a *reduction* in SO₂ emissions from 0.38% to 0.48%. The differences in sign is likely due to the lack of control of heterogeneous country characteristics which biases coefficient estimates since Bernauer and Koubi use regular OLS in their panel estimation.

We are able to measure the technique effect, output scale effect and growth rate effects on pollution levels. Per capita household income has a significant and negative effect for SO₂ and significant and positive effect for DO for all specifications. We derive relatively inelastic income elasticities that range from -0.126 to -0.811 for SO₂. These estimates are lower than those derived by Antweiler et al. (2001) where they derive estimates between -0.9 to -1.5 for SO₂. To the extent that government expenditures are positively correlated with household income, the omission of the former in the regression could bias estimates upward in magnitude which could explain the disparity in coefficient estimates between the two models. The output scale effect, as proxied by GDP per land area, is positive and significant for SO₂ and BOD and negative and significant for DO in all estimations. Lastly, the growth rate effect is consistently positive and significant for lead and to a lesser extent, SO₂, as we hypothesized.

We can use the coefficients relating to the scale and technique effect to investigate the impact of growth on pollution. The scale and technique effects are not implausibly high. If we assume a 1% technologically neutral growth in the economy that does not change economic composition, this would raise GDP in the economy by 1%. Based on estimates from Table 4 for SO₂, the scale effect dominates the technique effect. However, reallocation towards public goods expenditure could help counteract the scale effect on pollution levels because it changes the composition of the economy away from production of dirty goods to clean goods. A reallocation towards public goods expenditure which alters economic composition along with the technique effect counteracts the scale effect on pollution leading to an increase in environmental quality.

The political economy variables generally have a negative effect on pollution when significant. This result is consistent with the notion that political economy factors are important in determining the emergence of institutions that regulate pollution levels. Particularities of the

political system, the degree of participation of the civil society in monitoring governments (Li et al, 1998, White and Anderson, 2001, Lundberg and Squire, 2003, Dollar and Kray, 2002), freedom of the press (Chong and Grandstein, 2004, Arimah, 2004) are some of the politico-economy factors that appear to play a role in improving social welfare and subsequently improving environmental quality.

5. Conclusion

This paper presents the first attempt at highlighting the importance of the composition of public goods expenditure in determining the air and water quality. Reallocating government expenditure towards the provision of public goods and correction of externalities while reducing private subsidies could improve environmental quality. An increase in the share of public goods in total government expenditure decreases significantly the concentration of lead and SO₂ in the atmosphere while improving water quality as measured by DO and decreasing BOD concentrations. Policies that induce economic growth can lead to a decrease in pollution emissions as long as the scale effect is offset by the technique effect and composition effect. Policies that promote stable political regimes also improve environmental quality.

One interesting avenue for future research is to extend the model to other pollutants. A possibility may occur where institution of stringent regulations on a particular pollutant will lead to a substitution away from the regulated pollutant to an unregulated pollutant. Regulation-induced pollution substitution in particular industries and how the composition of government expenditure mitigates these emissions to the environment is an important study area to investigate. Also, we focused our theoretical and empirical analysis on production pollutants. It would be interesting to extend the model to examine how consumption pollutants are affected by the size and composition of public expenditure.

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Table 1. Determinants of Air and Water Pollutants using OLS. Dependent Variables are in Logs

	Air Pollutants		Water Quality	Water Pollution
	SO2	Lead	Dissolved Oxygen	Biological Oxygen Demand
Log Share of public goods (as % of total govt exp)	-1.342*** [0.094]	-1.236*** [0.206]	0.095*** [0.022]	-0.247*** [0.040]
Log Share of government cons exp over GDP – Penn Tables	0.200* [0.118]	-1.244*** [0.245]	0.130*** [0.027]	-0.281*** [0.101]
Log of Household final consumption expenditure per capita (2000 US\$) average of current and previous two years	0.178*** [0.032]	0.316*** [0.065]	0.038*** [0.014]	-0.053* [0.032]
Log of Total GDP (2000 US\$) over land area (sq. km)	0.190*** [0.020]	-0.217*** [0.036]	-0.020*** [0.004]	0.284*** [0.015]
Growth rate of GDP	-0.517 [0.695]	5.901*** [1.279]	-0.102 [0.198]	-0.828* [0.502]
Trade – Asati Index	-0.003*** [0.001]	-0.003 [0.002]	-0.0018*** [0.0002]	0.007*** [0.001]
Log of Share of Investment over GDP	0.056 [0.099]	-1.125*** [0.166]	0.111*** [0.020]	-0.456*** [0.055]
Dummy Freedom of Press	-0.645*** [0.066]	0.083 [0.150]	0.038* [0.021]	0.120** [0.055]
Polity 2	-0.083*** [0.007]	-0.033** [0.014]	0.006*** [0.002]	0.003 [0.005]
Years of Democratic Stability	-0.061*** [0.007]	-0.111*** [0.016]	0.011*** [0.002]	-0.124*** [0.005]
Socialist Dummy 1986-1992	0.218 [0.282]	1.393*** [0.188]	-0.232 [0.276]	0.016 [0.130]
Former Socialist Dummy	-0.361*** [0.106]	-0.767*** [0.201]	0.078 [0.179]	0.103 [0.097]
City Center Dummy	0.109** [0.052]	0.216* [0.120]		
Other Urban Dummy	0.080* [0.048]	0.142 [0.104]		

Traffic Dummy	0.305*** [0.083]	1.847*** [0.136]		
Rural Dummy	-0.971*** [0.081]	-1.175*** [0.159]		
Dummy for Groundwater			-0.347*** [0.051]	-0.852*** [0.145]
Dummy for Lake			0.231*** [0.041]	-0.455*** [0.149]
Dummy for River			0.092** [0.037]	-0.13 [0.137]
Water Temperature			-0.145*** [0.034]	0.198*** [0.056]
Constant	0.014 [0.374]	-6.083*** [0.642]	2.662*** [0.160]	-3.658*** [0.327]
Observations	2057	688	4799	3810
Adjusted R-squared	0.44	0.3	0.34	0.44

Robust standard errors in brackets; * significant at 10%; ** significant at 5%; *** significant at 1%*

Table 2: Determinants of Air and Water Pollutants Using Two Way Fixed Effects (TWFE) with Political Economy Controls. Dependent Variables are in Logs.

	Air Pollutants		Water Quality	Water Pollution
	SO2	Lead	Dissolved Oxygen	Biological Oxygen Demand
Log Share of public goods (as % of total govt exp)	-0.363*** [0.078]	-0.605*** [0.131]	0.012 [0.013]	-0.126*** [0.034]
Log Share of government cons exp over GDP – Penn Tables	-0.380* [0.209]	-1.010* [0.520]	0.096 [0.066]	0.531** [0.211]
Log of Household final consumption expenditure per capita (2000 US\$) average of current and previous two years	-0.811** [0.333]	1.523* [0.801]	0.280*** [0.086]	-0.299 [0.198]
Log of Total GDP (2000 US\$) over land area (sq. km)	1.006*** [0.268]	0.831 [0.595]	-0.206*** [0.070]	0.502*** [0.150]
Growth rate of GDP	0.227 [0.410]	1.843** [0.818]	0.119 [0.125]	-0.178 [0.338]
Trade – Asati Index	-0.001 [0.001]	0.009** [0.004]	0.0003 [0.0006]	0.005*** [0.002]
Log of Share of Investment over GDP	0.285*** [0.110]	-0.036 [0.236]	0.034 [0.036]	-0.456*** [0.091]
Dummy Freedom of Press	-0.142*** [0.041]	-0.158 [0.099]	0.0005 [0.0163]	0.118*** [0.041]
Polity 2	-0.011 [0.011]	-0.075*** [0.017]	-0.0001 [0.0014]	0.0005 [0.0057]
Years of Democratic Stability	-0.005 [0.037]	0.142*** [0.053]	-0.01 [0.007]	-0.147*** [0.031]
Socialist Dummy 1986-1992	-0.271** [0.110]	-0.369 [0.241]	-0.048 [0.032]	0.014 [0.076]
Water Temperature			-0.017 [0.019]	-0.046 [0.040]
Observations	2057	688	4799	3810
Adjusted R-squared	0.28	0.69	0.01	0.1

Robust standard errors in brackets. Estimates include constant and year dummies not shown.

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 3: Determinants of Air and Water Pollutants Using Random Effects with Site Characteristics and Political Controls. Dependent Variables are in Logs.

	Air Pollutants		Water Quality	Water Pollution
	SO2	Lead	Dissolved Oxygen	Biological Oxygen Demand
Log Share of public goods (as % of total govt exp)	-0.421*** [0.061]	-0.879*** [0.136]	0.025* [0.013]	-0.137*** [0.029]
Log Share of government cons exp over GDP – Penn Tables	-0.483*** [0.168]	-0.790*** [0.302]	0.122*** [0.039]	0.162 [0.147]
Log of Household final consumption expenditure per capita (2000 US\$) average of current and previous two years	-0.126** [0.055]	0.288*** [0.104]	0.128*** [0.019]	-0.102** [0.047]
Log of Total GDP (2000 US\$) over land area (sq. km)	0.189*** [0.041]	-0.083 [0.060]	-0.044*** [0.008]	0.308*** [0.033]
Growth rate of GDP	0.823** [0.350]	2.732*** [0.735]	0.061 [0.113]	-0.287 [0.322]
Trade – Asati Index	0.0005 [0.0012]	0.001 [0.002]	-0.001*** [0.000]	0.007*** [0.001]
Log of Share of Investment over GDP	0.162* [0.096]	-0.431** [0.182]	0.122*** [0.039]	0.162 [0.147]
Dummy Freedom of Press	-0.254*** [0.041]	-0.207** [0.090]	0.021 [0.015]	0.081** [0.037]
Polity 2	-0.025*** [0.008]	-0.056*** [0.013]	0.001 [0.002]	0.002 [0.005]
Years of Democratic Stability	-0.064*** [0.012]	-0.082*** [0.024]	0.001 [0.004]	-0.112*** [0.011]
City Center Dummy	0.057 [0.105]	0.286 [0.234]		
Other Urban Dummy	-0.041 [0.121]	0.348 [0.221]		
Traffic Dummy	0.453** [0.218]	1.519*** [0.240]		
Rural Dummy	-0.713*** [0.158]	-0.573** [0.248]		

Dummy for Groundwater			-0.439*	-0.605
			[0.229]	[0.719]
Dummy for Lake			0.122	-0.318
			[0.211]	[0.719]
Dummy for River			0.036	0.039
			[0.208]	[0.697]
Water Temperature			-0.027	-0.015
			[0.019]	[0.036]
Observations	2057	688	4799	3810
No. of Sites	298	126	692	503
Hausman Test (P-value)	0.0000	0.0000	0.0000	0.0000
Overall R-squared	0.42	0.30	0.29	0.44

Robust Standard errors in brackets. Estimation includes constant, year, socialist and former socialist dummies not shown.

* significant at 10%; ** significant at 5%; *** significant at 1%

Table 4: Determinants of Air and Water Pollutants Using Hausman Taylor Random Effects with Site Characteristics and Political Controls. Dependent Variables are in Logs.

	Air Pollutants		Water Quality	Water Pollution
	SO2	Lead	Dissolved Oxygen	Biological Oxygen Demand
Log Share of public goods (as % of total govt exp)	-0.396*** [0.073]	-0.720*** [0.133]	0.019* [0.012]	-0.135*** [0.031]
Log Share of government cons exp over GDP – Penn Tables	-0.381** [0.154]	-0.572* [0.313]	0.097* [0.051]	0.325** [0.153]
Log of Household final consumption expenditure per capita (2000 US\$) average of current and previous two years	-0.223** [0.093]	0.990*** [0.285]	0.135*** [0.024]	-0.073 [0.060]
Log of Total GDP (2000 US\$) over land area (sq. km)	0.290*** [0.077]	0.457** [0.221]	-0.053*** [0.017]	0.329*** [0.044]
Growth rate of GDP	0.580* [0.334]	1.767*** [0.666]	0.042 [0.106]	-0.174 [0.315]
Trade – Asati Index	0.001 [0.001]	0.008** [0.003]	-0.001* [0.000]	0.006*** [0.001]
Log of Share of Investment over GDP	0.355*** [0.094]	-0.024 [0.188]	0.023 [0.028]	-0.446*** [0.079]
Dummy Freedom of Press	-0.189*** [0.037]	-0.189** [0.079]	0.019 [0.013]	0.089** [0.037]
Polity 2	-0.016* [0.010]	-0.077*** [0.015]	-0.0001 [0.0017]	0.002 [0.005]
Years of Democratic Stability	-0.044** [0.022]	0.045 [0.044]	-0.001 [0.005]	-0.129*** [0.014]
City Center Dummy	-0.064 [0.226]	-0.285 [0.866]		
Other Urban Dummy	-0.107 [0.248]	1.13 [0.939]		
Traffic Dummy	0.293 [0.912]	0.093 [2.845]		
Rural Dummy	-0.802 [1.600]	-2.671 [3.951]		

Dummy for Groundwater			-0.481 [0.613]	-0.932 [1.161]
Dummy for Lake			0.078 [0.612]	-0.641 [1.160]
Dummy for River			0.003 [0.607]	-0.267 [1.141]
Water Temperature			-0.019** [0.008]	-0.033 [0.021]
Observations	2057	688	4799	3810
No. of Sites	298	126	692	503
Hausman Test (P-value)	1.0000	0.1621	0.9855	0.9999

Robust Standard errors in brackets. Estimation includes constant, year, socialist and former socialist dummies not shown.

* significant at 10%; ** significant at 5%; *** significant at 1%

APPENDIX

Appendix 1. Relationship between various input elasticities in the model.

- The elasticity of government-provided input for clean goods and human capital to be equal, i.e. $\mu = \Omega$.

Recall that the elasticity effective labor in the clean sector is equal to one,

$$\frac{dy_c}{dh} \frac{h}{y_c} = 1. \text{ Using chain rule, we obtain}$$

$$\frac{dy_c}{dg} \frac{dg}{dh} \frac{h}{y_c} \frac{g}{g} = 1. \text{ Rearranging terms,}$$

$$\frac{dy_c}{dg} \frac{g}{y_c} \bigg/ \frac{dh}{dg} \frac{g}{h} = 1. \text{ Since, } \Omega \equiv \frac{dy_c}{dg} \frac{g}{y_c} \text{ and } \mu \equiv \frac{dh}{dg} \frac{g}{h} \text{ we have } \Omega = \mu.$$

- The elasticity of human capital in dirty goods is equal to ratio of government-provided input for dirty goods and human capital, i.e. $\alpha = \eta/\mu$.

$$\text{We have } \eta/\mu = \frac{dy_d}{dg} \frac{g}{y_d} \bigg/ \frac{dh}{dg} \frac{g}{h}. \text{ Rearranging,}$$

$$\eta/\mu = \frac{dy_d}{dg} \frac{g}{y_d} \frac{dg}{dh} \frac{h}{g}. \text{ Simplifying and using the chain rule,}$$

$$\eta/\mu = \frac{dy_d}{dh} \frac{h}{y_d}. \text{ Thus,}$$

$$\eta/\mu = \alpha.$$

Note that since $\Omega = \mu$ and $\alpha = \eta/\mu$ we obtain $\alpha\Omega - \eta = 0$.

Appendix 2. Deriving Cost Function

Take ratio of (6) over (7)

$$(A1) \frac{\tau}{w} = \frac{\beta h l_d}{\alpha Z} \text{ therefore}$$

$$h l_d = \frac{\tau}{w} \frac{\alpha}{\beta} Z. \text{ Substituting (A1) into (8) we derive:}$$

$$y_d = D \left(\frac{\tau}{w} \frac{\alpha}{\beta} Z \right)^\alpha Z^\beta (x+k)^{1-\alpha-\beta} g^\eta. \text{ Solving for } Z,$$

$$(A2) Z = \left[\frac{1}{D} \left(\frac{\alpha}{\beta} \right)^{-\alpha} w^\alpha \tau^{-\alpha} g^{-\eta} (x+k)^{\beta+\alpha-1} y_d \right]^{\frac{1}{\alpha+\beta}}.$$

Substituting (A2) into (A1), we obtain,

$$(A3) h l_d = \left[\frac{1}{D} \left(\frac{\alpha}{\beta} \right)^\beta w^{-\beta} \tau^\beta (x+k)^{\beta+\alpha-1} g^{-\eta} y_d \right]^{\frac{1}{\alpha+\beta}}.$$

Using (A2) and (A3) in the objective function we derive the following cost function,

$$C = D^{\frac{1}{\alpha+\beta}} (\alpha / \beta)^{\frac{\beta}{\alpha+\beta}} (1 + \beta / \alpha) y_d^{\frac{1}{\alpha+\beta}} (x+k)^{\frac{\alpha+\beta-1}{\alpha+\beta}} g^{-\frac{\eta}{\alpha+\beta}} w^{\frac{\alpha}{\alpha+\beta}} \tau^{\frac{\beta}{\alpha+\beta}}.$$

Table A1: Summary Statistics of the Data Used in Regressions

	Mean	Std. Dev	Min	Max
Sulfur Dioxide (SO2)	39	53.1	0.2	774
Lead	0.3	0.5	0.005	4.5
Dissolved Oxygen	8.5	2.7	0.03	84.7
Biological Oxygen Demand	4.3	19	0.01	604.0
Household final consumption expenditure per capita (2000 US\$) moving average of current and previous two years	5152	5247.2	111.2	22223.2
GDP growth (2000 US\$)	0.03	0.05	-0.32	0.15
Share of public goods (as % of total govt exp)	0.55	0.15	0.20	0.88
GDP Per Square Km	1,268,455	2,108,234	11,954	12,200,000
Share of Govt. Exp. over GDP	0.22	0.07	0.07	0.55
Share of Investment over GDP	0.18	0.075	0.029	0.441

Country List of Pollution Data Availability*Countries with Air Pollution Data:*

Argentina, Australia, Austria, Belgium, Brazil, Bulgaria, Canada, Chile, China, Costa Rica, Croatia, Denmark, Ecuador, Estonia, Finland, France, Germany, Greece, Hungary, India, Japan, Latvia, Lithuania, Mexico, New Zealand, Philippines, Portugal, Republic of Korea, Romania, South Africa, Spain, Sweden, Switzerland, Thailand Turkey, United Kingdom, United States, Uruguay

Countries with Water Pollution Data

Argentina, Australia, Austria, Bangladesh, Belgium, Brazil, Canada, Chile, China, Colombia, Denmark, Egypt, Fiji, Finland, France, Germany, Greece, Hungary, India, Indonesia, Ireland, Iran, Italy, Japan, Malaysia, Mexico, Morocco, Netherlands, New Zealand, Norway, Pakistan, Panama, Peru, Philippines, Poland, Portugal, Republic of Korea, Russia, Spain, Sweden, Switzerland, Thailand, Tunisia, Turkey, United States, United Kingdom, Uruguay

Table A2. Description of Variables

Variable	Description	Years Available	Source
Sulfur Dioxide (SO ₂)	SO ₂ concentration, micrograms per cubic meter	1986-1999	GEMS
Lead	Lead, micrograms per cubic meter	1986-1999	GEMS
Biological Oxygen Demand	Quantity of oxygen necessary for biological and chemical oxidation of water-borne substances in milligrams per liter.	1980-2005	GEMSWater
Dissolved Oxygen	Oxygen concentration in milligrams per liter	1980-2005	GEMSWater
Household final consumption expenditure per capita (2000 US\$) (3 year moving average)	Household final consumption expenditure (formerly private consumption) is the market value of all goods and services, including durable products (such as cars, washing machines, and home computers), purchased by households. It excludes purchases of dwellings but includes imputed rent for owner-occupied dwellings. It also includes payments and fees to governments to obtain permits and licenses. Here, household consumption expenditure includes the expenditures of nonprofit institutions serving households, even when reported separately by the country.	1980 – 2004	World Development Indicators (World Bank)
GDP growth (2000 US\$)	Real GDP per Capita growth (Constant US\$ 2000)	1980 – 2004	World Development Indicators (World Bank)
Share of Govt. Exp. in Public Goods	This is the share of government expenditure on public goods. Public goods are defined as a total of Public Goods is the total of: i) Education ii) Health iii) Social security iv) Transport v) Communication vi) Public order and safety vii) Housing and community amenities viii) Environmental Protection ix) Religion and Culture	1980 – 2004	Government Financial Statistics (IMF), Asian Development Bank, Country data Level of government: Consolidated central government is the level of government used apart from: Budgetary: Bangladesh, Ecuador, Greece Jordan New Zealand, Philippines Consolidated General: India
Trade Openness	Sati index which is the residual of the regression of Trade on population, area, gdp per capita, dummy for industrialized country, dummy for oil exporter, and imports over export prices. A positive residual implies a more open economy	1980-2001	Pritchett, Lant. 1996. Updated by López and Galinato (2007)
GDP Per Square Km	Total GDP (2000 US\$) over land area	1980-2004	World Development Indicators (World Bank)
Foreign Direct Investment over GDP	Foreign direct investment are the net inflows of investment to acquire a lasting management interest (10 percent or more of voting stock) in an enterprise operating in an economy other than that of the investor. It is the sum of equity capital,	1980-2005	World Development Indicators (World Bank)

	reinvestment of earnings, other long-term capital, and short-term capital as shown in the balance of payments. This series shows net inflows in the reporting economy and is divided by GDP.		
Share of Govt. Exp. over GDP		1980 – 2004	Penn World Tables (2006)
Share of Investment over GDP		1980 – 2004	Penn World Tables (2006)
Polity Index (Polity 2)	Score that indicates how democratic is a country	1980-2003	Polity IV www.cidcm.umd.edu
Years of Democratic Stability	Square root of Durability of Polity if Polity 2>0	1980-2005	From Polity IV and updated to 2005 www.cidcm.umd.edu
Dummy Freedom of Press	1 if print media is considered free	1980-2005	www.freedomhouse.org