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Abstract

This paper analyses interrelationships between 'economic development', 'health', and 'environment' in a simultaneous equations framework. Four structural equations have been postulated to explain changes in four endogenous variables in terms of several predetermined variables. The endogenous variables chosen for the model are GDPPC (per capita gross domestic product), LE (life expectancy), NOCRD (number of cases of respiratory diseases) and PM10 (respirable suspended particulate matter). We assume that GDPPC describes economic development prominently and, therefore, use it as one of the endogenous variables in lieu of economic development. LE and NOCRD are assumed to reflect health effects in the economy, and PM10 is used as a proxy of environmental stress. The four endogenous variables are supposed to be jointly determined in terms of several exogenous variables represented through indices of physical infrastructure (PI), social infrastructure (SI) and air pollution index (API). We construct the three indices by the principal components method and thus effectively use only these three predetermined (exogenous) variables to simultaneously determine changes in the four endogenous variables listed above. The model is postulated in loglinear form and estimated by the two-stage least-squares method using data from the Indian economy 1980-81 to 2004-05.

It follows from the estimated structural equations that while physical infrastructure is significant in determining GDPPC, the GDPPC is also directly influenced by improved health outcomes like longevity (LE) and lower morbidity from respiratory diseases (NOCRD). The long term health outcome (LE) is determined by the level of per capita GDP and it is positively affected by social infrastructure. The third structural equation shows that the immediate, or short run, health outcomes like morbidity from respiratory disorders are influenced by environmental stress (PM10) besides the level of GDPPC. Finally, the environmental stress (PM10) is determined by the level of per capita GDP and the air pollution index (API) representing various sources of air pollution.

It is true that our simplified model illustrates the effects of specific type of air pollutant, *viz*., respirable particulate matter, however, it is among the most significant environmental problems threatening human health in India. Nevertheless, there is scope to build more comprehensive environmental stress indices which reflect

surface water quality, ground water quality, soil pollution etc. which have feedback effects with health and economic development. Also many of the components of PI, SI and API may not be truly exogenous in a larger model (e.g. transport and communication in PI, education and health care systems in SI, and industrial production, vehicular traffic, urbanisation in API.) The two weaknesses of our model stem from data limitation and a concern to simplify the model.

Although our model is highly simplified, nonetheless, it provides key insights into the nature of economic development in India during the last 25 years: First, the environmental stress has had a high cost on income and health — from the derived reduced form, a 1 percent increase in the air pollution index leads to a decrease of about 8 percent in the per capita income, a decrease of about 0.7 percent in the life expectancy, and an increase of about 19 percent in the number of cases of respiratory diseases. Second, the social infrastructure plays a more vital role in economic development, health, and environment than the physical infrastructure, since the absolute values of elasticities of endogenous variables with respect to SI are invariably greater than those with respect to PI. Although physical infrastructure is important for economic development, it comes in the last of our preference order. In the final run-up, there is need to pay more attention to provide better social infrastructure and to reduce air pollution.

The Interface between Economic Development, Health and Environment in India : An Econometric Investigation

Introduction

Economic development and health and environment are mutually interrelated. While improvement in the health status of the people raises their productivity level and income, economic development provides amenities for improvement of health care systems in addition to environmental amenities like clean air, water, and nature parks associated with improved life-styles. However, the process of economic development is invariably linked with growth of industries, changes in agricultural patterns, technological innovations, changes in consumption patterns, urbanisation, etc., which lead to environmental degradation due to emissions of various kinds of hazardous gases and waste disposals from industries and households. Air, water, and land pollution, as also largescale deforestation adversely affect human health and productivity levels of individuals, and eventually economic development.

While the relationships between economic development and environment, development and health, and health and environment, have been individually addressed in the literature in a bi-causal manner, much of these studies do not adopt a comprehensive simultaneous equation framework to analyse how economic development interfaces with health and environment in an interactive manner for a single economy over time. This paper is an attempt to estimate such a simultaneous relationship between these three variables with the help of a structural model for the Indian economy for 1980-81 to 2004-05.

The paper is organised as follows: Section 2 provides a brief literature review and develops a conceptual framework for our study based on the existing literature. Section 3 describes our model, the methodology, variables and data sources. Section 4 summarises the results and analysis, and Section 5 concludes.

II. Literature Review and Conceptual Framework

There is a vast theoretical as well as empirical literature focusing on health as a determinant of economic growth as well as on the impact of economic growth on health. This literature indicates a strong positive relationship between health and economic growth and prosperity. The theoretical foundation of these relationships may be traced back to the endogenous growth models that highlight the importance of human capital in explaining growth trajectories (Barro, 1991; Lucas, 1988). However for a long time, education and technical skills were considered the primary indicators of human capital. Health as an important productivity augmenting factor that contributes to economic growth was explicitly recognised only in the 1990s (Barro, 1991; Fogel, 1994; Schultz, 1997). The empirical literature, establishing the positive relationship between health and growth, is based on evidence at both macro levels (Barro and Lee, 1996; Benhabib and Speigel, 1994; Bhargava *et. al*, 2001; Bloom *et al.,* 2004) as well as micro levels (Dinda *et. al.,* 2006, Glick and Sahn, 1998). Of course, there is another strand of argument that takes into account ageing of population as a consequence of better health, may adversely affect economic growth. Therefore, an inverted U-shaped relationship between life-expectancy and economic growth has been suggested by Cipriani (2000); Croix and Licardro (1999); Zang *et. al.,* (2001).[i]

Similarly, an inverted U-shaped relationship between economic growth and environment has been investigated extensively, popularly called the Environmental Kuznets Curve (EKC). The EKC indicated that as GDP per capita increases, the increase in demand for environmental quality (termed *income effect of growth*) and more stringent environmental regulation and enforcement (termed *regulatory effect*) offset the degradation experienced with economic growth. The EKC studies have differed based on the type of pollution under consideration. For, local environmental problems like inadequate sanitation and clean water, indoor air pollution (from biomass burning), land degradation are associated with lack of economic development or lower levels of income per capita. However, other environmental problems including atmospheric particulate matter, sulphur oxides, and water pollution (in terms of metal contamination, biological and chemical oxygen demand), the pollution were found to increase with increase in per capita income, but beyond a critical level of income the pollutant concentrations fell off. Moreover, with economic growth, as the relative significance of the underlying production structure shifted away from heavy industries towards the service sector (termed *composition effect*), the traditional air and water pollution reduced.[ii] These EKC studies have covered cross-national data rather than mapping a single economy through time (*see survey* Stern, 2004).

Among the country-specific studies testing the EKC hypothesis, a recent study for India (Mukherjee and Kathuria, 2006) showed that the trade-off between economic growth and environmental quality has been markedly different across the different states during the 1990s. Instead of using a specific environmental pollutant or resource, Mukherji and Kathuria (2006) construct a composite Environmental Quality Index that is enumerated for two time points (pre-and post-liberalisation years) for 14 major Indian states which are used to test the EKC hypothesis. Their result does not support the EKC hypothesis, and suggests that economic growth has mostly been at the cost of environmental quality in the high growth states.

There are a few macro studies on health and growth in the Indian context. World Bank (2004) found that per capita GDP is inversely related to infant mortality rates; Gupta and Mitra (2003) analysed the relationship between health, poverty, and economic growth in India based on data from fifteen major Indian states and established a two-way positive relationship between growth and health. Mahal (2005) found a strong positive impact of per capita income on health status (life expectancy and infant mortality rate) and also established the reverse causality, namely a positive and significant influence of life expectancy on state level domestic product.

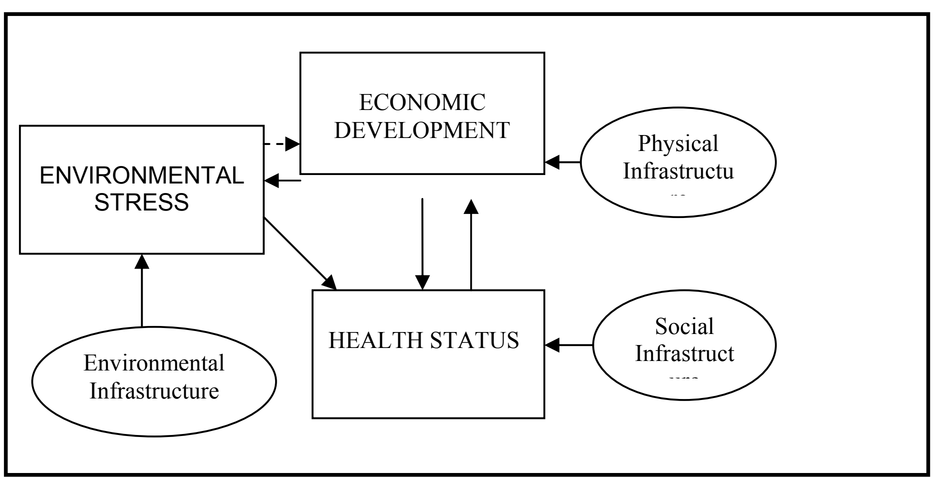
Among the micro studies on health and environment in India, particulate air pollution has attracted much attention as it is a major environmental problem in India and poses serious health hazards. In the city of Delhi, a positive significant relationship was found between particulate pollution on traumatic deaths and deaths from respiratory and cardiovascular problems (Cropper *et. al.,* 1997). Air-borne solid and liquid particles dispersed in the air lead to particulate pollution and the size of the particulate matter is an important physical characteristic as it determines the time for how long the particulates remain suspended in the atmosphere and the extent of health impact (CPCB, 2000). Since these small particles tend to enter the lungs more readily, they cause higher incidence of morbidity as also premature mortality. In our study here, we consider respirable particulate pollution to be responsible for morbidity that impacts human productivity and hence national output.

One study that attempts to integrate health outcomes with economic growth and environmental quality in an extended EKC framework is Gangadharan and Valenzuela (2001), which tested an extended EKC hypothesis after adding health outcome as a function of income growth, environmental quality, and social factors. Their results showed that environmental stress bears significant negative effect on health status while gross national product varies positively with health status. Environmental quality or stress in the model was represented by emission of air pollutants[iii], organic water pollutants, commercial energy use and deforestation; while health outcomes were measured through life expectancy and infant mortality rates. In their 2SLS model, environmental stress and health status of the population are the only two endogenous variables, while economic growth along with non-income factors affecting environment and factors affecting health are treated as exogenous variables.

2.1 Conceptual Framework

Ideally, one should conceptualise a simultaneous equations framework which enables measurement of feedback effects and establishes interdependence of economic development, health, and environment. We represent this mutual interdependence in terms of the following schematic diagram, with endogenous variables in squares and exogenous variable in circles.

Diagram: 1



We consider physical, social, and environmental infrastructure to be the key underlying exogenous drivers of the three endogenous variables – development, heath status and environmental stress – interfacing and interacting with each other. It is pertinent to note here that since economic growth both depends and determines environmental, physical and social infrastructure, it is difficult to term these as truly "exogenous". For instance the availability and quality of water determines economic growth (through agricultural growth), and in turn the extent and nature of economic growth determines the quantity and quality of water.[iv] While physical infrastructure directly affects development, social infrastructure is expected to influence health status, which in turn affects development. Indeed, development also affects health status in a simultaneous equation framework. Environment (or environmental stress) affects both health and development; and development in turn, is expected to affect the level of environmental stress, which is also a function of environmental infrastructure.

Economic development, health and environment are, in fact, **composite** variables which cannot be described in terms of any one single variable. For example, economic development may be described in terms of macroeconomic indicators such as per capita GDP and/ or its rate of growth as well as other structural variables like volume of employment and trade or the share of agriculture/ manufacturing/ services in GDP. The health status of the people may be described in terms of mortality/morbidity rates, life expectancy, etc; and environmental stress may be described in terms of air and water quality in the country, the magnitude of forest cover or, the level of deforestation.

As depicted in the schematic diagram, we intend to focus our attention on the endogenous nature of the relationship between development, health, and environmental pollution. We, therefore, construct a structural model for India where these three variables are determined simultaneously over the 25-year period from 1980-81 through 2004-05. During this time major changes in economic, environmental, and health policies were implemented and our macro model attempts to capture the interrelationship between some of the key performance measures of these variables.

While our empirical model accounts for the two-way relationship between economic development and health status, there is only a one-way direct feedback from economic development towards environmental stress. However, we model only an indirect feedback from environmental stress into economic development through health status, given the nature of pollution under consideration. Our macro model focuses only on one dimension of environmental stress, namely respirable particulate matter, which increases morbidity that in turn adversely impacts economic development. Thus although environmental stress can have a direct feedback effect on economic development (since depleted and/or degraded natural resources directly reduce productivity), in our model respirable particulate pollution does not directly impact economic development (hence a dotted arrow from environmental stress to economic development in *Diagram 1*)

III. The Model

In the present paper we formulate a log-linear structural model to simultaneously determine changes in **ℓn** GDPPC (gross domestic product per capita), **ℓn** LE (life expectancy), **ℓn** NOCRD (number of cases of respiratory diseases) and **ℓn** PM10 (respirable particulate matter) in terms of certain exogenous variables (to be described below) for the Indian economy 1980-81 to 2004-05. During this period the Indian government adopted major changes in its economic policy from an inward looking regime of controls to a more outward oriented and market driven approach, and implemented several institutional reforms.[v] Liberalisation and changes in trade pattern can improve environmental quality — either through the import of relatively pollution-intensive goods from other countries (often from developing countries); or through the import of cleaner technology from developed countries. The structural changes resulting from the new policies adopted in the Indian economy are captured in the three "exogenous" indices used in the model.

3.1 Motivation for the Four Endogenous Variables

The four endogenous variables of GDPPC (gross domestic product per capita), LE (life expectancy), NOCRD (number of cases of respiratory diseases) and PM10 (respirable particulate matter) used in our model represent the typical indicators of economic, health, and environmental performance. Our choice of variables is also guided by data availability considerations.

We assume that **GDPPC** (gross domestic product per capita) growth prominently (although not entirely) describes economic development. Notwithstanding the many limitations of this variable as an indicator of economic development, it has been widely accepted in the literature as a good proxy which correlates well with many other dimensions of economic development. **LE** (life expectancy at birth) reflects long term health condition of the people. In the health economics literature, **LE** has often been used as the principal outcome variable to measure health. One may, of course, argue that **LE** does not have an immediate effect on economic development, but in the long, or medium term, we may expect economic development (**GDPPC**) and **LE** to move together, reinforcing each other. Therefore, we include **LE** as another endogenous variable. Morbidity due to airborne/respiratory diseases have immediate implications on health and productivity of people and, in turn, on aggregate income, or, GDPPC. Therefore, we include **NOCRD** (number of cases of respiratory diseases) as an endogenous variable in the model. It is widely recognised that "*… acute respiratory infections are one of the chief causes of lost life-years in India"* (TERI, 1998: 196) and that "*… where as pollution due to SPM (suspended particulate matter) is widespread in most cities, only a few of them have a high concentration of* SO_2*, or* NO_x "(ibid, p. 175). Thus atmospheric particulate matter is a major cause of air pollution in India, and RSPM or, PM 10 (respirable suspended particulate matter with diameter less than 10 microns that can penetrate deep into the respiratory tract) in particular is responsible for most of the respiratory diseases. We include PM10 as the fourth endogenous variable to capture environmental effects of air pollution. While this is likely to be determined by the level of economic development, it would have significant impact on morbidity rate directly and on GDPPC indirectly.

3.2 The Structural Equations and Underlying Hypotheses

Four structural equations have been postulated to simultaneously determine changes in **ℓn** GDPPC, **ℓn** LE, **ℓn** NOCRD and **ℓn** PM10, in terms of several exogenous variables, clubbed together to form indices of physical infrastructure (PI), social infrastructure (SI) and air pollution index (API):

$$\ell n\ GDPPC = \alpha_1 + \alpha_2\ \ell n\ LE + \alpha_3\ \ell n\ NOCRD + \alpha_4 PI \ldots\ldots\ldots(i)$$

$$\ell n\ LE = \beta_1 + \beta_2 \ell n\ GDPPC + \beta_3 SI \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(ii)$$

$$\ell n\ NOCRD = \gamma_1 + \gamma_2\ \ell n\ GDPPC + \gamma_3\ \ell n\ PM10 \ldots\ldots\ldots\ldots\ldots(iii)$$

$$\ell n\ PMIO = \delta_1 + \delta_2\ \ell n\ GDPPC + \delta_3\ API \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(iv)$$

The **first** equation relates **ℓn** GDPPC with **ℓn** LE, **ℓn** NOCRD and **PI.** Our hypothesis is that the health condition of the people (represented by LE and NOCRD) and availability of physical infrastructure (*viz*., transport and communication facilities and power generation capacity installed) have a direct impact on per capita GDP. While GDPPC and LE have a long-run positive relationship, NOCRD has a negative relationship with GDPPC. Indeed, sickness among people reduces the productivity level and hence their income. Physical infrastructure is, of course, a necessary ingredient for economic growth and per capita GDP and bears positive relationship.

The **second** equation relates **ℓn** LE with **ℓn** GDPPC and social infrastructure index SI. We assume that there is feedback effect between LE and GDPPC, i.e, higher level of the per capita income should be accompanied with higher life expectancy, and *vice versa*. Availability of social infrastructure (in terms of facilities for education, health care systems, sanitation, safe drinking water, etc.) should have a positive impact on life expectancy.

The **third** equation of the model relates **ℓn** NOCRD with **ℓn** GDPPC and **ℓn** PM10. We note that exposure to PM10 is associated with a range of respiratory allergies and diseases (like asthma, bronchitis, other lung and heart diseases and even premature deaths). Since morbidity is a more widespread effect of respirable particulate matter, we include only the **number** of cases of respiratory disease reported annually and ignore respiratory associated deaths (where PM10 may not be the only cause of deaths). The incidence of respiratory diseases is lower when the population has better immunity, diet, living conditions, and invests in defensive measures (which reduce exposure to air pollution, like living in cleaner neighbourhoods, using air filters, traveling in closed vehicles, etc.), all of which can be associated with higher income. Thus in lieu of these multiple variables reducing the incidence of morbidity of the Indian population during the period of the study, we use the proxy variable of GDPPC.

Although long term exposure to particulate atmospheric pollution can also reduce life expectancy by altering lung function and making people more susceptible to chronic obstructive pulmonary diseases (Cropper *et. al.,* 1997), study of such effects would need tracking of a sample population through time in order to elucidate the chronic impact of long term exposure. However, in the context of the present macro model we do not include PM10 in the LE equation. Indirectly, the air pollution index does impact LE in the interdependent equation system.

The **fourth** equation of the model relates **ℓn** PM10 with **ℓn** GDPPC and API. It is pertinent to note that apart from the factors used to determine API (like industrial production, urbanisation, vehicular traffic) the annual ambient particulate pollution is determined by the technology of production (use of cleaner inputs and processes), level of particulate pollution abatement, stringency of environmental regulations and enforcement, as also the buffering capacity of the region (like tree cover and wind patterns which dissipate particulate pollution to some extent). However, given the lack of systematic annual data on these factors, we assume that higher income goes hand-in-hand with the economy's ability to use cleaner technology, increase pollution abatement, implement and enforce more stringent pollution standards. Hence we use GDPPC as a proxy variable for these factors. Increasing liberalisation as implemented in India over the 25 year period of the present study, has made cleaner technology more readily available in many sectors of the economy.

The postulated structural model has been estimated by the two-stage least squares (2SLS) method using the data for the Indian economy (1980-81 to 2004-05).

3.3 The Exogenous Variables and their Indices

Physical and social infrastructures are important determinants of economic development and health of the people. Economic development largely depends on transport and communication facilities, and on the availability of adequate power supply. Therefore, in this paper, we choose to include the following indicators of physical infrastructure (**PI**): *SRD* surfaced road density; *RLT* railway route length; *FLMS* fixed line and mobile telephone subscribers; *ECI* electricity capacity installed; *INTU* internet users; *ATF* Air transport freight; *PTT* port traffic transport.

The health status of the people is influenced by availability of facilities for education and healthcare, access to safe drinking water and nutrition, etc. Therefore, we include the following indicators of social infrastructure (**SI**): *GER* combined gross enrolment ratio; *NOS* total number of schools; *NOB* number of hospital beds per 1000 people; *NOD* number of doctors per 1000 people; *NON* number of nurses per 1000 people; *IMMDPT* immunisation DPT; *ACCDW* percent of population with access to safe drinking water.

It is undoubtedly true that measurement of `environment' at the macro level, for the country, is meaningless. Instead, we focus on a specific pollutant (respirable particulate matter RSPM or PM10), and we construct an air pollution index **API**, which captures the pollutant's causal factors. The structure of the economy, scale of polluting industries, nature of transport, fossil fuel use, forest cover, etc, are the different factors responsible for the emission of RSPM or PM10. However, for construction of API, in this paper, we include only 13 factors (given time-series data availability): *EPH* electricity production from hydroelectric sources[vi]; *STEEL* finished steel production; *COPMTL* **c**opper metal production; *ALMNM* aluminum ingots production; *CEMENTS* cement (all kinds) production; *PRP* petroleum refinery goods production, *SACS* soda ash and caustic soda production; *SUG* sugar production; *PAPER* paper and paper boards production; *COAL* coal production; *FER* fertiliser (nitrogenous and phosphatic) production; *URBPOP* total urban population; *NOV* number of vehicles per 1000 people.

The indices PI, SI and API have been constructed by the principal components method. *Appendix B* provides values of PI, SI and API for the period 1980-81 to 2004-05 and represents them graphically in *Figures 1-3*.

3.4 Computation of PI, SI and API

Using the method described in the *Appendix A* and data for the Indian economy 1980-81 to 2004-05 we may express:

$$PI = \underset{(17.24)}{0.35\,SRD} + \underset{(18.23)}{0.37\,RLT} + \underset{(11.82)}{0.24\,FLMS} + \underset{(17.24)}{0.35\,ECI} + \underset{(8.37)}{0.17\,INTU} + \underset{(11.33)}{0.23\,ATF} + \underset{(15.76)}{0.32\,PTT}$$

$$SI = \underset{(16.34)}{0.33\,GER} + \underset{(18.32)}{0.37\,NOS} + \underset{(2.48)}{0.05\,NOB} + \underset{(16.83)}{0.34\,NOD} + \underset{(16.83)}{0.34\,NON} + \underset{(12.87)}{0.26\,IMMDPT}$$

$$+ \underset{(16.34)}{0.33\,ACCDW}$$

$$API = \underset{(-8.92)}{-0.24EPH} + \underset{(9.29)}{0.25STEEL} + \underset{(6.69)}{0.18COPMTL} + \underset{(8.92)}{0.24ALMNM} + \underset{(9.29)}{0.25\,CEMENTS} + \underset{(8.18)}{0.22PRP}$$

$$+ \underset{(9.29)}{0.25\,SACS} + \underset{(9.67)}{0.26SUG} + \underset{(9.67)}{0.26\,PAPER} + \underset{(9.29)}{0.25COAL} + \underset{(9.67)}{0.26\,FER} + \underset{(9.67)}{0.26\,URBPOP}$$

$$+ \underset{(9.29)}{0.25\,NOV}$$

The quantities within brackets (under each coefficient) indicate percent share of contribution of individual indicators in the index. For example, the sum of coefficients in P1 is 2.03. Therefore, the percent share of contribution of SRD in P1 is obtained as

$$\frac{0.35}{2.03} \times 100 = 17.24\%$$ and so on.

PI is the index of physical infrastructure composed of the indicators of energy (ECI), transport (SRD, RLT, ATF, PTT) and telecommunication (FLMS, INTU). Improvement in infrastructural services has a direct effect (through the intermediate inputs) and an indirect effect (through efficiency enhancing) on economic growth. It may be interesting to figure out the relative contribution of energy, transport, and telecommunication in PI. We note that transport, (sum of contributions of SRD, RLT, ATF and PTT) contributes about 62.5 percent, telecommunication (sum of contributions of FLMS and INTU) contributes a significant 20.19 percent, whereas, energy contributes a lower share of 17.24 percent to PI.

SI: Social infrastructure index is an all-encompassing term reflecting the status of the society in fostering the well-being of its individual members. In other words, social infrastructure refers to those conditions and facilities that promote human development in all its dimensions — education, health, nutrition, sanitation, and equality among gender, class, caste, and income groups. One could conceivably draw a long list of variables to identify social infrastructure. In this study, we look at three sets of variables to capture social infrastructure, essentially dictated by data availability.

First, we consider access to education, and use as proxy enrolment rates (GER) and number of schools (NoS), which have a weight share of about 35 percent in SI. Next, we consider health infrastructure captured by the numbers of hospital beds (NoB), doctors (NoD), nurses (NoN) and child immunisation rates against DPT (IMMDPT) contributing about 49 percent to SI index. Finally, we introduce a measure of sanitation as reflected in access to safe drinking water (ACCDW) contributing about 16 percent to SI. Clearly, these three sets of variables correspond to three very important dimensions of social infrastructure. Needless to mention, the underlying variables capturing each dimension could be expanded to a considerable extent. But this was not possible due to data constraints. Moreover, we are unable to incorporate other important dimensions of social infrastructure like nutrition or gender equality. However, if we expect the society to be moving to a better infrastructure for an all-encompassing human development scenario, then the index SI derived from a smaller set of variables would be representative in a broad sense.

API: The main sources of atmospheric particulate pollution are vehicular exhausts, road and construction dust, incomplete combustion of fuel, industry emissions besides burning of garbage. Since data on road dust, construction dust, emissions from diesel generator sets and burning of garbage is not available, we use the proxy of urban population. Thus for construction of API, we include the number of vehicles (per 1000 people), total urban population, hydroelectric power generation and production of coal, steel, copper metal, aluminum, petroleum refinery products, cement, sugar, paper and paper boards, soda ash and caustic soda, nitrogenous and phosphatic fertilisers. While number of vehicles, coal and production of selected industries are directly contributing factors (contributing about 90 percent) to API, urban population contributes about 9.7 percent to API, Since hydroelectric power generation is a clean means of generating power, EPH has a negative contribution of -8.92 percent to API.

IV. Results

The following results have been obtained by the two stage least squares method used for estimating our structural model:

ℓn GDPPC=-16.89645+6.471494 **ℓn LE**-0.184414 **ℓn NOCRD**+0.036691 **PI:** $\overline{R}^2 = 0.99$
(0.00) (0.00) (0.02) (0.00)

ℓn LE = 3.288567 + 0.086830 **ℓn GDPPC** + 0.015292 **S1:** $\overline{R}^2 = 0.99$
(0.00) (0.00) (0.00)

ℓn NOCRD = -46.13876 + 3.906045 **ℓn GDPPC +** 2.778491 **ℓn PMIO:** $\overline{R}^2 = 0.94$
(0.00) (0.00) (0.02)

ℓn PMIO = 24.36485 – 2.172702 **ℓn GDPPC +** 0.156605 **API:** $\overline{R}^2 = 0.84$
(0.00) (0.00) (0.02)

(The quantities within brackets below the coefficient estimates are the P –values)

Our estimation vindicates our broad hypotheses depicted in the schematic framework. While physical infrastructure does appear to be important in determining GDP per capita, it is also directly influenced by improved health outcomes like higher longevity and lower morbidity (from respiratory diseases). Health outcomes in our estimated model, in turn, are determined by the level of per capita GDP. Interestingly, as hypothesised, our model does indicate that long term health status (life expectancy) is positively affected by social infrastructure and immediate health outcomes like morbidity from respiratory disorders are influenced by environmental stress (air pollution). Finally, air pollution stress is observed to be determined by GDP per capita and environmental infrastructure. The interface between economic development, health, and environment is only part of the story emerging from our study. Going beyond the structural model, we went on to obtain the reduced form equations, derived from the 2SLS estimated structural equations as follows:

$$\ell n\ \mathbf{GDPPC} = 9.078827 + 0.812952\ \mathbf{PI} + 2.192675\ \mathbf{SI} - 1.777927\ \mathbf{API}$$

$$\ell n\ \mathbf{LE} = 4.076882 + 0.070589\ \mathbf{PI} + 0.205682\ \mathbf{SI} - 0.154377\ \mathbf{API}$$

$$\ell n\ \mathbf{NOCRD} = 2.213702 - 1.732228\ \mathbf{PI} - 4.672125\ \mathbf{SI} + 4.223510\ \mathbf{API}$$

$$\ell n\ \mathbf{PMIO} = 4.639265 - 1.766302\ \mathbf{PI} - 4.764029\ \mathbf{SI} + 4.019510\ \mathbf{API}$$

The signs of all coefficients are in consonance with prior expectation. The elasticities of the endogenous variables (GDPPC, LE, NOCRD, and PMI0) with respect to PI, SI, and API are easily calculated from the derived reduced form in a straightforward manner. The absolute values of these elasticities are seen to increase over time (because the values of the indices PI, SI, API show a rising trend). The actual and estimated values of **ℓn GDPPC, ℓn LE, ℓn NOCRD** and **ℓn PMIO** are summarised in *Table 1*.

V. Conclusion and Policy Observations

Our macro model provides a broad view of the effects of changes in physical infrastructure, social infrastructure, and air pollution index on the per capita income, life expectancy, respiratory morbidity, and respirable particulate matter in a simultaneous equations framework in the Indian economy during the last 25 years. While our simplified model does help us to enumerate and vindicate the macro-relationship between income, environment and health for the Indian economy, we have done it as an illustration for a specific type of pollutant, namely respirable particulate matter. There is scope to build more comprehensive environmental stress indices that reflect surface water quality, groundwater quality, soil pollution, etc. that directly feedback into economic development and health. It is also pertinent to point out here that many of the variables included in PI, SI and API may not be truly *exogenous* in a larger model where policy shocks and trade regime may be used as the only exogenous factors in the time series analysis. Some of the factors used in our construction of the three indices here like transport and communication facilities, education and health infrastructure, vehicular traffic, industrial production etc. may be treated as endogenous variables in a larger model. The two weaknesses of our current exercise, namely selection of single pollutant to represent environmental stress and endogenous nature of some factors used in the indices stem largely from the constraint of time-series data availability. Indeed most of the empirical work on environment and development use cross-sectional data to bypass this issue.

Although our model is highly simplified, nonetheless the empirics from our estimation provide at least two critical insights on the nature of economic development experienced in India:

First, the *high cost of environmental stress*: The enormous cost of atmospheric environmental stress to the Indian economy is evident from the elasticities of the endogenous variables with respect to API. For example, for the most recent years (2003-04 and 2004-05), we find that a 1 percent increase in the air pollution index (API) would lead to a decrease of about 8 percent in the per capita income (GDPPC), a decrease of about 0.7 percent in the life expectancy (LE), an increase of about 19 percent in the number of cases of respiratory diseases and an increase of about 18 percent in the levels of respiratory particulate matter (PM10).

Second, the relative importance of SI vis-à-vis PI: The absolute values of the elasticities of endogenous variables with respect to SI are invariably greater than those with respect to PI. Thus, the social infrastructure plays a more vital role in economic growth, health, and environment than the physical infrastructure. For example, for the most recent years (2003-04 and 2004-05) a 1 percent improvement in the social infrastructure would lead to about 6 percent increase in per capita income, 0.6 percent increase in life expectancy, 13 percent decrease in the number of cases of respiratory diseases and a 13 percent decrease in the level of respiratory particulate matter, as against a 3 percent increase in per capita income (GDPPC) a 0.3 percent increase in life expectancy (LE), a 7 percent decrease in the number of cases of respiratory diseases (NOCRD) and a decrease of 7 percent in the levels of respiratory particulate matter (PMI0) for the same amount of increase in the physical infrastructure. Therefore, it is most important that we pay adequate attention to provide more social infrastructure facilities and pay up substantially to reduce air pollution. Physical infrastructure, although important, comes in the last of our preference ordering.

Table 1 : Actual and Estimated Values of ℓn GDPPC, ℓn LE, ℓn NOCRD, and ℓn PM10 from the 2SLS Derived Reduced Form

Years	Act ℓn GDPPC	Est ℓn GDPPC	Act ℓn LE	Est LE	Act ℓn NOCRD	Est ℓn NOCRD	Act ℓn PM10	Est ℓn PM10
1980-81	8.6718	8.4380	3.9864	3.9754	0.9738	1.5907	4.7387	5.3159
1981-82	8.7075	8.4217	3.9938	3.9769	0.9868	1.7777	4.7953	5.4062
1982-83	8.7157	8.4682	4.0013	3.9850	1.1859	1.8222	4.7970	5.3568
1983-84	8.7682	8.8199	4.0090	4.0194	1.2989	1.1642	4.7686	4.6256
1984-85	8.7893	9.0883	4.0169	4.0464	1.3964	0.7228	4.7330	4.0894
1985-86	8.8125	9.1839	4.0252	4.0602	1.2991	0.6931	4.7154	3.9443
1986-87	8.8332	8.8746	4.0337	4.0350	1.5648	1.5306	4.7720	4.6805
1987-88	8.8495	8.4436	4.0422	3.9959	1.6404	2.6665	4.7737	5.6953
1988-89	8.9282	8.3943	4.0506	3.9966	1.6677	3.0021	4.7454	5.8853
1989-90	8.9725	8.5522	4.0587	4.0152	2.1832	2.8442	4.7098	5.6065
1990-91	9.0065	9.0199	4.0666	4.0614	2.3524	1.9607	4.6972	4.6311
1991-92	8.9996	9.2678	4.0743	4.0936	2.4584	1.6848	4.7331	4.1832
1992-93	9.0309	9.7967	4.0818	4.1446	2.5279	0.6101	4.7627	3.0529
1993-94	9.0697	9.9461	4.0892	4.1614	2.6216	0.3917	4.7298	2.7642
1994-95	9.1217	10.5868	4.0962	4.2213	2.6082	-0.8211	4.6716	1.4271
1995-96	9.1747	9.7808	4.1031	4.1540	2.5503	1.2836	4.6731	3.3177
1996-97	9.2326	9.0091	4.1096	4.0889	2.6635	3.1673	4.6057	5.0805
1997-98	9.2620	8.5424	4.1158	4.0500	2.6619	4.3271	4.5686	6.1540
1998-99	9.3078	8.3498	4.1216	4.0345	2.7680	4.8941	4.5513	6.6288
1999-00	9.3497	8.1562	4.1271	4.0235	2.8182	5.6112	4.5562	7.1591
2000-01	9.3757	8.8009	4.1324	4.0829	2.9627	4.2854	4.5157	5.7757
2001-02	9.4158	9.1264	4.1376	4.1162	2.9912	3.7135	4.4633	5.1121
2002-03	9.4392	9.4535	4.1428	4.1467	3.0499	3.1079	4.4347	4.4343
2003-04	9.5060	9.7643	4.1498	4.1781	3.1260	2.6198	4.3644	3.8218
2004-05	9.5585	10.6007	4.1504	4.2518	3.1648	0.8986	4.2709	2.0265

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Appendix A

Construction of Indices

In general, suppose x_1, …, x_p are p indicator variables on whom T observations (x_{it}'s) are available for i=1, …, p and t=1, …, T. We transform the variables as

$$X_{it} = \frac{x_{it} - \bar{x}_i}{s_{x_i}}$$

where

$$\bar{x}_i = \frac{1}{T}\sum_{t=1}^{T} x_{it} \quad \text{and} \quad s_{x_i}^2 = \frac{1}{T}\sum_{t=1}^{T}(x_{it} - \bar{x}_i)^2.$$

The covariance matrix of the standardised variables, X_{it}'s, is, in fact, the correlation matrix R of the indicator variables.

Let $\lambda_1 > \lambda_2 > \cdots > \lambda_p$ be the eigen values of R in descending order of magnitude, and the corresponding eigen vectors be

$$\alpha_1 = \begin{pmatrix} \alpha_{11} \\ \vdots \\ \alpha_{1p} \end{pmatrix}, \cdots, \alpha_p = \begin{pmatrix} \alpha_{p1} \\ \vdots \\ \alpha_{pp} \end{pmatrix}$$

such that

$$\alpha_i'\alpha_i = 1 \text{ and } \alpha_i' \ \alpha_j = 0$$

for i ≠ j = 1, …, p. Then the successive principal components are

$$P_{1t} = \alpha_{11}X_{1t} + \cdots + \alpha_{1p}X_{pt}$$

$$\cdots$$

$$P_{pt} = \alpha_{p1}X_{1t} + \cdots + \alpha_{pp}X_{pt}$$

with var $P_{it} = \lambda_i$ for i=1, …, p.

We define the index as a weighted average of successive principal components as

$$I_t = \frac{\lambda_1 P_{1t} + \cdots + \lambda_p P_{pt}}{\lambda_1 + \cdots + \lambda_p};$$

maximum weight ($\lambda_1 / \sum \lambda_i$) has been assigned to the first principal component as it describes the largest proportion of total variation in all x's. The second principal component has the second highest weight ($\lambda_2 / \sum \lambda_i$), and so on.

The advantage of including **all** p principal components is that

(a) they account for total variation in all x's and

(b) we can express

$$(\sum \lambda_i) I_t = \lambda_1(\alpha_{11} X_{1t} + \cdots + \alpha_{1p} X_{pt}) +$$
$$\cdots$$
$$\lambda_p(\alpha_{p1} X_{1t} + \cdots + \alpha_{pp} X_{pt})$$

or,

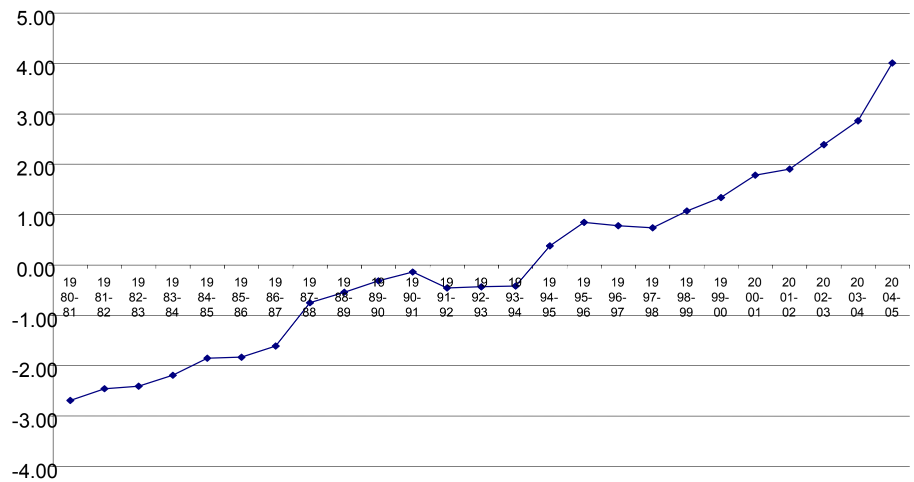
$$I_t = \frac{\sum \lambda_i \alpha_{i1}}{\sum \lambda_i} X_{It} + \cdots + \frac{\sum \lambda_i \alpha_{ip}}{\sum \lambda_i} X_{pt}$$

where summation over i is from 1, …, p, and X_{it} is standardised value.

Appendix B

Figure 1 Showing Values of PI

Year	PI
1980-81	-2.69
1981-82	-2.46
1982-83	-2.41
1983-84	-2.19
1984-85	-1.85
1985-86	-1.83
1986-87	-1.61
1987-88	-0.75
1988-89	-0.54
1989-90	-0.31
1990-91	-0.14
1991-92	-0.46
1992-93	-0.43
1993-94	-0.42
1994-95	0.38
1995-96	0.85
1996-97	0.78
1997-98	0.74
1998-99	1.07
1999-00	1.34
2000-01	1.78
2001-02	1.90
2002-03	2.39
2003-04	2.86
2004-05	4.01

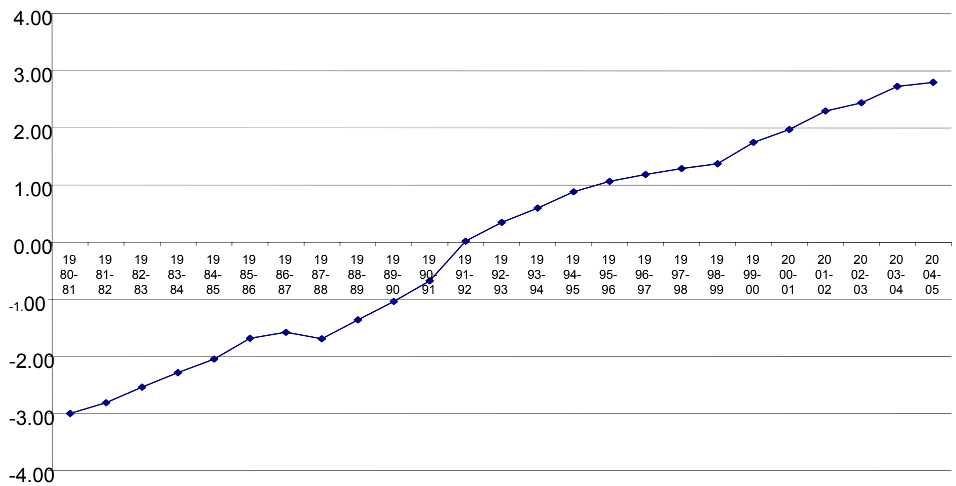


PI = 0.35 SRD + 0.37 RLT +0.24 FLMS + 0.35 ECI + 0.17 INTU + 0.23 ATF + 0.32 PTT

(17.24) (18.23) (11.82) (17.24) (8.37) (11.33) (15.76)

Year	SI
1980-81	-3.00
1981-82	-2.81
1982-83	-2.54
1983-84	-2.29
1984-85	-2.05
1985-86	-1.69
1986-87	-1.58
1987-88	-1.69
1988-89	-1.36
1989-90	-1.04
1990-91	-0.68
1991-92	0.02
1992-93	0.35
1993-94	0.60
1994-95	0.88
1995-96	1.06
1996-97	1.18
1997-98	1.29
1998-99	1.37
1999-00	1.75
2000-01	1.97
2001-02	2.30
2002-03	2.44
2003-04	2.73
2004-05	2.80

Figure 2 Showing Values of SI

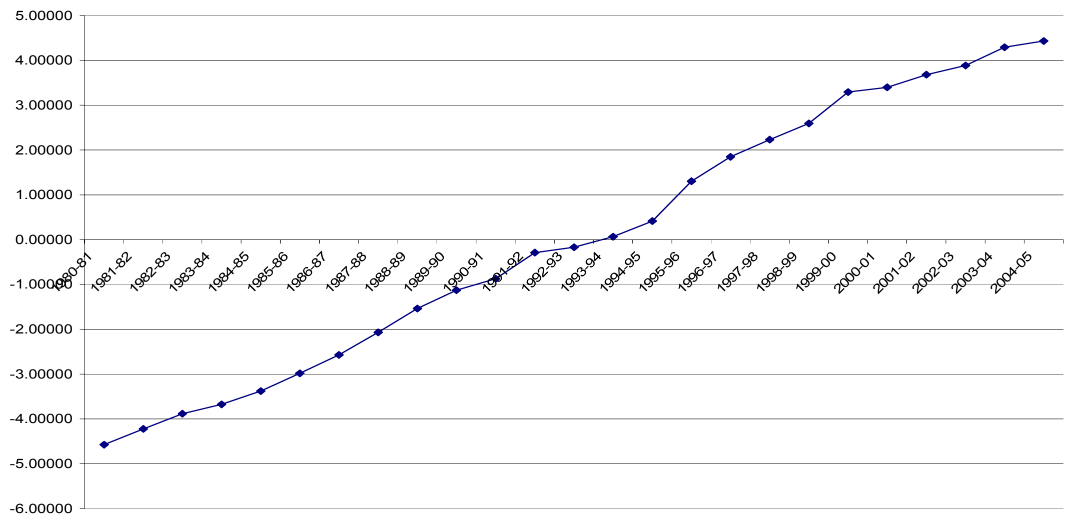


SI= 0.33 GER + 0.37 NOS + 0.05NOB + 0.34 NOD + 0.34 NON + 0.26 IMMDPT + 0.33 ACCDW

(16.34) (18.32) (2.48) (16.83) (16.83) (12.87) (16.34)

Year	API
1980-81	-4.57
1981-82	-4.22
1982-83	-3.89
1983-84	-3.68
1984-85	-3.38
1985-86	-2.98
1986-87	-2.57
1987-88	-2.07
1988-89	-1.54
1989-90	-1.13
1990-91	-0.87
1991-92	-0.29
1992-93	-0.17
1993-94	0.06
1994-95	0.41
1995-96	1.30
1996-97	1.85
1997-98	2.23
1998-99	2.59
1999-00	3.29
2000-01	3.40
2001-02	3.68
2002-03	3.89
2003-04	4.29
2004-05	4.43

Figure 3
Showing Values of API



API= -0.24 EPH + 0.25 STEEL + 0.18 COPMTL + 0.24 ALMNM + 0.25 CEMENTS + 0.22 PRP + 0.25 SACS + 0.26 SUG +0.26 PAPER+ 0.25 COAL
(-8.92) (9.29) (6.69) (8.92) (9.29) (8.18) (9.29) (9.67) (9.67) (9.29)
+ 0.26 FER + 0.26 URBPOP + 0.25 NOV
(9.67) (9.67) (9.29)

Endnotes

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[i] On the other hand, Tabata (2005) using an overlapping generation model, showed that life expectancy, when relatively high, negatively affects economic growth and *vice versa*. Indeed, the literature also articulates the reverse causality between health and growth pointing out both the positive and the negative influence of wealth/income on health. The positive impact is evident from macro studies, but micro evidence suggests that health is perhaps little influenced by short-term changes in wealth. On the contrary, there are reasons to expect a negative influence of income on health due to dietary as well as lifestyle changes arising out of higher incomes that may be detrimental to good health.

[ii] Earlier studies include World Bank (1992), Shafik (1994), Seldon and Song (1994), Grossman and Krueger (1995), and the EKC has seen many extensions with data as well as alternative measures of environmental quality and productivity measures (Harbaugh *et al* 2002). W*e do not test the EKC* in our paper, nor do we assume an EKC relationship.

[iii] Including carbon dioxide, sulphur dioxide, nitrogen dioxide, total suspended particulates emissions data at the different city levels was used based on availability for different countries.

[iv] We acknowledge that many of the exogenous variables included in PI, SI and API may not be truly exogenous in a larger model.

[v] In India, piecemeal liberalisation was initiated in the mid-1980s, and pursued more systematically since 1991-92. By the early 1990s, the air pollution from industry and vehicles, in particular, reached appalling levels. While the first Indian environmental legislation on atmospheric pollution dates back to the *Air Act of 1981*, the air quality standards for RSPM or PM10 were set later in 1994. Thus our period of study contains major economic and environmental reforms.

[vi] Whereas, the thermal power – coal and oil based – represents about 70 percent of the total power production, and consumes about three-fourth of the total domestic coal, the hydroelectric power accounts for barely a quarter of the total electricity produced. The electricity produced from other sources (like natural gas, nuclear, and oil) is negligible. Therefore, we choose EPH as **complementary** of thermal and other sources.