Massachusetts Institute of Technology
Department of Economics
Working Paper Series

Environmental Regulations, Air and Water Pollution, & Infant Mortality in India

Michael Greenstone
Rema Hanna

Working Paper 11-11
July 1, 2011

Room E52-251
50 Memorial Drive
Cambridge, MA 02142

Environmental Regulations,
Air and Water Pollution, and Infant Mortality in India*

Michael Greenstone, MIT and NBER
Rema Hanna, Harvard Kennedy School, NBER and BREAD

July 2011

Abstract

Using the most comprehensive data file ever compiled on air pollution, water pollution, environmental regulations, and infant mortality from a developing country, the paper examines the effectiveness of India's environmental regulations. The air pollution regulations were effective at reducing ambient concentrations of particulate matter, sulfur dioxide, and nitrogen dioxide. The most successful air pollution regulation is associated with a modest and statistically insignificant decline in infant mortality. However, the water pollution regulations had no observable effect. Overall, these results contradict the conventional wisdom that environmental quality is a deterministic function of income and underscore the role of institutions and politics.

JEL Codes: H2, Q5, Q2, O1, R5
Keywords: Air pollution; Water pollution; Benefits of environmental regulations; India

* Greenstone: MIT Department of Economics, E52-359, 50 Memorial Drive, Cambridge, MA 02142-1347 (e-mail: mgreenst@mit.edu) Hanna: Harvard Kennedy School, 79 JFK Street (Mailbox 26), Cambridge, MA 02138 and National Bureau of Economic Research, Bureau for Research and Economic Analysis of Development; (e-mail: Rema_Hanna@ksg.harvard.edu). We thank Samuel Stolper for truly outstanding research assistance. In addition, we thank Joseph Shapiro and Abigail Friedman for excellent research assistance. Funding from the MIT Energy Initiative is gratefully acknowledged. The analysis was conducted while Hanna was a fellow at the Science Sustainability Program at Harvard University. The research reported in this paper was not the result of a for-pay consulting relationship. Further, neither of the authors nor their respective institutions have a financial interest in the topic of the paper which might constitute a conflict of interest.

I. INTRODUCTION

There is a paucity of evidence about the efficacy of environmental regulation in developing countries. However, this question is important for at least two reasons.[1] First, "local" pollutant concentrations are exceedingly high in many developing countries and they impose substantial health costs, including shortened lives (Chen, Ebenstein, Greenstone, and Li 2011). Thus, understanding the most efficient ways to reduce local pollution could significantly improve wellbeing in developing countries. Second, the Copenhagen Accord makes it clear that it is up to individual countries to devise and enforce the regulations necessary to achieve their national commitments to combat global warming by reducing greenhouse gas emissions. Since most of the growth in greenhouse gas (GHG) emissions is projected to occur in developing countries, such as India and China, the planet's wellbeing rests on the ability of these countries to successfully enact and enforce environmental regulations.

India provides a compelling setting to explore the efficacy of environmental regulations in a developing country for several reasons. First, India's population of nearly 1.2 billion accounts for about 17 percent of the planet's population. Second, the country is experiencing rapid economic growth of about 6.4 percent annually over the last two decades, which is placing significant pressure on the environment. For example, Figure 1, Panel A demonstrates that ambient particulate matter concentrations in India are five times the level of concentrations in the United States (while China's are seven times the U.S. level) in the most recent years with comparable data, while Figure 1, Panel B shows that water pollution concentrations in India are

[1] There is a large literature measuring the impact of environmental regulations on air quality, with many of them finding that significant regulation-induced reductions in pollution concentrations in the United States. See, for example, Chay and Greenstone (2003 and 2005), Greenstone (2003), Greenstone (2004), Henderson (1996), Hanna and Oliva (2010), and so forth. However, given the institutional differences that exist between the United States and many developing countries, it is not clear that knowledge on what "works" in the United States is necessarily relevant in other contexts.

also higher. Third, India has a surprisingly rich history of environmental regulations that dates back to the 1970s, providing a rare opportunity to answer these questions with extensive panel data.[2] Finally, India remains below the income levels at which the Environmental Kuznets curve literature predicts that pollution concentrations turn downward (e.g., Grossman and Krueger, 1995; Shafik and Bandyopadhyay, 1992; Selden and Song, 1994; Stern and Common, 2001; Copland and Taylor, 2004), implying that it is at a stage of development where economic growth trumps environmental concerns. Consequently, taking the predictions of these models at face value, it may be reasonable to expect that most of the environmental policies implemented to date have been ineffective.

This paper presents a systematic evaluation of India's environmental regulations. The analysis is conducted with a new city-level panel data file for the years 1986-2007 that we constructed from data on air pollution, water pollution, environmental regulations, and infant mortality in India. The air pollution data cover about 140 cities, while the water pollution data comprises information from 424 cities (162 rivers). Neither the government nor other researchers have ever assembled a city-level panel database of India's anti-pollution laws. Furthermore, we are unaware of a comparable data set in any other developing country. Additionally, we believe that this is the first paper to relate infant mortality rates to environmental regulations in a developing country context.[3]

We considered two key air pollution policies—the Supreme Court Action Plans and the Mandated Catalytic Converters—that centered on stemming both industrial and vehicular

[2] Previous papers have compiled data sets for a cross-section of cities or a panel for one or two cities. A few notable papers that focus on a particular city include: Foster and Kumar (2008; 2009), which examines the effect of CNG policy in Delhi; Takeuchi, Cropper, and Bento (2007), which studies the impact of automobile policies in Mumbai; Davis (2008), which looks at the effect of driving restrictions on air quality in Mexico; and Hanna and Oliva (2011), which explores the effects of a refinery closure in Mexico City.
[3] See Chay and Greenstone (2003) for the relationship between infant mortality and the Clean Air Act in the United States. Burgess, Deschenes, Donaldson, and Greenstone (2011) estimate the relationship between weather extremes and infant mortality rates using the same infant mortality data used in this paper.

pollution.[4] We also consider the primary water policy, the National River Conservation Plan, which focused on reducing industrial pollution in the rivers and creating sewage treatment facilities. These regulations resemble environmental legislation in the United States and Europe, thereby providing an interesting study of the efficacy of similar regulations across very different institutional settings.

The results are mixed: the air regulations have led to improvements in air pollution, while the water pollution regulations have been ineffective. In the preferred econometric specification which controls for city fixed effects, year fixed effects and pre-existing trends among adopting cities, we find that the Supreme Court-mandated Action Plans are associated with declines in NO_2 concentrations; however, we do not observe an effect of the policy on SO_2 or PM. Additionally, the requirement that new automobiles have catalytic converters is associated with economically large reductions in PM, SO_2, and NO_2 of 19 percent, 69 percent, and 15 percent, respectively, five years after its implementation. In contrast, the National River Conservation Plan, which is the cornerstone of water policy in India, had no impact on the three measures of water quality we consider.

In light of these findings, we tested whether the catalytic converter policy was associated with changes in measures of infant health. The data indicate that a city's adoption of a policy is associated with a decline in infant mortality, but this relationship is not statistically significant. As we discuss below, there are several reasons to interpret the infant mortality results cautiously.

In sum, our findings shed light on two broader questions. First, the results suggest that environmental policies can be effective in developing countries, even in cases where income level falls within the range where the environmental Kuznets curve would predict that

[4] We also documented the implementation of other key anti-pollution efforts. However, these policies (such as the Problem Area Action Plans, and the multiple sulfur requirements for fuel) had insufficient variation in their implementation across cities and/or time to obtain reliable estimates.

environmental quality should be decreasing. Second, the results suggest that bottom-up environmental policies are more likely to succeed than policies, like the water pollution regulations that are initiated by political institutions. Thus, while the results suggest that developing countries are able to effectively curb pollution, regulations imposed by international treaties, like those contemplated as part of an effort to confront climate, may have limited success without widespread political support from within.

The paper proceeds as follows. Section II provides a brief history of environmental regulation in India and the policies under consideration, while Section III describes our data. Section IV describes the trends in pollution in India. Section V describes our empirical methods, and Section VI provides our results. Section VII discusses the results, and Section VIII concludes.

II. BACKGROUND

India has a relatively extensive set of regulations designed to improve both air and water quality. Its environmental policies have their roots in the Water Act of 1974 and Air Act of 1981. These acts created the Central Pollution Control Board (CPCB) and the State Pollution Control Boards (SPCBs), which are responsible for data collection and policy enforcement, and also developed detailed procedures for environmental compliance. Following the implementation of these acts, the CPCB and SPCBs quickly advanced a national environmental monitoring program (responsible for the rich data underlying our analysis). The Ministry of Environment and Forests (MoEF), created in its initial form in 1980, was established largely to set the overall policies that the CPCB and SPCBs were to enforce (Hadden, 1987).

The Bhopal Disaster of 1984 represented a turning point in the course of Indian environmental policy. The government's treatment of victims of the Union Carbide plant explosion "led to a re-evaluation of the environmental protection system," with increased participation of activist groups, public interest lawyers, and the judiciary in the environmental space (Meagher 1990). The Supreme Court instigated a wide expansion of fundamental rights of citizens and there was a steep rise in public interest litigation (Cha, 2005). These developments led to some of India's first concrete environmental regulations, such as the closures of limestone quarries and tanneries in Uttar Pradesh in 1985 and 1987, respectively.[5]

Throughout the 1980s and 1990s, India continued to adopt a series of policies designed to counteract the effects of growing environmental damage. The analysis focuses on two key air pollution policies, the Supreme Court Action Plans and the catalytic converter requirements, and the primary water pollution policies, the National River Conservation Plan. These policies were at the forefront of India's environmental efforts. Importantly, these policies were also phased into different cities in different years, providing the basis for this paper's research design.

The first policy we focus on is the Supreme Court Action Plans. The Action Plans are part of a broad, ongoing effort to stem the tide of rising pollution in cities identified by the Supreme Court of India as critically polluted. Measured pollution concentrations are clearly a key ingredient in the determination of these designations. In 1996, Delhi was the first city order to develop an action plan, while the most recent action plans were mandated in 2003.[6] To date, 17 cities have been given orders to develop action plans.

[5] See *Rural Litigation and Entitlement Kendra v. State of Uttar Pradesh* (Writ Petitions Nos. 8209 and 8821 of 1983), and *M.C. Mehta v. Union of India* (WP 3727/1985).

[6] As documented in the court orders, the Supreme Court ordered nine more action plans in critically polluted cities "as per CPCB data" after Delhi. A year later, the Court chose four more cities based on their having pollution levels at least as high as Delhi's. Finally, a year later, nine more cities (some repeats) were identified based on Respired SPM (smaller diameter) levels.

In light of the Supreme Court's reputation as a driver of environmental reform in India, as well as the overwhelming approval of Delhi's CNG bus program as part of its action plan, many believe that these policies have made significant gains in improving air quality. At least one round of plans was directed at cities with unacceptable levels of Respired Suspended Particulate Matter (RSPM), which is a subset of particulate matter (PM) that includes particles of especially small size. Given the heavy focus on vehicular pollution, it is reasonable to presume that the plans affected NO_2 levels. Finally since SO_2 is frequently a co-pollutant, it may be reasonable to expect the Action Plans to affects its ambient concentrations.

We then examine a policy that mandated the use of catalytic converters. The fitment of catalytic converters is a common means of reducing vehicular pollution across the world, due to the low cost of its end-of-the-pipe technology. In 1995, the Supreme Court required that all new petrol-fueled cars in the four major metros (Delhi, Mumbai, Kolkata, Chennai) were to be fitted with converters. In 1998, the policy was extended to 45 other cities. It is plausible that this regulation could affect all three of our air quality indicators; however, the prediction is strongest for NO_2.[7]

Finally, we study the cornerstone of efforts to improve water quality, the National River Conservation Plan (NRCP). Begun in 1985 under the name Ganga Action Plan (Phase I), the water pollution control program expanded first to tributaries of the Ganga River, including the Yamuna, Damodar, and Gomti in 1993. It was later extended in 1995 to the other regulated rivers under the new name of NRCP. Today, 164 cities on 34 rivers are covered by the NRCP. The criteria for coverage by the NRCP are vague at best, but many documents on the plan cite

[7] Public response to the catalytic converter policy was unfavorable for several reasons: petrol's lower fuel share made the scope of the policy somewhat narrower than, for example, the mandate for low-sulfur in diesel fuel; unleaded fuel, which is known to be a prerequisite for smooth catalytic converter functioning, was at best inconsistently available until 2000; and selective implementation in only certain cities of India caused leakage of automobile purchases to other cities not covered by the policy.

the CPCB Official Water Quality Criteria, which include standards for BOD, DO, FColi, and pH measurements in surface water. Much of the focus has centered around domestic pollution control initiatives over the years (Asian Development Bank, 2007).

The centerpiece of the plan has been and continues to be the Sewage Treatment Plant (STP). The interception, diversion, and treatment of sewage through piping infrastructure and treatment plant construction has been coupled with installation of community toilets, crematoria, and public awareness campaigns to curtail domestic pollution. The NRCP has been panned in the media for a variety of reasons, including poor cooperation among participating agencies, imbalanced funding of sites, and inability to keep pace with the growth of sewage output in India's cities (Suresh et al, 2007, p. 2). If the policy is found to have had an effect, it may be expected to be particularly visible in FColi levels, since this is the parameter most correlated with domestic pollution in the data.

III. DATA

To conduct the analysis, we compiled the most comprehensive city-level panel data file ever assembled on air pollution concentrations, water pollution concentrations, and environmental policies in India. We supplemented this data file with a city-level panel data file on infant mortality rates. This section provides details on each data source.

A. Air Pollution Data

This paper takes advantage of an extensive and growing network of environmental monitoring stations across India. Starting in 1987, India's Central Pollution Control Board (CPCB) began compiling readings of Nitrogen Dioxide (NO_2), Sulfur Dioxide (SO_2), and particulate matter with diameter less than 100 μm (PM). The data were collected as a part of the National Air Quality Monitoring Program (NAMP), a program established by the CPCB to help identify, assess, and prioritize the pollution controls needs in different areas, as well as to help in identifying and regulating potential hazards and pollution sources.[8] Individual State Pollution Control Boards (SPCBs) are responsible for collecting the pollution readings and sending the data to the CPCB for checking, compilation, and analysis. The air quality data are from a combination of CPCB online and print materials for the years 1987-2007.[9]

While the CPCB reports that there are currently 342 functional air quality monitoring stations in 127 Indian cities, there has been much movement and reclassification of these monitors over the years. In total, our full dataset includes 572 monitors in 140 cities. For some cities, data is collected in certain, but not all, years.[10] In 1987, the first year in our dataset, the functioning monitors cover 20 cities, while 125 cities are monitored by 2007 (see Appendix Table 1 for summary statistics of the data, by year). On average, there are 2.3 monitors per city, with 78 percent of cities including data from more than one monitor in a given year.[11] Figure 2 maps the location of the cities with air pollution data in at least one year.

The three pollutants can be attributed to a variety of sources. PM is regarded by the CPCB as a general indicator of pollution, receiving key contributions from "fossil fuel burning, industrial processes and vehicular exhaust." SO_2 emissions, on the other hand, are

[8] For a more detailed description of the data collection program, see http://www.cpcb.nic.in/air.php (accessed on June 25, 2011).

[9] From the CPCB, we obtained monthly pollution readings per city from 1987-2004, and yearly pollution readings from 2005-2007. The monthly data were averaged to get annual measures.

[10] The CPCB requires that 24 hour samplings be collected twice a week from each monitor for a total of 104 observations per monitor per year. As this goal is not always achieved, 16 or more successful hours of monitoring are considered representative of a given day's air quality, and 50 days of monitoring in a year are viewed as sufficient for data analysis. In some cities, readings are conducted more frequently. For example, readings are conducted daily in Delhi. This more frequent data is not included in our dataset.

[11] Each monitor is classified as belonging to one of three types of areas: residential (71 percent), industrial (26 percent), or sensitive (2 percent). The rationale for specific locations of monitors is, unfortunately, not known to us at this time so all monitors with sufficient readings are included in the analysis.

predominantly a byproduct of thermal power generation; globally, 80 percent of sulfur emissions in 1990 were attributable to fossil fuel use (Smith, Pitcher and Wigley, 2001). NO_2 is viewed by the CPCB as an indicator of vehicular pollution, though it is produced in almost all combustion reactions.

B. Water Pollution Data

The CPCB also administers water quality monitoring, in cooperation with state pollution control boards (SPCBs). As of 2008, 1,019 monitoring stations are maintained under the National Water Monitoring Programme (NWMP), covering rivers and creeks, lakes and ponds, drains and canals, and groundwater sources. We focus on rivers due to the consistent availability of data on river quality, the seriousness of pollution problems along the rivers, and, most significantly, the attention that rivers have received from public policy. We have obtained from the CPCB, in electronic format, observations from 489 monitors in 424 cities along 162 rivers between the years 1986 and 2005 (see Appendix Table 1).[12] Figure 3 maps the location of the water quality monitors on India's major rivers.

The CPCB collects either monthly or quarterly river data on 28 measures of water quality, of which nine are classified as "core parameters." We focus on three of these core parameters: Biochemical Oxygen Demand (BOD), Dissolved Oxygen (DO), and Fecal Coliforms (FColi). We chose these measurements largely because of their presence in CPCB Official Water Quality Criteria, and also their continual citation in planning, analysis, and commentary, as well as the consistency of their reporting.[13]

[12] From 1986 to 2004, monthly data is available. For 2005, the data is only available yearly.
[13] See *Water Quality: Criteria and Goals* (February 2002); *Status of Water Quality in India* (April 2006); and the official CPCB website, http://www.cpcb.nic.in/Water_Quality_Criteria.php.

These indicators can be briefly summarized as follows. BOD is a commonly-used broad indicator of water quality that measures the quantity of oxygen required by the decomposition of organic waste in water. High values are indicative of heavy pollution; however, since water-borne pollutants can be inorganic as well, BOD cannot be considered a comprehensive measure of water purity. DO is similar to BOD except that it is inversely proportional to pollution; that is, lower quantities of dissolved oxygen in water suggest greater pollution because water-borne waste hinders mixing of water with the surrounding air, as well as hampering oxygen production from aquatic plant photosynthesis. The third water parameter, FColi, is a count of the number of coliform bacteria per 100 milliliters (ml) of water. While not directly harmful, these organisms are associated with animal and human waste and are correlated with the presence of harmful pathogens. FColi is thus considered to be an indicator of domestic pollution. It is measured as the most probable number of fecal coliform bacteria per 100 milliliters (ml) of water. Since its distribution is approximately ln normal, FColi is reported as ln(number of bacteria per 100 ml) throughout the paper.

C. Regulation Data

India has implemented a variety of environmental initiatives over the last two decades. We have assembled a dataset that systematically documents changes in policy at the city-year level for the cities in the air and water pollution datasets. To the best of our knowledge, we believe that a comparable data set has never been compiled.

The data were compiled from a variety of sources. We first collected and utilized print and web documents from the Indian government, including the CPCB, the Department of Road Transport and Highways, the Ministry of Environment and Forests, and several Indian SPCBs.

Next, we used reports and data from secondary sources, including the World Bank, the Emission Controls Manufacturers Association, and Urbanrail.net.

Table 1 summarizes the prevalence of these policies in the data file of city-level air and water pollution concentrations by year. Columns (1a) and (2a) report the number of cities with air and water readings, respectively. The remaining columns detail the number of these cities where each of the studied policies is in force. The subsequent analysis exploits the variation in the year of enactment of these policies across cities.[14]

D. Infant Mortality Rate Data

We obtained annual city-level infant mortality data from annual issues of *Vital Statistics of India* for the years prior to 1996.[15] In subsequent years, city level data are no longer available from a central source; therefore, we visited the registrar's office for each of India's larger states and collected the necessary documents directly.[16] Many births and deaths are not registered in India and the available evidence suggests that this problem is greater for deaths so the infant mortality rate is likely downward biased. Although the infant mortality rate from the *Vital Statistics* data is about a third of the rate measured from state-level survey measures of infant mortality rates (i.e., the Sample Registration System), trends in the *Vital Statistics* and survey data are highly correlated. Although these data are likely to be noisy, we are unaware of reasons to believe that the measurement error is correlated with the pollution measures. Notably, Burgess et al. (2011) find that they are correlated with inter-annual temperature variation.

[14] Appendix Table 2 replicates Table 1 for all cities in India.
[15] We digitized the city-level data from the books. All data were double entered and checked for consistency.
[16] Specifically, we attempted to obtain data in all states except the Northeastern states (which have travel restrictions) and Jammu-Kashmir. We were able to obtain data from Andhra Pradesh, Chandigarh, Delhi, Goa, Gujarat, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, and West Bengal.

E. Additional Variables

We collected city-level, socio-economic variables that are used as controls in the subsequent analysis.[17] First, we obtained district-level data on population and literacy rates from the 1981, 1991, and 2001 Census of India. For non-census years, we linearly interpolated these variables. Second, we collected district-level expenditure per capita data, which is a proxy for income. The data are imputed from the survey of household consumer expenditure carried out by India's National Sample Survey Organization in the years 1987, 1993, and 1999 and are imputed in the missing years.

IV. TRENDS IN POLLUTION CONCENTRATIONS AND INFANT HEALTH

A. Trends in Mean Pollution Levels over Time

Figure 4 provides a graphical representation of the trends in national air and water quality. Panel A plots the average air quality measured across cities, by pollutant, from 1987 to 2007; Panel B graphs water quality measured across city-rivers, by pollutant, from 1986 to 2005. Table 2 provides corresponding sample statistics. Specifically, it provides the average pollution levels for the full sample, as well as values at the start and end of the sample timeframe.

Air pollution has fallen. As shown in Panel A, ambient PM concentrations fell quite steadily over the sample timeframe, from 252.1 $\mu g/m^3$ in 1987-1990 to 209.5 $\mu g/m^3$ in 2004-2007. This represents about a 17 percent reduction in PM. The SO_2 trend line is flat until the late 1990s, and then declines sharply. Comparing the 1987-1990 to 2004-2007 time periods, mean SO_2 decreased from 19.4 to 12.2 $\mu g/m^3$ (or 37 percent). Finally, NO_2 appears more volatile over the start of the sample period, but then falls after its peak in 1997.

[17] Consistent city-level data in India is notoriously difficult to obtain. We instead acquired district level data, and matched cities to their respective districts.

While air quality has generally improved over the past twenty years, the trends in water quality are more mixed. As seen in Panel B of Figure 4, BOD steadily worsens throughout the late 1980s and early 1990s but then begins to improve starting around 1997. The improvement, though, did not make up for early losses, as mean BOD worsens by about 19 percent from 3.47 to 4.14 mg/l over the sample period. FColi drops precipitously in the 1990s but rises somewhat in the 2000s. The general decrease in FColi is notable, as it suggests that domestic water pollution may be abating, in spite of the alarmingly fast-paced growth in sewage generation seen in India (Suresh et al, 2007). Over the sample period, the natural log of the number of fecal coliform bacteria per 100 ml declined from 6.41 to 5.28. DO declines fairly steadily over time (a fall in DO indicates worsening water quality) from 7.21 to 7.03 mg/l.

B. Trends in Infant Health

Infant mortality rates are an appealing measure of the effectiveness of environmental regulations, relative to measures of adult health. This is because it seems reasonable to presume that infant health will be more responsive to short and medium changes in pollution and the first year of life is an especially vulnerable one so losses of life expectancy may be large. Since 1987, infant mortality has fallen sharply in urban India (Panel C of Figure 4). As Panel C of Table 2 shows, the infant mortality rate fell from 29.6 per 1000 live births in 1987-1990 to 16.7 in 2001-2004.

C. A More Disaggregated Analysis

Is there spatial variation in these trends? To explore this, we next graph the distributions of air and water quality across cities at the start and end of the sample period. Specifically, we provide kernel density estimates of air pollutant distributions across Indian cities for 1987-1990 and

2004-2007 in Figure 5A, and similar estimates of water pollutant distributions for 1986-1989 and 2002-2005 in Figure 5B. We then construct similar graphs for infant mortality in Figure 5C.

Figure 5A shows that not only have the means of PM and SO_2 decreased, but their entire distributions have shifted to the left over the last two decades. The 10th percentiles of PM and SO_2 pollution both declined by about 10 percent from 1987-1990 to 2004-2007. Particularly striking, however, is the drop in the 90th percentile of ambient SO_2 concentration: 38.2 to 23.0 $\mu g/m^3$, or about 40 percent. Consistent with trends in Figure 2, the distribution of NO_2 across cities does not appear to change much over the sample time frame. In fact, if anything, the distribution of pollution appears to have worsened, with the 10th percentile rising from 8.5 to 10.4 $\mu g/m^3$ and the 90th percentile rising from 42.6 to 47.0 $\mu g/m^3$.

The changes in the distribution of water quality are more variable over time (Figure 5B). The distribution of BOD has widened over the last twenty years, with many relatively higher readings of BOD in the later time period.[18] While the 10th percentile of BOD has dropped slightly, the 90th percentile has increased from 5.78 to 7.85 mg/l between the earlier and more recent periods. In contrast, the FColi distribution has largely shifted to the left. The relatively clean cities show tremendous drops in FColi levels, with the 10th percentile value falling from 3.61 to 1.79, while dirtier cities show more modest declines. Lastly, the DO distribution does not appear to have changed noticeably, with very little difference between the graphs of the earlier and later periods.

Figure 5C reveals a marked improvement in infant mortality rates over this period. Indeed, the kernel density graphs reveal a leftward shift in the distribution of infant mortality rates.

[18] The right tail of the 2002-2005 period extends to 100 mg/l. In the figure, it has been truncated at 20 to give a more detailed picture of the distribution.

V. ECONOMETRIC APPROACH

This section describes a two-stage econometric approach for assessing whether India's regulatory policies impacted air and water pollution concentrations. The first-stage is an event study-style equation:

$$(1) \quad Y_{ct} = \alpha + \sum_{\tau} \sigma_\tau D_{\tau,ct} + \mu_t + \gamma_c + \beta X_{ct} + \epsilon_{ct}$$

where Y_{ct} is one of the six measures of pollution in city c in year t. The city fixed effects, γ_c, control for all permanent unobserved determinants of pollution across cities, while the inclusion of the year fixed effects, μ_t, non-parametrically adjust for national trends in pollution, which is important in light of the time patterns observed in Figure 2. The equation also includes controls for per capita consumption and literacy rates (X) in order to adjust for differential rates of growth across districts. To account for differences in precision due to city size, the estimating equation is weighted by the district-urban population.[19]

The vector $D_{\tau,ct}$ is composed of a separate indicator variable for each of the years before and after a policy is in force. τ is normalized so that it is equal to zero in the year the relevant policy is enacted; it ranges from -17 (for 17 years before a policy's adoption in a city) through 12 (for 12 years after its adoption). All τ's are set equal to zero for non-adopting cities; these observations aid in the identification of the year effects and the β's. In the air pollution regressions, there are separate $D_{\tau,ct}$ vectors for the Supreme Court Action Plan and catalytic converter policies, so each policy's impact is conditioned on the other policy's impact.[20]

[19] City-level population figures are not systematically available, so we use population in the urban part of the district in which the city is located to proxy for city-level population.
[20] The results are qualitatively similar in terms of sign, magnitude, and significance from models that evaluate each policy separately.

The sample for equation (1) is based on the availability of data for a particular pollutant in a city. For adopting cities, a city is included in the sample if it has at least one observation three years or more before the policy's enactment and four or more years afterward. If a city does not have any post-adoption observations or did not enact the relevant policy, then that city is required to have at least two observations for inclusion in the sample.

The parameters of interest are the σ_τ's, which measure the average annual pollution concentration in the years before and after a policy's implementation. These estimates are purged of any permanent differences in pollution concentrations across cities and of national trends due to the inclusion of the city and year fixed effects. The variation in the timing of the adoption of the individual policies across cities allows for the separate identification of the σ_τ's and the year fixed effects.

In the below, the estimated σ_τ's are plotted against the τ's. These event study graphs provide an opportunity to visually assess whether the policies are associated with changes in pollution concentrations. Additionally, they allow for an examination of whether pollution concentrations in adopting cities were on differential trends. These figures will inform the choice of the preferred second-stage model.

The second-stage of the econometric approach formally tests whether the policies are associated with pollution reductions with three different specifications. In the first, we fit the following equation:

$$\text{(2a)} \quad \widehat{\sigma_\tau} = \pi_0 + \pi_1 1(Policy)_\tau + \epsilon_\tau$$

where $1(Policy)_\tau$ is an indicator variable for whether the policy is in force (i.e., $\tau \geq 1$). Thus, π_1 tests for a mean shift in pollution concentrations after the policy's implementation.

In several cases, the event study figures reveal trends in pollution concentrations that predate the policy's implementation (even after adjustment for the city and year fixed effects). Therefore, we also fit the following equation:

$$\text{(2b)} \quad \widehat{\sigma_\tau} = \pi_0 + \pi_1 1(Policy)_\tau + \pi_2 \tau + \epsilon_\tau.$$

This specification includes a control for a linear time trend in event time, τ, to adjust for differential pre-existing trends in adopting cities.

Equations (2a) and (2b) test for a mean shift in pollution concentrations after the policy's implementation. A mean shift may be appropriate for some of the policies that we evaluate. On the other hand, the full impact of some of the policies may emerge over time as the government builds the necessary institutions to enforce a policy and as firms and individuals begin to take the steps necessary to comply with them. For example, an evolving policy impact seems possible for the Supreme Court Action Plans since they specify actions that polluters must take over several years.

To allow for a policy's impact to evolve over time, we also report the results from fitting:

$$\text{(2c)} \quad \widehat{\sigma_\tau} = \pi_0 + \pi_1 1(Policy)_\tau + \pi_2 \tau + \pi_3 (1(Policy)_\tau \times \tau) + \epsilon_\tau.$$

From this specification, we report the impact of a policy 5 years after it has been in force as $\pi_1 + 5\pi_3$.

There are three remaining estimation issues about equations (2a) through (2c) that bear noting. First, the sample is chosen so that there is sufficient precision to compare the pre- and post-adoption periods. Specifically, for two of the policies it is restricted to values of τ for which there are at least twenty city by year observations to identify the σ_τ's. For the catalytic converter regressions, the sample therefore covers τ = -7 through τ = 9 and for the National River Conservation Plan regressions it includes τ = -7 through τ = 10 (see Appendix Table 3). In the case of the Supreme Court action plan policies which were implemented more narrowly, the sample is restricted to values of τ for which there are a minimum of 15 and this leads to a sample that includes $\tau = -7$ through $\tau = 3$. Second, the standard errors for these second stage equations are heteroskedastic consistent. Third, the equation is weighted by the inverse of the standard error associated with the relevant σ_τ to account for differences in precision in the estimation of these parameters.

VI. RESULTS

A. Air Pollution

Figure 6 presents the event study graphs of the impact of the policies on PM (Panel A), SO_2 (Panel B), and NO_2 (Panel C). Each graph plots the estimated σ_τ's from equation (1). The year of the policy's adoption, $\tau = 0$, is demarcated by a vertical dashed line in all figures. Additionally, pollution concentrations are normalized so that they are equal to zero in $\tau = -1$, and this is noted with the dashed horizontal line.

These figures are "hands above the table" summaries of the data in the sense that they visually report all the data that underlie the subsequent regressions. It is evident that accounting for differential trends in adopting cities is crucial, because the parallel trends assumption of the simple difference in differences or means shift model (i.e., equation (2a)) is violated in many cases. This is particularly true in the case of the catalytic converter policies which were implemented in cities where pollution concentrations were worsening. This upward pre-trend in pollution concentrations is also apparent in the case of the Supreme Court Action Plans (SCAPs) and NO_2. In these instances, equations (2b) and (2c) are more likely to produce valid estimates of the policies' impacts. With respect to inferring the impact of the policies, the figures suggest that the catalytic converter policy was effective at reversing the trend toward increasing pollution concentrations.

To test these results more formally, Table 3 reports regression results from the estimation of separate equations for each pollutant and policy pair. For each pollutant-policy pair, the first column reports the estimate of π_1 from equation (2a), which tests whether σ_τ is on average lower after the implementation of the policy. The second column reports the estimate of π_1 and π_2 from the fitting of equation (2b) in the second column for each pollutant. Here, π_1 tests for a policy impact after adjustment for the trend in pollution levels (π_2). The third column reports the results from equation (2c) that allows for a mean shift and trend break after the policy's implementation. It also reports the estimated effect of the policy five years after implementation for the policies, which is equal to $\pi_1 + 5\pi_3$.

Reading across Panel A, it is evident that the SCAPs have a mixed record of success.[21] There is little evidence of an impact on PM or SO_2 concentrations. The available evidence for an impact comes from the NO_2 regressions that control for pre-existing trends. In column (8) the estimated impact would not be judged statistically significant, while in column (9) it is of a large magnitude and would be judged marginally significant.

In contrast, the regressions confirm the visual impression that the catalytic converter policies were strongly associated with air pollution reductions. In light of the differential pre-trends in pollution in adopting cities and that the policy's impact will only emerge as the stock of cars changes, the richest specification (equation (2c)) is likely to be the most reliable. It indicates that 5 years after the policy was in force, PM, SO_2, and NO_2 declined by 48.6 $\mu g/m^3$, 13.4 $\mu g/m^3$, and 4.5 $\mu g/m^3$, respectively. The PM and SO_2 declines are statistically significant

[21] Note that for the Supreme Court Action Plans, the analysis lags the policies by one year. The dates we have correspond to Court Orders, which mandated submission of Action Plans. However, the Plans were frequently reviewed by a special committee and only afterwards declared/implemented.

when judged by conventional criteria, while the NO_2 decline is not. These declines are 19 percent, 69 percent, and 15 percent of the 1987-1990 nationwide mean concentrations, respectively. These percentage declines are large and this reflects the rapid rates at which ambient pollution concentrations were increasing before the implementation of the catalytic converter policy in adopting cities-- put another way, if the pre-trends had continued then pollution concentrations would have reached levels much higher than those recorded in the 1987-1990 period.[22]

B. Effects of Policies on Water Quality

Figure 7 presents event study analyses of the impact of the National River Conservation Plan (NRCP) on BOD (Panel A), ln(FColi) (Panel B), and DO (Panel C). As in Figure 6, the figures plot the results from the estimation of equation (1). From the figures, there is little evidence that the NRCP was effective at reducing pollution concentrations.

Table 4 provides the corresponding regression analysis and is structured similarly to Table 3. The evidence in favor of a policy impact is weak. BOD concentrations are lower after

[22] There is a tradeoff to in including a greater or smaller number of event years or taus in the second-stage analysis. The inclusion of a wider range of taus provides a larger sample size, allows for more precise estimation of pre and post adoption trends. But, at the same time, it moves further away from the event in question so that other unobserved factors may confound the estimation of the policy effects. Further, it exacerbates the problems associated with estimating the taus from an unbalanced panel data file of cities. In contrast, including fewer taus would result in a smaller sample size (and number of cities) to estimate pre and post trends, but it the analysis would be more narrowly focused around the policy event. Appendix Table 3 reports on the number of city by year observations that identify the σ_τ's associated with each event year.

We investigated the sensitivity of the results to the number of taus included in the analysis. Specifically, we estimated models that include a wider range of taus (between [-14,4] for the SCAPs and [-9,9] for the Catalytic Converters), as well as models that limit the taus to a narrower range (between [-4,4] for the SCAPs and [-5,5] for the Catalytic Converters), The application of these alternative samples to the preferred specification, equation (2c), produces results that are qualitatively similar to those in Tables 3 and 4. The SCAP is associated with a large and significant decline in NO_2 with the narrower range. With the wider range, the SCAP continues to be associated with a decline in NO_2 but it no longer would be judged to be statistically significant; however, it is associated with a statistically significant decline in PM. The pattern of the coefficients for the Catalytic Converters policy is similar to that of Table 3, regardless of increasing or decreasing the range of taus.

the implementation of NRCP, but the decline occurs several years prior to the implementation of the plan (Panel A). While NRCP targets domestic pollution, the data fail to reveal an improvement in FColi concentrations (Panel B), which is the best measure of domestic sourced water pollution. The results from the fitting of equation (2c) are reported in column (9) and confirm the perverse visual impression that the NRCP is associated with a worsening in DO concentrations (recall, lower DO levels indicate higher pollution concentrations).[23]

The finding that the NRCP has not been successful is not surprising in light of some supplementary research into process outcomes. For example, as of March, 2009, 152 out of 165 towns officially covered under NRCP have been *approved* for Sewage Treatment Plant (STP) capacity building, but only 82 of those towns have actually *built* any capacity. Additionally, as of March, 2009, there has not been any spending of federal or state monies on the NRCP in fifteen NRCP towns (National River Conservation Directorate, 2009). Furthermore, the Centre for Science and Environment (CSE) in New Delhi calculates that the 2006 treatment capacity was only 18.5 percent of the full sewage burden (Suresh et al, 2007, p. 11).

C. Effects of Catalytic Converters on Infant Mortality

The catalytic converter policy is the most strongly related to improvements in air pollution. This subsection explores whether this policy is associated with improvements in human health, as measured by infant mortality rates. Specifically, we fit equation (1) and equations (2a) - (2c), where the infant mortality rate, rather than pollution concentration, is the outcome of interest.

We note several aspects of this estimation. First, despite a large data collection exercise to obtain the infant mortality data (including going to each state capital to obtain additional

[23] This finding that the NRCP had little impact on the available measures of water pollution is unchanged by increasing or decreasing the number of event years or taus (i.e., changing the event years to include [-9,12] or to include [-5,5]) in the second-stage analysis.

registry data), there are fewer cities in the sample.[24] Second, the dependent variable is constructed as the ratio of infant deaths to births, so we weight equation (1) by the number of births in the city that year. Third, it is natural to be interested in using the catalytic converter induced variation to estimate the separate impacts of each of the three forms of air pollution on infant mortality in a two-stage least squares setting. However, such an approach is invalid in this setting because, even in the best case where the exclusion restriction is valid, there is a single instrument for three endogenous variables. Fourth, the infant mortality rate data do not provide any characteristics of the parents or other covariates, so it is not possible to determine the degree to which the results are due to shifts in the composition of parents that alter the observed infant population's health endowment. This issue is a greater challenge in light of the possibly substantial underreporting of infant births and deaths in these data.

Figure 8 and Table 5 report the results. In light of the differential pre-existing trend, the column (3) specification is likely to be the most reliable. It suggests that the catalytic converter policy is associated with a reduction in the infant mortality rate of 0.86 per 1,000 live births. However, this estimate is imprecise and is not statistically significant.

VII. DISCUSSION

This paper's analysis is related to at least two key economics questions. First, is there a deterministic relationship between income and environmental quality? Second, why are some environmental policies so much more effective than others? The paper's results shed new light on these questions.

---

[24]When the air pollution sample is restricted to the sample used to estimate the infant mortality equations, the catalytic converter policy is associated with substantial reductions in PM and SO_2 concentrations but not of NO_2 concentrations.

A. Contradicting Predictions from the Environmental Kuznets Curve Literature

The Environmental Kuznets Curve (EKC) predicts greater environmental degradation as income rises for countries at low incomes levels (Grossman and Krueger, 1995; Bandypadhyay, 1992). When income levels rise beyond a high enough point, individuals will no longer be willing to trade off environment quality for economic growth and resources will be available to invest in enforcing environmental regulation. At this point, economic growth will be correlated with environmental improvements.

The range for the turning point varies considerably across empirical studies. For example, Grossman and Kruger (1995) estimate the turning point for SO_2 at around \$4,000, with the turning point for most pollutants around or below \$8,000. Similarly, Shafik and Bandyopadhyay's (1992) study (which was used in the 1992 World Development Report) estimated turning points of about \$3,000 to \$4,000 for local air pollutant concentrations. Using an updated data set, but following Grossman and Kruger's econometric specification, Harbaugh, Levinson, and Wilson (2002) find higher turning points (e.g., for SO_2 the turning points range from \$13,000 to \$20,000), but the results are not robust to changes in the specification. Similarly, they find high and varying turning points for PM, ranging from \$2,000 to \$13,000, depending on the specification.

Two of this paper's results contradict the EKC model. First, India's per capita GDP was \$374 in 1990 when environment regulations became salient there and this is substantially below the estimated turning point.[25] However, this paper demonstrates that that the catalytic converter mandate was associated with substantial improvements in air quality.

Second, the EKC model predicts similar trends for local pollutants. However, there are substantial differences in trends across the various types of air and water pollution. Moreover,

[25] India's GDP was obtained from the World Development Indicators.

the analysis documents that the air pollution policies were effective, while the water pollution regulations were largely ineffective. These differences in regulatory effectiveness across media are not predicted by the EKC model.

B. Political Power Matters

The EKC model fails to capture some of the dominant themes in the data. This subsection explores some political economy explanations for the differences in the success of the air and water regulations.

The legitimacy to enforce policies appears to be a strong predictor of success. In particular, the Supreme Court enjoys substantial power within the Indian government and there is an established history of the Court providing an effective and visible outlet for public activism. Indeed, the SCAPs, and somewhat more indirectly the catalytic converter policies, resulted from citizen suits filed in response to high levels of air pollution.[26] At least in the case of the catalytic converter policy, there is substantial qualitative evidence that these policies were enforced stringently by tying vehicle registrations to installation of a catalytic converter.[27] With this context, it may not be surprising that these two sets of policies were generally successful in reducing air pollution concentrations.

In contrast, the central government agencies, such as the CPCB/SPCBs and the Ministry of Environment and Forestry (MoEF), have a less clear mandate for action and less successful

[26] Court Order on April 5th, 2002, Supreme Court of India. Writ Petition (Civil) No. 13029 of 1985. M.C. Mehta vs. Union of India and Others.

[27] Narain and Bell (2005) write, "In 1995 the Delhi government announced that it would subsidize the installation of catalytic converters in all two- and three-wheel vehicles to the extent of 1,000 Rs. within the next three years (Indian Express, January 30, 1995). Furthermore, the Petroleum Ministry banned the registration of new four-wheel cars and vehicles without catalytic converters in Delhi, Mumbai, Chennai, and Calcutta effective April 1, 1995 (Telegraph, March 13, 1995). This directive was implemented, although it is alleged that some vehicle owners had the converters removed illegally (court order, February 14, 1996)." Further, Delhi currently has about 20 vehicle registration outposts.

track records of reform across a variety of domains. The NRCP was originally developed and launched by the MoEF and overseen by a newly-created authority chaired by the Prime Minister of India. The job of implementation and enforcement was delegated to CPCB/SPCBs and local departments for public health, development, water, and sewage (Ministry of Environment and Forests, 2006). The already difficult task of enforcing the NRCP was further complicated by the fact that the legislation is vague on the question of where the jurisdiction to enforce the policies lies.[28] For example, a former CPCB chairman summed up the problem quite clearly: "When it comes to doing things, it is not up to the CPCB, even in the area of air pollution." (Sharma and Roychowdhury, 1996, p. 128)

Further, an absence of a clear source of revenues for NRCP activities is likely to have contributed to the program's poor record of performance. The sewage plants that are frequently mandated by the NRCP had mandated cost sharing at various points in time.[29] State and local bodies have been accused of financial mismanagement, including diversion, underutilization, and incorrect reporting of funds (Ministry of Environment and Forests, 2006). Overall, the implementation of the NRCP through agencies that have traditionally not been very powerful, the jurisdictional opacity around implementation, and a failure to provide a clear source of revenues to fund clean-up activities mean that the NRCP was never politically empowered to succeed.[30]

---

[28] For example, the Public Accounts Committee Report to Parliament cited in this section (MoEF, 2006) only mentions the word "enforcement" once in over 100 pages.

[29] From the inception of GAP-Phase I in 1985, the central government was to be responsible for 100 percent of policy funding. In 1990, it was decided that the cost would be split between central and state administrations. This division was revoked in 1997, returning the full cost to the Union government. One final change was made in 2001, allocating 30 percent of the financial burden to states, a third of which was levied on local bodies themselves (Suresh et al, 2007, p. 3).

[30] For example, a MoEF (2006) report stated that: "The reasons for delay in the implementation of the Ganga Action Plan Phase-I are: (i) Lack of experience with the State implementing agencies, delay in land acquisition, litigations and court cases, contractual disputes and diversion of funds by the State Governments. (ii) Poor operation and

VI. Conclusion

Using the most comprehensive data file ever compiled on air pollution, water pollution, environmental regulations, and infant mortality for a developing country, this paper measures the success of air and water pollution regulations in India. The paper finds that air pollution regulations were very effective at reducing ambient concentrations of particulate matter, sulfur dioxide, and nitrogen dioxide and a key determinant of the observed improvements in air quality over the last two decades. In contrast, the results indicate that the National River Conservation Plan—the cornerstone of India's water policies—failed to lead to meaningful improvements in any of the three separate measures of water pollution that we consider.

There are several broader meanings of these results. First, the difference in the effectiveness of the air and water pollution regulations make it clear that the world is more complicated and nuanced that is suggested by simple theories, like the Environmental Kuznets Curve theory. There is substantial room for more modeling in this area.

Second, the findings demonstrate that environment regulations can be enforced successfully in countries with relatively low levels of income and weak institutions, which contradicts widely held perceptions. However, it leaves unanswered the fundamental questions of the magnitudes of the marginal benefits and costs of regulation-induced emissions reductions and whether the benefits exceed the costs. There is a virtual complete absence of information on the costs and benefits.

Third, the political economy findings may have implications for the development of successful climate change policy, which will require participation by developing countries,

---

maintenance of the assets created under the 'Ganga Action Plan' Phase–I. (iii) Erratic and poor availability of electricity for operating assets like pumping stations, sewage treatment plants and electric crematoria." (p. 3) including India and China. Specifically, they suggest that international efforts to reduce greenhouse gases in developing countries will have limited success if they do not enjoy local support.

REFERENCES

Asian Development Bank. "Yamuna Action Plan – India," in Asian Water Development Outlook 2007. Manila, Philippines: Asian Development Bank, 2007.

Burgess, Robin, Olivier Deschenes, Dave Donaldson, and Michael Greenstone. 2011. "Weather and Death in India: Mechanisms and Implications for Climate Change." Mimeo.

Cha, J. Mijin. 2005. "A Critical Examination of the Environmental Jurisprudence of the Courts of India," *Albany Law Environmental Outlook Journal*, 10: 197.

Chay, Kenneth and Michael Greenstone. 2003. "Air Quality, Infant Mortality, and the Clean Air Act of 1970," Mimeo.

Chay, Kenneth and Michael Greenstone. 2005. "Does Air Quality Matter? Evidence from the Housing Market," *Journal of Political Economy*, 113(2).

Chen, Yuyu,, Avraham Ebenstein, Michael Greenstone, and Hongbin Li. 2011. "The Long-Run Impact of Air Pollution on Life Expectancy: Evidence from China's Huai River Policy," Mimeo.

Copeland, Brian and M. Scott Taylor. 2004. *Journal of Economic Literature,* 42: 7-71.

Davis, Lucas W. 2008. "The Effect of Driving Restrictions on Air Quality in Mexico City." *Journal of Political Economy*, 116(1): 38-81.

Foster, Andrew D., and Naresh Kumar. 2008. "Have CNG regulations in Delhi done their job?" *Economic and Political Weekly*, 42(51): 48-58.

Foster, Andrew D., and Naresh Kumar. 2009. "Air Quality Interventions and Spatial Dynamics of Air Pollution in Delhi and its Surroundings." *International Journal of Environment and Waste*, 4(1/2): 85-111.

Greenstone, Michael. 2003. "Estimating Regulation-Induced Substitution: The Effect of the Clean Air Act on Water and Ground Pollution." *American Economic Review Papers and Proceedings*, 93(2): 442-448.

Greenstone, Michael. 2004. "Did the Clean Air Act Amendments Cause the Remarkable Decline in Sulfur Dioxide Concentrations?" *Journal of Environmental Economics and Management*, 47.

Grossman, Gene M., and Alan B. Krueger. 1995. "Economic Growth and the Environment." *Quarterly Journal of Economics*, 110(2): 353–77.

Hadden, Susan G. 1987. "Statutes and Standards for Pollution Control in India," *Economic and Political Weekly*, 22 (16): 709-711+713-720.

Hanna, Rema, and Paulina Oliva. 2010. "The Impact of Inspections on Plant-Level Air Emissions." *The B.E. Journal of Economic Analysis and Policy*, 10(1).

Hanna, Rema, and Paulina Oliva. 2011. "The Effect of Pollution on Labor Supply: Evidence from a Natural Experiment in Mexico City," Mimeo.

Harbaugh, William, Arik Levinson and David Wilson. 2002. "Reexamining the Empirical Evidence for an Environmental Kuznets Curve." *Review of Economics and Statistics*, 84(3): 541-551.

Henderson, J. Vernon. 1996. "Effects of Air Quality Regulation." *American Economic Review*, 86: 789-813.

Meagher, J. Patrick. 1990. "Environmental Protection and Industries in Developing Countries: The Case of India Since Bhopal." *The Georgetown International Environmental Law Review*, 3(1): 1-53.

Ministry of Environment and Forests. 2006. "26th Report of the Public Accounts Committee (Fourteenth Lok Sabha): Ganga Action Plan." Presented to Lok Sabha on March 17th, 2006. Lok Sabha Secretariat: New Delhi.

Narain, Urvashi and Ruth Greenspan Bell. 2005. "Who Changed Delhi's Air? The Roles of the Court and the Executive in Environmental Policymaking." Resources for the Future Discussion Paper.

National River Conservation Directorate. "M.I.S. Report of Programmes Under National River Conservation Plan, Vol. III." National River Conservation Directorate, Ministry of Environment and Forests, Government of India: New Delhi, March, 2009.

Selden, Thomas M., and Daqing Song. 1994. "Environmental Quality and Development: Is There a Kuznets Curve for Air Pollution?" *Journal of Environmental Economics and Environmental Management*, 27(2): 147-162.

Shafik, Nemat and Sushenjit Bandyopadhyay. 1992. "Economic Growth and Environmental Quality: Time Series and Cross-Country Evidence." The World Bank Policy Research Working Paper Series 904.

Sharma, Anju and Anumita Roychowdhury. Slow Murder: The deadly story of vehicular pollution in India. New Delhi : Centre for Science and Environment, 1996.

Smith, Steven J, Hugh Pitcher and T.M.L Wigley. 2001. "Global and regional anthropogenic sulfur dioxide emissions" *Global and Planetary Change*, 29 (1-2): 99–119.

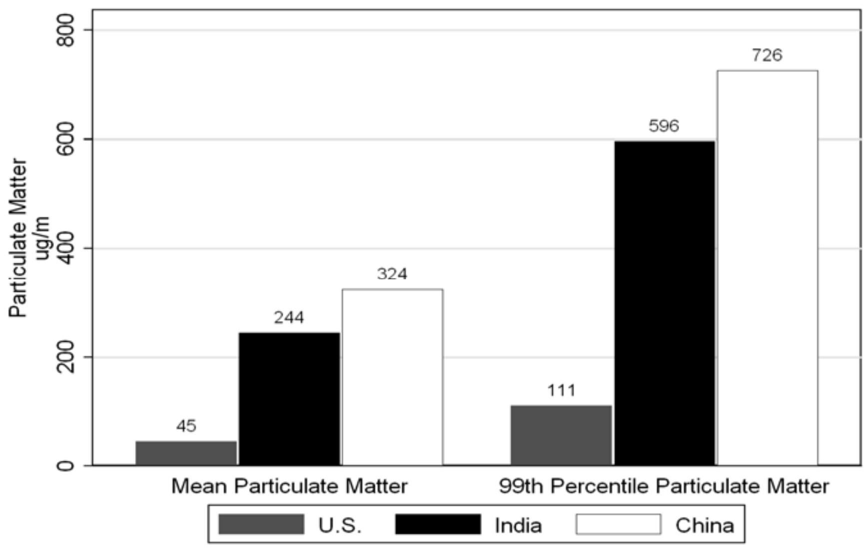
Stern, David and Michael Common. 2001. "Is There an Environmental Kuznets Curve for Sulfur?" *Journal of Environmental Economics and Environmental Management*, 41(2): 162-178.

Suresh, Babu S. V., Bharat L. Seth, Ajit Chak, Vasudha K. Dixit, and Sunita Narain. Sewage Canal: How to Clean the Yamuna. New Delhi: Centre for Science & Environment, 2007.

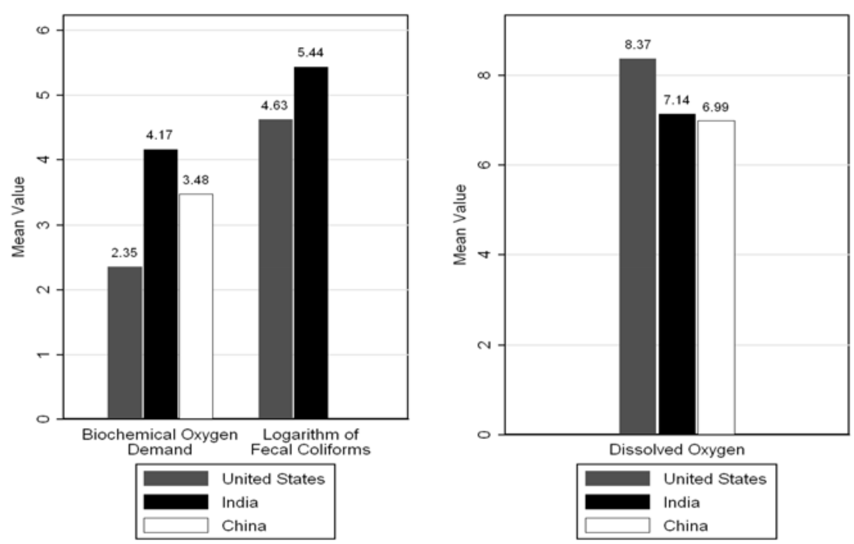
Takeuchi, Akie, Maureen Cropper, and Antonio Bento. 2007. "The Impact of Policies to Control Motor Vehicle Emissions in Mumbai, India." *Journal of Regional Science,* 47(1): 27–46.

Figure 1: Comparison of Pollution Levels in India, China, and the U.S.

Panel A: Air Pollution Levels



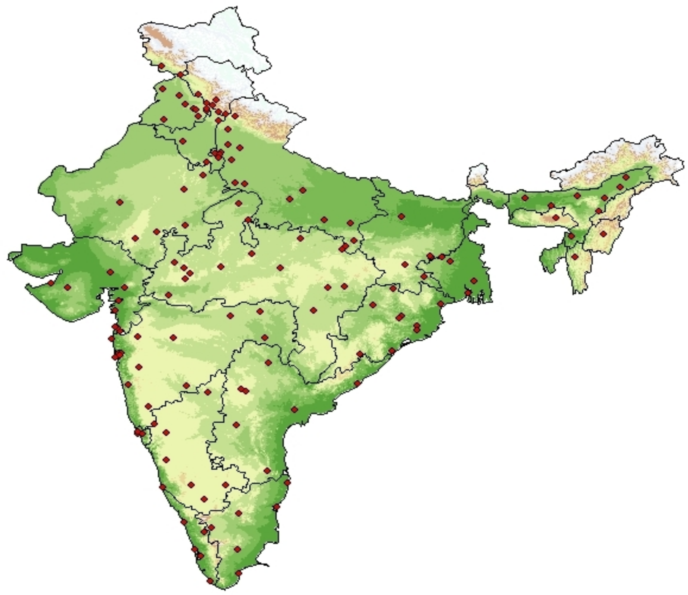
Panel B: Water Pollution Levels



Notes:

1. In Panel A, the air pollution values are calculated from 1990-1995 data. For India, only cities with at least seven years of data are used. In Panel B, water pollution values for India and the United States are calculated from 1998-2002 data. For India, only city-rivers with at least seven years of data are used. Pollution values for China are calculated across six major river systems for the year 1995 and are weighted by number of monitoring sites within each river system. Fecal coliform data for China were unavailable.
2. "Particulate Matter" refers to all particles with diameter less than 100 μm, except in the case of the United States, where particle size is limited to diameter less than 50 μm.
3. Units are mg/l for Biochemical Oxygen Demand and Dissolved Oxygen. For Logarithm of Fecal Coliforms, units are the most probable number of fecal coliform bacteria per 100 ml of water or MPN/100 ml. An increase in Biochemical Oxygen Demand or Fecal Coliforms signals higher levels of pollution, while an increase in Dissolved Oxygen signals lower levels of pollution.
4. Indian pollution data (both air and water) were drawn from the Central Pollution Control Board's online and print sources. Data for the United States (both air and water pollution) were obtained from the United States Environmental Protection Agency. Air pollution data for China came from the World Bank and China's State Environmental Protection Agency. Doug Almond graciously provided these data. Chinese water pollution data come from the World Bank; Avi Ebenstein graciously provided them.

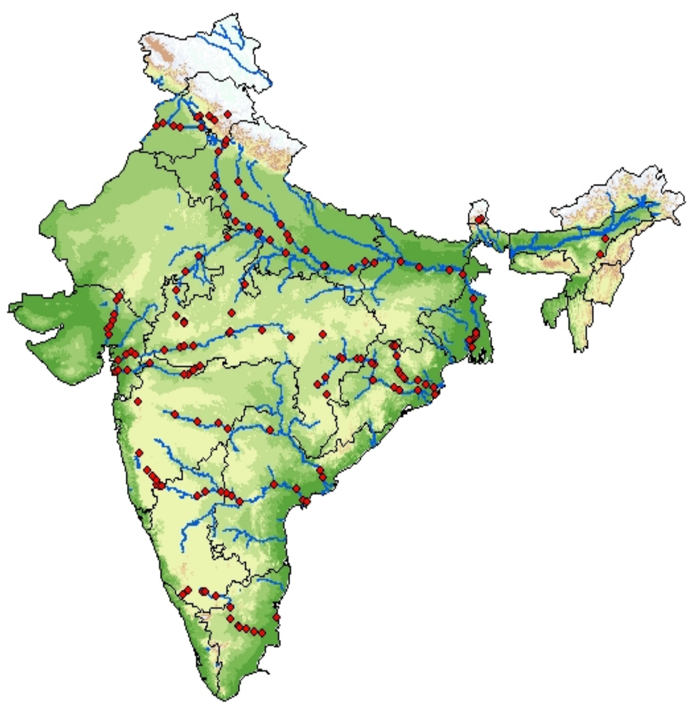
Figure 2: Air Quality Monitors Across India



Notes:

1. Dots denote cities with monitoring stations under India's National Ambient Air Quality Monitoring Programme (NAAQMP).
2. Geographical data are drawn from MIT's Geodata Repository. Monitoring locations are determined from CPCB and SPCB online sources and Google Maps.

Figure 3: Water Quality Monitors on India's Major Rivers



Notes:

1. Dots denote cities with monitoring stations under India's National Water Monitoring Programme (NWMP). Only cities with monitors on major rivers are included, as geospatial data for smaller rivers is unavailable.
2. Geographical data are drawn from MIT's Geodata Repository. Monitoring locations are determined from CPCB and SPCB online sources and Google Maps.

Table 1: Prevalence of Air and Water Policies

	Air			*Water*	
Year	All Cities (1a)	SCAP (1b)	Cat Conv (1c)	All Cities (2a)	NRCP (2b)
1986	--	--	--	104	0
1987	20	0	0	115	0
1988	25	0	0	191	0
1989	31	0	0	218	0
1990	44	0	0	271	0
1991	47	0	0	267	0
1992	58	0	0	287	0
1993	65	0	0	305	10
1994	57	0	0	316	10
1995	42	0	2	317	38
1996	68	0	4	316	39
1997	73	1	4	326	43
1998	65	1	22	325	43
1999	74	1	26	320	43
2000	66	1	24	303	39
2001	54	1	19	363	43
2002	63	1	22	376	41
2003	72	11	25	382	42
2004	78	15	24	395	41
2005	93	16	24	295	38
2006	112	16	24	--	--
2007	115	16	24	--	--

Notes:

1. Columns (1a) and (2a) tabulate the total number of cities in each year, while columns (1b), (1c), and (2b) tabulate the number of cities with the specified policy in place in each year.

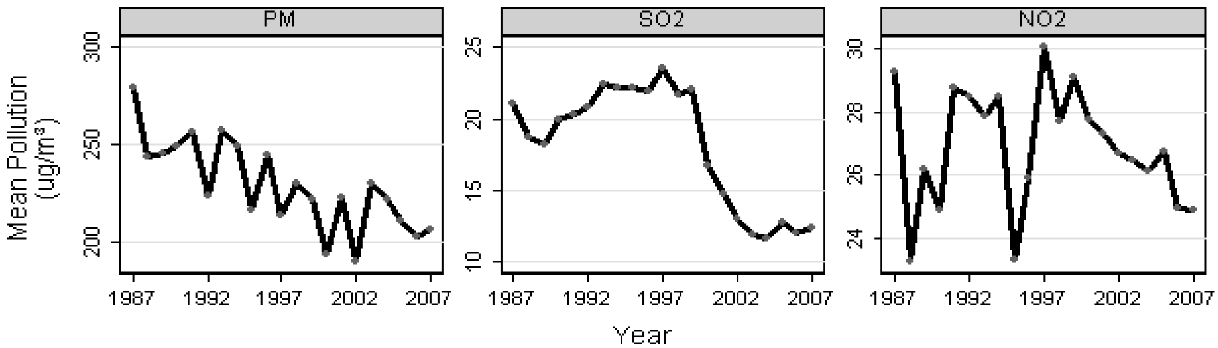
2. We subject the full sample to two restrictions before analysis, both of which are applied here. (1) If there is pollution data from a city after it has enacted a policy, then that city is only included if it has at least one data point three years or more before policy uptake and four years or more after policy uptake. (2) If there is no post-policy pollution data in a city (or if that city never enacted the policy), then that city is only included if it has at least two pollution data points.

3. In this table, a city is counted if it has any pollution data in that year. A city is only included in the subsequent regressions if it has pollution data for the specific dependent variable of that given regression. Thus, the above city counts must be interpreted as maximums in the regressions. Most city-years have available data for all pollutants studied here.

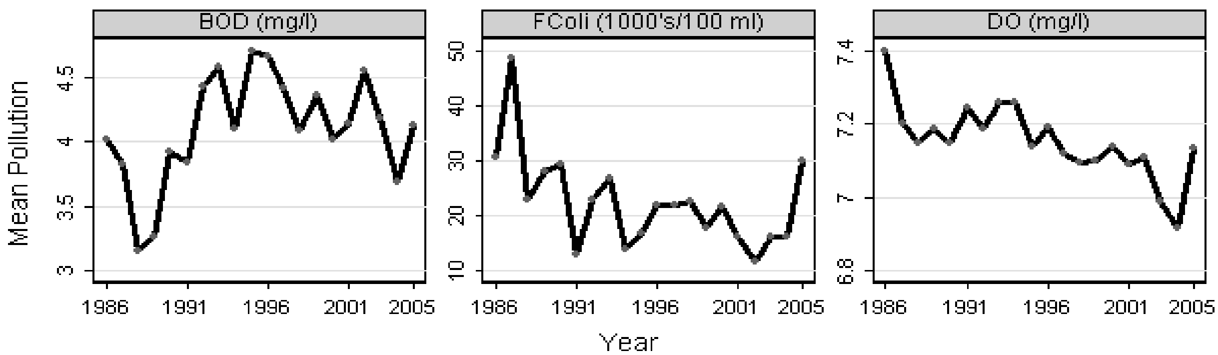
4. The data were compiled by the authors from Central Pollution Control Board's online sources, print sources, and interviews.

Figure 4: Trends in Air and Water Quality

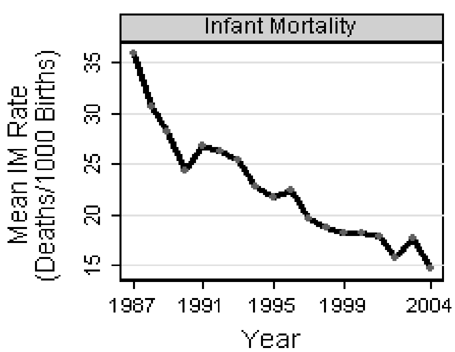
Panel A: Air Pollution



Panel B: Water Quality



Panel C: Infant Mortality



Notes:

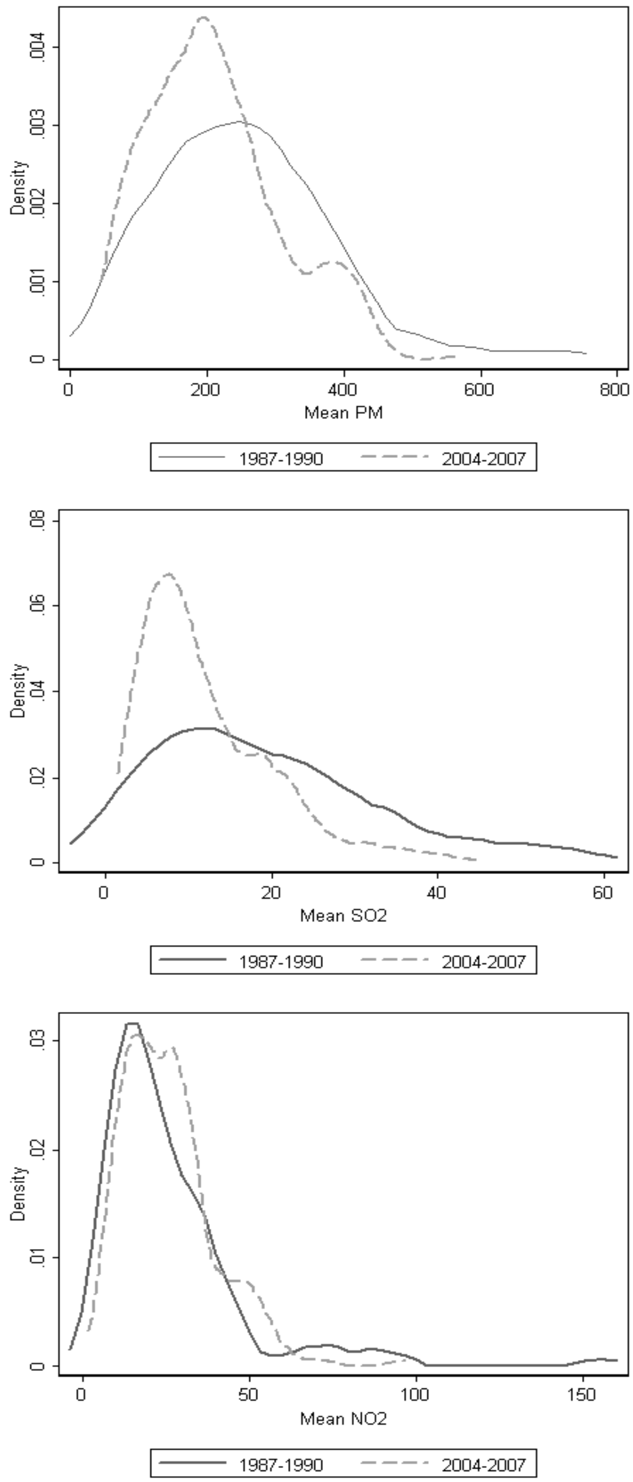
1. The figures depict annual mean pollution levels. There are no restrictions on the sample. Annual means are first taken across all monitors within a given city, and then across all cities in a given year.
2. Infant mortality data are restricted to those cities which have at least one air or water pollution measurement in the full sample.
3. Pollution data were drawn from Central Pollution Control Board's online and print sources. Infant mortality data were taken from the book *Vital Statistics of India* as well as various state registrar's offices.

Table 2: Summary Statistics

Period	Mean	10th Percentile	90th Percentile	Mean	10th Percentile	90th Percentile	Mean	10th Percentile	90th Percentile
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: Air Pollution									
		PM			SO_2			NO_2	
Full Period	223.3	90.5	378.4	17.3	4.0	35.4	26.8	10.0	48.7
	(114.0)			(15.2)			(18.0)		
	1370			1344			1382		
1987-1990	252.1	101.6	384.3	19.4	4.4	38.2	25.5	8.5	42.6
	(126.4)			(13.3)			(21.5)		
	120			116			117		
2004-2007	209.5	92.0	366.6	12.2	4.0	23.0	25.6	10.4	47.0
	(97.1)			(8.1)			(14.0)		
	420			381			417		
Panel B: Water Quality									
		BOD			Ln(FColi)			DO	
Full Period	4.2	0.8	7.0	5.4	1.9	9.0	7.1	5.7	8.5
	(8.0)			(2.7)			(1.3)		
	5949			4986			5920		
1986-1989	3.5	0.9	5.8	6.4	3.6	9.7	7.2	6.0	8.5
	(6.9)			(2.3)			(1.2)		
	644			529			648		
2002-2005	4.1	0.9	7.9	5.3	1.8	9.1	7.0	5.5	8.4
	(7.9)			(2.9)			(1.5)		
	1509			1340			1487		
Panel C: Infant Mortality									
		IM Rate							
Full Period	23	3	46						
	(22.1)								
	1246								
1987-1990	30	5	56						
	(31.5)								
	357								
2001-2004	17	3	36						
	(14.1)								
	216								

Notes:
1. This table provides summary statistics on air and water quality. Standard deviations are provided below the mean in parantheses.
2. Infant mortality data are restricted to those cities which have at least one air or water pollution measurement in the full sample.
3. Pollution data were drawn from Central Pollution Control Board's online and print sources. Infant mortality data were taken from the book *Vital Statistics of India* as well as various state registrar's offices.

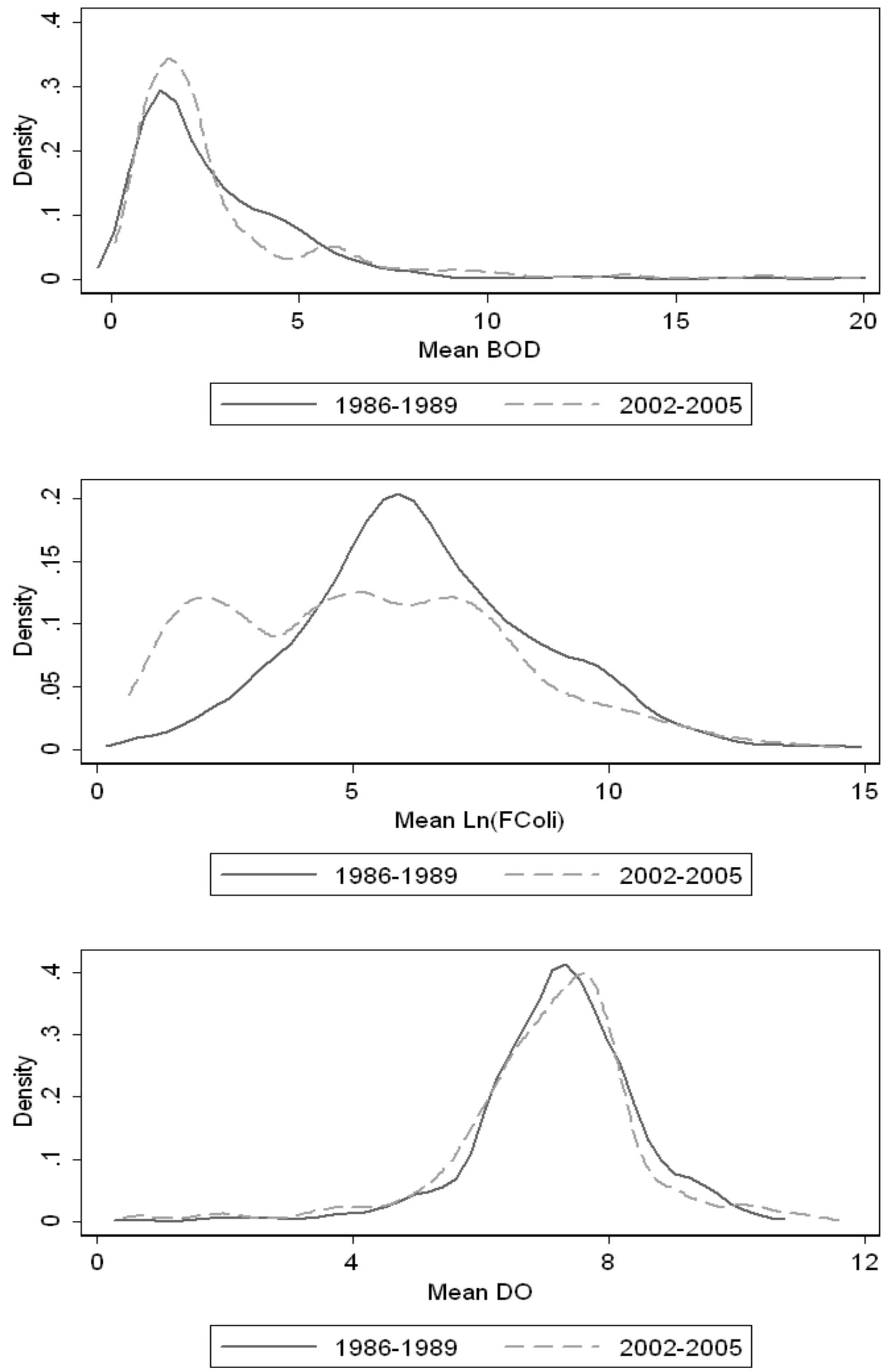
Figure 5A: Kernel Density Graphs of Ambient Air Quality



Notes:

1. The graphs provide the distribution of air pollution for the early (1987-1990) and later (2004-2007) periods of our sample. They are constructed using an Epanechnikov kernel function.
2. Units are μg/m³ for all pollutants.
3. The data were drawn from Central Pollution Control Board's online and print sources.

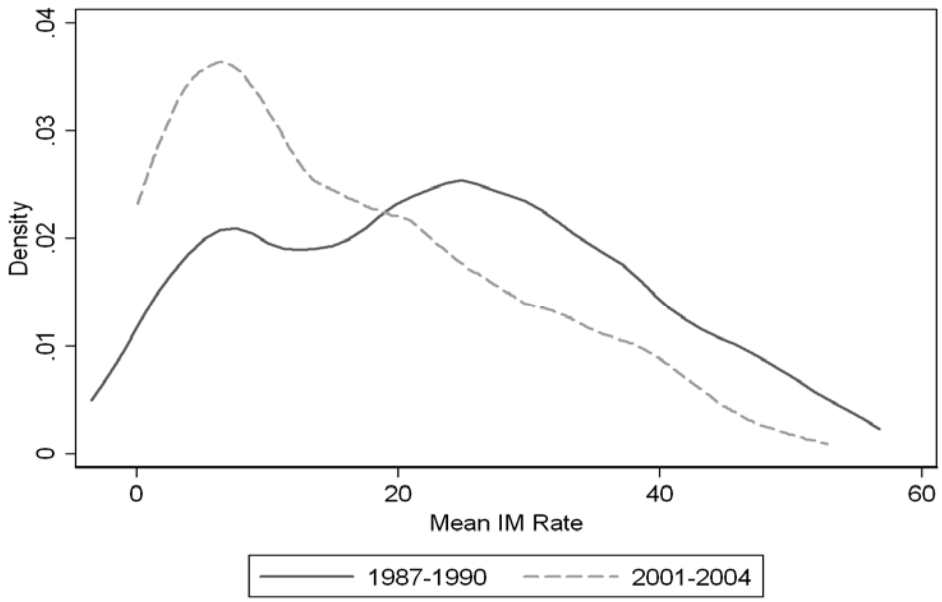
Figure 5B: Kernel Density Graphs of Surface Water Quality



Notes:

1. The graphs provide the distribution of water pollution for the early (1986-1989) and later (2002-2005) periods of our sample. They are constructed using an Epanechnikov kernel
2. Units are mg/l for BOD and DO, and Ln(MPN/100 ml) for FColi.
3. The right tail of the BOD distribution extends to 100 mg/l but is truncated to provide a more detailed picture of the distribution.
4. The data were drawn from Central Pollution Control Board's online and print sources.

Figure 5C: Kernel Density Graphs of Infant Mortality

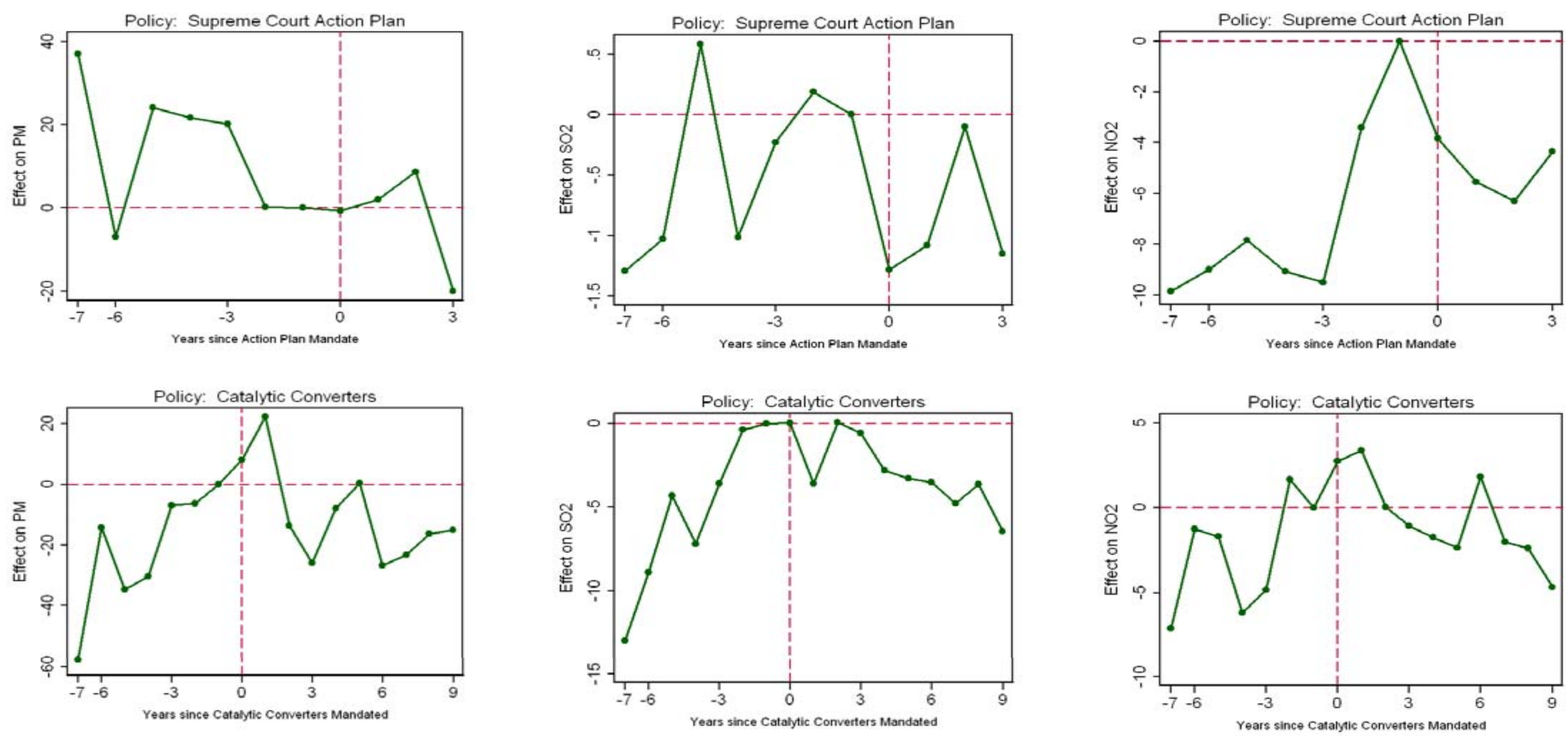


Notes:

1. The graph provides the distribution of infant mortality for the early (1987-1990) and later (2001-2004) periods of our sample. They are constructed using an Epanechnikov kernel function.
2. Infant mortality data are restricted to those cities which have at least one air or water pollution measurement in the full sample.
3. Units of infant mortality rate are Deaths per 1000 Births.
4. The right tail of the IM distrbution extends above 100 but is truncated to provide a more detailed picture of the distribution.
5. The data were drawn from the book *Vital Statistics of India* as well as various state registrar's offices.

Figure 6. Event Study of Air Pollution Policies

Panel A. PM *Panel B. SO2* *Panel C. NO2*



Notes: The figures provide a graphical analysis of the effect of the Supreme Court Action Plans and mandated Catalytic Converter policies on air pollution. The figures plot the estimated σ_τ's against the τ's from the estimation of equation (1). Each pair of graphs within a panel are based on the same regression. See the text for further details.

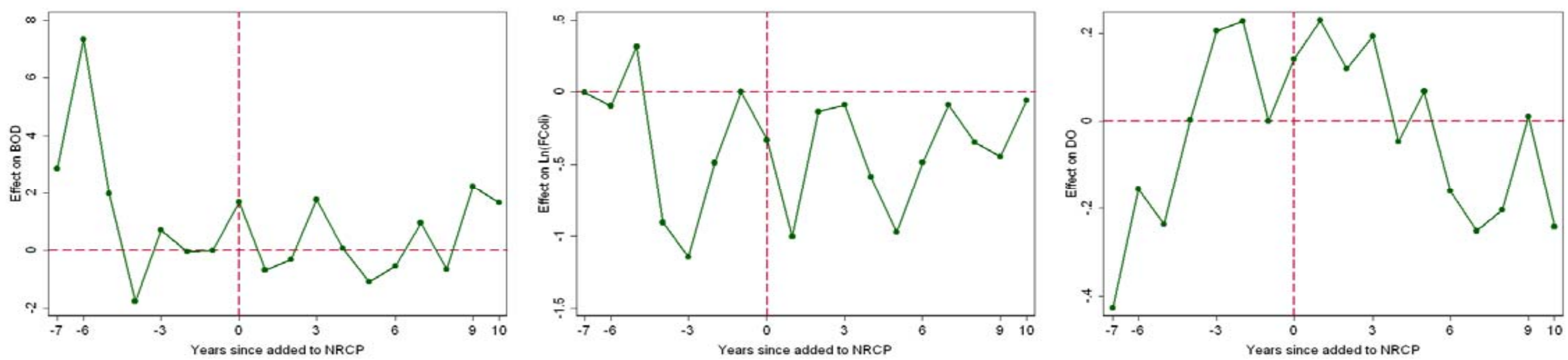
Table 3. Trend Break Estimates of the Effect of Policy on Air Pollution

	PM			SO_2			NO_2		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: Supreme Court Action Plans									
Time Trend		-3.8	-3.6		0.2	0.2		1.2**	1.4**
		(2.4)	(2.8)		(0.1)	(0.1)		(0.4)	(0.4)
1(Policy)	-16.2	4.9	7.5	-0.5	-1.5*	-1.4	1.9	-4.4	-1.7
	(9.4)	(15.8)	(20.6)	(0.4)	(0.7)	(0.9)	(2.0)	(2.7)	(3.1)
1(Policy) * Time Trend			-1.5			-0.1			-1.6
			(7.1)			(0.3)			(1.1)
5-Year Effect			-0.2			-1.7			-9.8*
p-value			0.99			0.21			0.06
N	11	11	11	11	11	11	11	11	11
Panel B: Catalytic Converters									
Time Trend		-0.3	7.8***		0.1	2.0***		-0.3	0.9*
		(1.8)	(2.5)		(0.3)	(0.3)		(0.3)	(0.4)
1(Policy)	11.9	14.7	5.6	2.5	1.5	-0.5	2.2	4.5	3.2
	(8.8)	(17.4)	(12.8)	(1.7)	(3.3)	(1.5)	(1.4)	(2.8)	(2.2)
1(Policy) * Time Trend			-10.8***			-2.6***			-1.5***
			(2.9)			(0.3)			(0.5)
5-Year Effect			-48.6***			-13.4***			-4.5
p-value			0.04			0.00			0.25
N	17	17	17	17	17	17	17	17	17
Equation (2a)	Y	N	N	Y	N	N	Y	N	N
Equation (2b)	N	Y	N	N	Y	N	N	Y	N
Equation (2c)	N	N	Y	N	N	Y	N	N	Y

Notes: This table reports results from the estimation of equations (2a), (2b), and (2c). Panel A reports on the estimated impact of the Supreme Court Action Plans for PM (columns (1) – (3)), SO2 (columns (4) – (6)), and NO2 (columns (7) – (9)). Panel B reports on the same exercise, except for the catalytic converter policy. Rows denoted "5-Year Effect" report $\Pi_1 + 5\Pi_3$, which is an estimate of the effect of the relevant policy 5 years after implementation from equation (2c). The p-value of a hypothesis test for the significance of this linear combination is reported immediately below the 5-year estimates. Asterisks denote significance at the 90% (*), 95% (**), and 99% (***) levels. See the text for further details.

Figure 7. Event Study of Water Pollution Policy

Panel A. BOD | *Panel B. Ln(Fcoli)* | *Panel C. DO*



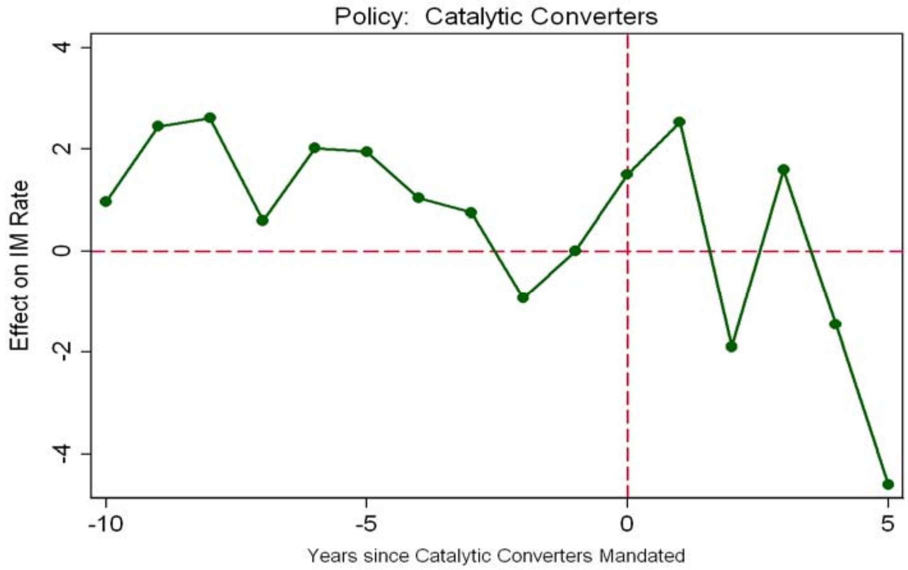
Notes: The figures provide a graphical analysis of the effect of the National River Conservation Plan policy on water pollution. The figures plot the estimated σ_τ's against the τ's from the estimation of equation (1). See the text for further details.

Table 4. Trend Break Estimates of the Effect of the National River Conservation Policy on Water Pollution

	BOD			Ln(Fcoli)			DO		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Time Trend		-0.12	-0.88**		0.01	-0.08		-0.02	0.09***
		(0.18)	(0.34)		(0.04)	(0.08)		(0.02)	(0.02)
1(NRCP)	-1.11	-0.06	1.07	-0.08	-0.14	-0.01	0.04	0.19	0.03
	(0.99)	(1.88)	(1.67)	(0.20)	(0.39)	(0.40)	(0.10)	(0.18)	(0.12)
1(NRCP) * Time Trend			0.96**			0.11			-0.13***
			(0.38)			(0.09)			(0.03)
5-Year Effect			5.87*			0.54			-0.62***
p-value			0.06			0.45			0.01
N	18	18	18	18	18	18	18	18	18
Equation (2a)	Y	N	N	Y	N	N	Y	N	N
Equation (2b)	N	Y	N	N	Y	N	N	Y	N
Equation (2c)	N	N	Y	N	N	Y	N	N	Y

Notes: This table reports estimates of the impact of the National River Conservation Policy on three measures of water pollution from the fitting of equations (2a), (2b), and (2c). The three measures of water pollution are BOD (columns (1) – (3)), Ln(Fcoli) (columns (4) – (6)), and DO (columns (7) – (9)). The row denoted "5-Year Effect" reports $\Pi_1 + 5\Pi_3$, which is an estimate of the effect of the relevant policy 5 years after implementation from equation (2c). The p-value of a hypothesis test for the significance of this linear combination is reported immediately below the 5-year estimates. Asterisks denote significance at the 90% (*), 95% (**), and 99% (***) levels. See the text for further details.

Figure 8. Event Study of Catalytic Converters and Infant Mortality



Notes: The figure provides a graphical analysis of the effect of the Catalytic Converter policy on the infant mortality rate. The figure plots the estimated σ_τ's against the τ's from the estimation of equation (1). See the text for further details.

Table 5. Trend Break Estimates of the Effect of the Catalytic Converter Policy on Infant Mortality

	(1)	(2)	(3)
Time Trend		-0.40**	-0.25
		(0.16)	(0.15)
1(Policy)	-1.55	1.67	3.49**
	(0.97)	(1.53)	(1.49)
1(Policy) * Time Trend			-0.87**
			(0.36)
5-Year Effect			-0.86
p-value			0.61
N	16	16	16.00
Equation (2a)	Y	N	N
Equation (2b)	N	Y	N
Equation (2c)	N	N	Y

Notes: This table reports estimates of the impact of the Catalytic Converter Policy on infant mortality rates from the fitting of equations (2a), (2b), and (2c). The row denoted "5-Year Effect" reports $\Pi_1 + 5\Pi_3$, which is an estimate of the effect of the relevant policy 5 years after implementation from equation (2c). The p-value of a hypothesis test for the significance of this linear combination is reported immediately below the 5-year estimates. Asterisks denote significance at the 90% (*), 95% (**), and 99% (***) levels. See the text for further details.

Appendix Table 1: Summary Statistics, by Year

	Panel A: Air Quality			*Panel B: Water Quality*			*Panel C: Infant Mortality*
Year	PM	SO_2	NO_2	BOD	Ln(Fcoli)	DO	IMR
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1986	--	--	--	4.0	6.1	7.4	--
	--	--	--	111	100	110	--
1987	279.3	21.0	29.3	3.8	6.5	7.2	35.9
	20	17	18	122	101	119	87
1988	243.6	18.7	23.2	3.2	6.3	7.2	30.6
	25	25	25	190	162	195	87
1989	245.7	18.2	26.2	3.3	6.7	7.2	28.2
	31	31	31	221	166	224	87
1990	249.1	19.9	24.9	3.9	6.6	7.2	24.4
	44	43	43	273	205	275	96
1991	256.2	20.3	28.8	3.8	5.6	7.2	26.9
	47	46	45	264	212	268	80
1992	223.5	20.9	28.5	4.4	6.1	7.2	26.2
	58	57	57	287	206	286	76
1993	257.2	22.5	27.9	4.6	5.9	7.3	25.3
	66	64	63	307	246	308	79
1994	249.3	22.2	28.5	4.1	5.7	7.3	22.8
	58	65	65	327	256	324	78
1995	216.0	22.2	23.3	4.7	5.1	7.1	21.7
	42	41	43	327	285	327	79
1996	244.9	21.9	25.9	4.7	4.9	7.2	22.3
	70	68	68	328	279	326	58
1997	213.6	23.6	30.0	4.4	4.9	7.1	19.6
	76	72	72	338	290	335	59
1998	229.8	21.7	27.7	4.1	4.9	7.1	18.7
	68	66	66	329	282	334	58
1999	221.5	22.1	29.1	4.4	4.9	7.1	18.2
	77	75	75	326	265	324	55
2000	193.5	16.7	27.8	4.0	4.9	7.1	18.1
	68	71	71	313	270	311	52
2001	223.0	14.7	27.3	4.2	5.1	7.1	17.8
	57	69	70	377	321	367	63
2002	189.4	13.0	26.7	4.6	5.2	7.1	15.7
	67	77	77	389	335	380	61
2003	230.3	11.9	26.5	4.2	5.1	7.0	17.6
	76	76	76	393	350	382	62
2004	222.0	11.6	26.1	3.7	5.1	6.9	14.6
	82	85	85	417	370	417	30
2005	210.6	12.7	26.7	4.1	5.9	7.1	--
	97	86	93	310	285	308	--
2006	202.9	12.0	25.0	--	--	--	--
	116	104	115	--	--	--	--
2007	206.7	12.4	24.9	--	--	--	--
	125	106	124	--	--	--	--

Notes:

1. The figures depict annual mean pollution levels. There are no restrictions on the sample. Annual means are first taken across all monitors within a given city, and then across all cities in a given year.
2. Number of city-year observations is reported below the mean in each year.
3. Units are ug/m³ for all air pollutants; mg/l for BOD and DO; Ln(MPN/100 ml) for Fcoli; and Deaths per 1000 Births for infant mortality.
4. Pollution data were drawn from Central Pollution Control Board's online and print sources. Infant mortality data were taken from the book *Vital Statistics of India* as well as various state registrar's offices.

Appendix Table 2: Pollution Policy Coverage in India

	Air		*Water*
Year	Supreme Court Action Plans (1)	Catalytic Converters (4)	National River Conservation Plan (6)
1986	--	--	25
1987	0	0	25
1988	0	0	25
1989	0	0	25
1990	0	0	25
1991	0	0	25
1992	0	0	25
1993	0	0	25
1994	0	0	97
1995	0	0	160
1996	0	4	160
1997	0	4	160
1998	1	4	160
1999	1	49	160
2000	1	49	160
2001	1	49	160
2002	1	49	160
2003	12	49	160
2004	17	49	160
2005	17	49	160
2006	17	49	--
2007	17	49	--

Notes:

1. This table describes the incidence of each policy across all of India.
2. Policy data were drawn from a variety of sources that are detailed in the text.

Appendix Table 3: Distribution of Air and Water Policies, by Relative Year

	Air		*Water*
Relative Year	Supreme Court Action Plans (1)	Catalytic Converters (4)	National River Conservation Plan (6)
-17	1	0	0
-16	6	0	0
-15	6	0	0
-14	10	0	0
-13	12	0	0
-12	12	0	0
-11	12	5	0
-10	14	8	0
-9	13	10	13
-8	10	19	14
-7	16	20	26
-6	17	22	30
-5	17	23	37
-4	17	18	37
-3	16	18	41
-2	17	26	39
-1	17	26	36
0	17	20	42
1	16	26	42
2	17	24	42
3	17	19	39
4	12	22	43
5	1	25	43
6	1	24	43
7	1	24	39
8	1	24	42
9	1	24	39
10	1	4	38
11	0	4	11
12	0	4	11

Notes:

1. This table describes the prevalence of policies in the dataset by year *relative to policy uptake* . Thus, a value of '-17' in the first column signifies '17 years before a policy is implemented'. We use relative year ('tau') as the year variable in event study regressions and figures.
2. Cities which enact a policy are subjected to the same inclusion rules as in event study analysis. That is, a city is only included here if it has at least one pollution data point 3 years or more before policy uptake as well as at least one data point 4 years or more after policy uptake.
3. In this table, a city is counted if it has *any* pollution data in that year. In analyses, a city is only used if it has pollution data for the specific dependent variable in a given regression. Thus, the above city counts must be interpreted as maximums among our regressions. Most city-years have available data for all pollutants studied here.
4. Since infant mortality data is only available up to the year 2004, the table above is not representative for analysis which uses infant mortality as the dependent variable.
5. Policy data are drawn from a variety of sources detailed in the text.