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# The Solvable Challenge of Air Pollution in India<sup>§</sup>

**ABSTRACT** More than 660 million Indians breathe air that fails India's National Ambient Air Quality Standards. Research suggests that meeting those standards would increase the average life expectancy in India by one year. Going further and meeting the international benchmarks of the World Health Organization is estimated to add 4.7 years to the life expectancy. Notwithstanding these large benefits, successfully implementing policies that deliver clean air has proved difficult. This paper reviews a breadth of empirical evidence from within and outside India, as well as new data from Delhi's recent program to ration driving, and industrial emissions in Gujarat and Maharashtra. It distills three lessons for designing effective reforms: (a) ensuring that regulatory data is reliable and unbiased, (b) framing regulations that are both economically efficient and incentive-compatible across the range of actors affected, and (c) introducing a culture of piloting and evaluating new policies as a scientific route to achieving better outcomes. It makes the case that market-based policy instruments may solve several problems with existing regulation in India, and have the potential to reduce air pollution *and* cut compliance costs at the same time.

**Keywords:** *India, Pollution, Regulation, Transparency, Emissions Trading, Markets, Congestion Pricing*

**JEL Classification:** *Q52, Q53, Q56, Q58, I18*

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§ The paper has benefited from comments by the editors Karthik Muralidharan and Shekhar Shah, the reviewers Nathaniel Keohane and E. Somanathan, and Sanjib Pohit at NCAER.

## 1. Introduction

The costs to society from air and water pollution can be extraordinarily high. Greenstone et al. (2015) combine ground-level in-situ measurements with satellite-based remote sensing data, and estimate that 660 million Indians live in areas that exceed the National Ambient Air Quality Standard (NAAQS) for fine particulate pollution.<sup>1</sup> India is also estimated to have the worst access to safe drinking water of any country in the world (WaterAid 2016) with over 100 million people living in areas without safe drinking water.<sup>2</sup>

The medical literature has documented several mechanisms through which polluted air and water may lead to more illness and higher mortality. For instance, evidence shows that river water pollution causes an increase in diarrhea-related deaths (Do 2014). In the case of air quality, recent research now allows us to go beyond isolating effects on specific diseases and to quantify the *long-term, cumulative* effects of being exposed to sustained air pollution. The Air Quality Life Index<sup>3</sup> (AQLI) provides a means to predict the overall reduction in life expectancy caused by living in places with high levels of air pollution. Figure 1 maps life-expectancy loss based on the AQLI across the districts of India. These health costs are not restricted to a few urban areas. If India were to achieve its own air quality standards, we could increase life expectancy across India by one year on average; this number increases to 4.7 if we were to meet the World Health Organization (WHO) norms. In a similar vein, Lim et al. (2012) estimated that ambient particulate matter air pollution accounts for 6 percent of global deaths, and that over 10 percent of premature deaths are due to lower respiratory diseases. To put this number in perspective, this is higher than deaths due to tuberculosis and malaria combined (Lim et al. 2012).

The economic costs of this pollution, owing to higher health care expenditures and a less productive workforce, are significant.<sup>4</sup> An estimate from the OECD suggests ambient air pollution alone may cost India more than 0.5

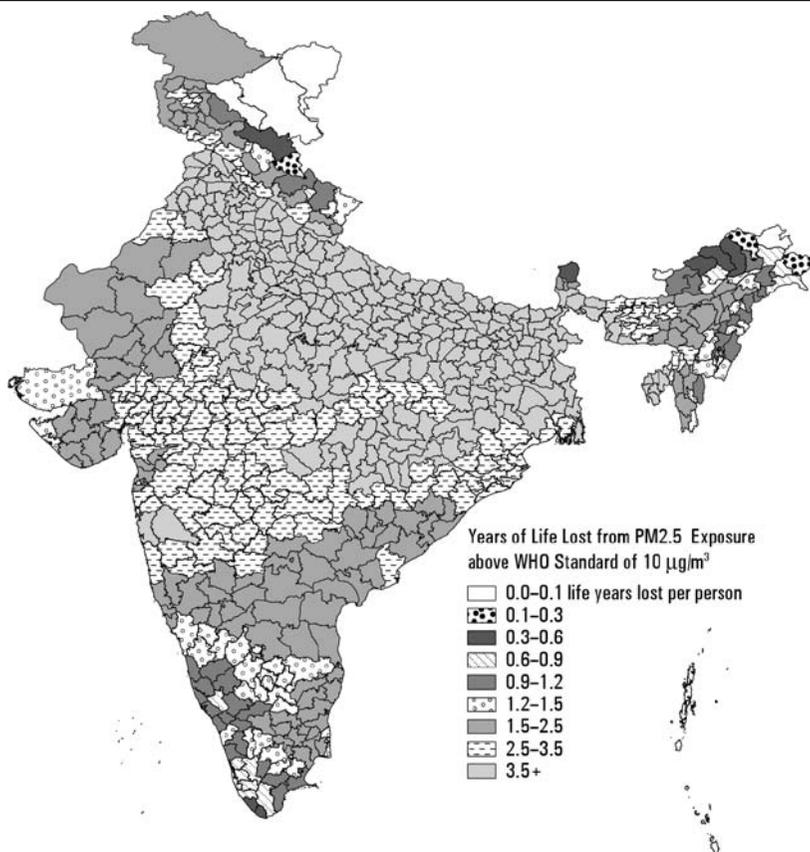
1. The phrase “fine particulate pollution” refers to solid particles suspended in the air, having a diameter smaller than 2.5 microns. These particles are produced from various sources, including the combustion of fossil fuels, biomass, solid wastes, and natural dust.

2. Estimated using data from India Water Tool, a collaborative database put together by the World Resources Institute and the Confederation of Indian Industry. See <http://www.indiawatertool.in/> for more detail.

3. The AQLI is a useful metric developed by the Energy Policy Institute at the University of Chicago. The AQLI is generated using global datasets on air pollution, in combination with published scientific evidence on the causal effects of pollution on life expectancy. See <https://aqli.epic.uchicago.edu/>.

4. Quantifying the effects of pollution on productivity is an active area of research. The evidence that does exist suggests that productivity may be significantly reduced in polluted environments (Adhvaryu et al. 2016; Chang et al. 2016).

**FIGURE 1. Increase in Life Expectancy If PM<sub>2.5</sub> Levels were to Meet WHO Norms: Districts of India**



Source: Air Quality Life Index. See <https://aqli.epic.uchicago.edu/>.

Note: This map is not to scale and may not depict authentic boundaries.

trillion dollars per year (OECD 2014). It is these costs that motivate environmental regulation. If policy instruments are able to reduce the pollution associated with productive economic activity at reasonably low costs, they would significantly improve welfare.

Using these facts as our point of departure, this paper reviews the state of environmental regulation in India, with the goal of identifying a roadmap for reform. In Section 2 we describe the nature of existing regulation in India, which is overwhelmingly composed of “command-and-control” policy instruments. We draw upon a rich set of empirical evidence to show that widespread non-compliance has undercut the impact of existing regulation on pollution. We discuss Delhi’s car-rationing pilot, the so-called

‘Odd-even’, as a recent and prominent example of a command-and-control program. In Section 3, we use a new survey of industrial plants in Gujarat, Maharashtra, and Tamil Nadu to show that even if compliance problems were somehow resolved, command-and-control instruments are likely to be significantly more expensive than lower cost, market-based regulation. In Section 4, we identify three principles that we believe provide a roadmap for more effective environmental regulation in India: (a) improving the reliability and transparency of data, (b) designing instruments that properly account for the incentives of those affected by regulation, and (c) encouraging a culture of piloting and testing regulatory innovation, as a prelude to scaling up good ideas. Section 5 concludes the paper.

## 2. Assessing Command-and-control in India

Virtually all environmental regulation in India are derived from three fundamental legislations: The Environment Protection Act (1986), the Air Act (1981), and the Water Act (1974). Although a detailed discussion of these laws is outside the scope of this paper, they are noteworthy for the freedom they provide regulators to determine how pollution should be regulated.

Unfortunately, even though this legal framework provides a relatively blank canvas to start with, the government has engaged in very little experimentation with different types of policy instruments. Most environmental regulations in India can be classified as rigid command-and-control instruments. Examples include technology mandates, bans on production processes, and absolute emissions standards. Since these regulations largely focus on the industrial sector, our discussion here will also focus primarily on the merits of command-and-control regulation of industrial pollution.<sup>5</sup>

The regulation of industrial pollution broadly fits into three categories. *First*, and most common, the regulator or the government establishes absolute standards relating to the production of pollutants that need to be adhered to, failing which penalties may be levied. *Second*, the regulator may explicitly mandate the use of specific technologies, production processes, or fuels. This may include a requirement to install pollution abatement equipment or

5. Transport regulation has largely originated from judicial action, with the resources of State Pollution Control Boards almost uniformly skewed towards regulating industry. Later in this paper, we discuss an example of a command-and-control policy intervention applying to vehicles in Delhi, although it is worth noting that this policy did not originate from the state environmental regulator.

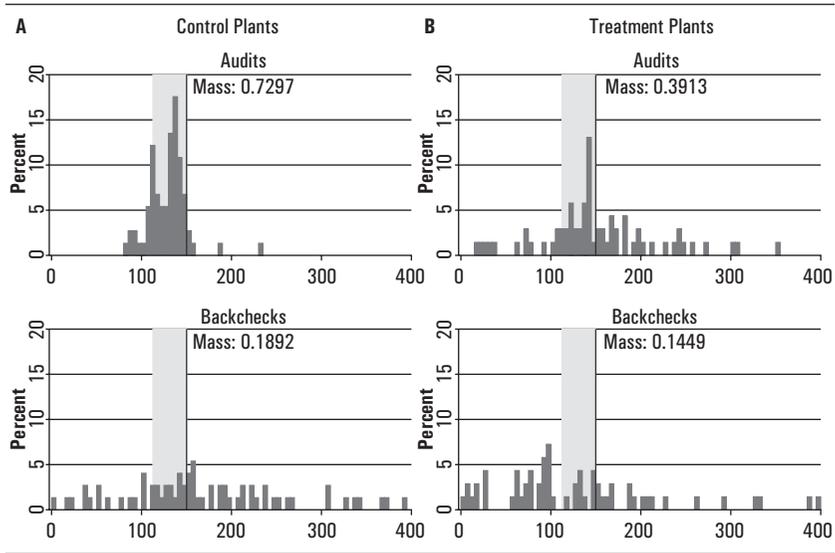
switching to natural gas as a combustion fuel. *Third*, the government may ration or even entirely ban certain types of polluting economic activity. We discuss all three command-and-control approaches below.

### *2.1. Enforcing Pollution Standards*

To control industrial emissions, India's Central and State Pollution Control Boards (SPCBs) set a permissible limit on the concentration of pollutants that can be emitted by industries from their stacks or chimneys. These limits are generally denominated in terms of concentrations: the mass of pollutants in a unit volume of air leaving a stack. For instance, the limit on the concentration of particulate matter in stack emissions is set at 150 mg/Nm<sup>3</sup> for many industries in the country.

A key indicator of whether such regulation is successful at reducing pollution is the degree to which industries comply with these limits. Although anecdotally we know that pollution norms are frequently violated, a lack of good data has limited systematic analysis of compliance. Regulatory inspections of plants are often infrequent, and access to these emissions records is generally restricted to the regulator. Furthermore, information on the results of compliance tests is often unavailable in a manner conducive to easy analysis. For instance, data is often scattered across regional offices in paper form, with no centralized database available.

That said, the work by some of the authors of this paper provides a basis for statistical statements about compliance. This evidence highlights serious problems with the enforcement of existing regulations across India. Duflo et al. (2013) collected data from regulatory inspections in the state of Gujarat for which third-party auditors were paid by the plant itself. Panel A in Figure 2 provides a snapshot of the initial conditions observed in the distribution of regulatory samples obtained from industries in that study, with the vertical line denoting the regulatory standard. High levels of non-compliance and widespread falsification of data were evident from backchecks, with several plants falling to the right (above) the regulatory standard. Panel B shows the results post the pilot that incentivized accurate reporting in a number of ways, including with auditors no longer paid by the plant. This work is discussed in detail later in this paper. In Maharashtra, another highly industrialized state, we digitized the results of over 13,200 regulatory pollution tests spanning a period between September 2012 and February 2018. In Figure 3, we plot the distribution of pollution readings taken over this extended period of time. Over half of all samples exceed the regulatory standard.

**FIGURE 2. Readings for Suspended Particulate Matter Emissions in the Stack (milligram/Nm<sup>3</sup>)**

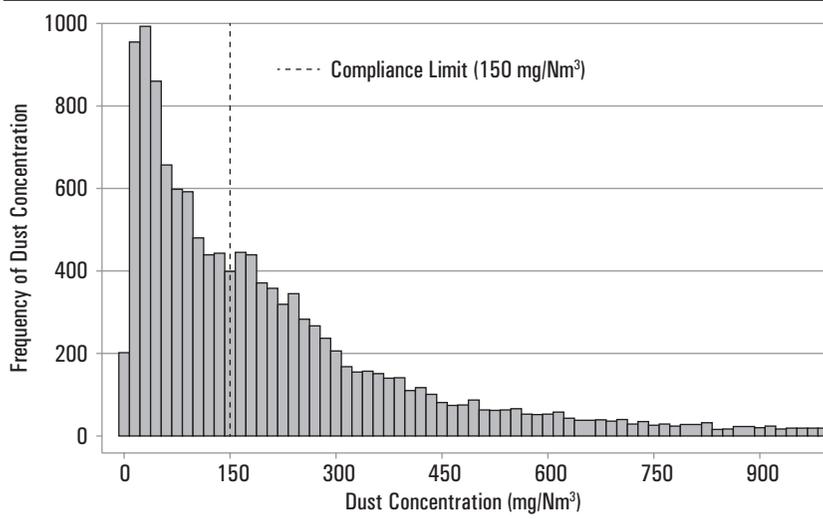
Source: Duflo et al. (2013).

Note: The figure shows distributions of pollutant concentrations for particulate matter in boiler-stack samples taken during the midline survey of the project, with data collected in 2009 and 2010 from a sample of industries in Ahmedabad and Surat. Panel A shows the distributions of readings at control plants from audits and backchecks, respectively. Panel B shows readings at treatment plants from the same two sources. The regulatory maximum concentration limit of 150 mg/Nm<sup>3</sup> is marked with a vertical line; the area between 75 percent and 100 percent of the limit is shaded in gray and shows the probability mass in this zone where auditors might be expected to place their measurements if they are trying to show plants to be compliant without being too conspicuous.

## 2.2. Mandates on Technology and Process to Reduce Emissions

The transport sector is a setting where technology and fuel mandates are commonly used across the world. Such mandates do not directly target pollution; rather, they seek to enforce specific choices on polluting sources. When this choice does not represent the cheapest means of reducing emissions, technology mandates raise the costs of reducing pollution higher than is economically efficient. Nevertheless, technology mandates are often perceived as being easier to enforce and monitor than directly measuring and regulating emissions.

Catalytic converters are an end-of-pipe technology to reduce emissions from vehicular exhaust, and have been used all over the world. Catalytic converters convert carbon monoxide and unburnt carbon into more benign carbon dioxide, and convert nitrogen oxides (NO<sub>x</sub>) into nitrogen gas. In the 1990s, the Delhi Government and the Ministry of Petroleum and Natural Gas mandated the installation of this technology in automobiles, especially

**FIGURE 3. Particulate Matter Emissions from Maharashtra Industries**

Source: Maharashtra Pollution Control Board and authors' calculations.

Note: The histogram plots the number of samples from industrial plants in Maharashtra corresponding to various emissions levels, using over 13,200 digitized regulatory inspections data between September 2012 and February 2018. While 150 mg/Nm<sup>3</sup> is the most common norm for particulate matter compliance, some industries have even more stringent limits.

in the aftermath of orders issued by the Supreme Court (Narain and Bell 2006). In January 1995, the Delhi government also introduced subsidies for catalytic converters in all two- and three-wheeler vehicles. The Ministry of Petroleum and Natural Gas then announced that all new vehicles in the four metros—Delhi, Mumbai, Kolkata and Chennai—needed to have these devices installed. In 1998, this order was extended to 45 cities.

Since vehicle registrations were linked to the installation of catalytic converters, enforcement was stringent. The impact of the installation of catalytic converters was expected to increase over time, as the fleet composition changed with newer vehicles on the roads. Greenstone and Hanna (2014) use an event-study approach to examine the program's impact on concentrations of SO<sub>2</sub>, NO<sub>2</sub>, and suspended particulate matter in ambient conditions. Five years after the implementation of the catalytic converters policy, they observe statistically significant declines in particulate matter and SO<sub>2</sub> by 19 percent and 69 percent of their 1987–90 nationwide mean concentrations, respectively. Similarly, Narain and Krupnick (2007) evaluate a subsequent court-mandated shift to CNG fuel for all public transportation in New Delhi, accompanied with a ban on diesel fuel in such vehicles. They also identify reductions in fine particulate and sulphate emissions in response to this change.

This history suggests that transport-sector fuel and technology mandates have sometimes been effective in reducing pollution. This has not always been true in other settings. In the industrial sector, environmental regulators across the country have mandated that plants install different types of air pollution control equipment. For example, industries that have a high probability of emitting particulate matter are often required to install bag filters, even if their existing air pollution control equipment could potentially be designed and maintained well enough to ensure that industries comply with the norms. Similarly, all thermal power plants are required to install flue gas desulphurization units to control their SO<sub>2</sub> emissions.

In 2015, the authors in partnership with the Central Pollution Control Board (CPCB) conducted a survey of nearly 1,000 industrial plants in Gujarat, Maharashtra, and Tamil Nadu. This survey provided a rare opportunity to systematically examine the relationship between pollution and mandatorily installed equipment.

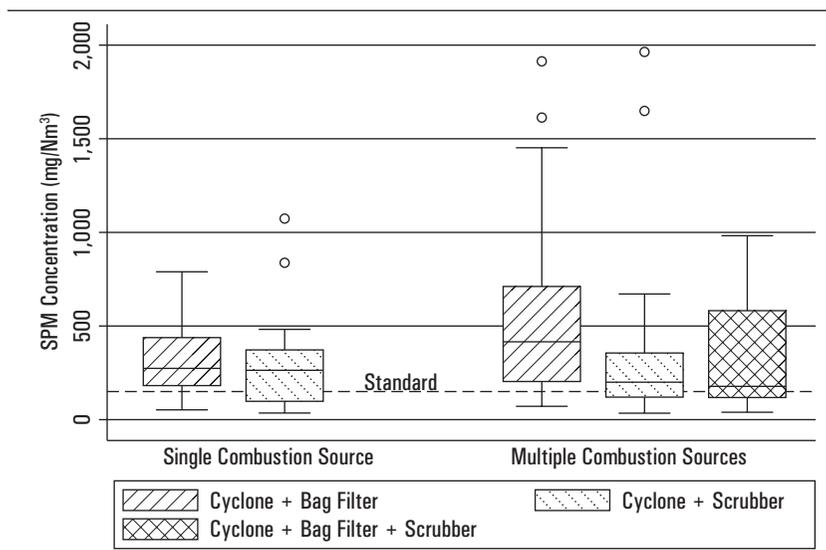
For example, in Gujarat the survey covered 311 plants in and around the city of Surat. These manufacturing plants were primarily in the textile sector. We found that industries typically had sophisticated air pollution control devices (APCDs) such as bag filters, which in theory ought to ensure that the plants meet emissions norms. Nearly 60 percent of the 311 plants had bag filters, often with other APCDs. And yet, as Figure 4 shows, these plants continued to have very high pollution levels, and the mean emissions of the three most common combinations with bag filters exceeded the prescribed standard by two times or more.

This divergence between meeting a technology mandate and reducing pollution underscores a key weakness of this type of regulation. The government can mandate and enforce the installation of equipment, but it cannot observe or enforce their regular maintenance and use. Thus, even if a bag filter is installed in a factory smokestack, it may never be used, and in some cases, the equipment may be in such disrepair as to be useless even when being operated. Since operating and maintaining capital equipment can cost a significant amount of money, it is not surprising that plants have an incentive to fulfill the letter of the law but not the spirit. It seems clear, therefore, that without reliable information on what plants emit on a day-to-day basis, technology mandates in the industrial sector are unlikely to solve the pollution problem.

### *2.3. Bans and Rationing of Polluting Activities*

The most severe forms of command-and-control regulation involve banning or restricting the operations of specific categories of polluters, independent of actual emissions. This type of regulation may impose net social costs, if

**FIGURE 4. Distribution of Measured Concentrations of Particulate Matter from Stacks with the Most Common Configuration of Emissions Source and Air Pollution Control Devices (APCD)**



Source: CPCB and authors' calculations.

Note: In the graph, the box shows the interquartile range (25<sup>th</sup> percentile and 75<sup>th</sup> percentile), with the median value in the middle. The dots are outliers.

the externality damages from pollution are lower than the economic value of the restricted activity. Consequently, blanket bans should ideally only be used in special cases where the potential environmental damages are very large (e.g., activities associated with extremely hazardous wastes) and enforcement in other ways is likely to be difficult.

In practice, bans in India have frequently been imposed in the backdrop of ongoing government failures to satisfactorily regulate pollution in the first instance, for example, in cases where governments have failed to ensure that manufacturing plants install *and* use pollution control equipment. The judiciary has often driven this prohibitory form of regulation by ruling in favor of public interest litigants in cases where regulators have been unable to show that they can satisfactorily control pollution.

One example is the decision of the Delhi government in the late 1990s, backed by the Supreme Court, to relocate highly polluting industries out of Delhi. More recently, the process of relocating industrial units in residential areas in Delhi has also occurred under the directions of the Supreme Court (Narain and Bell 2006). Geographic bans also commonly form part of Action Plans mandated by the Supreme Court in several cities. These

Action Plans have targeted industries in different ways, including “closure of clandestine units (Faridabad), moving various industries and commercial activities outside of city limits (Jodhpur, Kanpur), installation of electrostatic precipitators in all boilers in power generation stations (Lucknow), surprise inspections (Patna), and promotion of alternative fuels in generators (Hyderabad)” (Harrison et al. 2015).

Restrictions on operations and ownership are also common in the transport sector. These include compulsory retirement of old vehicles, or restrictions on the use of heavy commercial vehicles during the day in cities. Often, the effectiveness of these environmental policies is difficult to evaluate.

A recent prominent example of rationing economic activity to reduce pollution was the Odd-Even driving restriction program imposed by the Government of Delhi. An important characteristic of the policy was that it was implemented as a pilot for a limited period of time. In what follows, we describe the Odd-Even scheme in greater detail, and exploit its limited duration and restricted geographic applicability (no rationing was imposed outside Delhi) to estimate the impacts this scheme had on air pollution in Delhi. The Odd-Even scheme is worth discussing because of the significant amount of public attention it garnered. Independent of its effectiveness, the pilot was uncommon in initiating a fairly widespread (but sadly short-lived!) discussion around what types of policy instruments are the most efficient ways of reducing pollution.

#### *2.4. The Effectiveness of Driving Restrictions in Reducing Air Pollution*

On December 1, 2015, the Delhi government announced that the Odd-Even program for privately owned cars would be launched as a pilot during January 1–15, 2016. The scheme worked as follows: First, cars were classified into odd and even categories on the basis of the last digit of the car licensing plates. Next, it was mandated that only vehicles with odd numbered license plates could run on odd numbered dates and even numbered plates on even dates. The scheme was effective during the hours of 8 AM to 8 PM for the first 15 days of January 2016.<sup>6</sup> Cars with registration plates from outside Delhi were also required to comply. Alongside, the Delhi government announced other measures to reduce air pollution, as follows:

- November 6, 2015: Environment Compensation Charge (ECC) for commercial vehicles (light diesel vehicles and three-axle vehicles)

6. Vehicles driven by women or cars with more than two passengers were exempt from the policy.

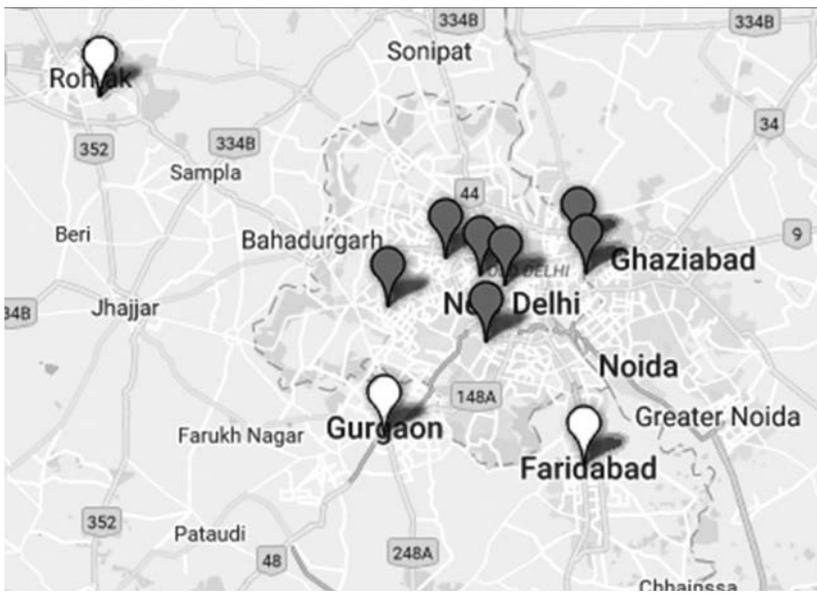
entering the city limits (Central Pollution Control Board 2013b; Supreme Court 2015a). On December 16, 2015, the ECC was doubled (Supreme Court 2015b).

- On December 16, 2015, the Supreme Court banned the registration of new diesel cars (larger than 2,000 cc) till March 31, 2016 (Supreme Court 2015b).
- From January 1, 2016, the Delhi government increased the restriction on entry of trucks into Delhi. Entry, earlier possible from 9 PM, was pushed to 11 PM.

After the first Odd-Even pilot was completed, the government re-introduced the scheme for another two-week period during April 15–30, 2016. This provides an opportunity to test not only the effectiveness of the scheme but also the repeatability of initial outcomes.

Our analysis uses data from 10 ambient air quality monitors in Delhi and three satellite cities just outside Delhi. Figure 5 shows monitor locations (operated by the CPCB for Delhi, and by the Haryana SPCB for the neighboring towns of Faridabad, Gurgaon and Rohtak). We compiled

**FIGURE 5.** Locations of Pollution Monitors in Delhi and Haryana



Source: Google Maps and authors.

Note: Pollution monitor locations are shown by gray balloons in Delhi and white balloons in Haryana.

hourly monitoring data for the six months spanning November 2015 to April 2016.

A simple comparison of air quality before and during the program may be misleading. There are multiple sources of particulate matter in Delhi, and concentrations vary substantially with weather conditions. We, therefore, focus on a difference-in-difference analysis where we examine how the difference in air quality between Delhi and neighboring cities changes during the program relative to the time-period before and after. We also consider a “triple difference” variant where we additionally examine whether during program days the impact is concentrated during the hours that the program was in effect (i.e., between 8 AM and 8 PM). More formally, we estimate a regression model that takes the form:

$$Y_{tm} = \alpha + \beta.1(m \in \text{Delhi}) + \gamma.1(t \in \text{oddeven}) + \delta.1(m \in \text{Delhi}) \times 1(t \in \text{oddeven}) + \lambda_m + \eta_t + \varepsilon_{tm}$$

where  $Y_{tm}$  is the particulate (PM2.5) concentration at time  $t$  (on hour  $h$  and day  $d$ ) for monitor  $m$ . Explanatory variables include an indicator variable for the treatment area (Delhi), an indicator variable for the times that the Odd-Even program was enforced (termed *oddeven*), and their interaction term.  $\beta$  and  $\gamma$  are the coefficients for the treatment area and period indicator variables. The interaction coefficient  $\delta$  estimates the program impact on particulate concentration.  $\lambda_m$  and  $\eta_t$  capture fixed effects at the monitor level and for each hour.

Our empirical analysis assumes that, in the absence of the program, pollution in Delhi and neighboring cities would have evolved similarly. The relatively unanticipated nature of the pilot and short program duration, combined with the geographic proximity of the satellite cities to Delhi, makes this a plausible assumption.

The results in Table 1 show a statistically significant and substantial reduction in PM2.5 concentrations during the days and hours that the Odd-Even program was implemented in New Delhi in the January round. Across specifications, the estimated reduction ranges from 24 to 37 microgram/m<sup>3</sup>. In percentage terms, we estimate a reduction of 13 percent.<sup>7</sup>

7. Percentage reduction is estimated using a variant of the regression models described in the paper, with the dependent variable as a natural logarithm of PM2.5 concentrations. With these specifications, the coefficient of the triple difference can be directly interpreted as the percentage change. Specifically, this estimate of 13 percent comes from a model using the combined six-month data, with separate estimates for the two rounds (as in Model 2 in Table 1).

**TABLE 1. Impact of the Delhi Odd-Even Program on Ambient PM2.5 Concentrations**

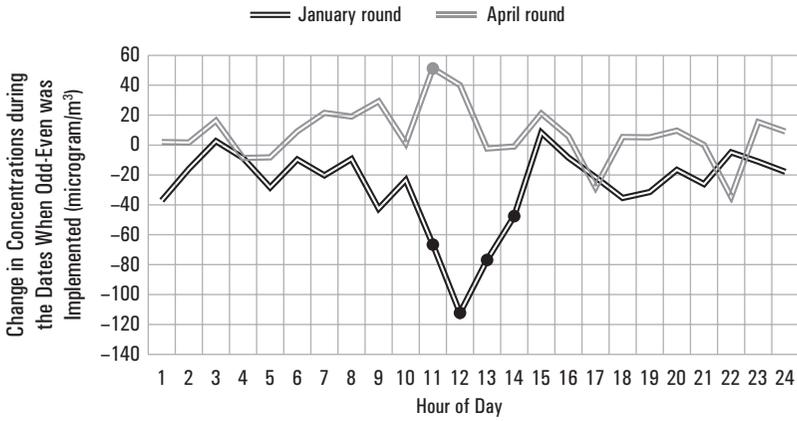
	(1)	(2)	(3)	(4)
<i>Variables</i>	<i>Six Months Joint Estimate</i>	<i>Six Months Separate Estimates</i>	<i>Jan and April Joint Estimate</i>	<i>Jan and April Separate Estimates</i>
Delhi X Odd-Even dates (Jan)		-14.9 (21.5)		-6.0 (24.2)
Delhi X Odd-Even dates (April)		-3.9 (17.1)		12.8 (13.0)
Delhi × Odd-Even dates (Jan) × Odd-Even hours		-24.4*** (6.4)		-31.6** (12.9)
Delhi × Odd-Even dates (April) × Odd-Even hours		11.6 (12.2)		-6.7 (15.5)
Delhi × Odd-Even dates both	-8.9 (13.5)		5.7 (13.6)	
Delhi × Odd-Even dates (both × Odd-Even hours)	-7.0 (8.3)		-18.5* (9.2)	
Observations	21,197	21,197	7,105	7,105
R-squared	0.472	0.473	0.486	0.489
Number of monitors	8	8	10	10
Monitor fixed effects	Y	Y	Y	Y
Day fixed effects	Y	Y	Y	Y
Hour of day fixed effects	Y	Y	Y	Y
Day FE × Odd-Even dates fixed effects	Y	Y	Y	Y
Range of dates of the observations	November 2015– April 2016		January and April, 2016	

Source: Authors' calculations.

Note: The table regresses PM2.5 concentrations in monitors at various locations within and outside Delhi against the difference in difference interactions (Delhi × Odd-Even dates) and triple difference interactions (Delhi × Odd-Even dates × Odd-Even hours), with fixed effects for monitor, date, and hour of day. Columns 1 and 2 use a six-month panel from November 2015–April 2016, and Columns 3 and 4 use a more restricted panel of January and April 2016. On average, PM2.5 concentrations in Delhi monitors were at 277  $\mu\text{g}/\text{m}^3$  in January 2016 and 141  $\mu\text{g}/\text{m}^3$  in April 2016. Robust standard errors in parentheses \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , and \*  $p < 0.1$ .

We also estimate hourly effects and find large, statistically significant reductions in concentration between 11 AM and 2 PM (see Figure 6), which could be attributed to reduction in traffic during the morning peak hours. During other times of the day, our estimates are noisy and indistinguishable from zero. This may reflect dispersion (wiping out any local improvements in air quality) and other sources of PM2.5 (reducing the significance of reductions from traffic alone). Importantly, no impacts were observed at night when the Odd-Even rationing was not enforced.

**FIGURE 6. Hourly Effects during the Delhi Odd-Even Program, 2016**



Source: Authors' calculations.

Note: The difference-in-difference coefficient has been plotted for each hour of the day. The hours with statistically significant results are shown as a circled point.

Three factors could explain the decline in concentrations: First, reduction in PM from vehicular exhaust due to cars taken off the road; second, reduced congestion and consequently, reduced idling and emissions from vehicles (from allowed cars as well as buses and other vehicles); and third, reduced re-suspension of road-dust due to reduced vehicular volumes.

However, for the Odd-Even period in April we observe no significant reduction in concentrations. It is possible that compliance decreased in the second round. Primary traffic surveys by the School of Planning and Architecture in New Delhi along several junctions around the city find that traffic volumes were higher during the second round of the program than the first round, and that there was a large shift to two-wheelers (*Hindustan Times* 2016). This contrasts with the January pilot when commuters reportedly chose to carpool or use public transportation. Compliance levels that fall over time may also reflect weak monitoring and enforcement.<sup>8</sup>

8. Not all evidence points in the direction of reduced compliance. Kreindler (*The Indian Express* 2016) uses high frequency queries on travel times from Google Maps along several routes and finds that the two rounds show consistent reductions in speeds in both rounds. Kreindler did find that the April round was marginally less effective along a few dimensions: a larger percentage of drivers used other four-wheelers (including taxis) than their principal vehicle on restricted days, and fewer moved to public transportation.

It is also possible that despite steady compliance and similar reduction in emissions from cars, measured *ambient* concentrations (the quantity measured by pollution monitors) may have been affected less in April than January. A plausible reason is greater dispersion during warmer months. Dispersion is faster when atmospheric mixing heights are greater, as is the case in the summers compared to winters (Guttikunda and Gurjar 2012). For this reason, modest increases and decreases in emission sources on the ground may disperse upwards and not translate into observable changes in pollution concentrations near the ground. On the other hand, in winter, when dispersion is minimal, these changes are immediately noticeable.

Although in this paper we are unable to evaluate the causes of divergent effectiveness, the fact that this vehicle rationing scheme did not produce consistent reductions in air pollution should lead us to question whether even an extreme ban of this type necessarily leads to the desired environmental outcomes. Furthermore, the effects on air pollution are just one side of the cost-benefit ledger. A key concern with bans on economic activity is the incredibly high costs that this may impose on society, possibly exceeding any environmental benefits. It is possible that this type of scheme may have some utility as an emergency measure during the winters, but it is highly unlikely to provide any sort of long-term solution to pollution concerns.

Indeed, although this work does not study long-term behavior in Delhi, evidence from elsewhere in the world underscores the challenges involved in getting this type of regulation to work. Davis (2008) studies similar driving restrictions introduced in Mexico City in 1989. The author compares vehicle registrations with new vehicle sales to show that the restrictions led to an increased adoption and use of used cars. Substitution to relatively older vehicles on restricted days for the principal vehicle may have actually led to a net *increase* in pollution.

In Beijing, where similar car rationing schemes have been in force, Wang et al. (2014) find that non-compliance may have been as high as 48 percent, with car owners who traveled “during peak hours and/or for work trips, and whose destinations were farther away from the city center or subway stations, were more likely to break the driving restriction rules.”

Overall, it is unclear that large and sustained benefits are obtained through such vehicle bans. When policy instruments impose large costs on people, they also encourage efforts to avoid compliance. As we have already shown, compliance has been a major challenge for regulation in India, and for this reason, it is critical that policy be framed to minimize the economic costs associated with achieving a given reduction in pollution.

### 3. Mitigation Costs under Command-and-control and Market-based Instruments

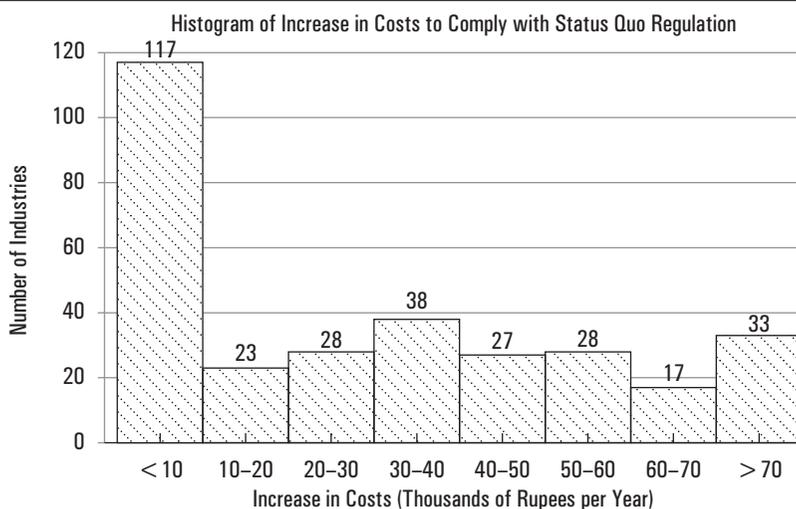
The relationship between the costs of regulation, and the likelihood that regulated entities will comply with the law, means that it is important that we explicitly evaluate the economic burden imposed by different policy instruments on regulated entities. This is especially true for a country such as India, where compliance levels can be abysmal, and where significant tension exists between maximizing economic activity and preventing already poor environmental outcomes from getting worse.

A key benefit of market-based environmental policy instruments is that they are designed to minimize the costs associated with reaching any specified level of pollution abatement. In settings where the difference between the costs of a status-quo command-and-control regulation and a market-based policy instrument is very large, the case for the market instrument becomes particularly strong.

To estimate abatement costs under different regulatory regimes, we need rich information on emissions levels, existing abatement measures in plants, the capacity of emission sources, the efficiency of abatement equipment, and the estimates of the costs of retrofits, repairs, and new capital equipment. In this section, we utilize the rich, plant-level data from the 2015 CPCB survey of industrial plants in Surat to carry out a comparison between a status-quo command-and-control regulation and a cap-and-trade scheme. Using an engineering-economic model, we show that there would likely be large reductions in compliance costs if industry clusters were regulated using an emissions market as opposed to command-and-control regulation.<sup>9</sup>

Industrial emissions are a byproduct of the combustion of fuels like coal. Combustion generates pollutants, including carbon dioxide, oxides of sulphur, carbon monoxide, and particulate matter, which leave the boiler as a cocktail called “flue gases.” The flue gas is passed through a series of APCDs that together form an APCD system. Common APCDs to reduce particular matter emissions include cyclones, scrubbers, bag filters, and electrostatic precipitators, which use different methods to remove the particulates from the flue gas. The resulting cleaner flue gas passes through the stack outlet to the atmosphere. In theory, the APCD configuration would be designed based on the anticipated emissions from the boiler and the norms to which the plant has to restrict their emissions.

9. This model and additional results are discussed in greater detail in Harish and Nilekani (2018).

**FIGURE 7. Distribution of Estimated Annualized Abatement Costs to Meet Concentration Standards**

Source: Authors' calculations using industrial plant data from a survey conducted by authors with CPCB.

Our engineering-economic model optimizes the net abatement costs under each regulatory regime, with the emissions norms as constraints. To abate emissions from their existing level, the model allows each industry to retrofit any of the existing abatement devices, or purchase a new one to be added in series.

How would abatement costs change under alternative regulatory regimes? The model estimates abatement costs under two command-and-control instruments—a concentration standard (with norms on instantaneous concentration levels as is typical in status quo) and a load standard (with norms on total mass of emissions)—and two market-based instruments—an emissions tax and a cap-and-trade. We report here the findings for the concentration-standard and the cap-and-trade approaches.

With status quo command-and-control regulation, the model has two major findings.

*First*, Figure 7 shows substantial heterogeneity in abatement costs despite the industrial units being largely homogenous: 95 percent of the industrial units in the sample are small and medium textile processing units, with similar emission sources. As Figure 4 shows, even for identical APCD combinations, there is substantial heterogeneity in emissions. This is mirrored in the abatement costs. *Second*, the costs of compliance are very modest. This is largely because many industries in this sample have already

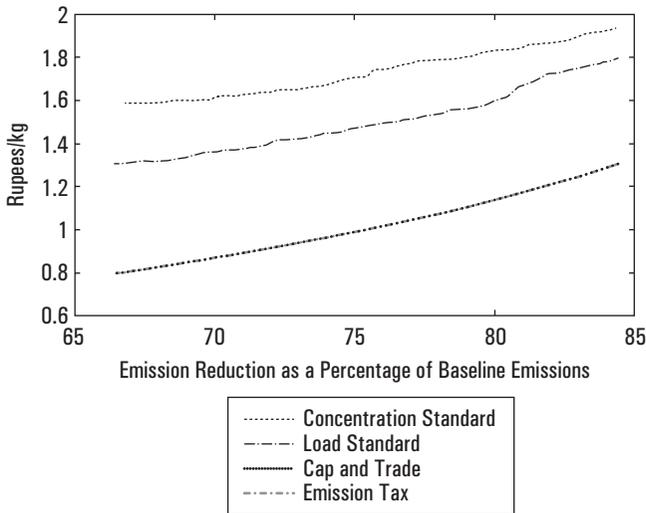
invested in the capital costs of the abatement equipment. Therefore, the costs of compliance are limited to costs of retrofits, and improved operations and maintenance for these industries.

Under cap-and-trade, the aggregate emissions from all the regulated industries are capped at some level. Industries need to hold a permit for each unit of emissions, and the total available permits equal the cap. In this model, permits equivalent to the command-and-control levels are grandfathered (i.e., allocated free of charge), and industries are allowed to trade permits among themselves. In the case of market-based instruments, industries can strike a balance between reducing their own emissions through various abatement measures and purchasing permits or paying emissions taxes. The model finds the optimal solution for each industry.

A cap-and-trade regime is expected to be more efficient than a command-and-control, and takes advantage of heterogeneity among the regulated industries to achieve the same aggregate emissions levels with lower costs on average. With cap-and-trade, industries with low marginal abatement costs are incentivized to reduce their emissions even if they would be under their allowable levels in a concentration standards-based system. With a cap-and-trade, the average abatement costs are reduced by 39 percent, compared to the concentration-standards approach to meet standards equivalent to the existing norms. Estimates for alternative standards are plotted in Figure 8.<sup>10</sup> We discuss global experience with market-based-instruments and our recommendations in the Indian context later in the paper.

Comparing the abatement costs and the benefits of improved life expectancy due to pollution abatement in Surat district, we estimate benefit-cost ratios of 57–75 to 1 for a concentration standard, or 93–123 to 1 for market-based instruments if all industries were compliant to existing levels of emission norms (reduction of baseline emissions by 66 percent). Of course, these estimates involve numerous assumptions and uncertainties; for example, they only include the costs of abatement, and not monitoring and enforcement costs to the regulator, or costs to the plants of purchasing continuous monitoring systems, or other associated costs of reform. We also ignore benefits unrelated to mortality, such as days of work lost, morbidity, and quality of life. Nevertheless, it is apparent that the health benefits of abatement are likely to substantially exceed abatement costs, and the benefit-cost ratios would be much higher under a market-based approach.

10. With an emissions tax, industries need to pay for each unit of emissions at the rate of the tax, with no free allowances. The per-unit tax is set at the level at which the aggregate emissions cap is expected to be achieved. Hence, average abatement costs are equal between emission tax and cap-and-trade.

**FIGURE 8. Average Abatement Cost per kg of Emissions Reduction**

Source: Authors' calculations using industrial plant data from a survey conducted by authors with CPCB.

#### 4. A Roadmap for Regulatory Reform

India's existing command-and-control regulation leaves much to be desired both in terms of reducing pollution and reducing costs. This leads us to the question of how the effectiveness of our regulatory framework may be improved. Although incremental improvements may be achieved through several mechanisms, we identify three promising avenues based on completed or ongoing research evidence:

1. Improving the reliability and transparency of data
2. Accounting for the incentives of those affected by regulation
3. Encouraging a culture of piloting and testing regulatory innovation

Some of the suggestions we provide may imply allocating more money to regulators, in the interests of developing a better regulatory framework for everyone else. Central and state expenditures on environmental governance in India are extraordinarily low. For instance, the total annual budget of the CPCB in India was just ₹74.3 crores<sup>11</sup> (US \$11 million) in 2017. This number is simply inadequate to carry out the mandate of the apex environmental

11. See <https://www.financialexpress.com/budget/union-budget-2017-budgetary-allocation-to-environment-ministry-up-by-19-percent/533986/>, accessed April 22, 2018.

regulator, which includes standard setting, new research, policy guidance to states, and a limited amount of enforcement activity.

This level of expenditure is too low and hard to justify even taking into account India's still low per capita income. One way to see this as a back of the envelope calculation is to compare the value of environmental improvements in India relative to a much richer country such as the United States. Consider that the population density of India is about 12 times that of the United States (UN 2017). Conversely, PPP-adjusted GDP per capita (assumed to be approximately proportional to a statistical value-of-life measure) is about nine times higher in the United States than in India. Putting together India's higher population density and lower per capita income, a unit of pollution in India may still cause about 1.3 times as much economic damage in health costs in India as in the United States.<sup>12</sup> This is of course a very simplistic calculation, but it helps to clarify that India spends too little money, and has too few qualified regulatory staff, to expect very good outcomes from status quo command-and-control regulation.

#### *4.1. High-Quality and Transparent Data*

Effective regulation relies heavily on high-quality data. In addition, when information available with the regulator is also made transparent to the public, there are reasons to believe that environmental performance may also improve. Although quality and transparency are two distinct concepts, making data visible to the public may also have the indirect benefit of forcing regulators to improve the reliability of disclosed information. In health care, for example, Marshall et al. (2001) argue that disclosure initiatives in the United Kingdom also improved the quality of report cards issued by hospitals. In what follows, we begin by discussing the role that environmental disclosure and ratings initiatives may play in improving environmental outcomes. We then turn to mechanisms to improve the quality of monitoring data.

Transparency and disclosure initiatives have been common in the United States, with the Toxic Release Inventory being the most prominent, and public, disclosure programs around safe drinking water. Indonesia initiated

12. We are grateful to E. Somanathan for this suggestion. Given any pollution externality, the marginal physical damage from that additional pollution is likely to be 12 times as high in India as it is in the United States, simply because there are 12 times as many people to suffer that damage. On the other hand, if damage is measured by the willingness to pay, the value of the marginal damage per person would be correspondingly low in India because an individual on average may be able and willing to pay less to avoid that damage because their income would on average be much lower. Dividing 12 by 9 gives us the 1.3 number.

a ratings regime for industrial water pollution in 1995 called the Program for Pollution Control, Evaluation and Rating (PROPER). Research suggests that PROPER resulted in improved environmental performance of firms (Blackman et al. 2004) through a mix of improving the information available to firm management, and making data public. Likewise, evidence from a disclosure scheme in China called Green Watch found similar results (Wang et al. 2004). Public ratings may also create competition among plants on environmental performance, and there is evidence that when a firm is seen as being better for the environment, it also does better on the stock market (Klassen and McLaughlin 1996). A rich literature on the power of peer household comparisons in developing (Sudarshan 2017) and developed (Allcott and Rogers 2014) countries suggests that making information available on relative performance may be a particularly important mechanism of change.

There is also significant evidence suggesting that public pressure and reputation are also important. Greenstone and Hanna (2014) make the case that regulation is likely to be more effective in the presence of significant public engagement. Indeed even the release of data on ambient air or water pollution—which is not tied to an individual violator—can lead to the involvement of the judiciary and civil society organizations. Wide public release can both play an important role as a health advisory system and increase pressure on polluters to comply with regulatory standards (Afsah et al. 2013; Tietenberg 1998; Wang et al. 2004).

In November 2014, the Centre for Science and Environment, a civil society group, collected individual exposure data from eight prominent individuals identifying dangerously high levels of air pollution in the capital city of New Delhi. This data was used as part of a legal petition requesting the Supreme Court to introduce surcharges on the entry of commercial vehicles into Delhi. These legal proceedings resulted in additional fees on heavy vehicles entering the city. The Supreme Court Justice adjudicating the case observed, “My grandson wears a mask. He looks like a ninja. When I asked him why he was wearing a mask, he said it was due to pollution.... This is one case where newspapers should report as to what transpired in the court during the hearing.”

One of the most well-known directions passed under India’s Air Act (1981) also happened because of public pressure as opposed to proactive regulatory action. A Supreme Court judgment in 1997 responding to a public interest litigation filed by the lawyer M.C. Mehta, required 500 plants near the Taj Mahal to reduce damages from air pollution by closing down, relocating, or changing the fuels they burned.

Despite the evidence, there are hardly any examples of transparency initiatives in India. India lags behind China in this regard. In 2006, the China Institute of Public and Environmental Affairs began collating public information on air and water pollution, and environmental violations at plants across the country. This ground-breaking step came from civil society, not the government. However, since then, the Chinese government has gone further and made available a large amount of real-time data on ambient and plant pollution levels, including the 2014 disclosure of industrial emissions for around 13,000 enterprises.

In India, possibly the first such initiative was launched on June 5, 2017, in Maharashtra where hundreds of large industrial plants are now publicly rated on a 1 to 5 star scale based on how much particulate air pollution they emit.<sup>13</sup> This initiative has begun as a pilot, designed with the explicit goal of evaluating the effects of disclosure on performance. This emphasis on rigorous evaluation makes this pilot possibly the first of its kind anywhere in the world.

The Maharashtra Star Rating Programme targets large plants with capital investments exceeding ₹25 crore in the cement, chemicals, metal works, paper, pharmaceuticals, power, sugar, distilleries, and textiles sectors. Data from the last four times a plant was tested for particulate emissions is used to generate a star rating, and the median test value is used to assign a rating based on the scale in Table 2. The pilot has continued to expand in the year since it was launched.

Disclosing information may be a helpful addition to the different mechanisms through which India seeks to regulate pollution. However, making data transparent is clearly most useful when high-quality information is being released. Regulatory action under command-and-control relies on the information regulators have on plants, and where this information is poor, outcomes are also likely to be suboptimal.

**TABLE 2. Maharashtra Star Rating Programme**

<i>Rating</i>	<i>Range of PM Emissions (Milligram per Cubic Meter)</i>		<i>Rating Key</i>	<i>Representation</i>
	<i>Minimum</i>	<i>Maximum</i>		
1 star	250	–	Very poor	★ ☆ ☆ ☆ ☆
2 star	150	250	Poor	★ ★ ☆ ☆ ☆
3 star	100	150	Moderate	★ ★ ★ ☆ ☆
4 star	50	100	Good	★ ★ ★ ★ ☆
5 star	0	50	Very good	★ ★ ★ ★ ★

Source: Maharashtra Pollution Control Board, see <http://mpcb.info>.

13. The Maharashtra Star Rating Programme can be accessed at <http://mpcb.info>.

The primary mechanism through which environmental regulators enforce command-and-control norms is plant inspections and vehicle testing. In the industrial sector, inspections are expected to occur when plants are first cleared for operation (a useful time to ensure technology mandates are followed), and thereafter on an ongoing basis to determine actual pollution. Ongoing inspections are most directly linked to the outcome we care about, namely pollutants emitted.

There is a growing literature on the effect of inspections on industrial pollution in the developed country context. In the United States, for example, officials of the US Environment Protection Agency and the state governments have the power to conduct surprise inspections of industrial plants under the Clean Air Act of 1963. Hanna and Oliva (2010) find that, after controlling for plant level heterogeneity, an inspection resulted in a 15 percent average reduction in air emissions of plants. There is also evidence that the threat of an inspection could reduce emissions in plants in the paper and pulp industry (Laplante and Rilstone 1996), and in electric utilities (Keohane, Mansur and Voynov 2009). In other words, inspections work in reducing violations and in reducing emissions from industries.

In India, officials from the SPCBs, or accredited laboratories, perform inspections of plants. These visits could either be routine, as a response to an industrial plant applying for consent to operate, or as a follow-up to a violation discovered in a previous inspection (Duflo et al. forthcoming). The process is manual and time-consuming.

Consequently, a first-order challenge for the SPCBs is that their manpower is very limited. Bhushan et al. (2009) describe how the number of approved employees at the SPCBs has decreased over time, although the number of industries they regulate has increased two- or three-fold.

We see therefore that pollution testing data in India is not only unavailable to the public but also underfunded and infrequently carried out.<sup>14</sup> In addition, this data appears to be of a very poor quality. Systematically documenting this for all of India is impossible, partly because the data that is gathered is not easily obtained, but recent work also does not paint a promising picture of the veracity of the data. In the study cited earlier in Section 2.1, Duflo et al. (2013) studied the quality of inspections data in Gujarat in a field experiment, conducted with the Gujarat Pollution Control Board (GPCB), that was designed to improve the quality of reporting and, thus,

14. In Maharashtra, data collected to implement the Star Rating Programme suggests that even amongst the largest, most polluting plants that form part of the initiative, the average number of pollution tests per year is just 1.4/industrial plant.

environmental performance. In the status quo, they found that monitoring reports carried out by accredited, third-party laboratories were heavily biased (Figure 2). Between the official audits and independent backcheck readings, they found a difference of 0.3 standard deviations; 29 percent of status quo audits falsely reported compliance. The authors provide evidence that the primary reason for this may be the unsurprising collusion between plants, which pay for their own testing, and environmental laboratories, whose revenues depend on the very same industries that they are expected to test. Not all states suffer from the same incentive problem, and Gujarat has since moved to reform its testing protocols, but this study provides a sobering insight into how badly data collection can go wrong.

Nor is quality a problem only in the industrial sector. In India, vehicles are required to be tested periodically at pollution check centers. When the traffic police stop vehicles, they also check the pollution certificate, and any discrepancy can be penalized. However, these checks are meaningful only when the underlying testing is accurate. A recent audit report (CPCB 2013b) of pollution check centers by the CPCB for Delhi's Department of Transportation was alarming. Staff at the centers were found to be poorly trained and unaware of protocols for testing, and the equipment was not always maintained and was rarely properly calibrated. The auditing team also documented instances of unauthorized officials passing vehicles, and software being used to generate fake measurements. The auditing report ends with a call for greater scrutiny of the pollution centers.

Recently, the government has begun to take some steps to address this problem. Continuous emissions monitoring systems (CEMS) are instruments that attach to the chimney stack of factories and supply real-time data on the emissions being generated. In so doing, they allow for dramatic improvements in the time granularity of data available to regulators. In 2013, the CPCB released the first ever specifications for CEMS devices (CPCB 2013a), outlining allowable technology as well as auditing and maintenance procedures. These specifications are designed to produce data that could also underpin market-based regulatory frameworks such as cap-and-trade regimes. Following this initial standards document, which focused only on particulate emissions, the CPCB has since released a more general specification. With these regulatory instructions, in February 2014, the CPCB passed an order mandating the installation of continuous monitoring systems for air and water pollutants in 17 categories of highly polluting industries.

While CEMS technology improves the quantity of emissions data available to the regulator, the quality of data is vulnerable to similar corruption issues as manual auditing that we have discussed above. CEMS data are

only as reliable as the accuracy of the calibration of the CEMS. With particulate matter emissions in particular, calibration involves comparing sensor-measured data with manual measurements. For CEMS data to be useful, regulators need to introduce systematic protocols that take into account the incentives for industries, CEMS vendors, and auditors. We return to this issue in the next section.

We stress that better monitoring is not restricted to improved data collection from pollution sources. Effective policy depends very heavily on the information that regulators possess on the cumulative outcome of all emissions sources, whether this be river-water quality in the case of effluents, or air quality in the case of air pollutants. Recent developments in the use of networks of low-cost and mobile-ambient monitoring instruments allow dramatically increased insight into the spatial distribution of air pollution. Similarly, networks of water pollution monitors provide insights into effluent discharge upstream and downstream of industry clusters, and may allow a reconciliation of measured discharge levels into ambient water compared to self-declared or monitored discharge from individual plants. This becomes particularly important when limits are placed on the volume and concentration of effluent discharge into ambient water, since these mandates may create incentives to send water pollutants into sewer lines or ground-water instead.

Lastly, satellite data provides important information on ambient air pollution across large and often unmonitored geographies. Using all these sources in making and evaluating policy is critical to achieving targeted outcomes.

In the case of small mobile sources of pollution such as vehicles, individual source monitoring can be infeasible, and policy often focuses on targeting driving behavior, based on information on the spatial distribution of pollutants. Such policy instruments can be usefully informed by spatially disaggregated information on air pollution levels, using mobile pollution monitoring networks to identify the presence of hotspots and to estimate population exposures (Apte et al. 2011; Apte et al. 2017). The Odd-Even program is a good example of a targeted intervention aimed at changing driving behavior, both motivated by and evaluated using ambient air monitoring data.

#### *4.2. The Effect of Economic Incentives on Policy Effectiveness*

In the previous section, we described some of the challenges India faces around the quality of data used to regulate. Part of the solution might involve enhancing the resources made available for regulation, and appealing to modern technology. In this section, we show that by themselves these are unlikely to be solutions.

Consider the process by which legally enforceable pollution data is currently gathered in India. In addition to the inspections by the SPCBs, some highly polluting plants are required to file audit reports prepared by certified third party auditors. The auditors are hired and paid by the industries they audit and report to, creating incentives for them to under-report emissions. The experiment conducted by Duflo et al. (2013) in Gujarat, mentioned in the last section, sought to test a possible solution to reform this market and create incentives for truthful reporting.

In this two-year experiment, audit-eligible industrial plants were randomly allocated into either a treatment group with the altered auditing process, or in the control group with business as usual. The altered auditing process involved the following changes. First, treatment industries were allocated an auditor by GPCB. Second, auditors allocated to treatment industries were paid a flat charge that covered the costs of auditing plus a profit, and were paid through a central pool. Third, the auditors were told that another technical agency may do a follow-up visit to repeat the pollution readings. Follow-up visits were also conducted in the control group.

We have already discussed how the study found that status quo reporting was corrupted, with 29 percent of the status quo audits falsely reporting compliance. The incentives for accurate reporting improved the quality of monitoring substantially. Treatment auditors reported pollution readings 0.15–0.21 standard deviations (50 to 75 percent) higher than status quo. Auditors in the treatment group were 80 percent less likely to falsely report compliance. Finally, and most importantly, better monitoring reduced industrial emissions. Industries in the treatment group reduced emissions by 0.2 standard deviations or roughly 30 percent, with reductions highest among plants with the highest concentrations. These striking results are summarized in Figure 2.

Emissions monitoring for vehicles shares similar structural challenges. There is the literature from around the world showing evidence of cheating by emissions testing centers. Oliva (2015) finds that 79 percent of emission-testing centers in Mexico City accept bribes and substitute emissions readings of failing cars; cheating in this manner is an alternative to maintenance of the vehicles, and given that the bribes are low, there is little incentive for users to maintain the vehicle. Hubbard (1998) finds that private centers in California fail vehicles at half the rate at which government-run centers do—the probability of failure being lower in independently run garages and for vehicles that are not covered by warranty. Similarly, Wenzel (2001) compares private testing centers in California with government-owned centers in Arizona, and attributes the higher passing rates in California to fraud. The skewed incentives here for both vehicles owners and

the testing centers are strikingly similar to those of the third-party auditors studied in Duflo et al. (2013).

Vehicle emissions testing could also be unreliable because of variations due to fuel quality, speed and acceleration of the vehicle, and ambient and vehicle temperatures (Wenzel 2001). Although emission testing is required to be conducted under very specific conditions, even with the best of care, emissions variability can be significant (Zhang et al. 1996). Wenzel et al. (2004) find that 5 percent of cars in California and 8 percent in Phoenix, Arizona, that passed the test initially, would fail an immediate retest. As with the audits, vehicles and industries share similar challenges on point-in-time testing of emissions.

Skewed incentives are frequently unaffected by technology. For example, like any other metering device, CEMS also require calibration and auditing. These tasks must be carried out by trained regulatory staff or accredited third-party regulators. The lessons from Duflo et al. (2013) thus apply to the use of modern monitoring technology also, and suggest that technology mandates by themselves may not even fulfill the minimal goal of better information unless used within incentive-compatible and monitored contexts.

The State of Gujarat has carried out a unique roll-out of CEMS in Surat, with a significant amount of data collection to document the process of using this technology. This important effort has helped point to potential problems with mandating CEMS without simultaneously designing incentive-compatible regulatory norms around the technology. Specifically, the GPCB undertook a careful auditing exercise of plants installing CEMS devices following a regulatory mandate. In typical practice, these monitors are installed by technology vendors and calibrated on site, with payments made by industries. The accuracy of this calibration is fundamental to the accuracy of the monitoring system—if the calibration coefficients are falsified, the CEMS reported readings will also be under-estimates. Thanks to a careful data collection regime, the GPCB was able to document that when calibration was carried out by plants, the CEMS measurements were consistently lower than prior manual inspections had suggested they should be. The devices were therefore audited, and an independent calibration was carried out. Perhaps unsurprisingly, true calibration factors were found to be very different from those initially reported, and consequently, true emissions were much higher.

The point of this example is not to make the case that technology is not useful, but to note that it is not sufficient. There may be several ways of alleviating these problems, but it is critical that attention is paid to the incentives that cause them. One approach is to break payment links and remove incentive incompatibilities as in Duflo et al. (2013). Transparency

and disclosure may also improve matters since they allow the public, and other plants, to highlight discrepancies between the reported readings of plants and the actual behavior experienced on ground.

Economically efficient regulation should involve penalties that impose the same costs on plants as the plants impose on the public by producing pollution. Enforcing penalties involves certain subtle costs to the regulator—not in a monetary sense, but in balancing the net welfare impact of the penalty imposed against the environmental damages caused. This balance is also the focus of political pressure and pressure from industry lobbies on environment ministries and regulators. Balancing these costs and benefits unfortunately becomes difficult for regulators because of weaknesses in the legal penalties prescribed by India's environmental laws.

Enforcement options for regulators in India are legally restricted to criminal penalties and plant closures. These harsh penalties cannot be calibrated to the degree of the environmental offense in question. Thus, plants that exceed a norm by 5 percent are subject in theory to the same penalties as those that exceed norms by 200 percent. The outcome of such inflexible regulation is that regulators choose to target harsh punishments to a small fraction of the major violators, while letting many other plants off the hook with no penal action (Duflo et al. forthcoming). A necessary requirement for command-and-control regulation to work is a very well-informed regulator with the willingness and ability to systematically enforce fair penalties in cases of non-compliance. Ghosh (2015) points out how the lack of flexibility in penalties may significantly reduce the effectiveness of regulation.

The absence of civil fines in India lags behind not only the United States but also China, which has relied on financial penalties since the early 1980s. In China, although non-compliance could invite criminal legal sanction, the use of this penalty is extremely rare (Wang and Wheeler 2005). Instead, industries are charged a levy for non-compliance, which is proportional to the exceedance; since 1993, Chinese regulators have also been levying charges for air emissions or water discharges within the standards for some pollutants (Wang and Wheeler 2005). As a result, pollution levels become an economic choice for industries, as a response to the levies imposed on them. Wang and Wheeler (2005) determine the elasticity of pollution with levy rates and find a statistically significant, strong marginal deterrence for the pollution levy: for water pollution and SO<sub>2</sub> emissions, estimated elasticities are about -1.

#### *4.2.1. MARKETS IN ENVIRONMENTAL REGULATION*

Broadly speaking, economically efficient regulation requires identifying the source of negative externalities, quantifying the full social costs of

externalities from these sources, and putting in place rules that ensure that polluters must pay a price equal to this full social cost when undertaking polluting activities.<sup>15</sup> Ensuring that this price is paid requires enforcement mechanisms to ensure that regulatory constraints are binding and monitoring technology is sufficiently reliable to quantify emissions accurately.

With these principles in mind, an especially promising direction for regulatory reform is the use of market-based regulation. Emission markets and taxes seek to increase economic efficiency, reduce the costs of compliance, improve data quality and transparency, and remove incentive incompatibilities. In Section 3, we compared the costs of market-based regulation and command-and-control, drawing upon concrete empirical data, and showed that the additional costs imposed by existing regulation may be very large.

Over the last two decades, the Indian government has reviewed environmental regulation through the appointment of multiple task forces, high-level committees, and external consultants (Ministry of Environment, Forests and Climate Change 2014). Several expert committees have emphasized the need to use market-based regulation and fiscal instruments that align the incentives and reduce the costs of complying with regulations, following the “polluter pays” principle (Ministry of Environment, Forests and Climate Change 2014).

Notwithstanding these recommendations, India has rarely used markets as a means of regulation, with the notable exception of the Renewable Energy Certificates and the Bureau of Energy Efficiency’s Perform, Achieve and Trade scheme. These schemes were introduced by India’s Ministry of Power, and there exist no similar examples in the sphere of environmental regulation.<sup>16</sup> This situation indicates that India lags behind the rest of the world. There now exists significant experience with the use of market-based instruments, especially cap-and-trade markets, in both local air pollutants and carbon dioxide. Table A1 in the Appendix at the end of the paper summarizes evidence from a number of cap-and-trade markets across the world.

15. In practice, these goals are sometimes difficult to achieve. Externalities are spatially differentiated, and in theory, every emitting source might impose different social costs from its pollution (Muller and Mendelsohn 2009). Some forms of monitoring may be expensive or infeasible, and it may therefore become necessary to use proxy measures. For instance, it can be easier to monitor the presence or absence of a specific piece of pollution abatement equipment in a plant or vehicle, than real-time emissions or vehicle driving patterns.

16. India does have a cess on coal that was raised to ₹400 per ton in the 2016–17 Budget. This number is too low to be seen as meaningful environmental regulation. Mittal et al. (2012) use data from the Central Electricity Authority of India (CEA) to estimate specific coal consumption estimates of about 0.7 kg per kWh across Indian coal plants. At ₹65 per US\$, this works out to a price of about 0.5 cents per kWh, an order of magnitude below most estimates of the pollution externalities from burning coal.

The primary motivation for market-based instruments is that they minimize the costs of attaining any given level of emissions. The economic theory underpinning this claim is clear, but there have been limited empirical studies quantifying cost reductions relative to a well-defined counter-factual. The evidence that has been gathered points to significant benefits from environmental markets. In evaluating the US SO<sub>2</sub> market for tradeable allowances among electric utilities in 1995, Carlson et al. (2000) estimate savings of 45–55 percent compared to uniform standard regulating emissions rates. Burtraw et al. (1998) and Muller and Mendelsohn (2009) estimate that the improvements in public health and reduced acidification from these markets outweigh the costs by an order of magnitude. Fowlie et al. (2012) carry out a direct comparison of command-and-control regulation with a cap-and-trade scheme. By matching firms regulated under the RECLAIM NO<sub>x</sub> trading market in Los Angeles with nearby firms subject to command-and-control, the authors show that emissions from firms under RECLAIM were, on average, 24 percent lower than those regulated under command-and-control.

Absolute emission norms, as in the status quo in India, also do not provide any incentive for industries to reduce emissions above and beyond the minimum standard, even if the marginal costs of additional abatement are negligibly small in comparison with the externalities they impose. An additional advantage of economic instruments such as trading is that polluters have dynamic incentives to continue abating their emissions and innovating for cleaner equipment and processes (Jaffe and Stavins 1995). In the case of transport, market-based instruments like congestion pricing, as implemented in cities such as London, Singapore, and Stockholm, may be a sustainable tool over the long term to encourage shifts towards public transport.<sup>17</sup> Evidence from Sweden (Simeonova et al. 2017) shows that even in a relatively low pollution setting, congestion pricing schemes can create locally detectable reductions in ambient pollution.

The importance of experimenting with such regulation is particularly acute because using market-based regulation at scale requires a strong monitoring and enforcement infrastructure, as well as institutional knowledge. In developing countries in general, institutional readiness becomes a potential barrier for trading to be as efficient and cost-effective as it could be in theory. Coria and Sterner (2008) review the lessons from the trading

17. Congestion pricing schemes do not directly price emissions, and the metric by which their success is measured need not be pollution reduction. However, congestion can be strongly correlated with air pollution and evidence suggests that congestion pricing schemes can also have significant impacts on air pollution (Simeonova 2017).

program in Santiago launched in 1997 (the first application of emissions trading outside the OECD countries), and find that while the program was riddled with challenges due to suboptimal design, the cap set on the pollutants was adhered to from the very beginning, and with time the volume of transactions increased. They point out that “it took the United States some three or four decades of experimentation to learn how to design the institutions for a trading scheme,” and that the Chilean experience compares rather favorably. Putting in place infrastructure such as CEMS, and increasing public disclosure, create the enabling ecosystem in which market-based incentives could work more effectively.

### *4.3. Piloting and Testing Regulatory Innovation*

Thus far, this paper has focused on identifying some of the serious shortcomings with command-and-control regulation as it exists in India today. We have also discussed some avenues for improvement, including the use of market-based regulation.

In this section, we consider the need for a systematic procedural shift towards encouraging innovation. A precondition to achieving improvements in environmental performance, and reductions in cost, is a willingness to experiment with innovative new regulations. As we have shown previously, this experimentation must necessarily go beyond environmental technology, but must also recognize the need to fix the economics and incentives underlying the rules we make.

A useful approach to encouraging innovation, while recognizing the need to test new ideas, is to iteratively design and test new ideas through carefully evaluated pilots. This approach is rare in India, where a forward-looking, evidence-based approach to policy-making has not been common. Consequently, regulators seek to try new approaches only when all questions and uncertainties have already been resolved, which is impossible almost by definition. In a world where the introduction of new ideas is synonymous with scale-up, and a place is not reserved for testing and refining policy interventions, this type of risk minimizing approach is bound to occur. Furthermore, without testing new ideas we have failed to build up a playbook of effective policy, which means that under judicial, public, or political pressure to solve environmental problems, regulators must often simply duplicate what other countries have tried.

We have mentioned a few examples of ongoing pilots that represent this type of approach. In the transport sector, one policy innovation that does provide a good case study of the importance of explicit and rigorous

evaluation of innovative ideas is the driving-rationing scheme introduced by the Government of the National Capital Territory of Delhi in January 2015.

In June 2017, the Maharashtra SPCB launched an important new regulatory initiative that seeks to publicly release information on industrial air pollution in the form of a public star rating for regulated factories. Some of the authors of this paper have been involved in the design of this pilot, and the goal has been to implement some of the elements of policy design we recommend here. More broadly, global experience with this type of “third-way” regulation suggests these policies may increase the effectiveness of an underlying command-and-control structure at relatively low costs (Blackman et al. 2004).

In Surat in Gujarat, the authors of this paper are conducting a trial of the effect of CEMS on particulate emissions in collaboration with the GPCB. Plants in this pilot are largely small-scale, coal-burning textile units, and the costs of CEMS ranged from about ₹1 lakh to 5 lakhs per stack in 2016.

An intriguing pilot project initiated by India’s Ministry of Environment, Forests and Climate Change and the SPCBs in Gujarat, Maharashtra, and Tamil Nadu (Duflo et al. 2010) presents an opportunity to introduce India’s first cap-and-trade scheme, a city-level market in particulate matter from coal burning plants. If this pilot were implemented, it would represent a dramatic step forward in the regulatory instruments used to tackle industrial air pollution in India. Some of the authors of this paper have worked on the design of this market. As we describe in Section 3, we estimated that the industry costs of compliance under a cap-and-trade market in Surat would fall by nearly 40 percent relative to status-quo command-and-control emissions standards. Other research has come to similar conclusions, with Gupta (2002) showing that reducing particulate emissions by 50 percent using market-based instruments would allow for cost-savings between 26 percent to 169 percent for different industry sectors, relative to command-and-control regulation.

## 5. Conclusion

While reviewing existing environmental regulation in India, the T.S.R. Subramanian Committee bluntly notes that “*the legislations are weak, monitoring is weaker, and enforcement is weakest.*” In this paper, we assert the need for greater investments in monitoring that yields reliable data, taking advantage of advances in technology and reduced costs of monitoring equipment, and considering the incentives of third-party agencies tasked with

the monitoring. We argue that compliance, and hence enforcement, may improve if regulations are designed in a manner that is compatible with the incentives of the regulated entities.

We also make the case that market-based instruments, such as congestion pricing or cap-and-trade, offer the potential of a rare win-win in that they can reduce compliance costs and reduce pollution, allowing for urgent improvements in health. This is because these regulatory mechanisms seek to reduce to a minimum the costs of cutting total emissions into the ambient. As such, they seem particularly well suited to bridge India's perceived conflict between improving environmental performance and maintaining robust levels of economic growth.<sup>18</sup>

Finally, regardless of the type of regulation, it is essential that new interventions need to be piloted and rigorously tested. The examples set by the Maharashtra Star Rating Scheme, and the evaluation of continuous emissions monitoring in Gujarat are praiseworthy in this regard. The Ministry of Environment, Forests and Climate Change had envisaged a set of pilots in emissions trading regimes in Gujarat, Maharashtra, and Tamil Nadu. Although these pilots have not materialized so far, they would provide an exemplary pathway to carefully designing, testing, and then using more modern environmental regulation in India.

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18. Dr S.P. Singh Parihar, chairman of CPCB, chaired the IPF session where this paper was presented. Dr Parihar welcomed the possibility of including more economists in discussing regulatory instruments, including in a formal capacity on CPCB's Research Advisory Committee.

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## Appendix

**TABLE A 1 . Examples of Cap-and-trade Programs Globally**

<i>Country/ Region</i>	<i>Name</i>	<i>Year</i>	<i>Pollutant</i>	<i>Effects/Target</i>	
Mexico	Pilot Emissions Trading Scheme (ETS)	Expected 2018	CO <sub>2</sub>	Three-year pilot expected to start in the third quarter of 2018	
China	National ETS	2017	CO <sub>2</sub>	Phase 1 launched covering the power sector, which is roughly one-third of China's CO <sub>2</sub> emissions; this is twice as large in terms of emissions coverage than any other ETS	
	Beijing	Emissions Trading Pilot	2011–15	CO <sub>2</sub>	In first period, emissions fell 4.5% and the cost of cutting emissions fell by 2.5%
	Shanghai	Emissions Trading Pilot	2011–15	CO <sub>2</sub>	Emissions fell 3.5% from 2011 to 2013
	Shenzhen	Emissions Trading Pilot	2011–15	CO <sub>2</sub>	Emissions fell 11.7% from 2010 to 2013
	Tianjin	Emissions Trading Pilot	2011–15	CO <sub>2</sub>	Intensity target of 15% above 2010 levels
	Hubei	Emissions Trading Pilot	2011–15	CO <sub>2</sub>	Intensity target of 17% above 2010 levels
	Chongqing	Emissions Trading Pilot	2011–15	CO <sub>2</sub>	Intensity target of 20% above 2010 levels
	Guangdong	Emissions Trading Pilot	2011–15	CO <sub>2</sub>	Intensity target of 19% above 2010 levels
South Korea	Korean Emissions Trading Scheme (KETS)	2015– <i>present</i>	All GHGs	Targets 4% reduction below 2005 levels by 2020	
Kazakhstan	Kazakhstan Emission Trading System	2013– <i>present</i>	CO <sub>2</sub>	Targets 15% reductions below 1992 GHG levels by 2020	
Switzerland	Swiss ETS	2008– <i>present</i>	CO <sub>2</sub>	N/A	
New Zealand	New Zealand Emissions Trading Scheme	2008– <i>present</i>	All GHGs	Enabled New Zealand to meet emissions target for the first commitment period of the Kyoto Protocol	

<i>Country/ Region</i>	<i>Name</i>	<i>Year</i>	<i>Pollutant</i>	<i>Effects/Target</i>
Japan	Japan Voluntary Emissions Trading Scheme (JVETS)	2005– <i>present</i>	CO <sub>2</sub>	25% cut below 1990 levels by 2020
	Tokyo	2010– <i>present</i>	CO <sub>2</sub>	In 2012, emissions were reduced by 22% below base year levels
European Union	EU ETS	2005– <i>present</i>	CO <sub>2</sub>	21% cut below 2005 levels by 2020
Australia	New South Wales Green House Gas Abatement Scheme (NSW GGAS)	2003–12	All GHGs	Discontinued to avoid duplication with the Commonwealth's carbon price
Chile	Santiago Air Emissions Trading	1995– <i>present</i>	Total suspended particulates	Low trading volume; decrease in emissions since 1997 not definitively tied to TP system
Canada	ODS Allowance Trading	1993– <i>present</i>	CFCs, Methyl Chloroform, HCFCs, Methyl Bromide	Low trading volume, except among large methyl bromide allowance holders
	Pilot Emissions Reduction Trading (PERT)	1996– <i>present</i>	NO <sub>x</sub> , VOCs, CO, CO <sub>2</sub> , SO <sub>2</sub>	N/A
	Alberta	2007– <i>present</i>	All GHGs	Reduce emissions vis-a-vis GDP to 50% of 1990 levels by 2020
	Regulatory Framework for Air Emissions	2007– <i>present</i>	All GHGs	Industrial emission-intensity reduction of 26% by 2015
	British Columbia, California, Manitoba, Ontario, Quebec	2013– present	GHGs	First international cap-and-trade system to consist of subnational territories
United States	Leaded Gasoline Phasedown	1982– 1987	Lead in gasoline among refineries	More rapid phase out of leaded gasoline; \$250 m annual savings
	Water Quality Trading	1984–86	Point-nonpoint sources of nitrogen & phosphorus	No trading occurred, because ambient standards not binding

(Table A1 Continued)

(Table A1 Continued)

<i>Country/ Region</i>	<i>Name</i>	<i>Year</i>	<i>Pollutant</i>	<i>Effects/Target</i>
	CFC Trades for Ozone	1987– <i>present</i>	Production rights for some CFCs, based on depletion potential	Environmental targets achieved ahead of schedule
	Protection Heavy Duty Engine Trading	1992– <i>present</i>	NO <sub>x</sub> and particulate emissions	Standards achieved; cost savings unknown
	RECLAIM Program	1994– <i>present</i>	SO <sub>2</sub> ; NO <sub>x</sub>	NO <sub>x</sub> emissions fell by 60%; SO <sub>x</sub> emissions by 50%.
	Acid Rain Program	1995– <i>present</i>	SO <sub>2</sub> emission reduction credits	SO <sub>2</sub> reductions achieved ahead of schedule; savings of \$ 1billion/year
9 Northeastern states	Regional Greenhouse Gas Initiative (RGGI)	2005– <i>present</i>	CO <sub>2</sub>	10% cut below 2009 levels by 2018
27 eastern states	Clear Air Interstate Rule (CAIR) previously known as NO <sub>x</sub> Budget Program	2003– <i>present</i>	SO <sub>2</sub> ; NO <sub>x</sub>	61% reduction from 2003 levels; sharp reductions in compliance costs
California	CA AB32	2013– <i>present</i>	CO <sub>2</sub> , methane, N <sub>2</sub> O, sulfur hexafluoride, PFC	Target is 17% reduction from 2012 levels by 2020

Source: Authors' compilation.

# Comments and Discussion\*

## **E. Somanathan**

*Indian Statistical Institute*

I enjoyed reading the paper. I really want to commend the authors for having done a lot of really thorough, careful, and painstaking empirical research on air pollution in India. I think we all have some idea of the effort it takes to put all this data together; it is many years of work, and it has been done really carefully. We can see the value of that, and it speaks for itself.

I won't comment on the empirical studies, since I don't think that would be very useful. Let me turn to the policy section, which makes three recommendations. The first is that there should be reliable and transparent data and monitoring. The second is that regulatory design should be incentive-compatible and economically efficient. The third suggests piloting and evaluating the impact of new policies. I agree with all these recommendations, they are unexceptionable recommendations, with which everybody would agree. I have some reservations about the manner in which the third one is currently stated, but I will come to that at the end.

At the outset, let me note that adding a conceptual framework could improve the paper because I felt that the Section 3 recommendations don't really flow naturally from the studies in Section 2. Rather, they seem to have been decided *a priori*, or on the basis of other considerations, and then justified with examples. Let me suggest some ideas for an organizing framework.

Why is the pollution situation so bad and why are our regulatory institutions as weak as they are? Anant Sudarshan gave the example of the Maharashtra Pollution Control Board, where you have one person to inspect 750 factories. But, of course, it is not just about manpower, it is about resources, like money. If you have too small a budget, you can't really do it. So that has to be one consideration.

\* To preserve the sense of the discussions at the India Policy Forum, these discussants' comments reflect the views expressed at the IPF and do not necessarily take into account revisions to the conference version of the paper in response to these and other comments in preparing the final, revised version published in this volume. The original conference version of the paper is available on [www.ncaer.org](http://www.ncaer.org).

Why do we have some of the worst air pollution and water pollution in the world? One simple reason is the population density. This is obvious, but people somehow seem to forget about it. Our population density is about 400 persons per sq. km, compared to the world average of 56 persons per sq. km. Or if you look at the world country median, it is about 90. So ours is about 4.5 times that of the median country in the world. Our population density is about 12 times that of the United States, which has a population density of about 33 people per sq. km. This just means that if we don't regulate pollution effectively, we would get lot more of it, simply because there are a lot more people here.

There is another aspect to the population issue where the economics comes in. If you take any given pollution externality, the marginal external physical damage from that additional pollution is likely to be 12 times as high here as it is in the United States simply because there are 12 times as many people here to suffer that damage. If damage is measured by willingness to pay, there is a countervailing factor, which is that the per capita income in India is low. So the value of that external marginal damage per person must be correspondingly low because each person is able and willing to pay less to avoid that damage because their incomes are much lower.

Or if one is looking at externalities that reduce productivity, say labor productivity, then again, because labor productivity is roughly proportional to income, loss of productivity must be correspondingly lower in India on average as compared to the USA. So our real per capita income is about 12 percent of that of the USA last year. If you take both these factors into account, the population density is much higher and the real per capita income is much lower; you can put them together, you can just multiply them. The aggregate marginal external damage, therefore, can be expected to be about  $12\% \times 12 = 1.4$  times that of the USA for any given externality. Of course, this is just a back of the envelope calculation; you should not take the numbers seriously. But the point is that there are orders of magnitude here; one of them, the income measure, is going in one direction, and the other, the population density measure, is going in the other direction, and we should expect them to roughly cancel out. In terms of orders of magnitude, we should expect that Indians should be, I emphasize 'should be', willing to pay about as much at the margin to deal with any given pollution externality as people in the US.

However, of course, it is clear that pollution is vastly worse here. Why is that? Well, just look at the resources devoted to regulation. The US EPA,

when I last looked, had some 18,000 employees. The CPCB has about a few hundred. We just heard about the situation at the SPCB. We have much more pollution because we have devoted only a small fraction of the resources to regulate it. But, as I just said, if you look at the value of the marginal damage from any given externality, you should, *a priori*, not expect it to be very different from that in the US. Then, why is there this low level of regulation? There is an obvious answer to this question (Somanathan 2010). It is that in a poor country, fewer people are aware of the harms from many externalities because they don't have (a) the necessary education or (b) the necessary information. So the demand for environmental regulation from the general public is lower than it would be if people were well informed. Politicians in the final analysis respond to the demands of the public, however imperfectly.

This also comes back to the first recommendation of this paper, a feedback loop from regulation to information to more demand for regulation. If you have little regulation, if you have under-resourced regulators, then you have very little monitoring, and if you have very little monitoring, then you have very little data, and that in turn means you have very little information about pollution, and then there is low public demand to do something about it. That is the first recommendation of the paper, to increase environmental monitoring and make the data transparent. I think this is really important, and if we can make progress in this direction, then it can start off a virtuous circle of more awareness, more demand for regulation, more resources given to the regulator because of that public demand, and that means the regulator will have more capacity, there will be more monitoring, and so on. So I think that starting this virtuous circle is something that really would help. Maybe the one way it can be started is that regulators, even though they are under-resourced right now, make their data publicly available, whatever they have, and make the data very easy to use for the public.

I now come to the second recommendation about designing regulations well. We saw lots of examples in the paper where regulations could be better designed. Again, the underlying problem is that if the regulatory authorities are starved of resources, then they just don't have the qualified personnel who have the time to do this. There is always crisis management, jumping from one thing to the other. One possible way out is for the Centre and state governments to levy a fee on all industries, perhaps as a percentage of turnover unrelated to pollution, and earmark this for the pollution control boards of the states and the Centre. And that fee should

be sufficient, based on my back-of-the-envelope calculation, to expand the budgets of these regulatory authorities by about 20 times what it is today, giving us the chance to have more efficient regulation that internalizes externalities fully.

Of course, people have to be incentivized to do the right thing. To some extent, if you make the data transparent, there will be a feedback processes in the political domain that will help with this. Also, I completely agree with the point made in the study about giving the regulator more flexibility to make smaller penalties—penalties that are commensurate with the violation rather than those that either do nothing or impose an extreme penalty (Ghosh 2015). The law should also require that when you give the regulators more flexibility, they should also be charged with setting the rules, setting the standards, on the basis of the best available scientific evidence. So, the benefits of any given rule in terms of health and other benefits should be with reference to the best available scientific evidence.

Many will say that this is a non-starter in India. Industry will lobby against more resources for the regulator, because they will not want more regulation. To some extent that is true, but it is always the case that there are more technically advanced sections of industry that will benefit from better regulation because they are better at dealing with it than their competitors. Also, industry is suffering in the current environment. Anant did not really refer to it much, but it is in the paper—we have regulation by default by the judiciary. Because the executive is starved of resources, pollution gets to a crisis point, people go to the courts, and the courts then do something. Typically, the courts do something draconian at that point. This is really bad for industry, because the whole process is unpredictable; you cannot make investments ahead of time, you can't plan for this. So, industry, in fact, could be better off with smarter regulation that gives the regulator more flexibility.

I am a little leery about the last point, about piloting new schemes and conducting formal evaluations. In principle, it is a very good idea. We saw some really excellent examples in the study. But we should remember that there are always costs to doing these things. We are operating in an environment in which regulators are highly resource-constrained, not only in terms of money but also in terms of time. The problem is that it can suck up a lot of resources to find out things that are either obvious or are only valid in very particular circumstances. There are usually many different dimensions to any given pollution problem, and you have to take a decision about all those different things to decide the optimal thing to do in this dimension, and in this dimension, and in this dimension. With a

statistically rigorous study like a randomized control trial, for example, if you want statistical power, at the end of the day you are limited to dealing with one, or two, or three dimensions, but in the real world regulators have to deal with very many more, and they do need to take those decisions as well as possible. So if we take resources away because we are focusing on this particular thing, it can end up being harmful. So I do think that being careful about piloting and evaluation is a very good thing, but I am not sure that the way economists do it is necessarily the way that it should be done most of the time.

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## Nathaniel Keohane

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I think this paper is quite exciting from a research perspective in terms of the way the authors, over many studies, have been able to exploit a number of very interesting natural experiments and design randomized controlled trials. The result is a wealth of fascinating and revealing data, and a series of analyses that are both interesting to an economist and quite policy relevant.

For my remarks, I want to share a couple of quick thoughts on research, and then perhaps focus a little bit more on the policy conclusions. I can't help adding, at the very end, a point about political economy, which was part of what I focused on as an academic and is very closely connected to what I think about now in my day job at the Environmental Defense Fund (EDF).

First, on research. The research is excellent—the richness of the datasets, the ways in which these deceptively simple but very powerful difference-in-difference kind of approaches have been used—and yields some very interesting results. Even so, I would like to push the authors a little bit with some further thoughts—recognizing that most of the studies presented here have already been completed.

On the odd-even study, one is left with a little bit of a “yes, but...” question. It is interesting that the program worked in January, but in April it did not; and you have the beginnings of the story about why that was. It would be good to see a little bit more on this. We want to know whether it is atmospheric conditions, or whether it is behavior, that is causing the policy not to work. So I would encourage you to keep digging into that: it looks like you have some data on traffic that could help you tease that out.

Your 2013 *Quarterly Journal of Economics* paper on inspections in Gujarat is fascinating. The question I came away with was what has happened since—did the SPCB implement this approach, and if so how, well has that worked? It sounds as if they did, and if so, I would suggest you make that point in the paper. There is an important point here about the durability of policy, and while I realize it is never easy to publish a second paper on the same topic, it would be surely interesting to see whether those effects have lasted. Ultimately, the policy relevance of this research will be the answer to the question, how well does it work in the long run once it is implemented. Do we still see the impact? Or is there a new way to get around the inspections that were put in place? While that might not be attractive from a purely academic point of view, it would be interesting to see the results and of great relevance for policy.

On policy, the paper makes three recommendations. I would characterize the first as: “Information is important in its own right.” Of course information is not enough by itself—it must be used somehow. But the simple value of collecting information is often overlooked, and I think there is some really good discussion in the paper about the importance of monitoring data, particularly data from continuous emissions monitoring systems. Among the most interesting examples was the “star rating” approach in Maharashtra. The approach is really interesting and quite innovative, but one must also ask how effective will it be in changing behavior. I think it would be valuable to see the evaluation of that policy. We could think about other roughly similar examples. In New York City, for example, there is a restaurant rating system that rates restaurants by cleanliness, giving them a grade of A (the best), B, C, and so on, which is displayed in the window of the restaurant. If we think about the effect that the program has on restaurants, it probably chops off the lower part of the distribution; in other words, it is pretty effective in getting rid of the worst offenders, but I don’t know how much effect it has above that. I think something similar has happened with other policies that have made information like that available in the United States and elsewhere. On pollution, there was a program EDF was involved in years ago called a ‘pollution scorecard’ that made public the information about pollution from

individual facilities. So I hope you will look at an evaluation of how much effect the star rating information had on firm behavior by itself. It's possible that it just chops off the worst offenders—nobody wants to have only one star. But how much does it do relative to regulatory standards? That would be interesting to see.

Your second point is about incentive-compatible policies. I would characterize the main takeaway here as that all policies create incentives; the question is, what are the incentives, and are they the outcomes of those policies or the unintended consequences of those policies? Some of the most interesting examples in the paper are about the pervasive importance of unintended incentives. For instance, the incentives around reporting and auditing in the pilot study in Gujarat, when third-party auditors were paid by the polluters, creating the incentives for the auditors to find, as we see in the data, that every plant was in compliance, just below the standard. Understanding what such incentives are, and showing how they operate and what impact they have, are valuable.

Another example involves technology standards, and the difference between installing pollution control technology and actually using it. The slide that the authors put up on this shows that all the plants in that dataset have the right pollution control equipment installed. If you go to the plant, the technology is there, but if you measure the actual emissions, they are not going down. So again we have unintended incentives: technology standards that require certain pollution control equipment can help ensure the presence of that equipment, but if we are not monitoring the outcomes then we end up creating a perverse incentive to install the equipment but not actually use it.

Perhaps one of the most interesting points made in the paper, but which doesn't receive as much attention as it deserves, is the enforcement of penalty design. The idea is that if the only penalties that are available to the regulator are draconian in nature—for example, to close the plant down completely—then the incentives all point against using that penalty, except as a very last resort. On the other hand, if you have more continuous penalties for non-compliance, you may get better enforcement, because it is not a life or death situation every time. That is a point made in the paper that I think is very interesting.

Another major point the paper makes is how to design policies that align the economic incentives of polluters and emitters with the social goal of reducing pollution. I think it is right to point out the successes that we have seen elsewhere in the world from market-based regulations. I have spent a lot of time studying the sulphur dioxide program in the United States under the Clean Air Act Amendments of 1990, which was the first large-scale

emission trading program. You said at the beginning of your presentation that air pollution problems are seen by many as not solvable; another example to counter that is acid rain in the United States, which was solved in large part by the sulphur dioxide trading program. If you look at before and after maps 20 years apart of acid deposition—a measure of acid rain caused by sulphur dioxide emissions—you see a huge change as a result of this very economically efficient, very effective program. The emission trading program created a market for pollution, and that created the right kind of economic incentives to reduce emissions at very low cost.

The only other point I would make about market-based policies, and it might be worth making in the paper given your review of all the different market approaches, is the diversity of approaches that you can use to designing market-based instruments. Economists sometimes make the mistake of talking about them as if it is a single approach. It is a class of approaches, and the way that market-based regulation has been implemented in practice has varied tremendously according to the priorities, the needs, the goals and the objectives of the regulators as well as the context. That diversity is important to keep in mind as you think about lessons.

The third point you make is the piloting point, which is really interesting and is consistent with the first point about information. You not only need information around data and monitoring but also need information about what works in practice. I think it is very interesting to take advantage of India's federal system here to have that variety of efforts going on in the states. I take Som's point about resource availability, but I think when you have the SPCBs that can implement some of those pilots, perhaps you can spread those resources around or at least share the learnings and the lessons more broadly.

Let me make my final point on political economy. This is rightly a paper about policy, and data and research, but I can't help thinking that politics and political economy are absent from the paper. If there is one thing the experience of not only incentive-based policies but other environmental policies, more generally, has shown, it is the importance of getting the support for those policies from key stakeholders, including in particular major emitters such as electric utilities, manufacturing companies, and so on. I do think that the record we have for economically efficient policies, including emission trading and other market-based policies, shows that stakeholders will come on board and that they will see the economic advantage to them in terms of cost-effectiveness and flexibility that those policies offer. But getting them to be on board with the policies will still be the key political challenge in terms of getting this implemented.

## General Discussion

Indira Rajaraman commented that the dominant source of pollution in Delhi, especially in winter, is the burning of crop residue, and wanted to know what the authors thought should be done to address the problem.

Shantayanan Devarajan noted that air pollution was a classic textbook case on an externality where the goal is not necessarily to eliminate pollution but to maximize welfare. The first-best way of doing it was to tax pollution. The paper had nicely pointed out the problems of compliance with the command and control mechanisms that India had largely adopted. Even if there was perfect compliance, command and control could have a huge welfare cost. It would be useful to get an estimate of the relative cost of command and control compared to other first-best mechanisms: the comparison with cap-and-trade, which is closer to a market mechanism, might hold clues. Besides compliance, command and control also has the problem of a lack of political support.

Rashmi Banga wondered if the odd-even type of interventions had worked in countries like Thailand and Singapore. She noted that the Commonwealth Secretariat was now championing regenerative development, which is not climate mitigation or climate adaptation but is climate reversal. It is important to start sensitizing the public on regenerative development to deal with climate change.

Likening it to a model IPF paper, Karthik Muralidharan said that the paper was built on many years of high quality work, and had now been presented at a forum where policymakers could actually implement its recommendations. He wanted to echo Somanathan's and Devarajan's point that the presentation of impacts was excellent, but the paper would benefit from a discussion of the costs of command and control relative to other, more cost-effective, market-oriented ways of dealing with air pollution.

He noted that state capacity to deal with pollution, as with so many other functions of government, remained a fundamental problem—he did a quick Google search and saw that the CPCB chairman had been appointed after four and a half years of vacancy. This led to his question about the current mechanisms within CPCB for judging whether it had the right kind of economic expertise, a panel of economist experts, or internal economic advisors, who could complement the strong technical expertise that the Board had. Could a forum like the IPF help in any way to curate the evidence, and to design and evaluate policy?

Picking up on this question, Shekhar Shah suggested think tanks like NCAER could easily provide the expertise that Karthik spoke about. S.K.

Parihar (chair) welcomed the offer and said he would come back to it in his closing remarks.

S.K. Shanthi felt that air pollution should be embedded in a general equilibrium framework. It should be an integral part of urban planning and city management, just as much as traffic management and public works are.

Bishwanath Goldar rued the fact that despite discussion of market-based instruments over more than 20 years, nothing much had happened. Even in power generation, where there was at least a mechanism of cap and trade, the amount of actual trading had been limited. He asked whether it was a problem of the lack of government initiative, or government understanding of market-based instruments, or that market-based instruments don't work. Seeing how the Maharashtra star rating program was working by creating citizen pressure on polluting plants to comply with regulations, he asked why the other states had not adopted such a program.

Tarun Ramadorai mentioned that in addition to the very useful discussion in the paper on the supply of pollution control, and on monitoring and incentives to avoid detection, it would be useful to understand the demand side of pollution reduction. He also noted that there were visible and invisible sources of pollution, and often the latter were more dangerous. He asked if knew much about the demand for pollution control in those cases.

Dipankar Saha said that Delhi was now equipped with an adequate number of pollution monitoring instruments; these were satellite linked, and there should be no dearth of monitoring data as far as the Delhi National Capital Region was concerned. He said that the Environment Protection Act requires industries to provide an environmental statement to the public, which if implemented, could help in bringing greater citizen pressure on polluting industries. On taxes, he noted that there is already a water cess on industries that are water intensive, both at the central and state government levels.

Rajesh Chadha explained that crop burning was the result also of the lack of knowledge among farmers about its impact on worsening soil quality and raising costs. He wanted to know if vehicle sharing through aggregators like Uber and Ola had any positive impact on air pollution by reducing the number of vehicles on the road.

S.P. Singh Parihar (chair) in his closing remarks noted the concern about the social and health costs of air pollution, especially in the context of Delhi, and mentioned that a working group in the Ministry of Environment, Forests and Climate Change was specifically studying this impact together with the Indian Council of Medical Research and other scientists. He said that the issue of regulators imposing civil penalties rather than closing down

industries, which is often difficult to do, has been proposed and is under consideration in the ministry.

He recognized that at the Centre, and even more so in the SPCBs, there were shortages of manpower, budgets, skills, and laboratories. Some SPCBs were well equipped, but others were not, and CPCB was providing capacity assistance to them. He stated that while the CPCB did not have a formal arrangement for involving economists, it did have a Research Advisory Council to which economists could be added, and this was something he would pursue. Besides formal deliberations, he would also welcome informal discussions with economists. In his ending, he noted that he had personally benefited a great deal from the paper and the discussion, and would request NCAER to discuss with CPCB on how best to take it forward.