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The Solvable Challenge of Air Pollution in India

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Abstract

More than 660 million Indians breathe air that fails India's National Air Quality Standards. Research suggests that meeting those standards would increase life expectancy in India by 1 year. Going further and meeting the international benchmarks of the World Health Organization is estimated to add 4.7 years to life expectancy. Notwithstanding these large benefits, successfully implementing policies that deliver clean air has proved difficult. We review 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. We distill three lessons for designing effective reforms: (i) ensuring that regulatory data is reliable and unbiased, (ii) framing regulations that are both economically efficient and incentive-compatible across the range of actors affected, and (iii) introducing a culture of piloting and evaluating new policy as a scientific route to achieving better outcomes. We make 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.

JEL Classification: *Q52, Q53, Q56, Q58, I18*
Keywords: *India, Pollution, Regulation, Transparency, Emissions Trading, Markets, Congestion Pricing*

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The Solvable Challenge of Air Pollution in India

Michael Greenstone, Santosh Harish, Rohini Pande and Anant Sudarshan[1]

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.[2] 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[3].

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 increases in diarrhea deaths (Do 2014). In the case of air quality, recent research now allows us to go beyond isolating effects on specific diseases and quantify the *long-term, cumulative* effects of being exposed to sustained air pollution. The Air Quality Life Index[4] (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 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 1 year on average; this number increases to 4.7 if we were to meet the WHO norms. In a similar vein, Lim et al. (2012) estimated that ambient particulate matter air pollution accounts for 6% of global deaths and that over 10 percent of premature deaths owe 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).

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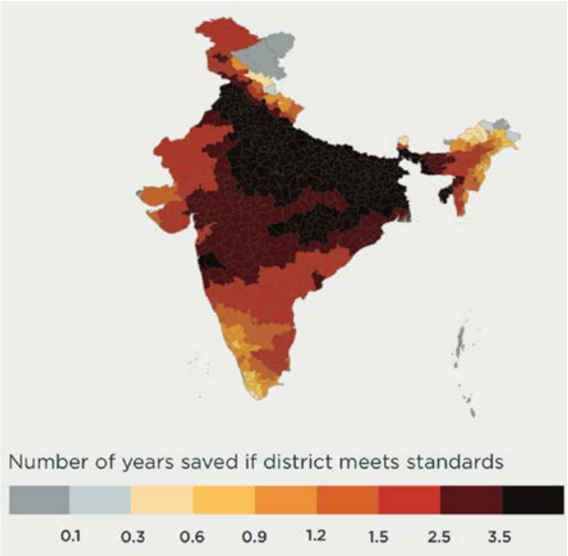
[2] The phrase fine particulate pollution refers to solid particles suspended in the air, having a diameter smaller than 2.5 microns. These particles are produced from various sources, including the combustion of fossil fuels, biomass, solid wastes, and natural dust.

[3] 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.wri.org/blog/2015/02/3-maps-explain-india\%E2\%80\%99s-growing-water-risks for more detail.

[4] The Air Quality Life Index 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 aqli.uchicago.edu

Figure 1: Increase in life expectancy if PM2.5 levels were to meet WHO norms



Source: Air Quality Life Index

The economic costs of this pollution, owing to higher health care expenditures and a less productive workforce, are significant.[5] An estimate from the OECD suggests ambient air pollution alone may cost India more than 0.5 trillion dollars per year (OECD 2014). It is these costs that motivate environmental regulation, and policy instruments that are able to reduce the pollution associated with productivity economic activity, at reasonably low costs, 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, "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: (i) improving the reliability and transparency of data, (ii) designing instruments that properly account for the incentives of those affected by regulation, and (iii) encouraging a culture of piloting and testing regulatory innovation, as a prelude to scaling up good ideas. Section 5 concludes.

[5] 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)

2. Assessing command-and-control in India

Virtually all environmental regulation in India derives from three fundamental pieces of legislation: 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. [6]

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 switching to natural gas as a combustion fuel. Third, the government may ration or even entirely ban certain types of polluting economic activity.

2.1 Enforcing Pollution Standards

To control industrial emissions, India's Central and State Pollution Control Boards set a permissible limit on the concentration of pollutants that can be emitted from industrial unit stacks (i.e. the 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 150mg/m^3 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 are 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, recent work by some of the authors of this paper provides a basis for statistical statements about compliance. This new evidence highlights serious problems with the enforcement of existing regulations across India. Duflo et. al (2013) collected data from several regulatory inspections in the state of Gujarat. **Figure 2**, Panel B presents the distribution of regulatory samples obtained from industries in that study, with the vertical line denoting the regulatory standard. High levels on non-compliance

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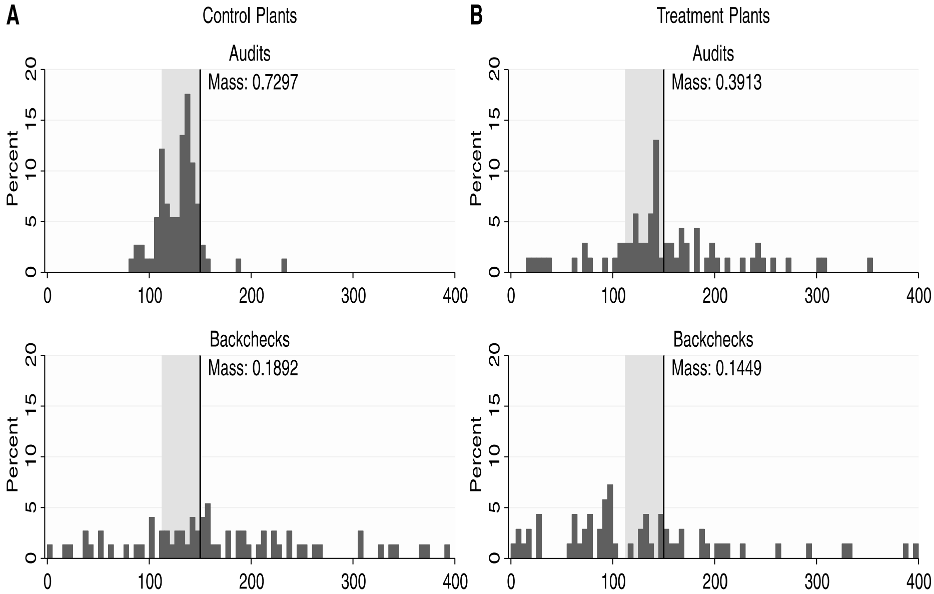
[6] Transport regulation has largely originated from judicial action with the resources of state pollution control boards almost uniformly skewed towards regulating industry. Later in this paper we discuss an example of a command and control policy intervention applying to vehicles in Delhi, although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

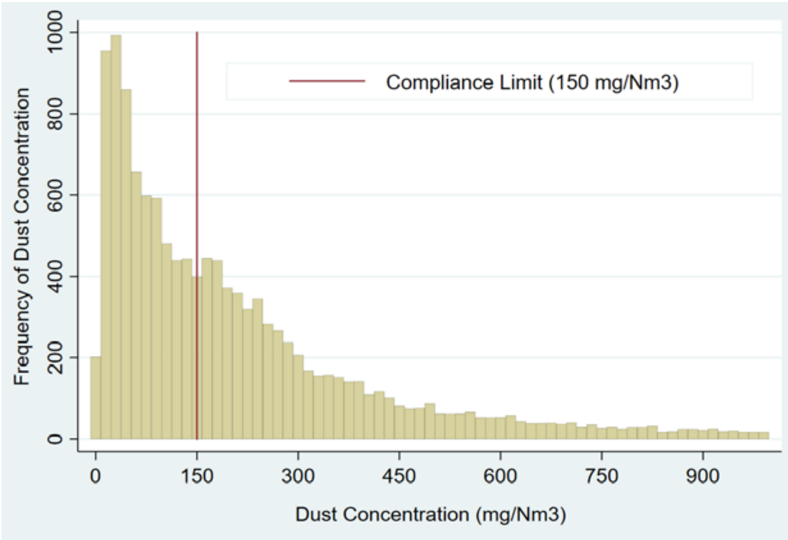
are evident, with several plants falling to the right (above) the regulatory standard. In Maharashtra, another highly industrialized state, we digitized the results of over 13,200 regulatory pollution tests spanning a period between September 2012 and February 2018. In **Figure 3**, we plot the distribution of pollution readings taken over this extended period of time. Over half of all samples exceed the regulatory standard.

Figure 2: Readings for particulate matter emissions in the stack (milligram/Nm3)



The figure shows distributions of pollutant concentrations for particulate matter in stacks during the midline survey of the project. 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 milligram/nm3 is marked with a vertical line, and the area between 75% and 100% of the limit is shaded in gray. Source: *Duflo et al (2013)*

Figure 3: Particulate matter emissions from Maharashtra industries



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. While 150mg/Nm3 is the most common norm for particulate matter compliance, some industries have even more stringent limits. *Source:* Maharashtra Pollution Control Board and authors' calculations

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 the vehicular exhaust, and have been used all over the world. Catalytic converters convert carbon monoxide and unburnt carbon into the more benign carbon dioxide, and convert nitrogen oxides (NOx) into nitrogen gas. In the 1990s, the Delhi Government and the Central Petroleum Ministry mandated the installation of this technology in automobiles, especially 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-wheel vehicles. The petroleum ministry 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_2, NO_2, 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_2 by 19 percent and 69 percent of their 1987–1990 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.

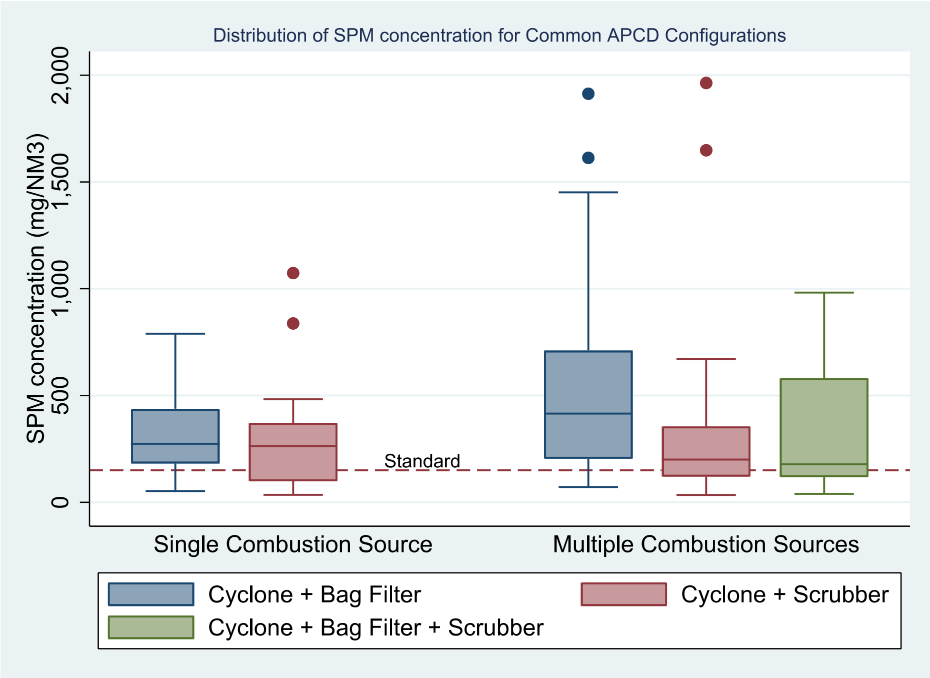
This history suggests that transport-sector fuel and technology mandates have sometimes been effective in reducing pollution. This has not always been true in other settings. In the industrial sector, environmental regulators across the country have mandated that plants install different types of air 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 have been required to install flue gas desulphurization units to control their SO2 emissions.

In 2015, the authors in partnership with the Central Pollution Control Board conducted a survey of nearly 1000 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 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 air pollution control devices. 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 cannot observe or enforce their regular maintenance and use. Thus, even if a bag filter is installed in a factory smoke-stack 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.

Figure 4: Distribution of measured concentrations of particulate matter from stacks with the most common configuration of emissions source and air pollution control devices



Source: Central Pollution Control Board and Authors' calculations

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 the externality damages from pollution are lower than the economic value of the restricted activity. Consequently, blanket bans would 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 they have failed to ensure that manufacturing plants install *and* use pollution control equipment. The judiciary has often driven this 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 nineties, 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 been 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 Dec 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 car licensing plates. Next, it was mandated that only vehicles with odd numbered license plates could ply on odd numbered dates and even numbered plates on even dates. The scheme was effective during the hours of 8 am and 8 pm for the first 15 days of January 2016. [7] Cars with registration plates from outside Delhi were also required to comply. Alongside, the Delhi government announced other measures to reduce air pollution

- November 6, 2015: Environment Compensation Charge (ECC) charged for commercial vehicles (light diesel vehicles and three-axle vehicles) entering the city limits. (Supreme Court, 2015a; Department of Environment, 2015) On December 16, 2015, the ECC was doubled (Supreme Court, 2015 b)
- On December 16, 2015, Supreme Court banned the registration of new diesel cars (larger than 2000 cc) till March 31, 2016 (Supreme Court, 2015 b)
- From January 1, 2016, Delhi government increased the restriction on entry of trucks during the day. Entry hours were pushed from 9 PM to 11 PM (Department of Environment, 2015)

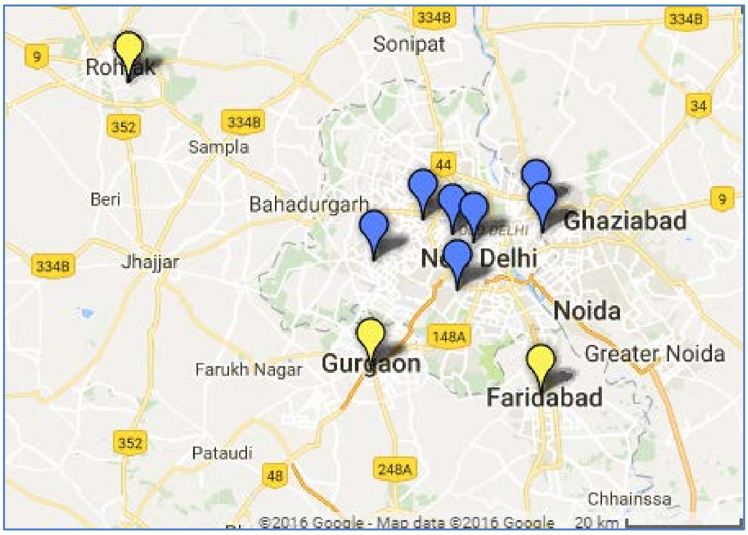
After the first odd-even pilot was completed, the government re-introduced the scheme for another two-week period during April 15-30, 2016. This provides an

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

opportunity to not only test the effectiveness of the scheme, but also the repeatability of initial outcomes.

Our analysis uses data from ten ambient air quality monitors in Delhi and three satellite cities just outside Delhi. **Figure 5** shows monitor locations (operated by the Central Pollution Control Board for Delhi and by the Haryana State Pollution Control Board for the neighboring towns of Faridabad, Gurgaon and Rohtak). We compile hourly monitoring data for the six months spanning November 2015 to April 2016.

Figure 5: Locations of pollution monitors in Delhi (blue) and in Haryana (yellow)



Source: Google Maps and authors

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 difference-in-differences analysis where we examine how difference in air quality in 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 hours that the program is effective (i.e. between 8 am and 8 pm). More formally, we estimate a regression model that takes the form:

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

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. β and γ are the coefficients for the treatment area and period indicator variables. The interaction coefficient δ estimates the program impact on particulate concentration. λ_m and η_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^3. In percentage terms, we estimate a reduction of 13 percent[8].

[8] Percentage reduction is estimated using a variant of the regression models described in the paper with the dependent variable as 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 6-month data, with separate estimates for the two rounds (like in Model 2 in Table 1)

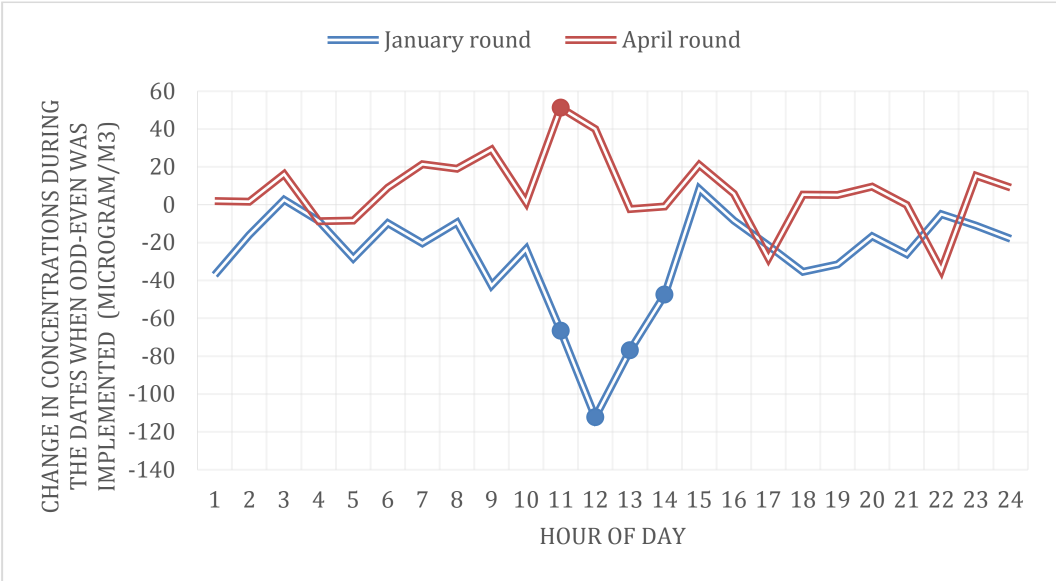
Table 1: Impact of the Delhi Odd-Even Program on ambient PM2.5 concentrations

	(1)	(2)	(3)	(4)
VARIABLES	**Six months joint estimate**	**Six months separate estimates**	**Jan and April joint estimate**	**Jan and April separate estimates**
Delhi X OddEvenDatesJan		-14.9		-6.0
		(21.5)		(24.2)
Delhi X OddEvenDatesApril		-3.9		12.8
		(17.1)		(13.0)
Delhi X OddEvenDatesJan X OddEvenHours		-24.4***		-31.6**
		(6.4)		(12.9)
Delhi X OddEvenDatesApril X OddEvenHours		11.6		-6.7
		(12.2)		(15.5)
DelhiXOddEvenDatesBoth	-8.9		5.7	
	(13.5)		(13.6)	
Delhi X OddEvenDatesBoth X OddEvenHours	-7.0		-18.5*	
	(8.3)		(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 FE	Y	Y	Y	Y
Day FE	Y	Y	Y	Y
Hour of Day FE	Y	Y	Y	Y
Day FE X OddEvenDates FE	Y	Y	Y	Y
Range of dates of the observations	November 2015- April 2016		January and April, 2016	

The table regresses PM2.5 concentrations in monitors at various locations within and outside Delhi against the difference in difference interactions (Delhi X OddEvenDates) and triple difference interactions (Delhi X OddEvenDates X OddEvenHours), with fixed effects for monitor, date, and hour of day. Columns 1 and 2 use a 6-month panel from November 2016- 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 $\mu g/m^3$ in January 2016, and 141 $\mu g/m^3$ in April 2016. Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. *Source:* Authors' calculations.

We also estimate hourly effects and find large, statistically significant reductions in concentration between 11 am – 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



Source: Authors' calculations. The difference-in-difference coefficient has been plotted for each hour of the day with the hours with statistically significant results shown as a circled point on the graphs.

Three factors could explain the decline in concentrations: one, reduction in PM from vehicular exhaust due to cars taken off the road; two, reduced congestion and consequently, reduced idling and emissions from vehicles (allowed cars as well as buses and other vehicles); three, reduced resuspension 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 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 the public transportation. Compliance levels that fall over time may also reflect weak monitoring and enforcement. [9]

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-ground may disperse upwards and not translate into observable

[9] Not all evidence points in the direction of reduced compliance. Kreindler (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.

changes in pollution concentrations near the ground. On the other hand, in winter when dispersion is minimal, these changes are immediately noticeable.

Although we are unable in this paper 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 we do not observe 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 with market based instruments

The relationship between the costs of regulation, and the likelihood that regulated entities 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 a 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 status-quo regulation and a market-based policy instrument is very large, the case for markets becomes particularly strong.

In this section we utilize the rich plant-level data from the 2015 Central Pollution Control Board survey of industrial plants in Surat to carry out a comparison between status-quo command and control regulation, and a cap-and-trade scheme. 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 estimates of the costs of retrofits, repairs, and new capital equipment. 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.[10]

Industrial emissions are a byproduct of 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 gas'. The flue gas is passed through a series of air pollution control devices (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 anticipated emissions from the boiler and the norms to which the plant has to restrict their emissions.

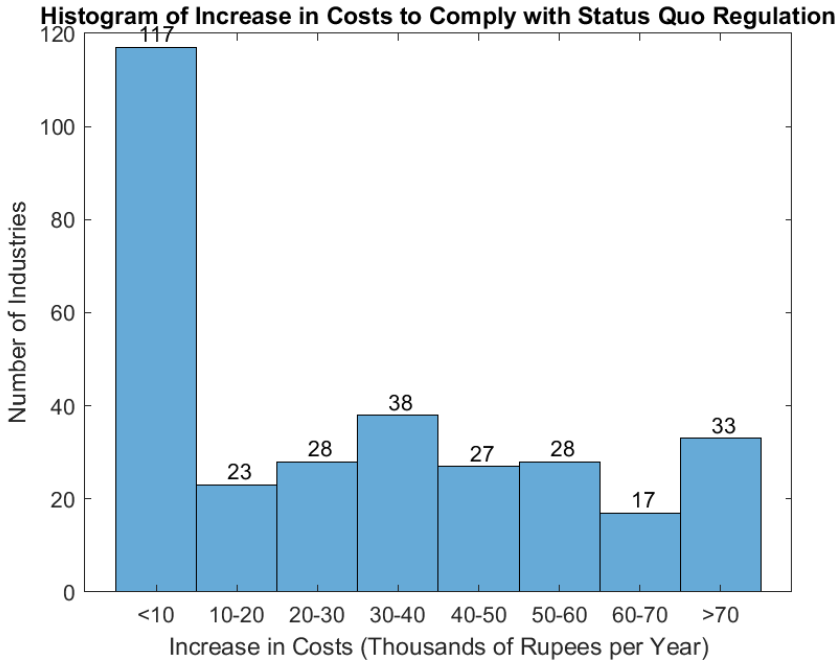
Our analysis uses an engineering economic model that optimizes the net abatement costs under each regulatory regime, with the emissions norms as constraints. To abate emissions from their existing level, the model allows each industry to retrofit any of the existing abatement devices, or purchase a new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

With status quo regulation, the model has two major findings.

First, **Figure 7** shows substantial heterogeneity in abatement costs despite the industrial units being largely homogenous: 95% of the industrial units in the sample are small and medium textile processing units, with similar emission sources. As **Figure 4** showed, even for identical APCD combinations, there is substantial heterogeneity in emissions. This is mirrored in the abatement costs. Second, 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.

[10] This model and additional results are discussed in greater detail in Harish and Nilekani (2018)

Figure 7: Distribution of estimated annualized abatement costs with concentration standards



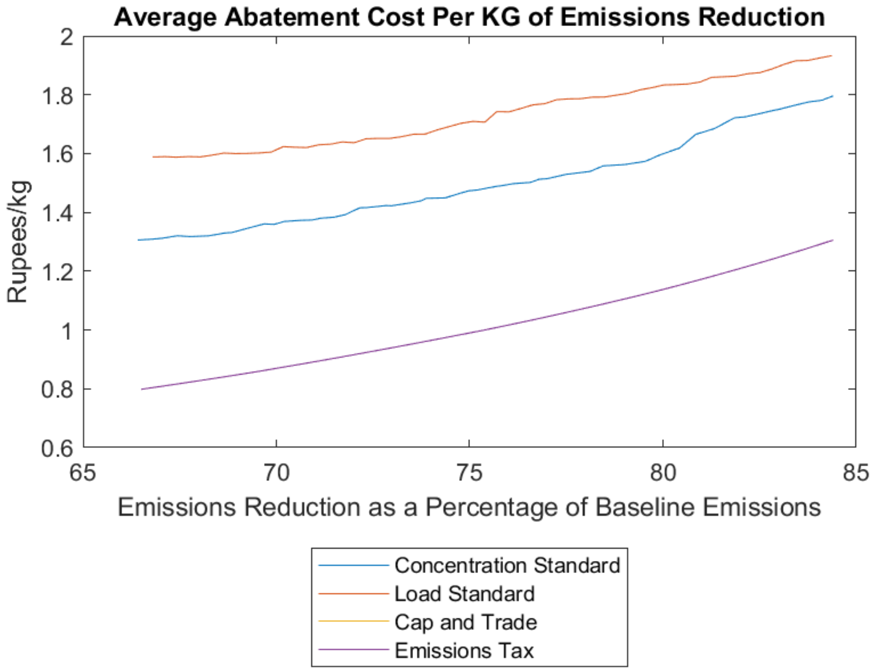
Source: Authors' calculations using industrial plant data from a survey conducted by authors with CPCB

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—emissions taxes, and cap-and-trade.

Under the 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 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%, compared to concentration standards to meet standards equivalent to the existing norms. Estimates for alternative standards are plotted in **Figure 8**. We discuss global experience with market-based-instruments and our recommendations in the Indian context later in the paper.

Figure 8: Abatement costs under alternative policy regimes[11]



Comparing against 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%). 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, etc. Nevertheless, it is apparent that the health benefits of abatement are likely to substantially exceed abatement costs.

4. A Roadmap for Regulatory Reform

India's existing command and control regulation has left 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:
(i) Improving the reliability and transparency of data

[11] With the 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.

(ii) Accounting for the incentives of those affected by regulation
(iii) 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 Central Pollution Control Board (CPCB) in India was just INR 74.3 crores[12] (USD 11 million) in 2017. This number is simply inadequate to carry out the mandate of the apex environmental regulator, which includes standard setting, new research, policy guidance to states, and a limited amount of enforcement activity.

This level of expenditure is hard to justify even given the fact that India is a poor country. One way to see this 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 World Population Prospects 2017). Conversely, PPP adjusted GDP per capita (assumed to be approximately proportional to a statistical value of life measure) is about 9 times higher in the United States than India. Putting these together, a unit of pollution in India may cause about 1.3 times as much economic damage through health costs as in the United States. This is very much a back of the envelope exercise but it helps 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 (2003) 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 a ratings regime for industrial water pollution in 1995 called Program for Pollution Control, Evaluation and Rating

[12] See: https://www.financialexpress.com/budget/union-budget-2017-budgetary-allocation-to-environment-ministry-up-by-19-percent/533986/. Accessed on 22 April 2018

(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 (Wu 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 comparisons in developing (Sudarshan 2017) and developed (Allcott and Rogers 2014) country households 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 an individual petition filed by the lawyer Harish Salve, requesting the 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 Chief 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 came about because of public pressure as opposed to proactive regulatory action. A Supreme Court judgment in 1997, delivered in response 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 through closing down, relocating, or changing the fuels they burned.

Despite the evidence, there are hardly any examples of transparency initiatives in India. Indeed in this regard, India lags behind China as well. In 2006, the China Institute of Public & Environmental Affairs began collating public information on air and water pollution and environmental violations at plants across the country. This first 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 the 5th of June 2017 in the state of 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.[13] 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 scheme targets large plants with capital investments exceeding 25 crore INR and belonging to the Cement, Chemicals, Metal Works, Paper, Pharmaceuticals, Power, Sugar and Distilleries or Textiles sector. 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.

Table 2: Maharashtra Star Rating Initiative

	RANGE OF PM EMISSIONS (milligram per cubic metre)			
Rating	**Minimum**	**Maximum**	**Rating Key**	**Representation**
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

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. In addition, 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.

The primary mechanism through which environmental regulators enforce command and control norms is plant or vehicle testing and inspections. 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 US, 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)

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[13] The star rating program can be accessed at: http://mpcb.info

find that, after controlling for plant level heterogeneity, an inspection has a 15 percent reduction in air emissions of a plant. There is also evidence that the threat of an inspection could reduce emissions in plants in the paper and pulp industry (Laplant 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 State Pollution Control Boards (SPCBs), or accredited laboratories, perform inspections of plants. These visits could either be routine, or 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 by two or three-fold.

We see therefore that pollution testing data is India is not only unavailable to the public, but is also underfunded and infrequently carried out.[14] 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 does not paint a promising picture. Duflo et al (2013) studied the quality of inspections data in Gujarat in a field experiment, conducted with the Gujarat Pollution Control Board, designed to improve the quality of reporting and thus environmental performance. In the status quo they found that monitoring reports carried out by accredited third party labs were heavily biased. Between the official audits and independent back-check 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 unsurprising collusion between plants, who pay for their own testing, and environmental labs whose revenues depend on the very same industries that they are expected to impartially 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 get 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 2013) of the Pollution Check Centers by the Central Pollution Control Board to Delhi's Department of Transportation officials was alarming. Manpower at the centers were found to be poorly trained and unaware of

[14] In Maharashtra, data collected to implement the star rating scheme suggests that even amongst the largest, most polluting plants - which form part of the initiative - the average number of pollution tests per year is just 1.4/ industrial plant

protocols for testing, the equipment was not always maintained, and were rarely properly calibrated. The auditing team also documented instances of unauthorized officials passing vehicles, and software being used to generate dummy 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 redress 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 Central Pollution Control Board released the first ever specifications for CEMS devices (CPCB, 2013), outlining allowable technology as well as auditing and maintenance procedures. Interestingly these specifications were 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 seventeen 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 their calibration. 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 consider the incentives of industries, CEMS vendors, and auditors. We return to this issue in the next section as well.

We stress that better monitoring is not restricted to improved data collection from pollution sources. Effective policy depends very heavily on the information 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 insight into effluent discharge upstream and downstream of industry clusters and may allow a reconciliation of measured discharge into the ambient 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 the ambient, 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. One, treatment industries were allocated an auditor by GPCB. Two, 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. Three, 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% of 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%, 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 literature from around the world showing evidence of "cheating" by emissions testing centers. Oliva (2015) finds that 79 percent 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 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 for whom repair is not covered by warranty. Similarly, Wenzel (2000) compares private centers in California 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, the speed and acceleration of the vehicle, ambient and vehicle temperatures (Wenzel et al, 2000). Although an emission testing is required to be conducted under very specific conditions, even under the best care, emissions variability can be significant (Bishop et al, 1996). Wenzel et al. (2004) find that 5 percent of cars in California and 8 percent in Phoenix that passed the test initially would fail an immediate retest. As with the audits, vehicles and industries share similar challenges in 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 a mandate of CEMS, without simultaneously designing incentive compatible regulatory norms around the technology.

Specifically the Gujarat Pollution Control Board 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 underlies the accuracy of the monitoring system - if the calibration coefficients are falsified, 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, CEMS measurements were consistently lower than prior manual inspections had suggested they should be. The devices were therefore audited and an independent calibration carried out. Perhaps unsurprisingly, true calibration factors were found to be very different from those initially reported, and consequently true emissions 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 it allows the public, and other plants, to highlight discrepancies between the reported readings of plants and the actual behavior experienced on ground.

Lastly, a subtler example of considering the incentives of different stakeholders comes from weaknesses in the legal penalties prescribed by India's environmental laws. Enforcing penalties involves certain 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. More precisely, economically efficient regulation would involve penalties that impose the same costs on plants as they impose on the public by producing pollution.

Unfortunately enforcement options 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 inflexible regulation is that regulators choose to target harsh punishments at a small fraction of major violators, while letting many other plants off 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 significant 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 that a statistically significant, strong marginal deterrence for the pollution levy: for water pollution and SO2 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.[15] Ensuring that this price is paid requires enforcement mechanisms to ensure regulatory constraints bind and monitoring technology that 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 & Climate Change, 2014). Several expert committees have emphasized the need to use market-based regulation and fiscal instruments that align incentives and reduce costs of complying with regulations, following the "polluter pays" principle (Ministry of Environment Forests & Climate Change, 2014).

Notwithstanding these recommendations, India has rarely used markets as a means of regulation, with the Renewable Energy Certificates and the Bureau of Energy Efficiency's Perform, Achieve and Trade scheme being notable exceptions. These schemes were introduced by India's Ministry of Power, and there exist no similar examples in the sphere of environmental regulation.[16]

This situation 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 3** at the end of the paper summarizes evidence from a number of cap and trade markets across the world.

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[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 pollution (Muller and Mendelsohn, 2009). Some forms of monitoring may be expensive or infeasible and therefore it may 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 and driving patterns.

[16] India does have a cess on coal that was raised to INR 400 per tonne in the 2016-17 budget. This number is too low to be seen as meaningful environmental regulation. Mittal (2012) use CEA data to estimate specific coal consumption estimates of about 0.7 kg per kWh across Indian coal plants. At 65 INR per USD 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 SOx markets of 1995 (expanded in 2000), Carlson et al (2000) estimate savings of 45-55% compared to a 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 NOx 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, also do not provide any incentive for industries to reduce emissions above and beyond the minimum they are expected to even if the marginal costs of additional abatement are negligibly small in comparison with the externalities they impose. An addition advantage of economic instruments such as trading is that polluters have dynamic incentives to continue abating their emissions and innovate of cleaner equipment and processes (Jaffe and Stavins, 1995). In the case of transport, market-based instruments like congestion pricing, as implemented in cities like London, Singapore, and Stockholm, may be a sustainable tool over the long term to encourage shifts towards public transport.[17] 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 program in Santiago launched in 1997 (the first application of emissions trading outside the OECD countries) and find that while on the one hand, the program was riddled with challenges due to suboptimal design, the cap set on the pollutants were adhered to from the very beginning and with time the volume of transactions increased. Coria and Sterner (2008) 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 the infrastructure, such as continuous emissions monitoring

[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 have significant impacts on air pollution also (Simeonova 2017).

systems, and increasing public disclosure create the enabling ecosystem where 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 regulation. As we have shown previously, this experimentation must necessarily go beyond environmental technology, but 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 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 outcomes, 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 State Pollution Control Board launched an important new regulatory initiative which 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 continuous emissions monitoring systems on particulate emissions in collaboration with the Gujarat Pollution Control Board. Plants in this pilot are largely small-scale, coal burning textile units and the costs of CEMS ranged from about 1 to 5 lakhs INR per stack in 2016.

An intriguing pilot project initiated by India's Ministry of Environment and Forests and the Central Pollution Control 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% 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.

4. Conclusion

While reviewing existing environmental regulation in India, the TSR 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, like 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 whilst maintaining robust levels of economic growth[18].

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

[18] Dr. SP Singh Parihar, Chairman 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.

exemplary pathway to carefully designing, testing, and then using more modern environmental regulation in India.

Table 3: Overview of cap-and-trade programs globally (Authors' compilation)

COUNTRY /REGION		NAME	YEAR	POLLUTANT	EFFECTS / TARGET
MEXICO		Pilot ETS	Expected 2018	CO_2	Three-year pilot expected to start in the third quarter of 2018.
CHINA		National Emissions Trading Scheme	2017	CO_2	Phase 1 launched covering the power sector, which is roughly one third of China's CO2 emissions. This is twice as large in terms of emissions coverage than any other ETS.
	Beijing	Emissions Trading Pilot	2011-2015	CO_2	In first period, emissions fell 4.5% and the cost of cutting emissions fell by 2.5%
	Shanghai	Emissions Trading Pilot	2011-2015	CO_2	Emissions fell 3.5% from 2011 to 2013
	Shenzhen	Emissions Trading Pilot	2011-2015	CO_2	Emission fell 11.7% from 2010 to 2013
	Tianjin	Emissions Trading Pilot	2011-2015	CO_2	Intensity target of 15% above 2010 levels
	Hubei	Emissions Trading Pilot	2011-2015	CO_2	Intensity target of 17% above 2010 levels
	Chongqing	Emissions Trading Pilot	2011-2015	CO_2	Intensity target of 20% above 2010 levels
	Guangdong	Emissions Trading Pilot	2011-2015	CO_2	Intensity target of 19% above 2010 levels
SOUTH KOREA		Korean Emissions Trading Scheme (KETS)	2015-*present*	All GHGs	Targets 4% reduction below 2005 levels by 2020
KAZAKHSTAN		Kazakhstan Emission Trading System	2013-*present*	CO_2	targets 15% reductions below 1992 GHG levels by 2020
SWITZERLAND		Swiss ETS	2008-*present*	CO_2	N/A
NEW ZEALAND		New Zealand Emissions Trading Scheme	2008-*present*	All GHGs	Enabled New Zealand to meet emission target for the first commitment period of the Kyoto Protocol
JAPAN		Japan Voluntary Emissions	2005-*present*	CO_2	25% cut below 1990 levels by 2020

		Trading Scheme (JVETS)			
	Tokyo	Tokyo Cap-and-Trade Program	2010-*present*	CO_2	In 2012, emissions were reduced by 22% below base year levels
EUROPEAN UNION		EU ETS	2005-*present*	CO_2	21 % cut below 2005 levels by 2020
AUSTRALIA		New South Wales Green House Gas Abatement Scheme (NSW GGAS)	2003-2012	All GHGs	Discontinued to avoid duplication with the Commonwealth's carbon price
CHILE		Santiago Air Emissions Trading	1995-*present*	Total suspended particulates	Low trading volume; decrease in emissions since 1997 not definitively tied to TP system
CANADA		ODS Allowance Trading	1993-*present*	CFCs, Methyl Chloroform, HCFCs, Methyl Bromide	Low trading volume, except among large methyl bromide allowance holders
		Pilot Emissions Reduction Trading (PERT)	1996-*present*	NOx, VOCs, CO, CO_2, SO_2	N/A
	Alberta	Climate Change and Emissions Management Act	2007-*present*	All GHGs	Reduce emissions vis-a-vis GDP to 50% of 1990 levels by 2020
		Regulatory Framework for Air Emissions	2007-*present*	All GHGs	Industrial emission-intensity reduction of 26% by 2015
	British Columbia, California, Manitoba, Ontario, Quebec	Western Climate Initiative (WCI)	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	1984-1986	Point-nonpoint sources of nitrogen & phosphorous	No trading occurred, because ambient standards not binding
		CFC Trades for Ozone	1987-*present*	Production rights for some CFCs, based on depletion potential	Environmental targets achieved ahead of schedule
		Protection Heavy Duty	1992-*present*	NOx and particulate emissions	Standards achieved; cost savings unknown

		Engine Trading			
		RECLAIM Program	1994-*present*	SO_2; NOx	NOx emissions fell by 60%; SOx emissions by 50 per cent.
		Acid Rain Program	1995-*present*	SO_2 emission reduction credits	SO_2 reductions achieved ahead of schedule; savings of $1billion/year
	9 northeastern states	Regional Greenhouse Gas Initiative (RGGI)	2005-*present*	CO_2	10% cut below 2009 levels by 2018
	27 eastern states	Clear Air Interstate Rule (CAIR) previously known as NOx Budget Program	2003-*present*	SO_2; NOx	61% reduction from 2003 levels; sharp reductions in compliance costs
	California	CA AB32	2013-*present*	CO2, methane, N2O, sulfur hexafluoride, PFC	Target is 17% reduction from 2012 levels by 2020

Source: Authors' compilation.

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