

# **Urban atmospheric pollution and decentralized fiscal governance: A tale of two Indian cities**

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## **Abstract:**

This paper empirically tests the suitability of local versus state government expenditure in providing an environmental public good, namely airborne pollution control in two municipal areas in India. We employ an innovative methodology where factual and counterfactual state and local expenditure regimes are constructed to capture different degrees of decentralization. Econometric results highlight higher efficacy of state level expenditure (centralization) as spillover/regional effects become important. Particularly, superiority of state expenditure is evident in the control of suspended particulate matter (SPM), which has wide cross-boundary effects. Local expenditure and the counterfactual of local expenditure for uniform provision (both decentralized provision modes) emerge as more effective than state to control point-source local pollutant SO<sub>2</sub>. However, they may also supplement the effects generated by state expenditure in the case of NO<sub>2</sub> emissions, which entail spillovers and seem amenable to pressure group influence at local level.

**Keywords:** environmental governance; fiscal decentralization; atmospheric pollution; spillover effects; non-point source pollution; India

## **Introduction**

This paper develops an innovative empirical framework derived from the first- and second-generation fiscal federalism theories to examine the relative efficacy of local government versus state government budgetary policy in controlling airborne pollution in an urban area. The literature reviewed in the paper is apparently highly skewed towards findings emanating from developed countries. This study attempts to fill this gap by analyzing air pollution control in developing country urban environments of Metropolitan Bombay and Delhi in India. We postulate that since local area air pollution is a subset of overall atmospheric pollution, the task of local environmental governance of such borderless airborne pollutants may be challenging, giving way to higher level government as well. Environmental quality, for instance, cannot be taken as a visible and divisible service that is amenable to allocation over local, regional, and national jurisdictions. This conjecture about local environmental governance would stand validated even if a strong case is made for decentralized provision of other localized goods and services, such as municipal water supply and primary health care and schools. Nevertheless, from our empirical analysis, local expenditures emerge as more effective than state intervention in controlling point-source pollution of local origin. And local intervention is shown to supplement the effects generated by state expenditure in the case of pollutants, which entail spillovers and seem amenable to pressure group influence at local level. The upshot is that despite the borderless nature of pollutants, the importance of local government in pollution alleviation strategies may not be underplayed in favor of centralized policies and governance.

## **Theoretical Underpinning**

Fiscal federalism refers to the general normative framework for assignment of functions to different levels of government and appropriate fiscal instruments for carrying out different functions. Musgrave (1959) describes the activities of the public household and classifies its functions as allocational, distributive and stabilization of macroeconomic indicators. Allocational function includes the provision of public goods and services by governments at different levels. Stabilization is the prerogative of central government because of its macroeconomic nature. The role of central government is dominant in distribution, but local government may play some limited role in distribution. This is because the latter's intervention can be thwarted by inter-locality migration of residents (Glaeser, 2013). Thus, local government operations would emerge significantly in allocating resources to provide local public goods and services. In this framework, local assignment of functions would depend on homogeneous preferences for a public good in the local/urban jurisdiction and lack of interjurisdictional spillover of benefits (Oates 2001). The examples of such goods are municipal water supply, primary health care and schools. The idea is that the benefit area of these services to a great extent should coincide with local jurisdiction. Both these pre-requisites however are not satisfied for local government assignment of pollution control in a local jurisdiction with cross border effects. Nevertheless, what is vital is that environmental problems present themselves differently in different situations, and local government, on the ground of the principle of subsidiarity, may seem to offer a better system of local environmental governance. Subsidiarity is one of the features of federalism, which asserts the rights of the parts over the whole. From green-building initiatives to local farmers' markets, local governments have become major players in addressing the most pressing environmental and public health concerns. Local governments have also used their zoning authority to ban or restrict land uses that pose environmental risks. However, allocational issues regarding

interjurisdictional environmental governance are complex and would necessitate design of appropriate institutional arrangement.

The proponents of the first-generation theories of fiscal federalism (FGFF) have argued that the decentralized provision of local public goods that are homogeneous in nature would lead to potentially large welfare gains (Bradford and Oates 1974; Rubinfeld 1987; Oates 1999). In the second-generation theories of fiscal federalism (SGFT), an alternative way to decentralize public sector is that the central government provides local public services with the help of representation of districts in central legislature and centrally appointed district officials at the local level (Seabright 1996; Lockwood 2002; Besley and Coate 2003). They however argue that sharing of costs in a decentralized system would create a conflict of interest between different districts both about the level of public spending as well as its allocation between the districts. This political economy dimension would render local legislative assemblies more suitable for local goods provision even if the problem of interjurisdictional spillovers remains unresolved. In both the approaches, the problem of benefit spillovers can be resolved by intergovernmental fiscal transfers to compensate the providing local governments.

It is further argued that sub-national governments may have informational advantages regarding local environmental issues, but state and central governments are repository of national and global information, technology, and financial power. Oates (2001) emphasizes that the central government, in addition to setting standards for “national” pollutants, has a fundamental contribution to make in supporting research in environmental science and pollution control technology and in providing needed information and guidance to state and local governments. In very distinct cases however local vs non-local role can be specified. For example, the control of pollution due to slaughterhouse in a locality or any other sources

of localized pollution can be assigned to a municipal government. Similarly, carbon dioxide (CO<sub>2</sub>) emissions would fall in national and international jurisdictions. Other environmental public goods or bads (summarized as environmental quality) would entail varying levels of interjurisdictional spillovers and their provision may necessarily require either centralization or integrated environmental governance across alternative levels of governments. This scenario of environmental governance would also imply that heterogeneity of preferences for environmental quality becomes irrelevant. Moreover, uniform provision of pollution control would necessitate increased role of higher-level government. For intermediate cases, however, environmental fiscal assignment of pollution abatement over layers of government may be worthy of empirical verification.

The rest of the paper is structured as follows. The following section reviews the relevant empirical literature. Next, we document the nature and trends of three monitored air pollutants (carbon dioxide, nitrogen dioxide and sulfur dioxide) with implications for efficacy of environmental governance at more decentralized levels of government. The subsequent sections develop empirical models to test our postulations of higher or lower regulatory efficiency of state, local and counterfactual state-cum-local expenditures in mitigating these air pollutants. Data sources and estimation strategies are also elaborated. Next part synthesizes and discusses empirical results emanating from various estimation methods and models. Last section concludes with policy implications.

### **Existing Literature on Environmental Governance and Fiscal Decentralization**

The celebrated Tiebout (1956) model of residential location does not discuss the significance of environmental quality of different jurisdiction in his migration model of optimal provision

of local public goods where local governments are self-contained. Banzhaf and Walsh (2008) however test the residential location model in the context of changing air quality and find strong empirical support for the notion that households ‘vote with their feet’ for environmental quality. Millimet (2013) argues that it is not clear from the available literature that individuals sort themselves across jurisdictions according to environmental preferences, although they may matter at the margin.

Oates (2001) presents an empirical literature on the ‘race to the bottom’ hypothesis and contends that decentralization may result in environmental degradation due to interjurisdictional competition to attract business and industry. He emphasizes that the central government, in addition to setting standards for “national” pollutants, has a fundamental contribution to make in supporting research in environmental science and pollution control technology and in providing needed information and guidance to state and local governments. Millimet (2003) analyzes theoretical models for the effects of decentralized environmental policymaking with predictions ranging from a ‘race to the top’, a ‘race to the bottom’, or no effect. His study shows that, by the mid-1980s, US data have been consistent with decentralization leading to a ‘race to the top’ (improving environmental quality). Anderson and Hill (1997) argue that most problems can be solved at the state or local level. They consider a wide variety of resource issues, including land, water, wildlife, pesticides, and pollution, and find no evidence that state or local control results in a ‘race to the bottom’ with bad policy driving out good policy. In other words, local intervention may reduce pollution despite externalities.

Alm and Banzhaf (2012) argue for local environmental policy and examine the implications of decentralisation for the design of corrective environmental policies, That is, how does one

design economic instruments in a decentralised fiscal system in which externalities exist at the local level and in which subnational governments have the power to provide local public services and to choose tax instruments that can both finance these expenditures and correct the market failures of externalities? Bahl (2013) examines three basic approaches to metropolitan governance, namely jurisdictional fragmentation, functional fragmentation, and governance emphasizing coordination and internalizing externalities. In the context of the latter, he argues that while advocates of metropolitan government make the case for combination of scale economies and elimination of duplication, they miss the advantages that might come from competition in a fragmented government setting. In other words, the problem would hinge around how to design greater local involvement in fiscal decision making while expanding jurisdictional boundaries to capture economies of scale and deal with inter-jurisdictional externalities.

Using a detailed simulation model of the US electricity sector, Banzhaf and Chupp (2012) empirically explore the tradeoffs for US air pollution. They find that US states acting in their own interest lose about 31.5% of the potential first-best benefits, whereas the second-best uniform policy loses only 0.2% of benefits. The centralized policy outperforms the state policy for two reasons. First, inter-state spillovers are simply more important than inter-state heterogeneity in this application. Second, because of the convexity of the marginal cost functions (decreasing returns to scale), costs are much lower over the range relevant to the centralized policy, dampening the distortions.

In his review of the literature, Millimet (2013) finds no empirical evidence to support the (intuitive) notion that subnational jurisdictions are better able to act on community preferences for environment than the central government. Moreover, the empirical evidence

concerning the importance of inter-jurisdictional externalities is compelling, particularly as it relates to transboundary pollution and strategic policymaking. In this line of research, jurisdictional differences would have implications for cost and benefit of a project and the nature of these effects may limit the scope of fiscal federalism. In a study of nutrient control for the Neuse River in North Carolina, Smith et al. (1997) develop area-specific measures of the benefits and costs of regulations and illustrate 'how changes in the composition of the areas allowed to "count" for policy design can affect decisions about the levels of control judged to meet the net benefit test'. This shows the difficulties in arriving at optimal solutions under an environmental policy. van't Veld and Shogren (2012) find that decentralizing the choice between these regimes does not, in general, induce the socially optimal outcome as some regions may choose negligence and others strict liability. It is only by combining negligence with a Pigouvian tax, or strict liability with a bonding requirement that harmonized regional and central environmental policies can be designed. Coria et al. (2018) analyze the effects of the interaction between national and local initiatives designed to reduce emissions that causes environmental damages both nationally and locally. Their analytical findings with Swedish data suggest that local regulators are not able to impose emissions standards stringent enough and that most emissions reductions can be attributed to the national tax, which supports the case for inter-governmental environmental policy.

Sigman (2014) empirically examines control of the two public bads, namely a pollutant with inter-jurisdictional spillovers and a pollutant with more local effects. The evidence points to higher levels of a regional pollutant with more decentralization. In this case, decentralization may provide more opportunities for free riding in regional pollutants. The research nevertheless provides limited support for more general problems from decentralization, such as destructive regulatory competition or greater sensitivity of local governments to interest group politics. As regards a pollutant with more local effects, decentralization is shown to be



welfare improving. In addition, the author's results suggest higher inter-jurisdictional variations in pollution in countries with federal systems. Such variations in pollution over regions may support the traditional view that decentralization would allow better tailoring of policies to local conditions. Two noteworthy studies on India by Lovo (2018) and Kattumuri and Lovo (2018) empirically examine the decentralization of environmental impact assessment (EIA) in 2006 from Center to state level, later extended to districts in 2016. They find that decentralization of EIA from Center to states has improved enforcement and reduced pollution through comparatively fewer firms being born in states with stricter environmental law enforcement. Their findings emphasize the significance of proactive implementation at the subnational level of a regulatory policy designed at the national level.

In a recent study, Steurer and Clar (2018) analyze the role played by federalism in Austria in greening the decentralized building sector (relevant for mitigation), on the one hand, and in improving regional flood risk management (relevant for adaptation), on the other. They show that federalism appears more appropriate for regional flood protection than for mitigating climate change. The latter require higher level governmental intervention. Chen and Liu (2020) capture both fiscal expenditure decentralization and fiscal revenue decentralization in China and show that the impact of fiscal decentralization on environmental pollution is positive and appears the phenomenon of "race to bottom." This research supports the case for limited role of local government in pollution control.

The upshot of the literature review with mixed results is that in the presence of negative externalities, borderless benefit areas of environmental quality, and limitations of environmental policy instruments, the design of environmental quality governance would remain a challenge for researchers and policymakers. The literature reviewed here is highly

skewed towards findings emanating from developed countries. Moreover, the suitability of local versus state governance in the context of addressing atmospheric quality has not been analyzed using developing country experiences. This study attempts to fill this gap by employing an innovative methodology.

### **Air Pollutants in India's Mega-cities – With Focus on Delhi and Mumbai**

We propose to analyze the relative efficiency of alternative government levels, more specifically, state vs local in alleviating air quality degradation measured by three air pollutants, namely sulphur dioxide (SO<sub>2</sub>), nitrogen dioxide (NO<sub>2</sub>) and suspended particulate matter (SPM). These municipal areas would entail pollution ranging from localized slaughterhouse gases to global CO<sub>2</sub> emissions. Our analysis does not consider carbon dioxide emissions for which information is not available in terms of municipal area. Moreover, CO<sub>2</sub> is considered a uniformly mixed air pollutant whose extent of damage (e.g. climate change) depends on total emissions worldwide. This is unlike SO<sub>2</sub>, NO<sub>2</sub> and SPM which have characteristics of non-uniformly mixed pollutants and tend to be localized in regions close to the site of emissions, with high incidence particularly in cities and urban areas (Guttikunda et al. 2014). This section looks at the nature, impact area and trends of these three air pollutants emphasizing implications on probable efficacy of decentralized environmental governance approaches.

#### ***Nature of Pollutants***

Table 1 attempts characterization of these atmospheric pollutants in terms of their nature, possible sources and range of impact with implications for the efficacy of control measures by different levels of government. SO<sub>2</sub> and NO<sub>2</sub> are gaseous in nature while SPM can be

microscopic solid or liquid matter suspended in the earth's atmosphere (except pure water). These particles can be of various sizes, the upper limit being 50-100µm (micrometer) in diameter (CPCB 2010). Our analysis focuses on particulate matter of size less than 10µm (also called PM<sub>10</sub>), regularly monitored by the Central Pollution Control Board (CPCB) in India since 1999.

While all three are non-uniformly mixed air pollutants, SO<sub>2</sub> and NO<sub>2</sub> are primary pollutants, that is, they are composed of material in the same chemical form as when they were emitted into the atmosphere. NO<sub>2</sub> however can act as precursor for formation of secondary pollutants, including secondary SPM. Examples of primary SPM are windblown dust, sea salt, road dust, mechanically generated particles, and combustion-generated particles such as fly ash and soot. Secondary particles are formed from condensable vapors generated by chemical reactions of gas-phase precursors. Secondary processes can result in either the formation of new particles or the addition of PM to pre-existing particles. Primary SPM, unlike secondary particles, can be correlated more straightforwardly to sources of emissions while secondary formation is a function of many factors like concentrations of precursors, concentrations of other gaseous reactive species (e.g., ozone), atmospheric conditions, and cloud or fog droplet interactions.

Table 1. Nature, Probable Sources and Range of Impact of SO<sub>2</sub>, NO<sub>2</sub> and SPM.

| <b>Nature / Characteristic</b>                                    | <b>SO<sub>2</sub></b> | <b>NO<sub>2</sub></b>                                                                                    | <b>SPM</b>                                                                                                                                  |
|-------------------------------------------------------------------|-----------------------|----------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Non-uniformly mixed pollutant (subject to spatial concentrations) | Yes                   | Yes                                                                                                      | Yes                                                                                                                                         |
| Primary vs secondary pollutant                                    | Primary               | Primary<br>- Can be a precursor for formation of secondary pollutants like ozone, and photochemical smog | Primary<br>Also secondary pollutant formed as a result of complex reactions with atmospheric constituents and other pollutants (precursors) |

|                      |                                                                                                                                                                |                                                                                                                                                                           |                                                                                                                                                                                                                             |
|----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Point source         | Yes (predominantly) -<br>Mainly localized e.g.<br>SO <sub>2</sub> emissions from a<br>power plant.<br>Also possible: long<br>range impacts like acid<br>rain   | No<br>Pollution comes from<br>multiple sources (e.g.<br>vehicular emissions,<br>power plants).<br>Difficult and /or<br>impractical to pinpoint<br>specific local sources. | Not straightforward –<br>Particles may be formed due<br>to local pollutants and<br>precursor pollutants that can<br>cross boundaries                                                                                        |
| Range of impact      | Mainly local as the<br>effects/ concentrations<br>get dissipated in the air<br>with distance.<br>In the case of acid rain,<br>effects may be<br>transboundary. | Mostly localized as<br>concentrations get<br>quickly dissipated in the<br>air.<br>However, formation of<br>secondary pollutants<br>may have spill over<br>effects.        | Mainly localized but with<br>source being local and<br>regional                                                                                                                                                             |
| Continuous pollutant | Yes                                                                                                                                                            | Yes                                                                                                                                                                       | Yes<br>But with seasonal peaks.<br>E.g., in Delhi, peak is<br>experienced during winters<br>due timing of regional crop<br>fires that coincide with the<br>period of temperature<br>inversion and clear sky in the<br>city. |

Source: Authors using information from CPCB (2010, 2016) and National Research Council (2010).

From Table 1, SO<sub>2</sub> is a point source pollutant whose emitters are identifiable whereas NO<sub>2</sub> and SPM are predominantly non-point source air pollutants due to widespread sources and impact area. Apportionment of sources of pollutants, particularly in case of secondary particles, is a daunting task due to mixture of activities in urban centers like industrial, commercial, transport, residential and slums. Shifting industries, land use patterns and changes in combustion practices increase the difficulty of source profiling. Moreover, heterogeneity of modes of transport, large number of vintage vehicles complicates estimation of vehicular emissions. While more localized and point source pollutants may be tackled at the local level, non-point source pollutants would require coordinated policies between decentralized and higher levels of government due to spillover effects and opportunities for free riding.

### ***Trends in air pollution and source apportionment***

Over the period 1996 to 2016, SO<sub>2</sub> levels in Delhi and Mumbai cities have complied to NAAQS (national ambient air quality standards) set by the CPCB, that is, not exceeding 50 µg/m<sup>3</sup> (CSO 2017). Particularly, Delhi records 10.1±4.9 µg/m<sup>3</sup> and Mumbai, 9.9±6.1 µg/m<sup>3</sup>. A declining trend in SO<sub>2</sub> emissions is observed over this timeline, which is more pronounced in Mumbai (-66.7%) than in Delhi (-59.5%). The reduction would be explained by the phasing out of diesel driven buses and implementation of clean fuel standards, particularly Bharat 4 diesel (50 ppm Sulphur) and Bharat Stage–III norms to commercial vehicles (CPCB 2016). Moreover, relocation or refurbishing of industries consuming coal and diesel with better efficiency norms have led to this compliance.

As regards NO<sub>2</sub> emissions, Delhi has witnessed a staggering 66.2% rise over years 1999-2016, with levels typically exceeding NAAQS and WHO 2005 standards of 40 µg/m<sup>3</sup> (47.4±14.2 µg/m<sup>3</sup>). Conversely, NO<sub>2</sub> emissions in Mumbai over the period has fallen by 15% and is within regulatory limits (25.8±8.3 µg/m<sup>3</sup>).

Coming to SPM, data published by the CPBC extends from years 1999 to 2016. SPM levels in the two mega-cities are found to exceed WHO 2005 standards of 20 µg/m<sup>3</sup> (WHO 2016) as well as national NAAQS limit of 60 µg/m<sup>3</sup> (CPCB 2016). Delhi city is the largest emitter of SPM in India with levels (200.8±44.6µg/m<sup>3</sup>) almost double that of Mumbai (104.1±21.9 µg/m<sup>3</sup>). Moreover, the growth rate of particulate matter has been higher in Delhi at 40.1% than in Mumbai (31.3%).

The most commonly and identified sources of airborne pollution in India's mega-cities are vehicles, manufacturing, construction, road dust, waste burning, and combustion of oil, coal and biomass in households. From Sindhwani and Goyal (2014), 72% of the total air pollution

load in Delhi can be attributed to vehicular pollution. A multi-city study by the CPCB reveals that in Delhi and Mumbai, vehicular contribution to total air pollution load is about 5-12% for SO<sub>2</sub>, 66-74% NO<sub>x</sub> (nitrogen oxides), and 3-12% for SPM (CPCB 2010). According to this study, vehicular pollution in Delhi contributes 67% of the total air pollution load, dust and construction 45%, waste burning 17%, and transport 14%. For Mumbai, contribution of dust, transport and waste burning are respectively 35%, 17% and 16%.

CPCB (2010) and NEERI (2010a, 2010b) also categorize sources of pollutants as area source, industrial source and line source as displayed in Table 2. Detailed sub-categorization for Delhi comparable to that of Mumbai (reported in Table 2) is however not available. SO<sub>2</sub> pollution emanates predominantly from industrial source – 93.8% in Mumbai and 98.8% in Delhi (NEERI 2010a). As suspected, the impact area of this air pollutant appears localized with identifiable and relatively few emitters (relative to NO<sub>2</sub> and SPM), namely power plants and industries. Hence, control of the pollutant may be feasible to address by local level government.

Table 2. Source Apportionment of Air Pollutants in Mumbai City (2010).

|                                    | SO <sub>2</sub> |         | NO <sub>2</sub> |         | SPM       |         |
|------------------------------------|-----------------|---------|-----------------|---------|-----------|---------|
|                                    | (T/yr)          | % Total | (T/yr)          | % Total | (T/yr)    | % Total |
| <b>A. Area source</b>              | 3266            | 5.8     | 32144.2         | 40.8    | 9815.3    | 36.6    |
| Bakeries, hotels & restaurants     | <i>n.</i>       |         | <i>n.</i>       |         | 21.8      |         |
| Open burning (incl. from landfill) | <i>n.</i>       |         | <i>n.</i>       |         | 37.1      |         |
| Construction activities            | <i>n.</i>       |         | <i>n.</i>       |         | 23.3      |         |
| Domestic sector                    | 38.6            |         | 30.9            |         | 5.8       |         |
| Locomotive                         | 44.4            |         | 61.3            |         | 5.2       |         |
| <b>B. Industrial source</b>        | 52983.5         | 93.8    | 37379.7         | 47.5    | 7526.3    | 28.1    |
| Power plant                        | 46.2            |         | 77.4            |         | 74.8      |         |
| Stone crushers                     | <i>n.</i>       |         | <i>n.</i>       |         | 18.5      |         |
| Industries                         | 53.8            |         | 22.6            |         | 6.7       |         |
| <b>C. Line source</b>              | 229.7           | 0.4     | 9169.2          | 11.7    | 9469.2    | 35.3    |
| Vehicular                          |                 |         |                 |         |           |         |
| 2- & 3-wheeler                     | <i>n.</i>       |         | 9.9             |         | <i>n.</i> |         |

|                       |         |     |         |     |         |     |
|-----------------------|---------|-----|---------|-----|---------|-----|
| Car (petrol & diesel) | 38      |     | 15.0    |     | n.      |     |
| HMV                   | 55.2    |     | 75      |     | 9.7     |     |
| Road dust             |         |     |         |     |         |     |
| Paved Road dust       | Nil     |     | Nil     |     | 33.4    |     |
| Unpaved Road dust     | Nil     |     | Nil     |     | 50.3    |     |
| Total (A+B+C)         | 56479.2 | 100 | 78693.1 | 100 | 26810.8 | 100 |

Source: Computed from NEEC (2010b). Figures in italics show percentage in respective sources of pollution, namely area, industrial and line. T/year: tons per year; n: negligible percentage (< 5%).

From Table 2, NO<sub>2</sub> emissions in Mumbai appear mainly distributed across industrial sector (47.5%) and area source (40.8%) - with the majority being emitted by locomotives (61% of area source) and the domestic sector. Only 11.7% is attributed to line source. By contrast, in Delhi, principal contributors of NO<sub>2</sub> load are the industrial sector (78.4%) and vehicular emissions (18.3%) (NEERI 2010a). While the fleet of vehicles in Delhi has been increasing tremendously over the years leading to rise in NO<sub>2</sub> emissions, installed air pollution devices in many industries are in idle conditions, resulting in emission of pollutants directly into the atmosphere without any filtration (CPCB 2016). Further, construction of short chimneys also restricts the polluting gases to escape into the upper layers of the atmosphere. In a nutshell, the greater number of NO<sub>2</sub> emitters (relative to SO<sub>2</sub>) makes targeting of emission control at point source an impractical task. Moreover, numerous sources of NO<sub>2</sub> emissions in Delhi may imply higher dispersion leading to spillover to (and from) regions in the periphery and outside the municipal areas warranting intervention from higher levels of government. Nevertheless, lax regulations of industries in Delhi may imply political economy dimensions such as pressure from industrial groups at local government level so that state regulation may emerge as more effective than local.

As regards SPM, emissions in Mumbai are spread amongst the three sources: 36.6% for area emissions predominantly from open burning and construction activities; 28.1% from

industrial sources and 35.3 % from line sources mainly road dust (Table 2). In Delhi, line source contributes 59.1% of SPM (88.8% being from road dust) (NEERI 2010a). Next is industrial source at 22% and area source, 18.8% – predominantly from the domestic sector (44% of area source) and locomotives (43%). In residential locations of Delhi, the major contributors of SPM ( $PM_{10}$ ) are construction activities and transportation; in kerbside locations, roadside dust and construction activities; and at industrial locations, road dust, garbage burning, and construction activities (CPCB 2016).

Source apportionment of SPM discussed above is however not totally comprehensive since it does not include regional (transboundary) pollution that contribute to particulate concentrations in the cities. For instance, regional agricultural emissions like stubble burning from neighboring state (Punjab) and industrial emissions from uncontrolled sources in Delhi's surrounding perimeter (where city regulations do not apply and those that apply are not followed stringently) contribute to secondary and primary SPM formation within Delhi city (Kumar et al. 2015).

To compound the problem, geography has a role to play regarding concentrations of pollutants. Delhi is landlocked, while Mumbai, a coastal city would have the opportunity to clean its pollution with the flow of sea breeze. Dense smog formation during winter months in Delhi can be attributed to vehicular pollution as well as the prevailing meteorological conditions in the months of December and January. Delhi and Northern India face temperature inversion in Winter, which creates a layer that traps pollutants, causing higher pollution concentrations in the city. Similarly, wind pattern also affects the weather conditions. According to a study, during the autumn and winter months, approximately 500 million tons of crop residues are burnt in Indo-Gangetic plains. With wind blowing from



north and north-west to the east direction during winters, pollution levels in Delhi are significantly impacted (Sharma et al. 2010). While geography cannot be controlled by the government, mitigation measures particularly to reduce transboundary impacts on city level SPM would necessitate higher level interventions and coordination at regional and peripheral levels.

### **Modelling Efficacy of Air Pollution Mitigation by State and Local Budgetary Sources**

The upshot of the previous discussion is that while SO<sub>2</sub> levels have been declining, NO<sub>2</sub> and SPM emissions are cause for concern. Our postulations of higher or lower regulatory efficiency of state and local expenditures in mitigating the above pollutants constitutes the central research enquiry in the empirical part of the paper. The dispersion or spread of the pollutants implied by high number of (identifiable) sources of emissions will have repercussions on feasibility and effectiveness of pollution mitigation by different levels of government.

What is crucial at this stage is to capture in the empirical model a measure of government intervention to control airborne pollution. There are variety of environmental fiscal instruments that are employed by governmental agencies, such as command and control measures (taxes, subsidies, fees and charges, quotas and standards) and market based transferable pollution rights (OECD, 2017). These economic instruments provide important market signals that can influence the behavior of producers and consumers. We however use the size of the budgetary resources available to the government agency as a measure of government intervention. In other words, we measure the capacity of the institution to

undertake the task of controlling pollution activity by the budgeted aggregate expenditure of the state and municipal governments.

We expect higher efficacy in controlling air borne pollution at local level for SO<sub>2</sub>, need for coordination between government at different levels for NO<sub>2</sub> control specially in presence of local interest groups, and higher-level government intervention for SPM mitigation due to wide transboundary effects and its nature as a secondary pollutant.

The sample in our study consists of municipal jurisdictions of Delhi and Mumbai. Municipal Corporation of Greater Mumbai is the financial capital of India and located in the big state of Maharashtra. Delhi Municipal Corporation falls in the State of Delhi, which is much smaller in area and population, but it is in the heart of national capital region (NCR). While the states of Maharashtra and Delhi are not comparable on several counts, the selection of the two major municipal corporations is based on the premise that besides facing high incidence of air pollution, these local bodies are major and most resourceful in terms of finance and human resource. Thus, the performance of these institutions can be compared with state government intervention in environmental quality control. The other important dimension is the geographical location of these municipal jurisdictions. Bombay municipal corporation covers a coastal city whereas Delhi is a landlocked city. The pollution levels in coastal locations are supposed to be lower than the levels obtained in landlocked area because of sea wind sweeping away a good part of pollution. In other words, these two corporations are characterized by climatic differences, the influence of which would need to be accounted for in any comparative analysis.

### ***Modelling and Construction of Counterfactuals***

We extend the models of Brueckner (1979, 1982) and Nath and Schroeder (2007) by replacing maximization of local property value with minimization of local pollution level through local and state government expenditure activity. Unlike direct interventions, it is assumed that state and local government expenditure on regulation through policies, institutions and projects would reduce pollution levels in cities. Three local air pollution abatement functions are specified as follows:

- $SO_2 = f(NSDP, SE, LE^*)$  (1)

- $NO_2 = f(NSDP, SE, LE^*)$  (2)

- $SPM = f(NSDP, SE, LE^*)$  (3)

In equations (1)-(3), NSDP (net state domestic product) is included as a control variable, capturing dual aspects of income on pollution, namely, an output effect resulting in increase in pollution due to production activities; and a capacity effect leading to decrease in pollution through enhanced investment in environmental protection. SE denotes state environmental expenditure, proxied by state revenue expenditure (due to unavailability of such information).  $LE^*$ , the variable of interest, is measured as factual expenditure of municipal corporations on pollution abatement and, alternatively, as counterfactual local expenditure as if incurred by the state government on behalf of local government.

While designing counterfactual local expenditure, we use the scenarios discussed in the first- and second-generation theories of fiscal federalism (see Box I). The measures of alternative local environmental governance are constructed in two ways: (i) as counterfactual state assembly (counterfactual 1 or CF1) providing uniform local goods, and (ii) as counterfactual

state assembly with representation of local representatives in state assembly (counterfactual 2 or CF2) using inputs provided by local assemblies.

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**Box I: Construction of alternative governments as counterfactual**

- LE: Local factual to capture decentralized provision (Oates, FGFT)
  - SE: State factual to capture uniform provision without consultation with local governments.
  - $LE_{AVG}$  (CF1) is a counterfactual of LE when expenditure decisions are taken by the state but in consultations with locally elected representatives in local assemblies. It represents average of LE of Bombay and Delhi municipal corporations to provide uniform environmental quality.
  - $LE_G$  (CF2) represents a counterfactual of LE when decisions are taken by the State government in consultation with locally elected representatives in the state assembly to provide differentiated local service (Besley and Coate, SGFT). This counterfactual is constructed using amounts of grants to local bodies. The contention is that differential grants to local bodies would carry information about differential need of different localities.
- 

***Sources of Data***

Local and state expenditure data are taken from Municipal Budgets and RBI (2016), respectively. Local municipal revenue expenditure figures are available over years 1981 to 2009 for the Municipal Corporation of Delhi (MCD), and years 1981 to 2013 for the Municipal Corporation of Greater Mumbai (MCGM). Moreover, published information on state level expenditure data for Delhi spans over years 1994 to 2016 while a longer series is obtained for the State of Maharashtra covering years 1981 to 2016. Net State Domestic

Product (NSDP) at constant prices is reported in the Handbook of Statistics on Indian States (RBI 2016) Monitored average annual levels of SO<sub>2</sub>, NO<sub>2</sub> and SPM emissions compiled by CPCB are reported in CSO (2017) and are available from 1996-2016 for SO<sub>2</sub>, 1996-2016 for NO<sub>2</sub> and 1999-2016 for SPM. In the absence of comparable and reliable data on expenditure on pollution abatement at state and local levels, total state expenditure and total local expenditure, respectively are taken to represent environmental expenditure at alternative levels. The use of aggregate municipal expenditure data in the empirical analysis to determine efficiency may be justified to satisfy the scale of local expenditure operation against the state level environmental programs. Since the pollution abatement programs will be implemented by state and municipal governments in the municipal jurisdictions of Delhi and Bombay, it is assumed that both governments would face similar labor, capital and technological cost opportunities.

### ***Estimation Strategy***

The crux of our empirical exercise hinges around testing the differential effectiveness of centralized state expenditure (SE) on air pollution control as against different modes of decentralized provision (LE<sub>factual</sub>, CF1 and CF2) as illustrated by the matrix in Figure 1. LE<sub>factual</sub> is at one extreme involving fully decentralized/municipal provision using local expenditure to satisfy the heterogeneous demands of the local population for air quality (locality-specific decentralization). The other extreme is centralized state provision to provide uniform services. The two counterfactuals, LE<sub>AVG</sub> (CF1) and LE<sub>G</sub> (CF2), may be viewed as intermediate decentralization models. More specifically, LE<sub>AVG</sub> (CF1) is constructed by averaging municipal expenditures of Mumbai and Delhi to provide uniform services within municipal jurisdiction. In other words, two municipal corporations decide to undertake similar steps to achieve uniform service (inter-locality decentralization). Conversely, LE<sub>G</sub> (CF2)

represents state provision of differentiated services by consulting locally elected representatives in state assembly (Besely and Coate approach) though grant finance. The local machinery is however used to implement aided expenditure projects. We can call it centralized decentralization or de-concentration.

|              | State          | Municipal             |
|--------------|----------------|-----------------------|
| Uniform      | SE             | $LE_{AVG} (CF1)^{**}$ |
| Heterogenous | $LE_G (CF2)^*$ | $LE_{factual}$        |

Figure 1. Decentralization regimes across uniform vs. heterogenous provision.

*Source:* Authors' postulations.

*Notes* \*: Average of municipal expenditure; \*\*: Grant financed municipal expenditure.

Models are first estimated with state expenditure (SE) and actual local expenditure ( $LE_{factual}$ ) as represented in equations (1), (2) and (3). Subsequently, the equations are also estimated using  $LE_{AVG} (CF1)$  in place of LE to provide uniform local services and using  $LE_G (CF2)$  to capture the decentralized provision of local service by the state government.

Due to constrained sample size for individual municipalities, we use pooled data arrangement to conduct the empirical analysis. Models (1)-(3) are estimated individually using pooled ordinary least squares (POLS) technique. Moreover, SURE (seemingly unrelated regression equations) and IV (instrumental variable) methodologies are also employed as robustness checks.

The attractiveness of the SURE strategy is that it produces more precise estimators than POLS in the event of contemporaneous correlation across equations in the system (Greene 2012). If the errors however are not correlated, SURE estimators would reduce to OLS. It is good to note that significant Breusch-Pagan test statistics for serial independence of errors between pollution equations (1)-(3) (reported in Appendix Table A.2) support estimation of these equations as a system (SURE method) rather than individually (as does POLS). Nevertheless, the interpretations remain constrained by small degrees of freedom. Addressing the problem of endogeneity of NSDP is also essential as, in a recent study, Hao et al. (2018) find that an increase in air pollution ( $PM_{2.5}$  concentration) in cities in North and East China has a significant negative impact on GDP per capita. We employ IV to addresses potential endogeneity between the air pollutants and income (NSDP), which would render POLS estimates biased and inconsistent Empirical findings from the different estimation approaches are presented in Appendix Tables A.1-A.3. As additional sensitivity check, we report results without and with Delhi climate dummy in Panels A and B of each Appendix Table, respectively. The climate dummy captures the climate as well as locational differences (coastal vs landlocked) between the two municipal corporations.

## **Empirical Results and Discussion**

The results are discussed according to factual and counterfactual state and local expenditure, respectively. In Table 3, effectiveness of these alternate forms of governance in terms of air pollution control is inferred when the coefficient on the respective expenditure variable is significantly negative (detailed results reported in Appendix Tables). From Panel A, in the case of a more localized pollutant like  $SO_2$  whose major emitters are relatively few and easily identifiable, control policies at the local level ( $LE_{\text{factual}}$ ) or in consultation with local

representatives in local assembly ( $LE_{AVG}$ ) appear successful in reducing the problem. This is facilitated as enforcement costs as well as administrative costs would be lower relative to more dispersed pollutants  $NO_2$  and SPM. SE, on the other hand, seems to have limited role in  $SO_2$  control. When we control for Delhi climate (Panel B), however, it now appears that both SE and  $LE_{AVG}$  would have some significant role in pollution control whereas  $LE_{factual}$  is now less important (insignificant). These findings may highlight success of well-designed and coordinated efforts at both local and state level for achieving reduced  $SO_2$  emissions.

Table 3. Summary of Results on Effectiveness of Expenditure Measures.

| Expenditure                                 | SO <sub>2</sub> control                    |                                            |                                            | NO <sub>2</sub> control                        |         |                                                | SPM control                        |            |            |
|---------------------------------------------|--------------------------------------------|--------------------------------------------|--------------------------------------------|------------------------------------------------|---------|------------------------------------------------|------------------------------------|------------|------------|
| Variables                                   | POLS                                       | SURE                                       | IV                                         | POLS                                           | SURE    | IV                                             | POLS                               | SURE       | IV         |
| <b>PANEL A: Without Delhi climate dummy</b> |                                            |                                            |                                            |                                                |         |                                                |                                    |            |            |
| SE                                          | No<br>(except<br>with<br>$LE_G$ )          | No<br>(except<br>with<br>$LE_G$ )          | Yes<br>(except<br>with<br>$LE_{factual}$ ) | Yes                                            | Yes     | Yes                                            | Yes<br>(except<br>with<br>$LE_G$ ) | No         | No         |
| $LE_{factual}$                              | Yes                                        | Yes                                        | Yes                                        | No                                             | No      | No                                             | No                                 | No         | No         |
| CF1: $LE_{AVG}$                             | Yes                                        | Yes                                        | Yes                                        | No                                             | No      | No                                             | No                                 | No         | No         |
| CF2: $LE_G$                                 | No                                         | No                                         | No                                         | No                                             | No      | No                                             | No                                 | No         | No         |
| <b>PANEL B: With Delhi climate dummy</b>    |                                            |                                            |                                            |                                                |         |                                                |                                    |            |            |
| SE                                          | No<br>(except<br>with<br>$LE_G$ )          | Yes<br>(except<br>with<br>$LE_{AVG}$ )     | Yes<br>(except<br>with<br>$LE_{AVG}$ )     | Yes<br>(except<br>with<br>$LE_{AVG}$ )         | Yes     | Yes<br>(except<br>with<br>$LE_{AVG}$ )         | No                                 | No         | No         |
| $LE_{factual}$                              | No                                         | No                                         | No                                         | No                                             | No      | No                                             | No                                 | No         | No         |
| CF1: $LE_{AVG}$                             | Yes                                        | No                                         | Yes                                        | No                                             | No      | No                                             | No                                 | No         | No         |
| CF2: $LE_G$                                 | No                                         | No                                         | No                                         | No                                             | No      | No                                             | No                                 | No         | No         |
| DL Climate                                  | -ve sig<br>(except<br>with<br>$LE_{AVG}$ ) | -ve sig<br>(except<br>with<br>$LE_{AVG}$ ) | -ve sig<br>(except<br>with<br>$LE_{AVG}$ ) | +ve sig<br>(except<br>with<br>$LE_{factual}$ ) | +ve sig | +ve sig<br>(except<br>with<br>$LE_{factual}$ ) | +ve sig                            | +ve<br>sig | +ve<br>sig |

Source: Estimated.

SE: Stated revenue expenditure;  $LE_{factual}$ : Municipal corporation revenue expenditure or local expenditure by local assembly;  $LE_{AVG}$ : Counterfactual 1 of Mumbai and Delhi municipal corporations to provide uniform environmental quality;  $LE_G$ : Counterfactual 2 constructed using amounts of grants to local bodies. POLS: robust Pooled OLS estimates; SURE: Seemingly Unrelated Regression Equations estimates; and IV: Instrumental Variable estimates.



As regards NO<sub>2</sub>, emitters are many (mainly vehicles and industries) so that the air pollutant is expected to be more dispersed than SO<sub>2</sub>. Externalities may also be higher with impacts spilling outside the municipal region. POLS and IV results in Table 3 indicate that the spillover effects are significant, state control is overwhelmingly warranted. This result is robust to the inclusion of Delhi climate dummy (favouring NO<sub>2</sub> accumulation) in our models. State level interventions would be more effective in addressing the free riding problem by spreading regulatory and abatement costs to beneficiaries outside the municipal area. Moreover, lax environmental regulations in cities and their periphery (CPCB 2016) may imply pressure group influence, particularly from the polluting industrial sector, on local governments rendering them unsuccessful in implementing regulations as opposed to state government.

Coming to SPM, which is both a primary and secondary air pollutant, sources of pollution appear more difficult to identify than in case of NO<sub>2</sub> and secondary effects would imply cross boundary effects of higher magnitude in and out of the municipal area. Thus, reduction of the pollutant is not solely in the control of local bodies. While POLS in Panel A demonstrate some success of state intervention in reducing SPM levels, this result just disappears when we use alternate estimation methods and control for Delhi climate (Panel B). Moreover, all localized interventions also emerge as unsuccessful. Delhi climate would appear to be a major culprit for SPM emission levels. If we believe POLS results, then state level effort would have potential in reducing yearly SPM emissions.

Nevertheless, in the light of these results, it can be conjectured that the situation would have worsened in both the cities due to lack of (any or) sustained efforts at the state level and coordination with sub-urban and other regional bodies in addressing the problem. For

instance, in Delhi, major sources of SPM pollution include road dust, but also industrial activities, construction and thermal power plant emissions located mainly outside the city boundaries (including nearby states). Road dust, which is also significantly felt in Mumbai would largely be attributed to vehicular concentration, network of unpaved roads as well as ongoing construction work. Expansion in the fleet of vehicles in these megacities over the sample period would have more than offset any power of regulations, worsening (or least not alleviating) the SPM problem. Ex post, the (occasional) shutting down of thermal plants such as National Capital Power Station NTPC Dadri (located outside Delhi state) and Badarpur Thermal Plant (in Delhi State), did not reduce severity of SPM pollution. The important pressure groups such as from industry and construction activities located in and outside the megacity (including other states) would imply constraint on any efforts by state government in designing regulations and performing effective monitoring and implementation. We conjecture that for a complex pollutant like SPM crossing city and state boundaries would involve more powerful players that may render even state officials less willing to regulate.

To be specific,  $LE_{\text{factual}}$  addressing localised effects, and CF1 (inter-locality uniform provision) appear to be effective for  $SO_2$  regulation due to minimal interjurisdictional spill-overs. SE seems to be instrumental in reducing  $NO_2$  levels on the grounds of uniform provision and interjurisdictional spill overs. As regard SPM, larger impact area covering the state and beyond would appear to work against decentralised intervention, rendering both local and state interventions ineffective. Nevertheless, CF2 (centralised decentralisation or de-concentration) as mode of environmental governance is found to be generally ineffective.

The coefficients on net state domestic product (NSDP) are usually positive but not always significant (Appendix Tables A.1-A.3). The impact of NSDP entails two dimensions: an

output effect that is higher output produces higher pollution and a capacity effect that increases the fiscal resources to invest in technology and meet higher expenditure needs to alleviate pollution. Significantly positive coefficient would indicate the polluting nature of production process overpowering the capacity effect. In some cases, negative and significant coefficients would convey a rise in the fiscal capacity factor as NSDP increases that would act as pollution reducing channel. Where insignificant, we may conjecture that the two effects (output and fiscal) cancel each other.

## **Conclusion and Policy Issues**

Recent advances in environmental governance literature concentrate on comparing the relative efficacy of central vs sub-national government involvement in environmental abatement strategies. It is argued that sub-national governments may have informational advantages as regards regional and local environmental issues, however central government is a repository of national and global information, technology development and financial power. An attempt is made in this paper to extend the above arguments at the subnational level, that is, between state/regional and local government. We test the efficacy of local government (municipal) expenditure and state level expenditure in alleviating air pollution in the municipal jurisdiction of Bombay and Delhi due to  $\text{SO}_2$ ,  $\text{NO}_2$  and SPM ( $\text{PM}_{10}$ ). The empirical exercise however does not yield any straightforward result in support of local intervention except in the case of  $\text{SO}_2$ , which is mainly localized. Thus, whereas a strong case is made for decentralization in the fiscal federalism literature, our results do not support environmental federalism to control borderless airborne pollutants, namely SPM and  $\text{NO}_2$ . Our findings highlight the difficult task of determining the benefit area of environmental

quality and employing policy instruments by different levels of government to correct negative externalities.

Our empirical results can be summarized as follows. Local municipal expenditure and decentralized provision measured by counterfactual CF1 are effective in reducing the more localized point source pollutant  $\text{SO}_2$ , but not in case of the dispersed non-point source pollutants,  $\text{NO}_2$  and SPM. In these cases, the spill over effects from and outside the municipal jurisdiction are significant, which implies that higher information costs (including on polluters/beneficiaries outside the locality), transaction costs and enforcement costs required for effective pollution control. Moreover, pressure group influence, for example, from industries in neighbouring areas or in the city may deepen the ineffectiveness of local interventions. State level expenditure thus emerges as overwhelmingly successful in controlling these two pollutants as opposed to other decentralised expenditure regimes. Nevertheless, in the case of  $\text{NO}_2$ , which seems more localized relative to SPM, results display some scope for success of coordinated efforts of local and state level to control these emissions.

These findings may be taken as exploratory due to restricted sample size and small stock of fiscal and real data available. However, this exercise provides a new framework to examine the issues underlying the allocation of pollution abatement functions across different layers of government. In the local context, the role of municipal expenditure in pollution mitigation should not be underplayed. Our findings point towards the possibility that, with proper monitoring from higher level governments, local governments can significantly contribute to environmental governance efforts of state and central governments. It is however important to note that the success of state level environmental policy in addressing pollution underlies

the notion that national level centralization may not be ideal. As Ryan (2015) puts it very aptly, environmental federalism is lighting a path away from the old “zero-sum” model of federalism (which treats every assertion of authority at one jurisdictional level as a loss of authority for the others) and pushes toward a model of negotiated federalism emphasizing consultation, compromise, and coordination.

An alternate counterfactual that is not explored in our empirical exercise is public-private partnership (PPP) whereby local governments may partner with private operators for example in attempts to (i) reduce number of private car commuters on the road such as by increasing the flight of public/private bus or other vehicular transport; (ii) help to finance develop clean modes of transport such as electric buses or vehicles running with fuel cells; and (iii) support to develop alternate modes of clean energy for industries. This partnership mode may constitute an important further research issue involving environmental managers of big cities.

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## Appendix Tables

Appendix Table A.1. Pooled OLS Results: Local vs. State Expenditure – SO<sub>2</sub>, NO<sub>2</sub> and SPM Emissions Control.

| Dependent variable: Pollution emissions (ln) |                       |                       |                       |                       |                       |                      |                     |                      |                      |
|----------------------------------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|----------------------|---------------------|----------------------|----------------------|
|                                              | ln(SO <sub>2</sub> )  |                       |                       | ln(NO <sub>2</sub> )  |                       |                      | ln(SPM)             |                      |                      |
|                                              | (1)                   | (2)                   | (3)                   | (4)                   | (5)                   | (6)                  | (7)                 | (8)                  | (9)                  |
| <b>Panel A: Without Delhi Dummy</b>          |                       |                       |                       |                       |                       |                      |                     |                      |                      |
| ln(NSDP)                                     | 0.306<br>(0.555)      | 0.170<br>(0.378)      | 1.916**<br>(2.347)    | 1.372**<br>(2.404)    | 1.373**<br>(2.644)    | 1.302*<br>(2.033)    | -0.047<br>(-0.162)  | 0.082<br>(0.400)     | -1.030**<br>(-2.295) |
| ln(LE <sub>factual</sub> )                   | -1.315***<br>(-4.596) |                       |                       | 0.506<br>(1.460)      |                       |                      | 0.487***<br>(4.236) |                      |                      |
| ln(LE <sub>AVG</sub> )                       |                       | -0.819***<br>(-7.012) |                       |                       | 0.404*<br>(1.873)     |                      |                     | 0.345***<br>(5.555)  |                      |
| ln(LE <sub>G</sub> )                         |                       |                       | 0.183*<br>(2.033)     |                       |                       | 0.077<br>(0.974)     |                     |                      | -0.121*<br>(-1.730)  |
| ln(SE)                                       | 0.281<br>(0.627)      | -0.139<br>(-0.451)    | -1.420**<br>(-2.750)  | -1.305***<br>(-2.817) | -1.081***<br>(-3.052) | -0.941**<br>(-2.339) | -0.401*<br>(-1.915) | -0.277**<br>(-2.095) | 0.459*<br>(1.734)    |
| Const                                        | 7.617***<br>(5.283)   | 8.878***<br>(7.978)   | 0.882<br>(0.578)      | 1.738<br>(1.265)      | 0.357<br>(0.216)      | 2.364*<br>(1.976)    | 6.076***<br>(8.345) | 5.026***<br>(8.680)  | 9.465***<br>(8.733)  |
| N                                            | 32                    | 28                    | 27                    | 32                    | 28                    | 27                   | 28                  | 28                   | 24                   |
| adj. R <sup>2</sup>                          | 0.739                 | 0.801                 | 0.597                 | 0.361                 | 0.360                 | 0.363                | 0.787               | 0.839                | 0.748                |
| <b>Panel B: Without Delhi Dummy</b>          |                       |                       |                       |                       |                       |                      |                     |                      |                      |
| ln(NSDP)                                     | 0.0758<br>(0.133)     | 0.153<br>(0.331)      | 0.613<br>(1.054)      | 1.477**<br>(2.717)    | 1.610***<br>(3.683)   | 1.857**<br>(2.803)   | 0.117<br>(0.808)    | 0.128<br>(0.955)     | -0.223<br>(-0.711)   |
| ln(LE <sub>factual</sub> )                   | -0.244<br>(-0.637)    |                       |                       | 0.0136<br>(0.0305)    |                       |                      | -0.164<br>(-1.115)  |                      |                      |
| ln(LE <sub>AVG</sub> )                       |                       | -0.754**<br>(-2.119)  |                       |                       | -0.540<br>(-1.289)    |                      |                     | -0.169<br>(-1.277)   |                      |
| ln(LE <sub>G</sub> )                         |                       |                       | 0.123***<br>(4.097)   |                       |                       | 0.103<br>(1.109)     |                     |                      | -0.074<br>(-1.168)   |
| ln(SE)                                       | -0.556<br>(-1.017)    | -0.184<br>(-0.454)    | -1.041***<br>(-3.012) | -0.920*<br>(-1.750)   | -0.434<br>(-1.017)    | -1.102**<br>(-2.748) | 0.154<br>(0.799)    | 0.138<br>(1.104)     | 0.179<br>(0.872)     |
| DL                                           | -1.237***<br>(-3.611) | -0.121<br>(-0.221)    | -1.388***<br>(-5.742) | 0.569<br>(1.384)      | 1.736**<br>(2.142)    | 0.591**<br>(2.158)   | 0.839***<br>(4.607) | 0.978***<br>(5.134)  | 0.605***<br>(5.700)  |
| Cons                                         | 9.576***<br>(7.394)   | 8.970***<br>(8.124)   | 7.859***<br>(6.061)   | 0.837<br>(0.527)      | -0.958<br>(-0.477)    | -0.607<br>(-0.341)   | 4.253***<br>(10.84) | 4.307***<br>(11.36)  | 5.685***<br>(7.934)  |
| N                                            | 32                    | 28                    | 27                    | 32                    | 28                    | 27                   | 28                  | 28                   | 24                   |
| adj. R <sup>2</sup>                          | 0.835                 | 0.793                 | 0.851                 | 0.373                 | 0.431                 | 0.448                | 0.882               | 0.883                | 0.858                |

Source: Estimated. t-statistics in parentheses \* p<0.10, \*\* p<0.05, \*\*\* p<0.01  
 Linear interpolation has been used to address missing observations; N: no. of obs.; NSDP: Net state domestic product; LE<sub>AVG</sub>: Average of local (municipal) revenue expenditure of Municipal Corporation of Delhi (MCD) and Municipal Corporation of Greater Mumbai (MCGM); LE<sub>G</sub>: Grants to municipal corporations; LE<sub>factual</sub>, SE: Local and state revenue expenditure, respectively.



Appendix Table A.2. SURE Results on Pollution Control: Local vs. State Expenditure  
(Dependent variables: SO<sub>2</sub>, NO<sub>2</sub>, and SPM emissions).

|                                      | ln(SO <sub>2</sub> )  |                       |                       | ln(NO <sub>2</sub> )  |                      |                       | ln(SPM)             |                     |                      |
|--------------------------------------|-----------------------|-----------------------|-----------------------|-----------------------|----------------------|-----------------------|---------------------|---------------------|----------------------|
|                                      | (1a)                  | (1b)                  | (1c)                  | (2a)                  | (2b)                 | (2c)                  | (3a)                | (3b)                | (3c)                 |
| <b>Panel A: Without Delhi Dummy</b>  |                       |                       |                       |                       |                      |                       |                     |                     |                      |
| ln(NSDP)                             | 0.804<br>(1.449)      | 0.654<br>(1.488)      | 1.524**<br>(2.039)    | 0.943*<br>(1.806)     | 1.008**<br>(2.145)   | 0.851<br>(1.434)      | -0.451+<br>(-1.623) | -0.362<br>(-1.489)  | -0.647**<br>(-2.071) |
| ln(LE <sub>factual</sub> )           | -0.426**<br>(-2.095)  |                       |                       | 0.090<br>(0.836)      |                      |                       | 0.078<br>(1.018)    |                     |                      |
| ln(LE <sub>AVG</sub> )               |                       | -0.376***<br>(-3.936) |                       |                       | 0.107<br>(1.612)     |                       |                     | 0.090**<br>(2.115)  |                      |
| ln(LE <sub>G</sub> )                 |                       |                       | 0.098<br>(0.967)      |                       |                      | -0.006<br>(-0.120)    |                     |                     | -0.026<br>(-0.665)   |
| ln(SE)                               | -0.461<br>(-1.149)    | -0.529*<br>(-1.832)   | -1.121**<br>(-2.410)  | -0.769**<br>(-2.192)  | -0.781**<br>(-2.552) | -0.664*<br>(-1.755)   | 0.078<br>(0.402)    | 0.048<br>(0.307)    | 0.238<br>(1.226)     |
| Cons                                 | 4.152***<br>(3.793)   | 5.546***<br>(5.632)   | 1.361<br>(0.856)      | 3.031***<br>(3.473)   | 2.519***<br>(2.887)  | 3.434***<br>(3.243)   | 7.669***<br>(14.32) | 7.190***<br>(13.55) | 8.315***<br>(12.90)  |
| N                                    | 23                    | 23                    | 23                    | 23                    | 23                   | 23                    | 24                  | 24                  | 24                   |
| R <sup>2</sup>                       | 0.577                 | 0.697                 | 0.497                 | 0.382                 | 0.440                | 0.352                 | 0.759               | 0.794               | 0.754                |
| B-P test:<br>chi2(3)                 |                       | 30.528                |                       |                       | 54.728               |                       |                     | 46.286              |                      |
| p-val                                |                       | [0.00]                |                       |                       | [0.00]               |                       |                     | [0.00]              |                      |
| <b>PANEL B: DELHI Dummy included</b> |                       |                       |                       |                       |                      |                       |                     |                     |                      |
| ln(NSDP)                             | 0.082<br>(0.152)      | 0.153<br>(0.325)      | 0.192<br>(0.339)      | 1.662***<br>(3.594)   | 1.678***<br>(3.782)  | 1.659***<br>(3.416)   | 0.132<br>(0.507)    | 0.133<br>(0.511)    | 0.095<br>(0.365)     |
| ln(LE <sub>factual</sub> )           | -0.048<br>(-0.325)    |                       |                       | -0.014<br>(-0.194)    |                      |                       | -0.003<br>(-0.108)  |                     |                      |
| ln(LE <sub>AVG</sub> )               |                       | -0.321<br>(-1.394)    |                       |                       | -0.068<br>(-0.505)   |                       |                     | -0.008<br>(-0.166)  |                      |
| ln(LE <sub>G</sub> )                 |                       |                       | 0.021<br>(0.463)      |                       |                      | -0.001<br>(-0.043)    |                     |                     | -0.007<br>(-0.513)   |
| ln(SE)                               | -0.701**<br>(-2.037)  | -0.502<br>(-1.543)    | -0.797**<br>(-2.452)  | -0.776***<br>(-2.772) | -0.738**<br>(-2.639) | -0.787***<br>(-2.777) | -0.006<br>(-0.039)  | -0.002<br>(-0.017)  | 0.011<br>(0.079)     |
| DL                                   | -1.376***<br>(-4.030) | -0.784<br>(-1.476)    | -1.395***<br>(-4.531) | 1.095***<br>(3.929)   | 1.217***<br>(3.271)  | 1.082***<br>(3.889)   | 0.665***<br>(4.350) | 0.677***<br>(3.849) | 0.656***<br>(4.544)  |
| Cons                                 | 9.459***<br>(5.571)   | 8.920***<br>(5.829)   | 9.107***<br>(4.961)   | -1.909<br>(-1.306)    | -2.020<br>(-1.425)   | -1.882<br>(-1.217)    | 4.486***<br>(5.174) | 4.476***<br>(5.141) | 4.616***<br>(5.327)  |
| N                                    | 23                    | 23                    | 23                    | 23                    | 23                   | 23                    | 24                  | 24                  | 24                   |
| R <sup>2</sup>                       | 0.727                 | 0.759                 | 0.733                 | 0.649                 | 0.656                | 0.647                 | 0.868               | 0.868               | 0.871                |
| B-P test:<br>chi2(3)                 |                       | 51.420                |                       |                       | 63.187               |                       |                     | 65.340              |                      |
| p-val                                |                       | [0.00]                |                       |                       | [0.00]               |                       |                     | [0.00]              |                      |

Source: Estimated. \* p<0.10, \*\* p<0.05, \*\*\* p<0.01.

t-statistics in parentheses adjusted for small sample size and low degrees of freedom.

Notes: As for Table A.1. BP test: Breusch-Pagan test of independence of equations in systems 1, 2, 3.



Appendix Table A.3. Robustness Test: IV Results – SO<sub>2</sub>, NO<sub>2</sub>, and SPM Emissions Control.

|                                     | ln(SO <sub>2</sub> )  |                       |                       | ln(NO <sub>2</sub> ) |                       |                     | ln(SPM)             |                     |                      |
|-------------------------------------|-----------------------|-----------------------|-----------------------|----------------------|-----------------------|---------------------|---------------------|---------------------|----------------------|
|                                     | (1)                   | (2)                   | (3)                   | (4)                  | (5)                   | (6)                 | (7)                 | (8)                 | (9)                  |
| <b>Panel A: Without Delhi Dummy</b> |                       |                       |                       |                      |                       |                     |                     |                     |                      |
| ln(NSDP)                            | 1.039**<br>(2.541)    | 0.813*<br>(1.846)     | 2.832***<br>(3.492)   | 1.456*<br>(2.006)    | 1.781***<br>(3.023)   | 1.312+<br>(1.648)   | -0.282<br>(-0.790)  | -0.0335<br>(-0.132) | -1.394**<br>(-2.635) |
| ln(LE <sub>factual</sub> )          | -1.194***<br>(-2.802) |                       |                       | 0.520<br>(1.500)     |                       |                     | 0.432***<br>(3.664) |                     |                      |
| ln(LE <sub>AVG</sub> )              |                       | -0.757***<br>(-6.820) |                       |                      | 0.444**<br>(2.163)    |                     |                     | 0.328***<br>(5.110) |                      |
| ln(LE <sub>G</sub> )                |                       |                       | 0.223**<br>(2.336)    |                      |                       | 0.077<br>(1.014)    |                     |                     | -0.162*<br>(-1.891)  |
| ln(SE)                              | -0.254<br>(-0.611)    | -0.562*<br>(-1.880)   | -1.994***<br>(-3.963) | -1.367**<br>(-2.496) | -1.349***<br>(-3.472) | -0.947*<br>(-1.912) | -0.222<br>(-0.862)  | -0.201<br>(-1.243)  | 0.680**<br>(2.170)   |
| Cons                                | 6.316***<br>(3.367)   | 7.627***<br>(8.223)   | -0.650<br>(-0.386)    | 1.588<br>(0.997)     | -0.437<br>(-0.277)    | 2.348+<br>(1.651)   | 6.562***<br>(7.895) | 5.295***<br>(7.750) | 10.25***<br>(7.895)  |
| N                                   | 32                    | 28                    | 27                    | 32                   | 28                    | 27                  | 28                  | 28                  | 24                   |
| R <sup>2</sup>                      | 0.751                 | 0.806                 | 0.621                 | 0.422                | 0.422                 | 0.437               | 0.806               | 0.856               | 0.770                |
| <b>Panel B: With Delhi Dummy</b>    |                       |                       |                       |                      |                       |                     |                     |                     |                      |
| ln(NSDP)                            | 0.604*<br>(1.710)     | 0.816*<br>(1.885)     | 1.262**<br>(2.097)    | 1.648**<br>(2.290)   | 2.215***<br>(3.864)   | 2.098**<br>(2.465)  | 0.033<br>(0.160)    | 0.023<br>(0.132)    | -0.325<br>(-1.030)   |
| ln(LE <sub>factual</sub> )          | -0.194<br>(-0.366)    |                       |                       | 0.030<br>(0.066)     |                       |                     | -0.175<br>(-1.120)  |                     |                      |
| ln(LE <sub>AVG</sub> )              |                       | -0.786*<br>(-1.951)   |                       |                      | -0.568<br>(-1.427)    |                     |                     | -0.179<br>(-1.402)  |                      |
| ln(LE <sub>G</sub> )                |                       |                       | 0.151***<br>(3.389)   |                      |                       | 0.113<br>(1.283)    |                     |                     | -0.084<br>(-1.354)   |
| ln(SE)                              | -0.908**<br>(-2.100)  | -0.540<br>(-1.312)    | -1.411***<br>(-3.768) | -1.034+<br>(-1.669)  | -0.760<br>(-1.422)    | 1.240**<br>(-2.556) | 0.209<br>(0.869)    | 0.203<br>(1.572)    | 0.231<br>(1.158)     |
| Delhi                               | -1.196***<br>(-2.994) | 0.052<br>(0.083)      | -1.274***<br>(-5.835) | 0.582<br>(1.438)     | 1.893**<br>(2.476)    | 0.634*<br>(2.060)   | 0.828***<br>(4.745) | 0.970***<br>(5.103) | 0.579***<br>(4.720)  |
| Cons                                | 8.587***<br>(8.912)   | 7.596***<br>(9.192)   | 6.378***<br>(5.184)   | 0.517<br>(0.274)     | -2.211<br>(-1.062)    | -1.157<br>(-0.502)  | 4.445***<br>(11.24) | 4.555***<br>(10.29) | 5.992***<br>(7.519)  |
| N                                   | 32                    | 28                    | 27                    | 32                   | 28                    | 27                  | 28                  | 28                  | 24                   |
| R <sup>2</sup>                      | 0.850                 | 0.806                 | 0.864                 | 0.453                | 0.496                 | 0.530               | 0.899               | 0.899               | 0.882                |

Source: Estimated. + p<0.12, \* p<0.10, \*\* p<0.05, \*\*\* p<0.01

t-stats in parentheses are heteroscedasticity robust and corrected for first-order autocorrelation. Stats adjusted for small sample size. Notes: As for Appendix Table A.1. Instruments for ln(NSDP) include lagged values of ln NSDP by one year and two years.