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The Effect of Public Health Expenditure on Infant Mortality: Evidence from a Panel of Indian States, 1983–84 to 2011–12[*]

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Abstract

Using a panel data set of Indian states between 1983–84 and 2011–12, this paper studies the impact of public health expenditure on the infant mortality rate (IMR), after controlling for other relevant covariates like per capita income, female literacy, and urbanization. We find that public expenditure on health care reduces IMR. Our baseline specification shows that an increase in public health expenditure by 1 percent of state-level GDP is associated with a reduction in the IMR by about 8 infant deaths per 1000 live births. We also find that female literacy and urbanization reduces the IMR.

JEL Codes: E12, E20.
Keywords: infant mortality rate, public health expenditure, female literacy, India

1 Introduction

Despite rapid economic growth over the past three decades, India has witnessed very slow improvements in average health indicators of its population. Thus, India's position with respect to key indicators of health are below what would be expected on the basis of its income level. According to data for 187 countries available in the 2014 Human Development Report, India is ranked 130-th in terms of gross national income per capita (2011 PPP $) but is ranked 136 in terms of life expectancy at birth (years), 139-th in terms of under-5 mortality rate (deaths before the age of 5 years for every 1000 live births), and 140-th in terms of the infant mortality rate (deaths before the age of 1 year for every 1000 live births).

One of the possible reasons for India's relatively worse performance on health indicators could be the low level of public expenditure on health care (Rao and Choudhury, 2012). India has not only one of the lowest levels of public expenditure on health care, but it also has one of the most privatized health care systems in the world. Drawing on data for the period 1995–2013 from the World Development Indicators, Figure 1 and 2 highlight this important fact about India's health care system. In Figure 1, we see that India has much lower public expenditure on health care (as a share of GDP) than most other regions of the world, including sub-Saharan Africa. Moreover, it has remained relatively stagnant over the last two decades, hovering around 1 per cent of GDP, whereas sub-Saharan Africa and the Arab World both have more than double that amount of public expenditure on health care for the same period. Figure 2 highlights the other important fact about India's health care system: its reliance, to a predominant extent, on a privatized system. For the period between 1995 and 2013, public expenditure has accounted for much lower than 40 per cent of total expenditure on health care in India. This is far lower than what is seen in other parts of the world, including sub-Saharan Africa.

If public expenditure on health care in the context of a poor country like India has any
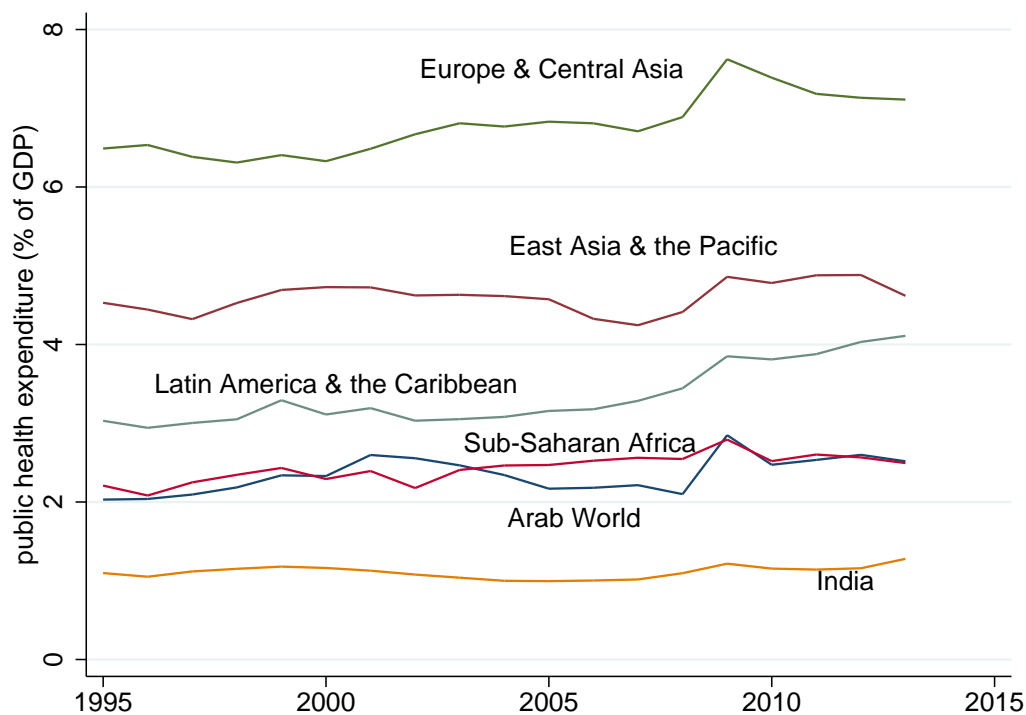
Figure 1: *Time series plot of public health expenditure (as a % of GDP) for major regions of the world and India, 1995-2013. Source: World Development Indicators, World Bank.*

positive impacts on health outcome, which seems likely, then Indian's exceptionally low level represents a potentially large opportunity. If it could increase its public expenditure on health care to the level of sub-Saharan Africa or Latin America, and if increases in public health expenditure has a positive impact on health outcomes, then India could rapidly improve the health status of its population. Such considerations have often been noted by Indian policy makers. The recently released Draft National Health Policy 2015 notes that perhaps "the single most important policy pronouncement of the National Health Policy 2002 articulated in the 10th, 11th and 12th Five Year Plans, and the NRHM framework was the decision to increase public health expenditure to 2 to 3 % of the GDP." (MoHFW, 2015). A similar target was also recommended by an earlier High Level Expert Group on Universal Health Coverage (Rao and Choudhury, 2012).
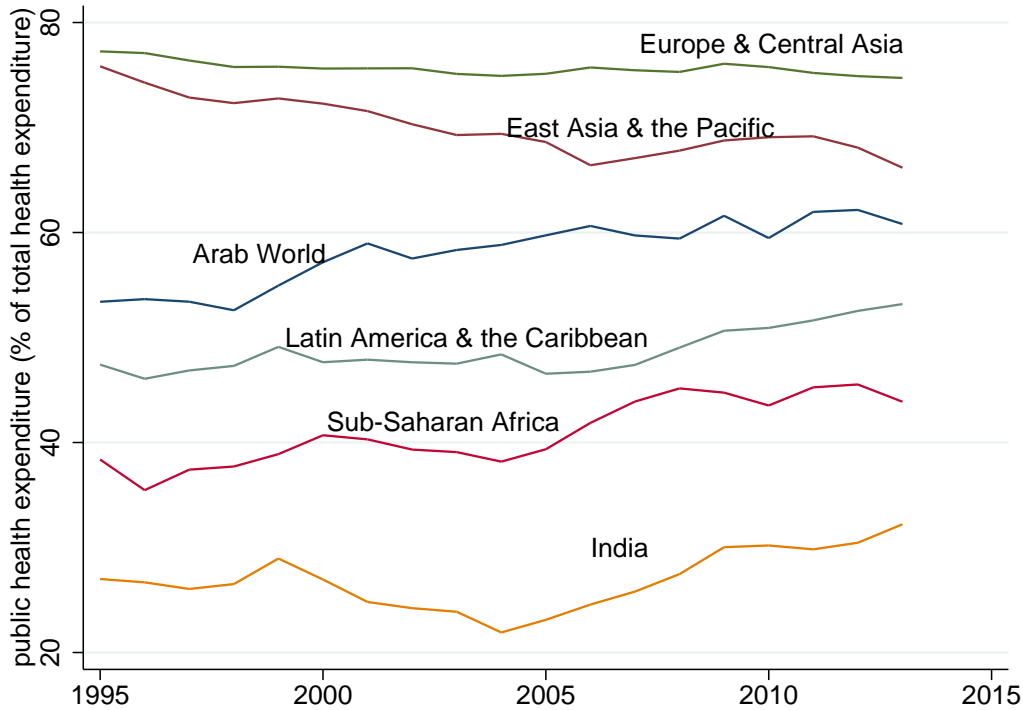
Figure 2: *Time series plot of public health expenditure (as a % of total health expenditure) for major regions of the world and India, 1995-2013. Source: World Development Indicators, World Bank.*

While the need for increasing public expenditure on health care seems necessary from a policy perspective, existing studies on the issue present at best a mixed picture. While some papers report that public expenditure on health care has very little effect, if at all, on health outcomes (Filmer and Pritchett, 1999; Kaur and Misra, 2003; Deolalikar et al., 2004), others find some positive impact (Anand and Ravallion, 1993; Bhalotra, 2007; Farahani et al., 2010). In this paper, we revisit the issue of the effect of public expenditure on health care on health outcomes in the context of Indian states.

There are two reasons for focusing on states in India. First, as we explain in greater detail below, even though health is a joint domain of State and Central governments, the former play a much larger role in funding health service provision. This brings in variation in public health spending across states that can be exploited to estimate its effect on health

outcomes, as we do in this paper. Second, the advantage of studying states within India is that data on public expenditure on health care and other key covariates is largely consistent and comparable. Hence, working on Indian states can allow us to avoid many difficult issues related to data comparability that becomes important in cross country settings.

We use the infant mortality rate (IMR) as the key health outcome for our study because it is widely accepted among demographers, health economists, and policy makers as one of the most important indicators of the well-being of a population. In India, the acceleration of the rate of growth after the economic reforms in the early 1990s was accompanied by a slowdown in the rate of decline in infant mortality (Dreze and Sen, 2002). Following a period of rapid decline in the 1970s, the IMR in India stagnated for close to a decade, before declining again. For instance, the IMR in India fell from 80 (per 1000 live births) in 1990 to 68 in 2000 and further down to 50 in 2009. Even as average IMR for India has declined over the past few decades, states have displayed large variation in performance. While some states like Kerala, Maharashtra and West Bengal have shown rapid improvement and are on their way to meet the Millenium Development Goals by 2015, others like Bihar, Gujarat, Orissa and Uttar Pradesh have lagged far behind (NIMS et al., 2012).

Using this observation as the point of departure, this paper aims to investigate the factors that determine the spatial and temporal variation of IMR across Indian states, in particular public expenditure on health care. Building on the empirical framework in Pritchett and Summers (1996), Filmer and Pritchett (1999), and NIMS et al. (2012), we use a panel data set for 31 Indian states and union territories between 1983–84 and 2011–12 to analyze the impact of public health expenditure on IMR, after controlling for other relevant covariates like the female literacy rate, per capita net state domestic product, sex ratio (females per 1000 males), and urbanization.

In poor countries like India, public expenditure on health care is an important component of progressive policy. Where household incomes are low and credit market imperfections

high, the vast majority of the population are unable to provide adequate health care through private expenditure. In such a scenario, public expenditure can be an important mechanism to ensure health care services to the population, especially the poorer sections of the population. Large hospitals with expensive equipment and facilities, proper sanitation, safe drinking water, nutritional programs, and similar interventions with impact on average health status can only be properly supported by public policy. This aspect is especially important for India because it has one of the most privatized health care systems in the world (Sengupta, 2013). Recent studies have also noted the poverty deepening impact of out-of-pocket payments (Garg and Karan, 2009; Shahrawat and Rao, 2012), which is another dimension of the distributional aspect of public health expenditure in a poor country like India.

As noted above, previous studies of the effect of public health spending on health outcomes have found mixed results. This is true for the few studies that exist on India too. Studies which use state-level panel data sets usually report that there is no significant relation between public health expenditure and health outcomes (Kaur and Misra, 2003; Deolalikar et al., 2004). On the other hand, some studies that have used individual level cross-sectional data from the National Family and Health Surveys do find some effect of public health expenditure on the probability of infant death (Bhalotra, 2007; Farahani et al., 2010).

One of the reasons for weak results of the effect of public health expenditure on the IMR in a panel data setting could be the presence of simultaneity bias. While it is intuitively clear that public expenditure on health care – at the country or state level – will reduce the state-level IMR, it is also possible that there is a causation running in the opposite direction. It is not unlikely that states (or countries) with sub-par health outcomes react to that fact by increasing the public expenditure on health care. In fact, it has been documented that many of the worst performing states – in terms of health outcomes – in India also register a larger public expenditure on health care as a share of state GDP (Rao and Choudhury, 2012). If the bi-directional causality between public health expenditure and the IMR holds,

then the OLS estimate of the effect of the former on the latter will be biased. The key contribution of this paper is to address this possible problem of endogeneity in two ways.

First, we use a simultaneous equation model to capture the bi-directional causality between public expenditure on health care and the IMR. Using this model, we show that the asymptotic bias in the OLS estimate of the effect of public health expenditure on the IMR is likely to be positive. To the extent that researchers have been unable to adequately address the problem of endogeneity, this can partly explain why many studies report insignificant effects of public health expenditure on the IMR: since the expected sign is negative (because higher public health expenditure is expected to reduce IMR), a positive bias will push the OLS estimate towards zero.

Second, using a panel of 31 Indian states and union territories between 1983–84 and 2011–12, we estimate the causal effect of public health expenditure on the IMR using an instrumental variables strategy. We use two types of instrumental variables for public expenditure on health care: fiscal variables (a state's own tax and non-tax revenue) and political variables (the effective number of parties in a state government). We include a full set of controls that have been highlighted as important determinants of IMR in existing studies: female literacy (Subbarao and Raney, 1995; Caldwell, 1986, 1990; Anand and Barnighausen, 2004), per capita income (Pritchett and Summers, 1996), and urbanization (NIMS et al., 2012), sex ratio, and state and year fixed effects.

The main results from our empirical analysis are the following. First, we find that public expenditure on health care has a significant effect on the IMR, i.e., states which have higher public expenditure on health have lower IMR. Our preferred specification shows that an increase in public expenditure on health care by 1 per cent of state-level GDP can reduce the IMR by about 8 infant deaths per 1000 live births. Second, we find, in line with existing results, that female literacy and urbanization improves the IMR. Our preferred specification shows that an increase in the female literacy rate by 10 percentage points would reduce the

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IMR by 9.5, and an increase in the share of urban population by 10 percentage points would be associated with an IMR reduction of 3.3.

In addition to addressing long-standing debates in health economics and demography, our research also has immediate policy relevance. Even as India has grown rapidly over the past three decades, health indicators (infant mortality rates, life expectancy at birth, calorie intake, child malnutrition, prevalence of anemia in women, etc.) of the vast majority have improved, if at all, sluggishly. Policy makers have been puzzled by this apparent disconnect between economic growth and improvement in living standards. A clue to this puzzle is provided by the results of this paper: public health expenditure has been stagnant over this period of growth. This could potentially explain why India has not witnessed big health improvements despite rapid economic growth.

The rest of the paper is organized as follows. In section 2, we introduce the empirical model and discuss the issue of simultaneity bias; in section 3, we describe our data sources; in section 4, we discuss our main results; and, section 5, concludes the discussion. Mathematical proofs are collected in the appendix.

2   Empirical Model

To motivate the empirical investigation in this paper, we start from a discussion of Figure 3. It is a scatter plot of public expenditure on health care (as a percentage of state-level GDP) against the infant mortality rate for a pooled sample of 31 India states and union territories over the period 1983–84 to 2011–12. The scatter plot also includes the line from a bivariate regression of the IMR on public expenditure on health care and a constant. The line slopes downward, suggesting that state-years with higher public expenditure on health care witness lower IMR. Our primary interest in this paper is to investigate whether the effect of public expenditure on health care on IMR, as depicted by the regression line in Figure 3, can be

interpreted as a causal effect. To address the question of causal effect, we will need to address at least two sets of issues.
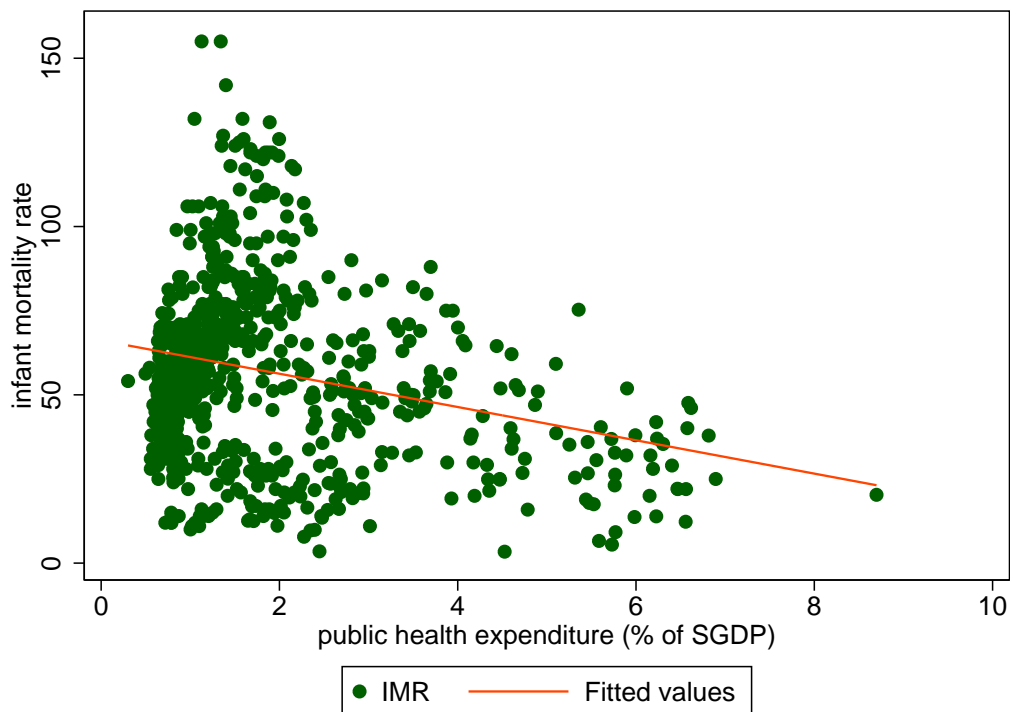
Figure 3: *Scatter plot of public expenditure on health care and infant mortality rate (IMR) across India states, 1981-2012, with a linear regression line. Source: Authors' calculations.*

First, the scatter plot and regression line in Figure 3 leaves out many other covariates that could be correlated with both public expenditure on health care and IMR. To account for the possible of effect of many such determinants of IMR, we can use the following structural relationship:

$$y_{irt} = z_{it}\alpha_1 + \mathbf{x}'_{it}\boldsymbol{\beta_1} + \mu_i + \delta_t + \sum_r \eta_r t + \varepsilon_{1,it}, \tag{1}$$

where $i = 1, 2, \ldots n$ indexes states, $t = 1, 2, \ldots T$ indexes years (so that we have a total of $N = n \times T$ observations), y_{irt} denotes average infant mortality rate, z_{it} denotes public expenditure on health care (expressed as a proportion of state-level net domestic product),

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$\mathbf{x'}_{it}$ is a $((k-1) \times 1)$ vector of controls that include the female literacy rate, per capita net state domestic product (expressed in 2004–05 prices), the sex ratio (measured by the number of female for every 1000 males) and urbanization rate, μ_i denotes a state-level fixed effect, δ_t is a year fixed effect, and $\sum_r \eta_r t$ are regional time trends.

The set of controls correspond to important determinants of the IMR that have been highlighted by existing studies. Most studies find female literacy rates to be important because standard public health interventions that can reduce the IMR is enhanced by the ability of the mother to read and follow basic instructions. Per capita real income is an important determinant because it acts as a proxy for the level of private expenditure that can complement public expenditure in improving health status. The sex ratio (females per 1000 males) is a proxy for the level of patriarchal attitudes in society, with a lower sex ratio corresponding to a more onerous burden of patriarchy. Urbanization is meant to capture the relative difference in the availability of health infrastructure – like hospitals, primary health centers, doctors, nurses – between rural and urban areas. Finally, state fixed effects control for unobserved state-level factors (like cultural norms) that change slowly over time, and time fixed effects control for factors that impact all states over time (like technological change).

The second issue relates to dealing with the possibility of bi-directional causality and, by implication, the problem of simultaniety bias.

2.1 Simultaneity Bias

To fix ideas, let us posit the bi-directional causality in terms of two structural relationships. The first is a re-written version of (1), and captures the causal effect of public health expenditure (z) on IMR (y),

$$y_{it} = z_{it}\alpha_1 + \mathbf{u'}_{it}\boldsymbol{\beta_1} + \varepsilon_{1,it}, \tag{2}$$

and the second captures the causal relationship running the opposite direction from IMR (y) to public health expenditure (z)

$$z_{it} = y_{it}\alpha_2 + \mathbf{v}'_{it}\boldsymbol{\beta_2} + \varepsilon_{2,it}, \tag{3}$$

where $i = 1, 2, \ldots n$ indexes states, $t = 1, 2, \ldots T$ indexes years, $\mathbf{u}'_{it} = (1, u_{1,it}, u_{2,it}, \ldots, u_{k-1,it},)$ and $\mathbf{v}'_{it} = (1, v_{1,it}, v_{2,it}, \ldots, v_{k-1,it},)$ are k-vectors of strictly exogenous variables (including a constant), $\boldsymbol{\beta_1}, \boldsymbol{\beta_2}$ are vectors of parameters, and $\varepsilon_{1,it}, \varepsilon_{2,it}$ are structural errors with

$$\begin{pmatrix} \varepsilon_{1,it} \\ \varepsilon_{2,it} \end{pmatrix} \sim \begin{pmatrix} \sigma_1^2 & 0 \\ 0 & \sigma_2^2 \end{pmatrix}.$$

Basic economic theory and intuition suggests that the partial effect of public health expenditure on IMR will be negative so that $\alpha_1 < 0$; similarly, the partial effect of IMR on public health expenditure is likely to be positive, so that $\alpha_2 > 0$. These will be crucial for our subsequent analysis and so we re-write them as

Assumption 1. *For the models in (2) and (3), the key parameters have $\alpha_1 < 0, \alpha_2 > 0$.*

We can re-write the structural relationships given by (2) and (3) as

$$\begin{bmatrix} 1 & -\alpha_1 \\ -\alpha_2 & 1 \end{bmatrix} \begin{bmatrix} y_{it} \\ z_{it} \end{bmatrix} = \begin{bmatrix} \mathbf{u}'_{it}\boldsymbol{\beta_1} + \varepsilon_{1,it} \\ \mathbf{v}'_{it}\boldsymbol{\beta_2} + \varepsilon_{2,it} \end{bmatrix}.$$

As long as the matrix on the left is non-singular, which is guaranteed by Assumption 1 $(\alpha_1\alpha_2 \neq 1)$, we can get the following reduced form equations

$$\begin{bmatrix} y_{it} \\ z_{it} \end{bmatrix} = \begin{bmatrix} 1 & -\alpha_1 \\ -\alpha_2 & 1 \end{bmatrix}^{-1} \begin{bmatrix} \mathbf{u}'_{it}\boldsymbol{\beta_1} + \varepsilon_{1,it} \\ \mathbf{v}'_{it}\boldsymbol{\beta_2} + \varepsilon_{2,it} \end{bmatrix}.$$

This gives us the following reduced form equation for public health expenditure,

$$z_{it} = \left(\frac{\alpha_2}{1 - \alpha_1 \alpha_2} \right) \mathbf{u'}_{it} \beta_\mathbf{1} + \left(\frac{1}{1 - \alpha_1 \alpha_2} \right) \mathbf{v'}_{it} \beta_\mathbf{2} + \left(\frac{\alpha_2}{1 - \alpha_1 \alpha_2} \right) \varepsilon_{1,it} + \left(\frac{1}{1 - \alpha_1 \alpha_2} \right) \varepsilon_{2,it},$$

which shows that

$$E(z_{it} \varepsilon_{1,it}) = \left(\frac{\alpha_2}{1 - \alpha_1 \alpha_2} \right) \sigma_1^2 \tag{4}$$

because $\mathbf{u'}_{it}$ and $\mathbf{v'}_{it}$ are vectors of strictly exogenous variables, $\varepsilon_{1,it}$ and $\varepsilon_{2,it}$ are uncorrelated (because they are zero mean, structural errors), and we use the fact that $E(\varepsilon_{1,it}^2) = \sigma_1^2$.

Suppose a researcher did not pay attention to the possible bi-directional causality and estimated the parameters in (2) by OLS. This would give her biased and inconsistent parameter estimates because of (4). We can go further and find the sign of the asymptotic bias in the OLS estimator of α_1.

To proceed, let us replace the full set of exogenous variables in (2) with a constant and a linear combination of the non-constant exogenous regressors as

$$\mathbf{u'}_{it} \boldsymbol{\beta} = \beta_0 + \beta_1 x_{1,it} \tag{5}$$

where

$$x_{1,it} = u_{1,it} + \frac{\beta_2}{\beta_1} u_{2,it} + \cdots + \frac{\beta_{k-1}}{\beta_1} u_{k-1,it}$$

which can always be done without loss of generality by choosing the exogenous regressor with a non-zero coefficient as u_1. Using this, we can re-write (2) as

$$y = \mathbf{W} \boldsymbol{\beta} + \boldsymbol{\varepsilon_1} \tag{6}$$

where $\mathbf{W} = (\mathbf{z} \quad 1 \quad \mathbf{x_1})$, with $\mathbf{z}$ a $(N \times 1)$ vector (where $N = n \times T$) and $\mathbf{x_1}$ a $(N \times 1)$ vector, and $\boldsymbol{\beta'} = (\alpha_1 \quad \beta_0 \quad \beta_1)$, with α_1 the scalar parameter of interest (the partial effect of public health expenditure on IMR). Our main result about the asymptotic bias in the OLS estimator of α_1 is given as

Proposition 1. *Let $\hat{\alpha}_1$ denote the OLS estimator of α_1 in the model in (2). Let $V(z) > 0$ denote the variance of z and r_{z,x_1} denote the correlation coefficient between z and x_1. Then, the asymptotic bias is given by*

$$plim_{N \to \infty} \hat{\alpha}_1 - \alpha_1 = \frac{1}{V(z)\left\{1 - r_{z,x_1}^2\right\}} \left(\frac{\alpha_2}{1 - \alpha_1 \alpha_2}\right) \sigma_1^2 \geq 0.$$

Proposition 1 has an important implication.[1] Since the expected sign of α_1 is negative, a positive bias might lead to an estimate of α_1 that is not distinguishable from zero. To the extent that researchers did not address the simultaneity bias adequately, this would explain why many existing studies have reported lack of significant effect of public health expenditure on the IMR.

2.2 Identification through Instrumental Variables

To deal with the possible problem of endogeneity of public health expenditure and the resulting simultaneity bias in (1), we will use an instrumental variables estimation strategy. We will use two different types of instruments for public expenditure on health care: fiscal variables, and political variables.

2.2.1 Fiscal Instruments

We use two fiscal variables as instruments for public expenditure on health care: a state's own tax revenue, and a state's own non-tax revenue. In India, total revenue of a state

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[1]The proof of Proposition 1 is given in the Appendix.

is the sum of tax and non-tax revenue (in the main, the latter are user fees for various services offered by the government). The tax revenue, in turn, is the sum of *own* tax revenue (tax revenue collected by the state government) and tax revenue provided by the Central government.[2] Similarly, the non-tax revenue is the sum of *own* non-tax revenue and grants from the Central government. Thus, the sum of a state's *own* tax and non-tax revenue can be used to capture the "fiscal space" of a state. The larger the tax and non-tax revenue a state can collect, the easier will it be for the state to finance public expenditure on health care.[3]

2.2.2 Political Instrument

The political variable that we use as an instrument is an index of the effective number of parties in the government. For state level assembly election years, the index of the effective number of parties in any state government is computed as

$$N = \frac{1}{\sum_{i=1}^{n} p_i^2}$$

where N is the effective number of parties in a state government, $i = 1, 2, \ldots, n$ indexes parties in the state government, and p_i is the share of party i in the government. The value of the index remains unchanged until the next election year, when a new government is formed and a new configuration of parties emerge as the governing coalition. N measures the amount of "hyper-fractionalization" of political power in the state government, a process that is accentuated by the growth to prominence of coalition governments over the last two

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[2]In India's federal structure, tax collection is divided between the Central and State governments. The Central Government collects direct taxes like income, corporation & personal, dividend and wealth tax, and indirect taxes like central excise, customs, and service tax. On the other hand, state governments collect the value added tax, excise on alcohol, luxury tax, electricity duty, entertainment tax, stamp duty, property tax and professional tax.

[3]Heller (2006) defines fiscal space as "the capacity of government to provide additional budgetary resources for a desired purpose without any prejudice to the sustainability of its financial position."

decades. If a single party forms a government, the value of N is unity, and as the number of parties increase, the value of N increases.

The effective number of parties in power can have contradictory effects on public health expenditure. On the one hand, higher fractionalization can reflect higher political competition and lead to higher expenditure by governments on health care. For instance, higher competition among political parties might mean that parties which increase public expenditure on education, healthcare, nutrition, etc., increase their chances of getting re-elected. Thus, higher fractionalization might be associated with higher public expenditure on health care.

On the other hand, it might also lead to higher rent seeking behaviour, and militate against expenditures that are in the long term benefit of the general population. For instance, coalition governments with a higher number of parties in the ruling coalition make the coalition unstable and increases the probability of dissolution of the government before the end of the full 5 year term. This increases the incentive for each party in the coalition to make expenditure that cater to their narrow support bases, rather than undertake expenditure that would have long term benefits for the population. Thus, depending on the strength of these opposite effects, fractionalization might have a positive or negative effect on public health expenditure.

We will discuss possible concerns about the instrumental variables when we discuss robustness checks of our main results, but before that we would like to introduce the data set used for the analysis in this paper.

3 Data: Sources and Variables

We use an unbalanced panel data set covering the period between 1983–84 and 2011–12 for 31 major Indian states and union territories: Andhra Pradesh, Arunachal Pradesh, As-

sam, Bihar, Chandigarh, Dadra & Nagar Haveli, Delhi, Goa, Damand & Diu, Gujarat, Jammu & Kashmir, Karnataka, Kerala, Lakswadeep, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Mizoram, Nagaland, Orissa, Puducherry, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh, and West Bengal.[4] Our primary interest in this paper is to analyze the impact of public expenditure on health care on the infant mortality rate. So, we begin by discussing our data sources for these variables.

3.1   Infant Mortality Rate

The outcome variable of interest in our analysis is the state-level infant mortality rate (IMR). The IMR is the probability of death faced by infants of age one year or lower and is measured as the number of deaths of infants under the age of one year per 1000 live births. The main source of data on the IMR, and other vital health statistics, in India is the Sample Registration System.[5] The Sample Registration System (SRS) is an annual demographic survey covering 1.2 million households - one of the largest, continuous demographic surveys in the world - conducted since 1970 by the Registrar General of India and provides reliable data on fertility and mortality indicators for the country and larger states (Mahapatra, 2010). We have downloaded state-level IMR data compiled from annual reports of the SRS by the Government of India and made available through the Open Government Data Platform India.[6]

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[4]In the early 2000s, the states of Jharkhand, Chhattisgarh and Uttarakhand were carved out of Bihar, Madhya Pradesh and Uttar Pradesh, respectively. For comparability, we keep them as part of the larger states all through.

[5]There are 4 main sources of vital statistics in India: (a) Sample Registration System (SRS), (b) Civil Registration System (CRS), (c) indirect estimates from the decennial Census, and (d) indirect estimates from the National Family Health Surveys (NFHS). Among these 4 sources, the SRS remains the most important source for reliable data at an annual frequency (Mahapatra, 2010).

[6]See https://data.gov.in/

3.2 Public Health Expenditure

In India, public expenditure on health care is undertaken at all three levels of government: central (federal), state, and local. The central government undertakes expenditures in two forms: direct expenditure, and grants-in aid to state governments. State governments incur expenditures out of the grants-in aid and other resources, e.g., tax revenues, available to them. Some state-level expenditure also takes the form of transfers to local government bodies. Local government bodies, in turn, incur expenditures out of these transfers and from other resources that they have. The total of all the expenditures incurred at the three tiers of government provides an estimate of public expenditure on health care in India.

In this paper, we are interested in analyzing the effect of state-level public health expenditure on state-level IMR. Hence, the data for our research project relates only to state-level expenditure on health care. This includes expenditures incurred by state governments from Central grants-in aid and from other resources available to the state government (e.g., through taxation, etc.). Thus, our data set does not include direct central government expenditure and local-level expenditure funded by resources other than state-level transfers.[7] The state-level public health expenditure data comes from the Economic and Political Weekly Research Foundation's *India Time Series* data base, which, in turn, uses data from the *Handbook of Statistics on State Government Finances* published by the *Reserve Bank of India* in 2010.[8]

According to data compiled by Gupta and Chowdhury (2014), the bulk of health care spending is contributed by states. In 2010–11, about 64% of total public health care spending came from expenditure by states, about 31% came from expenditure by the central government (direct expenditure and grants-in aid to states), and the rest was accounted for by expenditure of local government bodies. If we count the grants-in aid as part of state-level

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[7]According to NHAC (2009), the local-level expenditure funded by resources other than state-level transfers is a negligible part of total expenditure.

[8]For details see `http://www.epwrf.res.in/home.aspx`

expenditure, then the contributions of the central government varies between 20 and 30 percent of total public health care expenditure (Choudhury and Nath, 2012). Thus, the figures for state-level public health expenditure used in this paper covers between 70 and 80 percent of total public expenditure on health care in India.

To understand the place of health care expenditure in the budgets of state governments, it will be useful to have an idea of the composition of total expenditure. From budget documents, we can see that total expenditure of a state government can be broken up into expenditures on three types of services: (a) social services, (b) economic services, and (c) general services. Expenditures on (a) and (b) are together called "development expenditure", and expenditure on (c) is called "non-development expenditure".

Each of the first two expenditure categories can be further broken down into revenue expenditure (current expenditure including interest payments) and capital expenditure (capital outlays like construction of roads, buildings, irrigation projects). Revenue expenditures are financed through current income, the main source of which are taxes & duties. Capital expenditures are not financed from current income, but instead rely on loans, surplus revenue from previous years, etc.

The category that is relevant for this paper is "social services" (category (a) above). Expenditure on social services is often referred to as "social sector expenditure" and includes the following sub-categories: education, sports, arts and culture; medical and public health; family welfare; water supply and sanitation; housing; urban development; welfare of SCs, STs, and OBCs; labour and labour welfare; government servants; social security & welfare; nutrition (expenditure relating to the nutrition program under child welfare); relief on account of natural calamities; others. Thus, public health expenditure falls under "social services" and we measure it in the most expansive manner by including expenditure on medical and public health, family welfare and nutrition.

Expenditure on "medical and public health" can be broken down, in turn, into the

following sub-categories, with the figures in parenthesis referring to percentages in 2012–13: general (4.52%); public health (12.43%); medical education, training & research (13.2%); rural health services - other systems of medicine (3.03%); rural health services - allopathy (22.3%); urban health services - allopathy (39.26%); urban health services - other systems of medicine (5.26%) (NHAC, 2012).

In a similar manner, the components of expenditure on "family welfare" are: rural family welfare services (45.5%); urban family welfare services (3.28%); maternity & child health (11.46%); assistance to local bodies (10.35%); training (6.84%); direction and administration (5.49%). As before, the figures in parenthesis refer to the percentage in 2012–13 (NHAC, 2012).

Expenditure on "nutrition" is mainly incurred on account of the Integrated Child Development Scheme (ICDS). This program includes supplementary nutrition, immunization, health check-up, referral services, pre-school non-formal education, nutrition & health education. The ICDS is a centrally-sponsored scheme implemented by State governments.[9]

3.3 Other Covariates

Our measure of per capita real income at the state level is per capita net state domestic product (NSDP). We have taken data on per capita NSDP (at 2004-05 prices) from the *Handbook of Statistics on Indian Economy*, an annual publication of the Reserve Bank of India. We use the sex ratio (females per 1000 males) as a proxy for the strength of patriarchal attitudes; data on state-level sex ratios comes from various issues of the *Economic Survey*.[10] A key determinant of IMR (and other health indicators) is women's education. In this paper, we measure women's education by the (adult) female literacy rate, which is defined as the proportion of women aged 15 years and more who can read, write and carry out simple

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[9]For details, see http://wcd.nic.in/icds.htm
[10]For details, see http://indiabudget.nic.in/survey.asp

arithmetic calculations. We downloaded data on state-level female literacy from the Open Government Data Platform India. Data on the state-level own tax and non-tax revenue is taken from IndiaStat.[11] The index of effective number of parties and the index of the ideology of a state government is constructed from state-level election data available from the website of the Election Commission of India.[12]

3.4   Summary Statistics

Table 1 provides summary statistics - mean and standard deviation - for the variables used for the analysis in this paper. Summary statistics are reported roughly every 5 years roughly spanning our sample period from 1983–1984 to 2011–2012.

The average IMR has declined secularly over time, falling from 91.18 in 1985–86 to 36.35 in 2010–11. The average public expenditure on health care (which includes medical & public health, family welfare, and nutrition) as a share of state-level GDP increased over the decade of the 1980s, but has more or less declined since then. It started rising again from the mid-2000s.

Female literacy and per capita real NSDP have both increased secularly over the two and a half decade period from 1983–84 to 2011–12. The (adult) female literacy has nearly doubled over this period, increasing from 42.12% in 1985–86 to 70.96 in 2010–11. Average per capita real NSDP has increased by about 3.2 times over the sample period (from 13227 rupees in 1983–84 to 42617 rupees in 2011–12, both expressed in 12004–05 rupees), growing at an annual compound rate of 4 per cent per annum.

The average sex ratio follows a U-shaped pattern: it worsened from 922.12 in 1985–86 to 917.20 in 2000–01, and then improved to 925.83 in 2011–12. Urbanization has increased steadily from 1983–84 onwards, other than a small dip since the mid-2000s. Average values

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[11]For details, see http://www.indiastat.com/default.aspx
[12]For details, see http://eci.nic.in/eci/eci.html

of both own tax revenue and own non-tax revenue (measured as share of state-level GDP) has been stagnant over the period of analysis. The effective number of parties has been increasing over time, with a small decline since the mid-2000s.

4   Empirical Results

4.1   Main Results

The main results of our empirical analysis are summarized in Table 2. The dependent variable in the model is the infant mortality rate; the independent variables are public expenditure on health care (as a share of state-level GDP), log of per capita net state domestic product (at constant prices), the female literacy rate, the sex ratio of the population, the urbanization rate, and state and year fixed effects. Our primary interest is in the partial effect of the public expenditure on health care on the IMR.

In the first column of the table, we report OLS estimates of the bivariate regression of IMR on the public expenditure on health care with state and year fixed effects. The estimate of the coefficient on public expenditure on health care is -1.75 but it is imprecisely estimated. In the next column, we report 2SLS estimates for the same model (with own tax revenue, own non-tax revenue and the effective number of parties in government as instrumental variables for public expenditure on health care). The coefficient on public expenditure on health care becomes -7.63 and is significant at the 5 percent level. Given that the OLS estimate is likely to be biased upwards (according to Proposition 1), this is expected.

As we move from column 2 through 6 in Table 2, we keep adding controls – log of of per capita NSDP, the female literacy rate, the sex ratio, and the rate of urbanization. The coefficient on public expenditure on health care does not change much and remains statistically significant at standard levels of significance.

Our preferred specification is the model in column 6 in Table 2, which includes all the

controls, and state and year fixed effects. We will use the estimates in this model for interpretation. The coefficient of -7.86 on public expenditure on health care means that an increase in public expenditure on health care by 1 percent of state-level GDP would reduce the infant mortality rate by about 8 deaths (of infants) per 1000 live births. This is an economically meaningful and statistically significant effect and suggests that increasing public expenditure on health care would have a large effect on the reduction of IMR in India.

In Table 2, we also see that the female literacy rate and urbanization emerge as significant and strong determinants of IMR. An increase in the female literacy rate by 10 percentage points would reduce the IMR by 9.5, and an increase in the share of urban population by 10 percentage points would reduce the IMR by 3.3. These results are in line with existing studies and suggests two things. First, increasing female literacy must figure as one of the important elements of any strategy to improve the health status of the population in India. Second, urbanization improves the IMR, possibly through better access to basic health care facilities that are lacking in remote and rural areas.

4.2   Reduced Form and First Stage Regression

In Table 3, we report estimates from the reduced form model – where the dependent variable (IMR) is regressed on the excluded instruments and the included regressors – and the first stage model – where the endogenous regressor (public health expenditure) is regressed on the excluded instruments and the included regressors. The parameter estimates for the reduced form model are meaningful in magnitude and sign. The three instruments – own tax revenue, own non-tax revenue and political competition – have negative coefficients in the reduced form model and positive coefficients in the first stage regression (though some of these effects are imprecisely estimated). This implies that that increases in own revenue of states – both tax and non-tax – reduces the IMR through increasing fiscal space. On the other hand, political competition reduces IMR by increasing public expenditure on health care. This

suggests that the positive effect of political competition outweighs its negative (rent seeking) effect.

4.3   Robustness Checks

The identification of the causal effect of public expenditure on the infant mortality rate rests on the validity of our instruments. To assess the validity of our instruments, we conduct standard tests and also carry out several robustness checks. The standard tests relate to the strength of the first stage regression, which we capture through the Kleibergen-Papp (Wald) F-stat, and the overidentification test, which we capture through the J-statistic. Both these statistics are reported for all specifications estimated by 2SLS in Table 2. All specifications have F-stats that are significantly larger than 10, the rule of thumb value for ruling out weak instrument problems with a single endogenous regressor. The p-values associated with the over-identification tests are generally larger than 0.01, which suggests that the instruments pass the exogeneity test.

Model 7 in Table 2 reports results of estimating the model by LIML. It is well-known that LIML is less precisely estimated but is also less biased. Thus, comparing the overidentified model 6 in Table 2 (that has been estimated with 2SLS) and model 7 in Table 2 (that has been estimated with LIML) is useful. We see that the coefficient on public health expenditure does not change a lot, going from -7.86 to -10.07. Moreover, the coefficients on female literacy and urbanization also remains stable. This increases the confidence in the overidentified 2SLS results of the basic model (column 6 in Table 2).

While the KP (Wald) F-stat and the J-stat are good for ensuring validity of instruments, we discuss some additional concerns that might arise about the crucial exogeneity assumption for the instruments. Recall that the exoegneity of the instrumental variables means that they have an impact on IMR only through their impact on public expenditure on health care. Thus, we need to be reasonably sure that there are no other channels through which the

instrumental variables might have an impact on IMR.

One immediate concern might be that rainfall shocks could operate as an omitted variable. For instance, an adverse rainfall shock might reduce agricultural output and incomes, and thereby lead to higher mortality of infants, and also lead to lower state-level tax revenue. This is not a problem for our identification strategy because agricultural income is not taxed in India. A second concern would be that state-level negative demand shocks would reduce state-level GDP, leading to higher mortality of children and also lower state-level tax revenue. We block off this possible channel by explicitly controlling for state-level real GDP in Table 2.

In Table 4, we report additional results that provide robustness checks; column 1 reproduces the results for our preferred specification for comparison. In columns 2 through 6, we make one change at a time with respect to the preferred specification to compare the effect of that change on our results. First, it is possible for own tax and nontax revenue to be correlated with other items of state level expenditure - like food subsidy, transfer to the poor, sanitation & drinking water - that are determinants of state level IMR. We address this possible concern in two ways. First, we have defined public expenditure on health care in the broadest possible manner. It includes expenditure on medical & public health, family welfare, and nutrition. Second, in column 2 in Table 4, we include log aggregate state level social sector expenditure as an additional control. In column 3, we include log of total non-public health expenditure (total expenditure less public health expenditure) as an additional control. Neither of these additional controls changes our result in column 1 too much: the coefficient on public expenditure on health care changes to -7.84 and -9.10.

Second, it is possible that the ideological bent of state governments is correlated with the error. This might be driven by the fact that left parties are more likely to favour public over private expenditure on health care. Political ideology might also have an independent effect on the IMR through other non-public health spending channels like a generally more pro-people orientation of policies that improve the quality of services conditional on the

quantity of expenditure. To block this possible channel, we include an index of political ideology in column 4. To compute this index we first assign an ideology score ranging from 1 to 5 to each political party, with 1 denoting a Left ideology and 5 a Right ideology. The index of political ideology of the government is the weighted average of ideology scores of the parties in the government, with share of seats won by parties used as weights. Inclusion of this regressor does not change the results from column 1 too much with the coefficient on public expenditure on health care becoming −8.12.

Third, it is possible that states which offer higher services might be able to collect more user fees (and hence, more non-tax revenue). If some of these services improve state-level IMR, then one of our instrument – own non-tax revenue – would be correlated with the error term. Moreover, the effective number of parties in government might be correlated with other items of welfare expenditure by the state government. We address both these problems by including lags of public health expenditure (which capture the provision of government services) in column 5. The results are more or less unchanged, and the coefficient on public expenditure on health care increases a little to −13.14. The long run impact of public health expenditure on IMR, i.e., the sum of the coefficients on all the lags of public health expenditure, is −5.34 and statistically significantly different from zero (p-value = 0.002).

The last robustness check is to account for a possible "South India" effect. It is well known that states in South India, like Kerala and Tamil Nadu, are generally better performing in terms of human development indicators. To make sure that our results are not driven by rapid improvements in the South Indian states, we include a South India time trend (a dummy for South India interacted with a linear time trend) in column 6. Again, the results remain relatively unchanged, with the coefficient on public expenditure on health care estimated as −7.49.

5 Conclusion

In this paper, we have investigated the relationship between public expenditure on health care and the infant mortality rate using an unbalanced panel of 31 Indian states from 1983–84 to 2011–12. To investigate whether the relationship can be interpreted in a causal manner, we have focused on the possibility of bi-directional causation between public expenditure on health care and the infant mortality rate. We have shown that the simultaneity bias arising from bi-directional causation is likely to be positive. This might explain why many existing studies do not find any significant negative association between public expenditure on health care and the infant mortality rate.

In our own empirical analysis, we address the issue of simultaneous causation by using an instrumental variables strategy. We use a state's own tax revenue, a state's own non-tax revenue, and the effective number of parties in a state government as instruments for public expenditure on health care. Our estimation results show that public expenditure on health care as a share of state-level GDP is negatively associated with state-level infant mortality rates. Our baseline specification suggests that an increase in public expenditure on health care by 1 percent of GDP will reduce the infant mortality rate by 8 deaths per 1000 live births. This suggests that Indian states can reduce the IMR rapidly by increasing what is now an extremely low level of public expenditure on health care (as a share of state-level GDP).

We also find that an increase in female literacy and urbanization is associated with lower infant mortality rates. We estimate several alternative specifications as robustness checks of our main findings. Since our main results hold under different specifications and for different ways of addressing possible problems of our instruments, we are reasonably confident about the robustness of our results.

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Table 1: *Descriptive Statistics*

	1985–86	**1990–91**	**1995–96**	**2000–01**	**2005–06**	**2010–11**
IMR	91.18	58.01	58.58	49.98	41.78	36.35
	(27.15)	(28.04)	(21.95)	(22.03)	(18.11)	(13.93)
Pub Health Exp	2.04	2.84	2.19	2.19	1.74	1.85
	(1.18)	(2.07)	(1.30)	(1.54)	(1.47)	(1.62)
Female Literacy	42.12	47.51	53.40	59.64	65.36	70.96
	(17.30)	(17.43)	(15.72)	(14.07)	(12.30)	(10.76)
Log PCNSDP	9.55	9.74	9.88	10.07	10.29	10.66
	(0.43)	(0.41)	(0.43)	(0.47)	(0.50)	(0.52)
Sex Ratio	922.12	921.19	919.31	917.20	920.80	925.83
	(62.22)	(55.04)	(54.48)	(65.37)	(71.45)	(76.38)
Urbanization	0.32	0.29	0.28	0.25	0.24	0.35
	(0.25)	(0.21)	(0.17)	(0.13)	(0.14)	(0.19)
Own Tax Revenue	0.06	0.07	0.06	0.06	0.05	0.05
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Own Non-Tax Revenue	0.03	0.03	0.06	0.07	0.04	0.03
	(0.02)	(0.02)	(0.14)	(0.24)	(0.11)	(0.04)
Parties in Govt	2.13	2.37	2.36	2.60	2.94	2.60
	(1.06)	(0.89)	(0.77)	(1.11)	(1.49)	(0.88)
Observations	31	31	31	32	31	31

This table reports mean and standard deviations (in parentheses below the mean) for key variables for a selected number of years. IMR = infant mortality rate (deaths of infants below the age of 1 year per 1000 live births); PHE = public health expenditure, i.e., expenditure on medical & public health, water & sanitation, and nutrition, measured as a percentage of the state-level GDP; Female Literacy = proportion of women aged 15 years and more who can read, write and carry out simple arithmetic calculations; PCNSDP = per capita net state domestic product (at $2004-05$ prices); Sex Ratio = females per 1000 males; Urbanization = proportion of population living in urban areas; Own tax revenue = total tax revenue less the tax revenue transferred by the Central government (measured as % of state GDP); Own non-tax revenue = total non-tax revenue less the amount transferred from the Central Government (measured as % of state GDP); Parties in the government = index of the effective number of political parties in the state government.

Table 2: *Basic Regression Results*

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Pub Health Exp	-1.75	-7.63*	-8.93**	-7.23**	-7.13**	-7.86**	-10.07**
	(0.198)	(0.079)	(0.029)	(0.031)	(0.028)	(0.017)	(0.028)
Log PCNSDP			-0.64	-0.87	-0.97	-0.69	-1.06
			(0.841)	(0.771)	(0.750)	(0.813)	(0.735)
Female Literacy				-0.95***	-0.91***	-0.95***	-0.96***
				(0.000)	(0.001)	(0.000)	(0.000)
Sex Ratio					0.08	0.09	0.09
					(0.510)	(0.425)	(0.438)
Urbanization						-33.27***	-35.47***
						(0.003)	(0.002)
State Fixed Effects	Y	Y	Y	Y	Y	Y	Y
Year Effects	Y	Y	Y	Y	Y	Y	Y
KP (F-stat)		161.797	138.809	131.495	123.297	127.122	127.122
P-value (J-Stat)		0.092	0.142	0.048	0.096	0.144	0.162
N	677	548	540	532	532	532	532

The dependent variable in all regressions is the state-level infant mortality rate. Public Health Expenditure = expenditure on medical & public health, water & sanitation, and nutrition (% of state GDP); Female Literacy = proportion of women aged 15 years and more who can read, write and carry out simple arithmetic calculations; PCNSDP = per capita net state domestic product (at $2004-05$ prices); Sex Ratio = females per 1000 males; Urbanization = proportion of population living in urban areas. P-values (clustered by state) appear in parenthesis below estimates; *p<0.10, **p<0.05, ***p<0.01. Specification 1 is estimated by OLS. For all other specifications public health expenditure has been instrumented with "own" tax revenue, "own" non-tax revenue, and effective number of parties in the government. Models 1 through 6 have been estimated by 2SLS; model 7 has been estimated by LIML. The KP (F-stat) refers to the Kleibergen-Paap rk Wald statistic for weak identification; the J-stat refers to Hansen's overidentification test.

Table 3: *Reduced Form and First Stage Estimates*

	(1)	(2)
Own Tax Revenue	-46.68	8.27*
	(0.701)	(0.055)
Own Non-Tax Revenue	-14.72**	1.84***
	(0.017)	(0.000)
Parties in Govt	-1.87*	0.00
	(0.076)	(0.854)
Female Literacy	-0.85***	-0.01
	(0.002)	(0.466)
Log PCNSDP	-1.78	-0.02
	(0.435)	(0.924)
Sex Ratio	0.05	-0.00
	(0.712)	(0.773)
Urbanization	-21.59*	-0.94*
	(0.076)	(0.068)
State Fixed Effects	Y	Y
Year Fixed Effects	Y	Y
Observations	532	532

Specifications (1) and (2) refer to the reduced form and first stage regressions, respectively, for the model referred in specification (6) in Table 2. All variables as defined in Table 2. P-values (clustered by state) in parenthesis; *p<0.10, **p<0.05, ***p<0.01.

Table 4: *Regression Results: Robustness Checks*

	(1)	(2)	(3)	(4)	(5)	(6)
Pub Health Exp	-7.86**	-7.84**	-9.10*	-8.12**	-13.14***	-7.49**
	(0.017)	(0.017)	(0.085)	(0.015)	(0.006)	(0.015)
Female Literacy	-0.95***	-0.96***	-0.84***	-0.96***	-0.90***	-0.78***
	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.004)
Log PCNSDP	-0.69	-0.76	4.26	-0.42	-0.35	-2.25
	(0.813)	(0.803)	(0.673)	(0.886)	(0.875)	(0.393)
Sex Ratio	0.09	0.09	0.09	0.06	0.11	0.05
	(0.425)	(0.432)	(0.483)	(0.599)	(0.264)	(0.698)
Urbanization	-33.27***	-33.78***	-40.02***	-32.27***	-29.34**	-39.16***
	(0.003)	(0.002)	(0.000)	(0.004)	(0.016)	(0.000)
State Fixed Effects	Y	Y	Y	Y	Y	Y
Year Effects	Y	Y	Y	Y	Y	Y
Log SPHE	N	Y	N	N	N	N
Log NPHE	N	N	Y	N	N	N
Index of Ideology of Govt.	N	N	N	Y	N	N
Pub Health Exp (2 Lags)	N	N	N	N	Y	N
South India Time Trend	N	N	N	N	N	Y
KP (F-stat)	127.122	126.702	10.946	121.766	33.121	145.519
P-value (J-Stat)	0.144	0.149	0.119	0.188	0.121	0.172
N	532	532	507	532	497	532

The dependent variable in all regressions is the state-level infant mortality rate. Public Health Expenditure = expenditure on medical & public health, water & sanitation, and nutrition (% of state GDP); Female Literacy = proportion of women aged 15 years and more who can read, write and carry out simple arithmetic calculations; PCNSDP = per capita net state domestic product (at $2004-05$ prices); Sex Ratio = females per 1000 males; Urbanization = proportion of population living in urban areas; SPHE = total state-level social sector expenditure less public health expenditure; NPHE = total state expenditure less public health expenditure. P-values (clustered by state) appear in parenthesis below estimates; *$p<0.10$, **$p<0.05$, ***$p<0.01$. For all specifications, public health expenditure is instrumented with "own" tax revenue, "own" non-tax revenue, and effective number of parties in the government. The models have been estimated by 2SLS.

Appendix

Here we give a proof of Proposition 1.

Proof. Denoting the OLS estimator of $\boldsymbol{\beta}$ in (6) as $\hat{\boldsymbol{\beta}}$, we have

$$\hat{\boldsymbol{\beta}} - \boldsymbol{\beta} = \left(\frac{\mathbf{W}'\mathbf{W}}{N}\right)^{-1}\left(\frac{\mathbf{W}'\boldsymbol{\varepsilon_1}}{N}\right)$$

We know that

$$\frac{\mathbf{W}'\mathbf{W}}{N} = \frac{1}{N}\begin{pmatrix} \sum_i z_i^2 & \sum_i z_i & \sum_i z_i x_{1i} \\ \sum_i z_i & \sum_i 1 & \sum_i x_{1i} \\ \sum_i z_i x_{1i} & \sum_i x_{1i} & \sum_i x_{1i}^2 \end{pmatrix}$$

so that, under standard regularity conditions,

$$\mathrm{plim}_{N\to\infty}\frac{\mathbf{W}'\mathbf{W}}{N} = \mathbf{A}^{-1}, \text{ where } \mathbf{A} = \begin{pmatrix} E(z^2) & E(z) & E(zx_1) \\ E(z) & 1 & E(x_1) \\ E(zx_1) & E(x_1) & E(x_1^2) \end{pmatrix}.$$

On the other hand, we have

$$\mathrm{plim}_{N\to\infty}\frac{\mathbf{W}'\boldsymbol{\varepsilon_1}}{N} = \begin{pmatrix} \mathrm{plim}_{N\to\infty}\frac{\mathbf{z}'\boldsymbol{\varepsilon_1}}{N} \\ \mathrm{plim}_{N\to\infty}\frac{\mathbf{X}'\boldsymbol{\varepsilon_1}}{N} \end{pmatrix} = \begin{pmatrix} E(z\varepsilon_1) \\ \mathbf{0}_{(2\times1)} \end{pmatrix} = \begin{pmatrix} \left(\frac{\alpha_2}{1-\alpha_1\alpha_2}\right)\sigma_1^2 \\ \mathbf{0}_{(2\times1)} \end{pmatrix}$$

where we have used the expression for $E(z\varepsilon_1)$ from (4). Hence

$$\mathrm{plim}_{N\to\infty}\hat{\boldsymbol{\beta}} - \boldsymbol{\beta} = \begin{pmatrix} E(z^2) & E(z) & E(zx_1) \\ E(z) & 1 & E(x_1) \\ E(zx_1) & E(x_1) & E(x_1^2) \end{pmatrix}^{-1}\begin{bmatrix} \left(\frac{\alpha_2}{1-\alpha_1\alpha_2}\right)\sigma_1^2 \\ 0 \\ 0 \end{bmatrix}.$$

Letting a_{11} denote the $(1,1)$ element of the matrix $\mathbf{A}^{-1}$, we can then see that the asymptotic bias in the OLS estimate for α_1 (the partial effect of public health expenditure on IMR) is given by

$$\text{plim}_{N\to\infty}\hat{\alpha}_1 - \alpha_1 = a_{11}\left(\frac{\alpha_2}{1-\alpha_1\alpha_2}\right)\sigma_1^2 \tag{7}$$

To determine the expression for a_{11}, let $det(\mathbf{A})$ denote the determinant of $\mathbf{A}$. Then

$$a_{11} = \frac{V(x_1)}{det(\mathbf{A})}. \tag{8}$$

The determinant of $\mathbf{A}$ can be written as

$$\begin{aligned}
det(\mathbf{A}) =& E(z^2)\left\{E(x_1^2) - [E(x_1)]^2\right\} - E(z)\left\{E(z)E(x_1^2) - E(x_1)E(zx_1)\right\} \\
& + E(zx_1)\left\{E(z)E(x_1) - E(zx_1)\right\} \\
=& V(z)V(x_1) - \left\{E(zx_1) - E(z)E(x_1)\right\}^2 \\
=& V(z)V(x_1)\left\{1 - \left[\frac{E(zx_1) - E(z)E(x_1)}{\sqrt{V(z)V(x_1)}}\right]^2\right\} \\
=& V(z)V(x_1)\left\{1 - r_{z,x_1}^2\right\}
\end{aligned}$$

where r_{z,x_1} is the correlation coefficient between z and x_1. Plugging this in (8), we get

$$a_{11} = \frac{1}{V(z)\left\{1 - r_{z,x_1}^2\right\}}.$$

Now, plugging this expression in (7), we get

$$\text{plim}_{N\to\infty}\hat{\alpha}_1 - \alpha_1 = \frac{1}{V(z)\left\{1 - r_{z,x_1}^2\right\}}\left(\frac{\alpha_2}{1-\alpha_1\alpha_2}\right)\sigma_1^2 \geq 0 \tag{9}$$

where the inequality arises because $\alpha_1 < 0, \alpha_2 > 0$, so that $1 - \alpha_1 \alpha_2 > 0$, and $\sigma_1^2 > 0$, and $|r_{z,x_1}| \le 1$. $\qquad \square$