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The Unintended Consequences of Infrastructure Development

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Abstract

I investigate the social costs imposed by poor implementation of public infrastructure. Focusing on the period from 2005 to 2015 in Peru, when the government embarked on a nationwide initiative to expand sewerage systems, I leverage quasi-random variation in initiation of the implementation phase. By combining several sources of administrative data, I find that infrastructure development increased infant and under-5 mortality. These effects are driven by health and safety hazards associated with construction work, leading to increased deaths from accidents and waterborne diseases. The severity of these effects is more pronounced in areas where construction activity was more intense. (JEL: H54, I15, J18, N36, O18)

Keywords: state capacity, public expenditure, public goods, implementation, infrastructure, mortality.

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The effective provision of public goods plays a crucial role in fostering economic growth, development, and poverty reduction, as underscored by the state capacity literature (Isham and Kaufmann, 1999; Acemoglu et al., 2005; Besley and Ghatak, 2006; Besley and Persson, 2011). Economic analyses of public service delivery have largely focused on the planning and completion phases, delving into resource misallocation (Hodler and Raschky, 2014; Burgess et al., 2015) and procurement during planning (Krasnokutskaya and Seim, 2011; Lewis-Faupel et al., 2016), and the post-completion effectiveness of public infrastructure in enhancing living standards (e.g. Duflo and Pande, 2007; Dinkelman, 2011; Rud, 2012; Lipscomb et al., 2013; Donaldson, 2018; Alsan and Goldin, 2019; Asher and Novosad, 2020; Banerjee, Duflo, and Qian, 2020). However, there has been comparatively less focus on the welfare implications of the implementation phase, i.e. when public projects are initiated but not yet completed.

This paper's contribution is to provide an empirical examination (possibly the first) of the under-considered social costs imposed by poor implementation in public infrastructure projects. This study is situated in the context of nationwide implementation of sewerage infrastructure in Peru: an emerging upper-middle-income economy displaying above-worldwide-average well-being, but performing weakly in terms of institutional capacities (OECD, 2019).

Sewerage is widely regarded as the greatest technological advance in public health (British Medical Journal, 2007). Once completed and in use, water and sewerage systems have been proven to reduce early-life mortality in both advanced and low- and middle-income countries (Cutler and Miller, 2005; Galiani et al., 2005; Watson, 2006; Kesztenbaum and Rosenthal, 2017; Alsan and Goldin, 2019; Bhalotra et al., 2021). With trillions of US dollars estimated to be destined for basic infrastructure such as sewage systems (Fay et al., 2019), it becomes essential to maximize the social benefits derived from these projects.

However, the full realization of these benefits hinges on effective implementation. A recurring issue involves non-compliance with health and safety regulations during the construction phase. The media frequently report accidents at government construction sites and highlight indirect effects on public health stemming from breeding grounds for infection, resulting in child fatalities.[1]

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[1] The following headlines serve as graphic examples: (i) 'Child dies after falling in a sew-

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The Government of Peru invested over 3 billion US dollars to develop sewerage infrastructure in urban areas as part of the National Sanitation Plan over the period 2005 to 2015. The effective implementation of projects as part of this Plan was compromised by significant deficiencies, including poor adherence to health and safety guidelines, ineffective supervision, and substandard technical planning, leading to tangible hazards such as unsafe open ditches and increased health risks (World Bank, 2015; Defensoria del Pueblo, 2015; Von Hesse, 2016).

Using an event-study design, I assess the impact of the poor implementation of sewerage infrastructure on infant and under-five mortality rates –outcomes expected to improve following the completion of such projects. To this end, I create a novel link of several sources of administrative data, vital registries, census and spatial data, generating a panel encompassing 1,467 districts for the years spanning from 2005 to 2015.[2] Through budgetary reports, I identify the timing of the initiation of the implementation phase across districts – the period when sewerage projects remain incomplete within a district. The estimation strategy exploits the facts that the infrastructure roll-out pushed by the National Sanitation Plan was mostly based on engineering considerations and that there were no pre-trends in mortality rates before the start of the implementation phase.

My findings reveal an increase in mortality rates during the implementation of sewerage infrastructure in Peruvian district municipalities. Specifically, infant mortality rates rose by an average of 0.74 deaths per 1,000 infants, while under-5 mortality rates increased by 0.16 deaths

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erage ditch' in Colombia (Sanchez Flores, 2017); (ii) 'Children drown in an open ditch from sewerage project' (Serquen, 2018) and 'Mosquitoes due to abandoned sewerage project' in Peru (Malpartida Tabuchi, 2018); (iii) 'Deaths at government construction projects' in India (Jain and Matharu, 2017); (iv) 'Vietnamese boy trapped in 35-metre concrete pillar dies' in Vietnam (Reuters, 2023); (v) 'Construction sites are a "death trap"' in South Africa (Macupe, 2020); and (vi) 'Construction company fined £600K after death of seven-year-old' (UK Health and Safety Executive, 2022) and 'Schoolboy fell to his death through open manhole' (BBC News, 2023) in the United Kingdom.

[2] Districts are the lowest jurisdictional level in Peru. Peru had 1,830 districts belonging to 196 provinces and 25 regions in 2005.

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per 1,000 children under 5. These effects translate to a 5% and 4% increase in infant and under-5 mortality rates, respectively, when compared with the pre-construction average rates. A dynamic event-study specification further reveals that the effects intensified with the length of exposure, ranging between 1.00 and 3.12 additional deaths per 1,000 for infant mortality and between 0.26 and 0.77 additional deaths per 1,000 for under-5 mortality. Notably, in the fourth to seventh years after the project's initiation, the increase is equivalent to about 13% compared with average pre-construction mortality rates, and in the eighth to tenth years, it surges close to 20%. The magnitude of the estimated increases is noteworthy, especially considering that at the beginning of the study, average mortality rates stood at 1.65 per 1,000 infants due to malformations and 0.06 per 1,000 children under 5 due to cancer.

These effects on mortality rates are driven by construction-related health and safety hazards. Roughly 80% of the estimated impact can be ascribed to waterborne mortality, encompassing infectious, parasitic, and gastrointestinal diseases, as well as deaths during the perinatal period. The remaining mortality effect is ascribed to accidents and external causes, including traffic-related incidents, falls, exposure to mechanical forces, drowning, and submersion. Notably, I observe no discernible impact on mortality unrelated to construction works, namely mortality caused by congenital malformations and non-communicable diseases. This placebo test bolsters the causal interpretation of the results.

Moreover, I examine heterogeneous effects by intensity of the construction activity. Districts with greater geographic suitability for sewerage systems started more projects but also completed fewer, resulting in more intense construction activity. Leveraging this variation, I find that the effect on under-5 mortality is eight times greater in districts where infrastructure activity was more intense.

My findings serve as a cautionary message within the field of research on government effectiveness. They stress the need for stricter enforcement of health and safety regulations in public projects to prevent accidents and the spreading of disease. These results also underscore the importance of avoiding unnecessary halting and delays that expose local populations to hazards for extended periods. In line with previous literature, I find a significant decline in mortality once all infrastructure works were completed in a district. Yet, it is worth noting

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that only 13% of municipalities that started projects successfully completed all by the end of the National Sanitation Plan in 2015. Furthermore, nearly 85% of district municipalities that initiated sewerage projects stalled them for at least one year, with an average pause per project lasting approximately two-and-a-half years. Districts experiencing project halts endured the implementation phase for over double the duration. Moreover, by the last year of the study in 2015, over 40% of all initiated projects remained halted, and thus at risk of abandonment in mid-construction.

This work contributes most directly to the literature on welfare loss in public service delivery. Prior research has predominantly emphasized loss through waste in government spending, encompassing both active distortions such as corruption and passive issues stemming from poorly functioning bureaucracies (Olken, 2007; Ferraz and Finan, 2008; Bandiera et al., 2009), as well as the inefficient allocation of public resources often favoring less productive regions and areas with stronger political influence (Robinson and Torvik, 2004; Hodler and Raschky, 2014; Burgess et al., 2015). In contrast, this study focuses on a particularly tangible form of welfare loss. It underscores the social costs incurred due to non-compliance with health and safety regulations, highlighting the human toll associated with such negligence. This emphasis on government regulation aligns closely with the findings of Fisman and Wang (2015), who documented higher mortality rates in politically connected private firms capable of circumventing safety measures. My study demonstrates that the social costs of inadequately implemented safety regulations are not exclusive to the private sector but are also pervasive in the public sector.

This paper also complements the findings of Galiani et al. (2005) and Alsan and Goldin (2019), both of whom estimated reductions in child mortality following the completion and adoption of water and sewerage infrastructure, by showing that poor implementation of this infrastructure can increase child mortality before its completion. Furthermore, this study relates closely to the work of Cesur et al. (2017) and Mettetal (2019), who have demonstrated that child mortality can rise because of environmental hazards associated with completed and operational infrastructure. In contrast to these studies, my focus is on the often-overlooked implementation phase of these projects, whereas they examine the post-completion phase. By viewing project

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allocation, implementation, and completion as distinct processes, this research holds significant implications for future investigations into the delivery of public goods and services.

More broadly, this study contributes to the literature on institutions, state capacity, and economic development by providing micro-level evidence of public goods provision that aligns with theoretical propositions. This body of research has underscored the concept of complementarities across dimensions of state development and effectiveness, which collectively enable the execution of policies that yield societal benefits (Acemoglu, 2005; Besley and Persson, 2011). The key finding in this paper, namely that significant social costs can arise from poorly implemented infrastructure projects, reinforces the imperative for the development of institutional capacity, as highlighted by Ashraf et al. (2016). As remarked by Page and Pande (2018), the emergent experimental literature that evaluates micro-level interventions rarely delves into the importance of administrative, monitoring, and enforcement infrastructures in facilitating effective at-scale implementation.

I Background

1 The implementation of sewerage infrastructure

After an initial infrastructure boost in the 1990s, the 2005–15 National Sanitation Plan represented the first nationwide effort towards expanding access to sewerage systems in Peru. This initiative was driven by low connectivity.[3] As part of this plan, the Government of Peru invested approximately USD 3 billion into developing public sewers in the urban areas of almost 80% of districts. On average, roughly half of projects in each district entailed constructing brand new public sewers, as opposed to improving existing systems (30% of the latter consisted of expanding piped networks from existing systems). Appendix A provides more details about the Plan and these projects.

The National Sanitation Plan used a decentralized approach to implement sewerage infras-

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[3] In 2005, on average across districts, less than a quarter had sewerage connections, while the majority used latrines (35%, primarily pit latrines) or practiced open defecation (42%). Details in Table B5 in the appendix.

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tructure. The decentralization process started in 2005, transferring responsibility for sewerage infrastructure to local municipalities, which are the governing bodies of districts and provinces. During the decentralization process, local municipalities received substantial financial transfers from the central government, albeit without adequate development of their bureaucratic capabilities (State Comptroller, 2014). It is important to note that not all municipalities could implement sewerage projects, only those incorporated into the National System of Public Investment (SNIP), which requires (i) an annual budget above 1 million soles (approximately USD 250,000) and (ii) access to the internet.

In an average district, more than 80% of projects were developed by the local (i.e. district or province) municipality using funds it had discretion over (i.e. property taxes and royalties); see Figure A1 in the appendix. Local municipalities generally opt for direct project implementation, employing manual labor and acquiring equipment, rather than resorting to a tendering process (State Comptroller, 2014).

The implementation of public infrastructure is a two-step process. Initially, projects must secure technical and economic viability, granted by local Ministry of Economy and Finance offices, which are independent of municipal authorities. Feasibility hinges on engineering and cost considerations. For sewerage infrastructure, factors such as elevation increase costs (e.g. expensive anaerobic treatment plants are required at higher altitudes), while steeper gradients (e.g. facilitating gravity-based flow instead of requiring costly pumps) and greater water availability (e.g. requiring shorter pipe networks) lower them (Hammer, 1986; Romero Rojas, 2000; Panamerican Center of Sanitation Engineering and Environmental Sciences, 2005). More complex projects, such as those that require the installation of electric water pumps in flat areas, undergo extensive technical planning and review. Thus, projects in districts with greater geographical suitability are more likely to achieve viability.

Next, projects that have been granted viability compete for funding every year to start and continue their implementation. Lacking established criteria or guidelines, as well as transparency and accountability, the mayor and council retain a great deal of discretion over the selection process. This process follows a top-down approach and is determined by municipal capabilities, technical knowledge, and political will. Although participatory budgeting was

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introduced in 2004, Alcazar and Jaramillo (2013) report that the selection process has rarely been driven by objective assessments of citizens' needs and often entails convincing citizens to support investment plans that have already been determined by the municipality.

Uncertainty over the timing and likelihood of the implementation of sewerage works in a district makes it difficult for households to adjust their behavior prior to the start of works. Typically, citizens are not notified of the schedule for infrastructure projects, and they often remain unaware until construction sites are established in their neighborhoods, with the arrival of machinery and labor. Moreover, participatory budgeting seldom involves specifying the location of projects within the jurisdiction (Alcazar and Jaramillo, 2013).

2 Health and safety hazards

The implementation of these infrastructure projects can pose hazards to the population if health and safety measures are not properly in place. While the Peruvian Normative provides general guidelines that include adequate signaling and safe removal of harmful waste, these are not clearly determined nor respected (Defensoria del Pueblo, 2015).[4]

A report from the Ministry of Housing, Construction, and Sanitation in Peru discloses that the Normative is unclear, that the Ministry lacks capacity to supervise and enforce norms, and that agents are involved in a disorganized manner when it comes to implementing sanitation infrastructure projects (Von Hesse, 2016). The report explains how the technical planning of sanitation infrastructure projects is generally of bad quality and does not rigorously assess potential health and environmental risks.

Along similar lines, a report from the World Bank's office in Peru reveals that the Normative to implement sanitation infrastructure does not guarantee adequate technical or operational planning. The report highlights that public agents charged with supervising health and safety measures and the physical progress of projects lack capabilities, and that communities are not involved in the supervision either (World Bank, 2015).

Moreover, interviews conducted with government engineers and senior specialists from the

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[4] The main Normative is the National General Rule for Construction, Norm G 050, published in April 2010.

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World Bank's Sanitation Program in Peru brought to light the significant hazards associated with poor implementation of sewerage infrastructure. A common issue is inadequately covered ditches, which often accumulate stagnant water or transform into makeshift landfills, thereby increasing the transmission of disease. Lack of fencing and signaling, coupled with chaotic traffic diversions in otherwise calm areas where youngsters roam freely, further compounds these challenges. Additionally, the interviews underscored concerns relating to the mishandling of effluent from existing sewerage pipes and inadequate provision of alternative safe water sources in response to service interruptions during construction, both of which can contribute to the transmission of waterborne diseases.

Young children, particularly those who are just starting to crawl and walk freely outdoors, are especially vulnerable to these hazards due to their lower awareness of dangers and their less mature immune systems. Several of these hazards have garnered media attention, with a notable incident involving children drowning in a two-meter-deep pool formed in an open ditch (RPP Noticias, 2018; Malpartida Tabuchi, 2018; Serquen, 2018). Photos in the appendix (Figures A2 and A3) illustrate the lack of health and safety measures during ongoing and abandoned sewerage works.

II Data

I construct a panel dataset of 1,467 districts by building a novel link of administrative data, including infrastructure reports, vital statistics, and spatial data. District-level data in Peru are a fine-grained measurement of local activity, as an average district had only above 18,500 inhabitants by 2005, and a density of 486 inhabitants per km^2. Another advantage of this level of analysis is that districts are the jurisdictional level at which public investment strategies and portfolios of projects are set, and thus dependences between infrastructure projects in the same portfolio can be considered. Furthermore, conducting the analysis at the district level enables a clear delineation between the implementation phase, where sewerage works are still in progress, and the completion phase. Finally, this is the lowest jurisdictional level at which the outcomes are measured.

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1 Implementation

The focus of this paper is the implementation of sewerage infrastructure. To measure this, I rely on technical reports from the National Investment System of Peru (SNIP), which I match with budget reports from the Integrated System of Financial Administration (SIAF) of the Ministry of Economy and Finances. These sources provide information on budgeted investment and accrued investment in each year, which I use to determine the start (first disbursement) and end year (accrued budgeted investment of at least 90%, the level at which officials indicated that construction works are completed and only paperwork is pending in most cases) for every project in a given district.

I use information from 6,099 sewerage projects started in districts across the national territory between 2005 and 2015. Only 35% of these projects were completed by 2015 (see Table C2 in the appendix) and the number of open projects (i.e. started and not yet completed) increased over time, with an average district completing a quarter of its projects by the end of the study period.

The start of the implementation phase is set as the year in which the first project in a given district was started, and the completion is set as the year in which all sewerage projects in a given district had been completed. The implementation phase is thus the period when at least one project in the district is still unfinished. Overall, 78% of districts were treated (1,141 out of 1,467), meaning that they implemented sewerage infrastructure during the period of study, and the percentage of district municipalities starting works is similar in all years, with a peak in 2009 (17% of treated municipalities). The rate of completion of the implementation phase was low, with only 13% of treated municipalities completing all infrastructure works by the end of the study period, the highest percentage being in 2015 (see Table C1 in the appendix).

With these data, I also construct a variable capturing the number of open projects in a given district and year. From the project-level data, I extract information on whether the project was halted in each year, measured as there being no additional disbursements for the project even though it is incomplete.

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2 Outcomes

The primary outcome variables are the mortality rates for infants (aged 0 to 12 months) and children under 5 at the district level. Following Galiani et al. (2005)'s and Alsan and Goldin (2019)'s approach, I calculate these mortality rates per 1,000 individuals within their respective age groups, so that they directly pertain to the population at risk.

The number of deaths is obtained from vital records supplied by the Ministry of Health of Peru. The denominator comes from population forecasts of five-year groups built by the National Institute of Statistics and Informatics (INEI) using data from the 2005 Population Census. For the denominator of the infant mortality rate, due to incompleteness of birth registries in Peru, I use the projected population of children under 5, divided by five, under the assumption that these cohorts have similar sizes.[5]

To facilitate meaningful comparisons with other national estimates, I compute the infant and under-5 mortality rates per 1,000 births using the study data aggregated at the national level. This approach and these data yield national mortality rates that closely mirror the official national infant and under-5 mortality rates per 1,000 births, as reported in vital records submitted by the Government of Peru to the UN/WHO Inter-agency Group for Child Mortality Estimation (UN IGME). Further details on the comparison with national mortality rates computed from different sources are provided in Section B.1 of the appendix.

Mortality data are disaggregated into pathological groups following the World Health Organization's International Classification of Diseases (ICD-10), which is used to compute infant and under-5 mortality rates by cause of death per 1,000 infants or under-5 children, respectively

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[5] This approach is rooted in the fact that, between 1999 and 2006, birth registration in Peru was estimated to be around 93% (UNICEF, 2008). Furthermore, while the Ministry of Health's births data cover 59 districts fewer than the deaths data, the population projections encompass all districts under analysis. As an alternative approach for the infant mortality rate denominator, I employ the projected population of under-5s, weighted by the proportion of infants within the under-5 population in each district, based on data from the 2005 Census. The results remain robust even when using this alternative denominator, as demonstrated in Section D.1 of the appendix.

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(see Table B1 in the appendix for the ICD-10 codes linked to each cause of death). Waterborne mortality includes deaths caused by infectious diseases (about 10%) and diseases of the digestive system, malnutrition, and other nutritional deficiencies (about 3%). Following Galiani et al. (2005), this study classifies deaths during the perinatal period, which account for approximately 44% of infant mortality and 34% of under-5 mortality, within the waterborne category. This classification is due to the fact that health units categorize deaths occurring within the first 28 days of life as perinatal deaths, irrespective of their cause. Perinatal deaths correspond to roughly 80% of waterborne infant mortality, and within this category, almost 40% are attributed to infections and 50% to cardiological complications, asphyxia, and bacterial pneumonia (see Table B2 and Figure B3 in the appendix).

The other relevant category is deaths caused by accidents and external causes, including traffic-related accidents, falls, exposure to mechanical forces, and drowning (about 10% of infant mortality and 15% of under-5 mortality). In addition, I construct mortality rates for diseases of the respiratory system (about 13%) and other deaths not associated with construction-related hazards (about 30%), including deaths due to congenital malformations, neoplasms, and diseases of the blood, skin, and genitourinary, nervous, circulatory, and musculoskeletal systems. Other causes of death not classified elsewhere (about 0.1%) are also included here. See the distribution of mortality rates by cause of death each year in Figure B2 in the appendix.

3 Spatial data

Finally, I measure the suitability of a district for building sewerage systems, which serves as a proxy for the intensity of construction activity (as discussed in Section I). I use spatial data provided by the Peruvian Ministry of Environment measuring terrain and river flow for multiple cells (1×1 km^2), matched to district boundaries for 2015. I identify the area of districts, their share in different parts of the distributions of elevation and gradient, and their river density.[6]

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[6] I consider quintiles of the elevation distribution: [0, 250] meters above mean sea level (mamsl), (250, 500] mamsl, (500, 1,000] mamsl, and above 1,000 mamsl; and of the gradient distribution: [0, 0.8]%, (0.8, 4.19]%, (4.19, 13]%, and above 13%. River density is measured as length in water bodies in km per km^2. See Section F.2 in the appendix for more details.

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With these characteristics, I compute a geographical suitability index that ranges from 0 to 1, with higher levels denoting higher suitability.

See Appendix B for more details of the data sources and variables used in the analysis.

III Empirical strategy

1 Specification

To study the impact of the implementation of sewerage infrastructure on early-life mortality, I exploit plausibly exogenous variation introduced by the staggered initiation of the implementation phase across districts and time. Over three-quarters (78%) of districts implemented sewerage projects (henceforth treated) and the remainder did not implement any during the period of study (henceforth 'pure' control). The roll-out of sewerage infrastructure, pushed by the National Sanitation Plan, was staggered across districts without a systematic time or spatial pattern (see Table C1 and the map in Figure C1 in the appendix highlighting the calendar year in which each district municipality started the implementation phase). The identification assumption is that, in the absence of infrastructure development, infant and under-5 mortality rates would have followed similar trends in districts with different starting years.

The conventional static event study implemented with two-way fixed effects (TWFE) regressions is denoted by:

$$Y_{dt} = \tau^{s} D_{dt} + \phi_d + \lambda_t + \nu_{dt} \tag{1}$$

where Y_{dt} is the infant (under-5) mortality rate in district d and calendar year t, and ϕ_d and λ_t are the district and calendar year fixed effects respectively. D_{dt} is a binary indicator that takes the value 1 for a treated district after the start of the implementation phase, and 0 otherwise. Standard errors are clustered at the district level to deal with serial correlation in the panel data and because the intra-cluster correlation is highest at this level.

τ^{s} captures the static effect, which is the weighted average of all possible 2×2 difference-

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in-differences (DD) identifying the average treatment effect on the treated (ATT). The DD estimators compare timing groups (i.e. districts treated at the same time) with each other and with the pure control group: (i) treated as the treatment group vs. never-treated as the control group; (ii) treated at period k as the treatment group vs. treated at period l as the control group; and (iii) treated at period l as the treatment group vs. treated at period k as the control group (where $k < l$). The weights on the 2×2 DDs are proportional to timing group sizes and the variance of the treatment dummy in each pair, which is highest for units treated in the middle of the panel (Goodman-Bacon, 2021).

To investigate heterogeneous impacts, I expand the specification in Equation 1 to:

$$Y_{dt} = \tau_1^s D_{dt} + \tau_2^s D_{dt} \times H_d + \phi_d + \lambda_t + \mu_{dt} \tag{2}$$

where H_d is an indicator for the heterogeneity dimension measured at the district level before the implementation phase. When the heterogeneity dimension is continuous, H_d is an indicator of whether the dimension in each district is above the median of the distribution. τ_2^s captures the heterogeneous effect.

The fully dynamic specification takes the form:

$$Y_{dt} = \sum_{\substack{h=-a \\ h \neq -1}}^{b} \tau_h 1[K_{dt} = h] + \phi_d + \lambda_t + \epsilon_{dt} \tag{3}$$

where the set of $1[K_{dt} = h]$ are the lead and lag treatment indicator variables tracking the number of years $K_{dt} = t - E_d$ since the year of the start of the implementation phase for a given district, E_d. $a \geq 0$ and $b \geq 0$ are the numbers of included leads and lags of the event indicator, respectively, chosen such that all possible leads and lags in the sample are covered (fully dynamic specification). The first lead is excluded as a normalization, while the coefficients on the other leads are the measure of ‘pre-trends’.

I also present alternative specifications binning together pre- and post-event horizons, which

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constrains τ_h to be constant across four-year periods ($b \geq 7$ is constrained to three-year periods) around the event. This alternative specification also constrains the pre-trend coefficient to a nine-year period. To evaluate heterogeneous impacts with this dynamic specification, I stratify the sample of analysis by H_d for simplicity.

τ_h captures treatment effect dynamics with respect to length of exposure to the treatment, i.e. the implementation of sewerage works. For each timing group treated at period k, never-treated, not-yet-treated, and already-treated serve as the control group (Goodman-Bacon, 2021).

An advantage of the dynamic event study is that it allows visual assessment of a change in trends before the start of the infrastructure works. Absent pre-trends, the coefficients on the lags can be interpreted as the dynamic path of causal effects: at $h = 0, ..., b$ years after the start of infrastructure development.

2 Internal validity

The validity of the empirical strategy rests on quasi-exogenous factors determining the *timing* of sewerage construction initiation, primarily engineering considerations influenced by geography (as discussed in Section I). A Cox hazard model reveals that rugged terrain played a crucial role in expediting initiation of the implementation phase (see Columns 3 and 4 of Table C4 in the appendix). Project commencement was also accelerated in coastal and Andean regions and districts with initially higher population density.

Notably, initial characteristics of municipalities and households, as well as historical political competition (measured as the re-election rate between 1993 and 2005), did not significantly affect the timing of construction initiation. When looking at changes before the implementation phase, municipalities that experienced greater improvements in their budget and internet connectivity are the ones that took longer to start the implementation phase, probably because they became eligible to implement projects later on (see Table C8 in the appendix).

While initial mortality rates were lower in the treatment than in the control group (a difference that persists even when comparing early-treated with later-treated as shown in Tables C6 and C7 in the appendix) and certain municipal characteristics differed between these groups (with treated districts generally being more prosperous and having better public services by

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2005; see Columns 1 and 2 of Table C4 and Table C5 in the appendix), these differences are effectively controlled for by district fixed effects.

Moreover, changes in mortality rates before the implementation phase do not predict the timing of the start (see Table C8 in the appendix). Importantly, I fail to reject parallel trends in mortality rates once including year and district fixed effects with the pre-trend tests shown in the next section.

IV Results

1 Main results

The main finding of this paper underscores an increase in early-life mortality during the implementation of sewerage infrastructure in Peru.

FIGURE 1 ABOUT HERE

Figure 1 reports the dynamic estimates for the years since the beginning of the implementation phase, along with the pre-trend coefficients (using the first lead as the reference period) following Equation 3. Notably, the pre-trend coefficients are close to zero for both the infant (Panel A) and under-5 (Panel B) mortality rates, with joint significance p-values of 0.81. In the year the implementation phase started and each subsequent year, the infant and under-5 mortality rates increased. The point estimates show a gradual increase with each additional year of exposure to implementation.

TABLE 1 ABOUT HERE

I present a formal analysis in Table 1. Columns 1 and 2 report the estimates for infant and early-life mortality rates, respectively, utilizing specification 3 with binned periods. Several key takeaways emerge from this table. First, the pre-trend coefficient, averaging effects between periods $t-10$ and $t-2$, lacks statistical significance, with p-values of 0.82 and 0.38 for infant and under-5 mortality, respectively. Second, the estimated mortality rates post-implementation differ significantly from the pre-implementation estimates. Third, the impact on early-life mortality intensifies with the duration of exposure, evident from statistically distinct effects across 'Post' periods. In the short term, infant mortality rises by 1.00 death per 1,000 infants, while

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under-5 mortality increases by 0.26 deaths per 1,000 children. Over a four- to seven-year period following the commencement of works, infant mortality increases by 2.10 deaths and under-5 mortality by 0.57 deaths (approximately a 13% increase compared with the pre-start averages). In years 8 to 10 post-initiation, these figures further escalate to 3.12 and 0.77 deaths (roughly 20% and 18%) for infants and under-5s, respectively.

TABLE 2 ABOUT HERE

In Table 2, I present the results of the static specification, as per Equation 1. Column 1 of Panels A and B reveals that, on average, the implementation phase leads to an increase in infant and under-5 mortality rates by 0.74 and 0.16 deaths per 1,000 infants and children, respectively. These static effects correspond to average increases of 5% and 4%, respectively, compared with pre-implementation district-level infant and under-5 mortality rates. However, the static estimation hides meaningful heterogeneity in point estimates across short- and long-term effects, as elucidated by the dynamic estimation.

It is worth noting that treated districts initially had a more favorable profile, characterized by a greater share of households with sewerage connectivity and lower mortality rates (as shown Appendix C). Consequently, the rise in mortality attributed to the implementation of works caused these districts to worsen, making them more closely resemble the district municipalities that did not implement sewerage infrastructure.

2 Robustness checks

i Alternative estimator

It has been well documented that traditional two-way fixed effects (TWFE) estimators, leveraging staggered roll-out, are subject to ‘negative weights’. Goodman-Bacon (2021) shows that when already-treated units act as the control group, and treatment effects vary over time, changes in the outcome post-treatment are subtracted from the true TWFE parameter. This downward bias in the static TWFE estimation is evident in Figure D3 in the appendix. The average treated vs. never-treated estimates are positive (1.60 for infant mortality and 0.35 for under-5 mortality), as are the comparisons across different timing groups (using both already- and later-treated as control for one another), although to a lesser extent (0.63 for infant mortal-

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ity and 0.17 for under-5 mortality). However, the 2×2 difference-in-differences (DD) estimates are negative when using 'always treated' as the control group (average estimates are –1.50 for infant mortality and –0.40 for under-5 mortality). Sun and Abraham (2021) show that the 'negative weight' problem is still applicable when considering dynamic specifications such as Equation 3. This problem does not imply a failure of the design in the sense of non-parallel trends in counterfactual outcomes, but it does suggest caution when interpreting TWFE estimators.

Callaway and Sant'Anna (2021) (CS henceforth) propose a procedure that never uses already-treated units as the control group, thereby avoiding the issue described above. The core of CS's approach is the estimation of the group-time average treatment effect (GATT), i.e. the average treatment effect for timing group g at time t, and against the first lead, which directly precedes treatment. For each timing group, there are $T - gt$ ATT parameters, where T is the last date of the panel and gt is the treatment date for that group. GATT estimates are then appropriately aggregated across timing groups and periods, weighting by the number of treated units underlying each timing group, without directly restricting heterogeneity with respect to the period in which units are first treated nor the evolution of treatment effects over time. Another important advantage of CS's approach is the flexibility that it provides to construct different aggregated causal parameters – for instance, to understand the effect of length of exposure through dynamic event-study estimates, as well as how the cumulative average treatment effects evolve over calendar time.

As expected, the static effect is larger when using CS's approach: 1.79 for the infant mortality rate and 0.45 for the under-5 mortality rate, compared with 0.74 and 0.16, respectively, when using the traditional static TWFE estimator (see Panel A of Table D3 in the appendix and Table 2). The correction is not pronounced because the problematic 2× 2 DD estimates (when using 'always treated' and 'already treated' as the control group) were assigned low weights in the traditional TWFE (see Figure D3 in the appendix).[7]

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[7] The low weight of the 2×2 DD estimates when using 'always treated' is due to only 6.84% of treated districts initiating works at the beginning of the analysis, as shown in Table C1 in the appendix.

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CS estimates validate the main findings based on the traditional event-study ordinary least squares (OLS) estimation, as the point estimates are very similar and there is no evidence of pre-trends (presented in Figure 1). The negative bias in the TWFE parameter is evident in the first year of implementation, as the point estimate is higher and statistically significant when using CS's approach rather than OLS. The point estimates of the remaining lags are either the same as or slightly lower than the OLS estimates, likely due to the differences in how weights are determined (weights in OLS are proportional to timing group sizes and the variance of the treatment dummy, while in CS they only depend on timing group sizes).[8]

ii Adding controls

Tables D4 and D5 in the appendix present a variety of specifications that bolster confidence in the internal validity of the findings.

First, I address concerns regarding the influence of geographical factors on mortality trends. I control for geographic-specific trends by using the geographic suitability index interacted with year (Column 1 of each table) and for regional trends by using dummies for coast, highlands, and Amazonian jungle interacted with year (Column 2). These specifications include linear time trends for each value of the geographic suitability index and each geographical region, effectively controlling for continuous changes in the expected value of mortality within each value of the time-invariant characteristics.

Second, I address concerns related to demographic changes introducing bias in the estimates. The results remain robust when controlling for population and population density in Column 3, mitigating these concerns.

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[8] In the appendix, Table D2 shows the formal fully dynamic CS estimates presented in Figure 1, and Table D3 presents aggregate estimates with Panel A showing the average dynamic effects and Panel B the average effect per calendar year. Panel B reveals that the lethal effects were more pronounced and significant during calendar years when more projects were started and only few completed. Moreover, Figure D6 shows that the results also remain robust to using the de Chaisemartin and D'Haultfoeuille (2020) and Sun and Abraham (2021) estimators, closely related to the Callaway and Sant'Anna (2021) estimator.

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Third, I address the possibility of changes in municipal features and local government effectiveness driving the results. The point estimates and statistical significance remain robust when controlling for municipal characteristics (initial budget, internet connectivity, technical capabilities, and willingness to invest in health) and investments in other infrastructure types (health, energy, and transportation) in Columns 4 and 5.

Finally, I rule out that changes in political factors introduce bias in the estimates by controlling for political turnover in Column 6. It is worth noting that the implementation timing was not correlated with initial local political competition (see Table C4 in the appendix), and that the potential impact of municipal elections in 2006, 2010, and 2014 is captured by the year fixed effects.

3 Mortality by cause of death

I now provide evidence in support of construction-related health and safety hazards driving the adverse effects on mortality, as discussed in Section I. For this, I estimate effects on mortality rates categorized by the cause of death. It is expected for waterborne mortality to be the most responsive to sewerage construction's infection risk due to the fecal–oral and vectorial transmission pathways that characterize infectious and parasitic diseases, and because mortality during the perinatal period has long been associated with unsafe water, sanitation, and hygiene (GBD 2019 Under-5 Mortality Collaborators, 2021).

Moreover, we anticipate an increase in deaths caused by accidents if construction works posed hazards. The effect of sewerage works on mortality rates could also operate through diseases of the respiratory system because pollutants are released into the air during excavation works. In contrast, we would not expect to see impacts on conditions unrelated to health and safety hazards from construction works, such as congenital malformations and other non-communicable diseases.

FIGURE 2 ABOUT HERE

Figure 2 displays the dynamic event-study plot following Equation 3 for infant (Panel A) and under-5 (Panel B) mortality rates by the cause of death. There are no evident pre-trends for mortality rates due to waterborne diseases or accidents. Pre-implementation estimates hover

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around zero. Only the point-wise confidence interval for waterborne mortality at $t - 5$ falls below zero, but this imbalance is in the opposite direction to the main effect and it disappears when using the CS estimator (see Figures D4 and D5 in the appendix).

The observed pattern aligns with the implementation phase exposing the local population to breeding grounds for infection and construction-related hazards. The change in trends is more pronounced for waterborne mortality. The start of construction immediately increases waterborne mortality for under-5s, and the effect becomes significant for infants two years after initiation. Effects magnify with prolonged exposure. Only a year after construction starts, under-5 mortality due to accidents rises, consistent with increased exposure of mobile children to the hazards of public works. This effect gradually intensifies with each additional year of exposure, and also becomes significant for infant mortality two years after initiation. Notably, these effects remain consistent when using the alternative CS estimator, addressing the 'negative weights' issue.

There is no significant effect on mortality due to respiratory diseases (though the point-wise confidence interval at $t + 2$ for under-5 mortality is above zero). Mortality unrelated to construction hazards, including congenital malformations and non-communicable diseases, serves as a placebo outcome. No positive effects are observed here post-construction initiation, reinforcing confidence in the identification strategy.

TABLE 3 ABOUT HERE

Table 3 presents results using mortality by cause of death as the outcome, which varies by column heading: waterborne diseases in Columns 1 and 5, accidents in Columns 2 and 6, respiratory diseases in Columns 3 and 7, and malformations and non-communicable diseases in Columns 4 and 8. The first block pertains to infant mortality rates and the second to under-5 mortality rates. The pre-implementation coefficient, averaging effects between $t-10$ and $t-2$, is statistically insignificant for all causes.

The short-term effects on mortality due to waterborne diseases are 0.14 under-5 deaths per 1,000 children under 5 (7%) and on mortality due to accidents are 0.12 under-5 deaths per 1,000 children under 5 (12%) and 0.33 infant deaths per 1,000 infants (11%). Between four and seven years after construction starting, on average, under-5 mortality rates for waterborne

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diseases and accidents increased by 0.36 and 0.25 deaths per 1,000 children under 5. Infant mortality from the same causes increased by 1.26 and 0.85, respectively, during that period. These effects differ significantly from pre-implementation effects but not from those estimated eight to ten years post-start. There are no effects on mortality due to respiratory diseases nor on mortality due to other causes.

Table 2 reports results for each cause of death in Columns 2 to 5, using the 'static' specification. On average, the implementation phase increased infant mortality due to waterborne diseases by 0.52 and under-5 mortality by 0.13 deaths per 1,000 children under 5 (roughly a 7% increase compared with pre-implementation waterborne mortality rates). Effects are statistically significant at the 10% level. Furthermore, effects on mortality due to accidents are positive but marginally insignificant at conventional levels.

Interestingly, Column 5 of Table 2 presents a static negative effect on under-5 mortality due to other diseases (–0.07 with p-value 0.09). This decline is also observed in the pointwise estimates at $t + 3$, $t + 5$, and $t + 6$ in Panel B of Figure 2, though no significant effect is estimated in the binned specification outlined in Column 8 of Table 3. Despite its lack of robustness, this negative effect may suggest that the weakest children, who would have later succumbed to other causes, perished earlier due to the construction works. Notably, there is no effect on infant mortality by other causes.

These findings support the core hypothesis that the absence of health and safety measures drove the main results. Further analysis in Appendix E demonstrates that changes in sociodemographic factors do not explain the observed positive effect on mortality during the implementation phase. Specifically, the implementation phase has no effect on the denominator (the forecasted under-5 population). Additionally, using three rounds of Census data, I rule out that changes in population (both total and negatively selected) and reductions in piped water and sewerage connectivity as plausible explanations for these findings.

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4 Additional tests

i Heterogeneous effects by intensity

The results suggest that the impact on early-life mortality increases with time, possibly due to the rising intensity of open projects (as shown in Figure F1 in the appendix). If health and safety risks during construction are the primary drivers, we expect to observe a greater severity of the effects if infrastructure activity was more intense. To gain deeper insights, I estimate heterogeneous effects. Because the number of open projects is endogenously determined during the implementation phase, I use a predictor that is pre-determined: the geographic suitability of a district for implementing sewerage projects. Municipalities in geographically suitable districts started more projects, but resources were also spread thinly and overcommitted across several projects. As a result, fewer projects were completed and more were left open for longer.[9]

TABLE 4 ABOUT HERE

Table 4 presents heterogeneous effects using ‘high intensity’, which is equal to 1 when the geographic suitability index is at or above the median of the distribution, and following Equation 2. As anticipated, the effects of the implementation phase are largest and only statistically significant for districts predicted to experience a higher intensity of open projects. The heterogeneity is most evident for the under-5 mortality rate and it is driven by the effect on waterborne mortality, suggesting that intense construction activity mainly jeopardized the disease environment. A ‘horse-race’-like heterogeneous analysis, which controls for heterogeneity along other socio-demographic and municipal dimensions, increases the magnitude and precision of the estimated heterogeneity by intensity of works (see Table F4 in the appendix).[10] A robust positive effect on under-5 mortality caused by waterborne diseases is consistent with the notion of older and more mobile children being less likely to be protected from water pollution through breastfeeding and more likely to be in contact with pathogens in the environment (e.g. crawling

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[9] The geographic suitability index is indeed positively correlated with the number of open projects and with the expedited start of projects, while it is negatively correlated with project completion (see Figures F2 and F3 in the appendix).

[10] Tables F2 and F3 in the appendix present results when using the binned specification and stratifying the sample by intensity level.

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and playing outdoors).

To understand further the relationship between the number of open projects and early-life mortality, I instrument 'Open projects' with 'D_{dt}' and '$D_{dt} \times H_d$' (see Appendix F for details). The identification assumption is that no other factors that affect mortality changed along the same spatial lines right after the implementation phase started. I find that, on average, an additional open project increased mortality by 0.49 infant and 0.12 under-5 deaths per 1,000. Again, the effects are driven mainly by waterborne mortality and accidents, and there is no significant effect on other types of mortality (see Table F5 in the appendix).

ii Completion

Although the study setting and available data are suboptimal for accurately studying the impact of completion (as only 13% of treated districts completed all started works by 2015), I estimate the effect of completion using an event study for robustness. The sample is restricted to district-years after the start of the first sewerage project. As expected, there is a negative effect on mortality post-completion (see Figure G1 in the appendix). Notably, this reduction materializes in the first year of completion.[11] With the aforementioned limitations acknowledged, it is also reassuring to find a static negative effect on mortality rates, mainly driven by a drop in accidents (see Table G2 in the appendix). The estimated effects are –2.67 and –0.57 deaths per 1,000 infants and under-5s, respectively, and are significant at the 5% level. The effect on under-5 mortality is only slightly larger in magnitude than the one estimated by Galiani et al. (2005). There is no drop in waterborne mortality post-completion, suggesting lingering effects in morbidity from the construction phase that occurred in the preceding years.

A remaining concern revolves around the potential downward bias of estimates stemming from districts finalizing projects post-implementation. Nonetheless, the results remain robust when excluding from the analysis districts where the implementation phase was completed during the period of study (see Figure G2 in the appendix). This robustness test is sensible as the statistical power is not greatly affected (recall that in 13% of treated districts, the 'treatment

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[11] The negative effect is also significant four years after completion, but this lag is observed for only 18% of municipalities that completed all work (27 municipalities).

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status' is reversed, i.e. all sewerage works were completed) and the sample is not selected (see Table G1 in the appendix).

The results also remain robust when setting as control the periods in between projects, where no project is occurring, but later on new projects are implemented (see Figure G3 in the appendix). However, I opted not to adopt this as the primary approach because it is applicable in only 6% of treated districts.

V Final remarks

1 Policy implications

The findings stress the need for stricter enforcement of health and safety regulations in government projects to prevent spreading diseases and causing accidents. The results also underscore the importance of avoiding unwarranted project halts, delays, and mid-construction abandonment, as these inefficiencies expose local populations to hazards for extended periods.[12] It is noteworthy that nearly 85% of district municipalities initiating sewerage projects halted them for at least a year, with an average pause per project lasting approximately two-and-a-half years. Treated districts were, on average, 3.6 years under project halts (see Figure H2 in the appendix).

These halts delayed infrastructure completion and prolonged the implementation phase. In districts that experienced project halts, the implementation phase lasted for an average of 5.3 years (with a median of 5 years), whereas districts without halts had an average exposure period of 2.6 years (with a median of 2 years). A back-of-the-envelope calculation suggests that the cost–benefit ratio for sewerage infrastructure, considering the estimated social costs in this

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[12] Halted and delayed projects are a remarked-upon issue in many countries. For instance, Samuels (2002) refers in passing to 'the literally thousands of unfinished pork-barrel projects that dot the Brazilian countryside'. Similarly, Williams (2017) and Rasul and Rogger (2018) estimate that over a third of public infrastructure projects are halted and abandoned mid-construction in Ghana and Nigeria. Delays are also common in OECD countries, where it has been estimated that cost overruns (ranging between 20% and 45%) in transportation projects are the main driving factor (Flyvbjerg et al., 2004).

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paper and the potential social benefits estimated by Galiani et al. (2005) and Alsan and Goldin (2019), doubles in district municipalities that halted projects. For further elaboration, refer to Appendix H. This observation underscores the importance of avoiding unnecessary delays.[13]

Finally, the social benefits of sewerage infrastructure cannot materialize if projects are never completed, perpetuating the social costs indefinitely. At the end of my analysis period, over 40% of projects were halted mid-construction (see Panel D in Figure H2 in the appendix). On average, these halted projects had disbursed 40% of the contractual sum. Half remained halted having disbursed more than 10% and below 80% of the contractual sum, meaning that they were not in the initial stages of commencement nor on the verge of completion. The total sunk cost represents a waste equivalent to 21% of all local government capital expenditure in Peru for 2015.[14] Besides the sunk cost of abandoned projects, a rough calculation suggests that districts would perpetually incur an annual social loss of USD 840,000 per 1,000 children if mid-construction abandonment persists (for further details, see Appendix H). Incorporating these social costs in cost–benefit analyses can generate the right incentives to mitigate inefficiencies and complete projects.

2 Conclusion

In this paper, I investigate the social costs stemming from inadequate public infrastructure implementation. Focusing on Peru from 2005 to 2015, a period marked by a nationwide effort

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[13] This amplification in the cost–benefit ratio is not due to an escalation of health and safety hazards during the pause but rather arises from the delays incurred due to project halts. Figure H4 shows that there is no trend break in mortality rates after the first project in a district is halted.

[14] This estimate of the fiscal waste from project non-completion is of similar magnitude to Williams (2017)'s estimated waste from project non-completion in Ghana (20%). Although not directly comparable, it is also similar to Olken (2007)'s estimate of resource loss from corruption in road building in Indonesia (24%) and to Finan and Mazzocco (2020)'s estimate of resource misallocation due to politically motivated distortions in Brazilian municipalities (27%).

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to expand sewerage systems through local municipalities, I exploit quasi-random variation in the initiation of the implementation phase to reveal an increase in infant and under-5 mortality rates. These adverse effects are driven by health and safety hazards associated with construction works, leading to increased deaths from waterborne diseases and accidents. The severity of these effects is more pronounced in areas where infrastructure projects were more intense.

Further research is needed to understand the extent to which the effects on mortality are exacerbated by temporary disruptions (e.g. halting, delays) and mid-construction abandonment. Moreover, more research is needed to comprehend the root causes of implementation failure in public goods provision. Although corruption has been a dominant focus (Banerjee et al., 2013), and it can explain the substandard quality of implementation (Olken, 2007), it does not fully explain why projects are halted, as agents have incentives to continue disbursing funds to secure private gains. Recent research has emphasized the role of clientelism and inconsistent collective choice processes among local political actors (Robinson and Torvik, 2004; Williams, 2017).

The good governance agenda points towards solutions. For instance, studies such as Lewis-Faupel et al. (2016) underscore the importance of implementing e-procurement auctions, showing that they enhance project quality and reduce delays. Additionally, Rasul and Rogger (2018) demonstrate that autonomy, incentives, and monitoring are associated with project completion. Recent findings also suggest that financing local public goods through local taxation, rather than grants or royalties, enhances their quality (Gadenne, 2015; Martinez, 2023).

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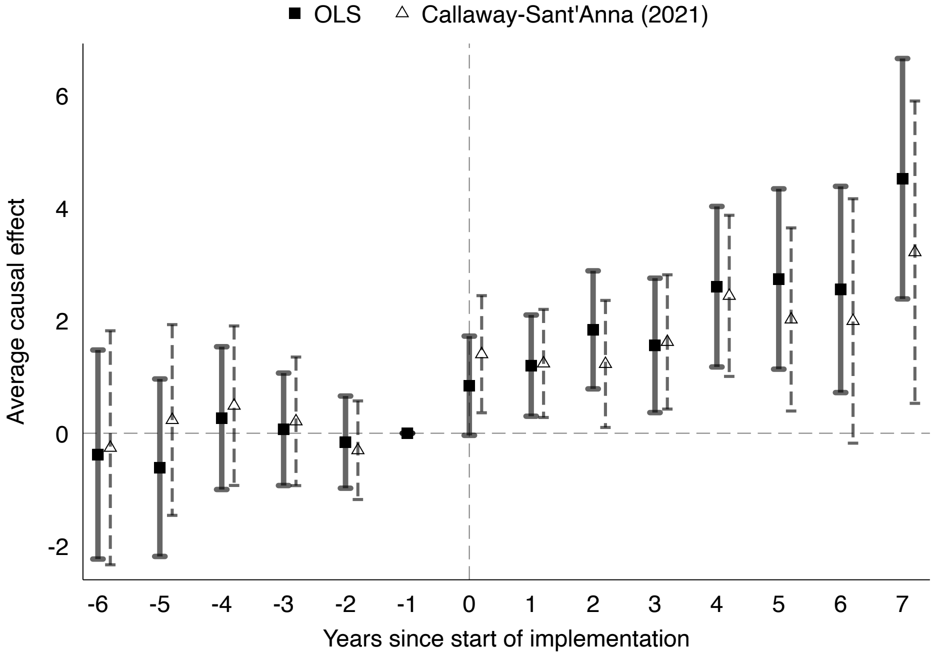
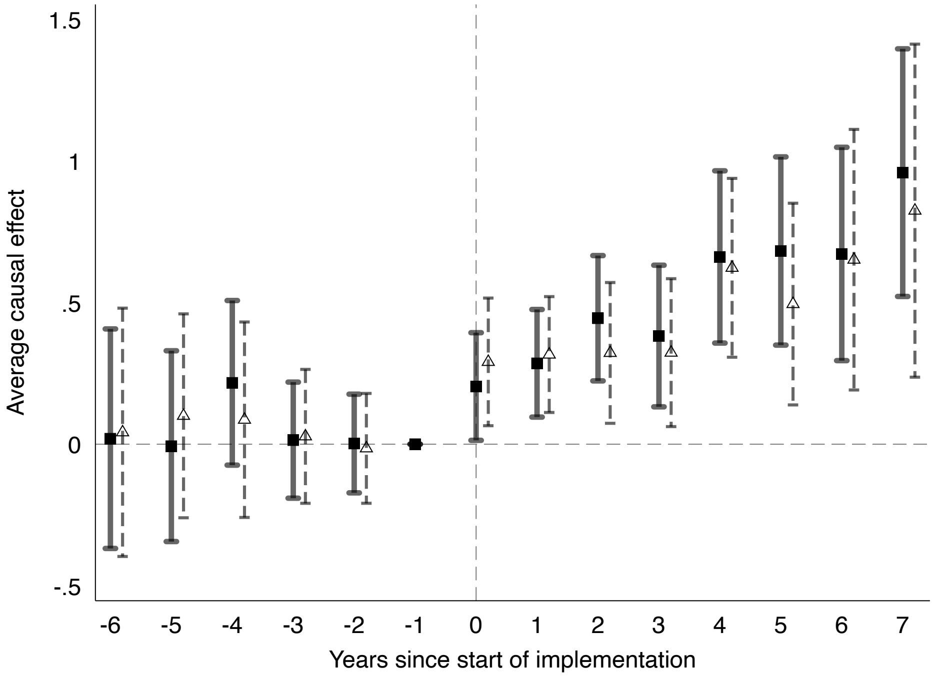


(A) Infant mortality rate



(B) Under-5 mortality rate

Figure 1
Effect of infrastructure development on early-life mortality (per 1,000)

Note. Event studies of the effect of infrastructure development on infant mortality per 1,000 infants in Panel A and on under-5 mortality per 1,000 children under the age of 5 in Panel B. Estimates of Equation 3, controlling for two-way fixed effects (district and calendar year), and their 90% confidence intervals are presented. The first lead is excluded as a normalization, and the periods at the extremes are trimmed (where fewer than 35% of 'treated' districts experienced h).

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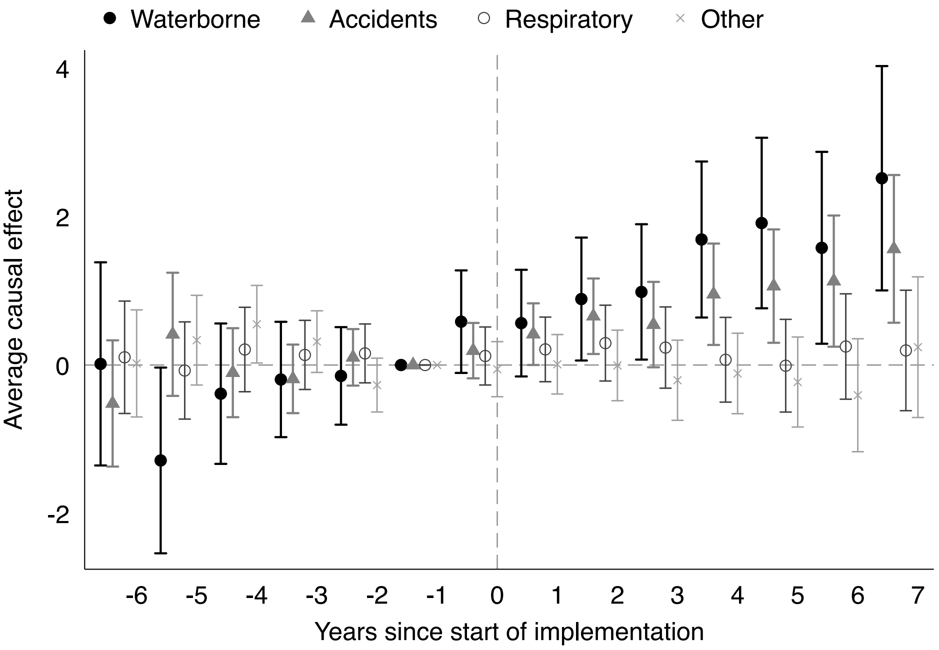
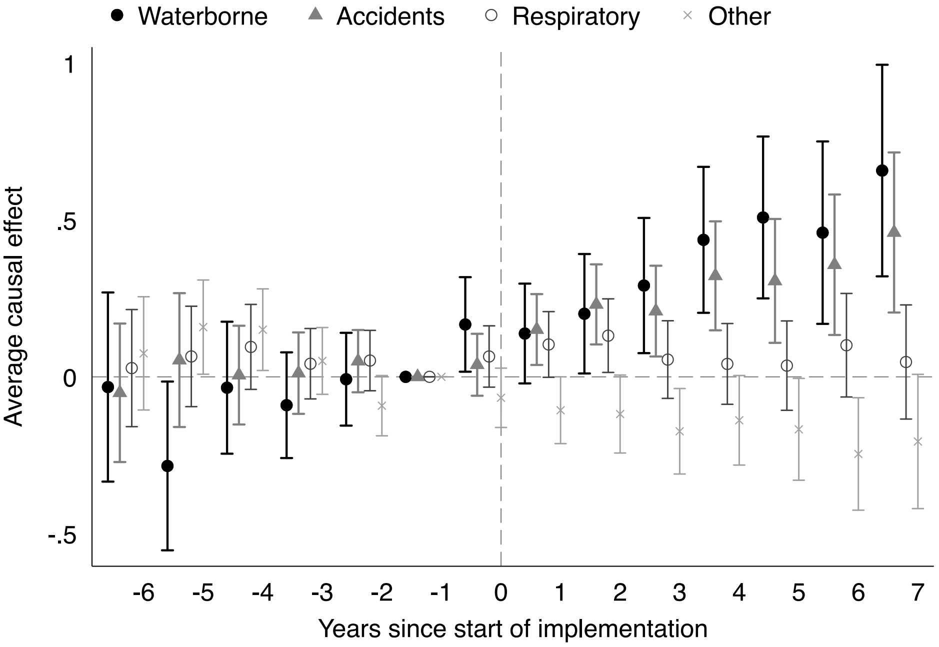


(A) Infant mortality rate



(B) Under-5 mortality rate

Figure 2
Effect of infrastructure development on early-life mortality, by cause of death

Note. Same notes as Figure 1. ‘Waterborne’ includes deaths by infectious diseases, perinatal complications, diseases of the digestive system, and malnutrition and other nutritional deficiencies; ‘Accidents’ are deaths by external causes; ‘Respiratory’ includes deaths by diseases of the respiratory system; and ‘Other’ includes deaths due to congenital malformations and other non-communicable diseases.

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Table 1
Dynamic effect of infrastructure development on early-life mortality

Dependent variable:	**Infant mortality rate**	**Under-5 mortality rate**
Unit:	Deaths per 1,000 infants or children under 5 years old	
	(1)	(2)
Years since start of implementation		
Pre (–10 to –2)	0.10	0.09
	(0.47)	(0.10)
	[0.82]	[0.38]
Post 1 (0 to 3)	1.00	0.26
	(0.45)	(0.10)
	[0.03]	[0.01]
Post 2 (4 to 7)	2.10	0.57
	(0.71)	(0.15)
	[0.00]	[0.00]
Post 3 (8 to 10)	3.12	0.77
	(1.03)	(0.21)
	[0.00]	[0.00]
Pre – Post 1 (*p*-value)	0.07	0.03
Pre – Post 2 (*p*-value)	0.02	0.01
Pre – Post 3 (*p*-value)	0.01	0.00
Post 1 – Post 2 (*p*-value)	0.01	0.00
Post 2 – Post 3 (*p*-value)	0.07	0.07
Mean (pre-start)	15.82	4.32
District-years	10632	10632
Districts	1467	1467

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Note. Estimates based on district-level panel data spanning the years 2005–15. Coefficients correspond to estimates of Equation 3. ‘Pre’ is an indicator variable equal to 1 for years before the start of the implementation phase for districts that developed sewerage infrastructure during the period of study, and 0 otherwise (leaving the first lead as the reference period). ‘Post 1’ is an indicator variable equal to 1 for years 0 to 3, ‘Post 2’ for years 4 to 7, and ‘Post 3’ for years 8 to 10 after the start of the implementation phase, and 0 otherwise. The dependent variables are the infant mortality rate per 1,000 infants in Column 1 and the under-5 mortality rate per 1,000 children under 5 years old in Column 2. All regressions include district and year fixed effects. Standard errors clustered by district are reported in parentheses and p-values in brackets. See Table B3 in the appendix for variable definitions.

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Table 2
Static effect of infrastructure development on early-life mortality

Dependent variable:	**All**	**Water-borne**	**Accidents**	**Respiratory**	**Other**
Unit:	Deaths per 1,000 infants or children under 5 years old				
	(1)	(2)	(3)	(4)	(5)
Panel A: IMR					
Implementation	0.74	0.52	0.24	0.03	-0.05
	(0.42)	(0.31)	(0.19)	(0.18)	(0.17)
	[0.08]	[0.10]	[0.22]	[0.85]	[0.75]
Mean (pre-start)	15.82	8.06	3.04	2.39	2.33
Panel B: U5MR					
Implementation	0.16	0.13	0.07	0.03	-0.07
	(0.09)	(0.07)	(0.05)	(0.04)	(0.04)
	[0.07]	[0.06]	[0.17]	[0.46]	[0.09]
Mean (pre-start)	4.32	1.90	1.04	0.70	0.69
District-years	10632	10632	10632	10632	10632
Districts	1467	1467	1467	1467	1467

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Note. Estimates based on district-level panel data spanning the years 2005–15. Coefficients correspond to estimates of Equation 1. 'Implementation' is an indicator variable equal to 1 after the implementation phase starts in a district that developed sewerage infrastructure. The dependent variables are the infant mortality rate per 1,000 infants in Panel A and the under-5 mortality rate per 1,000 children under 5 years old in Panel B, disaggregated by cause of death. 'Waterborne' (Column 2) includes deaths by infectious diseases, perinatal complications, diseases of the digestive system, and malnutrition and other nutritional deficiencies; 'Accidents' (Column 3) are deaths by external causes; 'Respiratory' (Column 4) includes deaths by diseases of the respiratory system; 'Other' (Column 5) denotes deaths by other diseases and complications that are not transmissible directly from one person to another. All regressions include district and year fixed effects. Standard errors clustered by district are reported in parentheses and p-values in brackets. See Table B3 in the appendix for variable definitions.

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Table 3
Dynamic effect of infrastructure development on early-life mortality, by cause of death

Dependent variable:	**Infant mortality rate**				**Under-5 mortality rate**			
	Waterborne	**Accidents**	**Respiratory**	**Other**	**Waterborne**	**Accidents**	**Respiratory**	**Other**
Unit:	Deaths per 1,000 infants				Deaths per 1,000 children under 5 years old			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Years since start of implementation								
–10 to –2	-0.19	0.05	0.18	0.07	-0.03	0.05	0.07	0.00
	(0.36)	(0.21)	(0.22)	(0.20)	(0.08)	(0.06)	(0.05)	(0.05)
	[0.59]	[0.82]	[0.42]	[0.71]	[0.70]	[0.38]	[0.21]	[0.97]
0 to 3	0.50	0.33	0.14	0.02	0.14	0.12	0.07	-0.07
	(0.35)	(0.20)	(0.23)	(0.20)	(0.08)	(0.05)	(0.05)	(0.05)
	[0.16]	[0.09]	[0.54]	[0.90]	[0.09]	[0.03]	[0.18]	[0.20]
4 to 7	1.26	0.85	-0.07	0.06	0.36	0.25	0.02	-0.07
	(0.50)	(0.33)	(0.31)	(0.26)	(0.11)	(0.09)	(0.07)	(0.07)
	[0.01]	[0.01]	[0.83]	[0.82]	[0.00]	[0.00]	[0.81]	[0.33]
8 to 10	1.57	1.04	0.11	0.40	0.45	0.30	0.07	-0.04
	(0.72)	(0.50)	(0.44)	(0.41)	(0.16)	(0.13)	(0.10)	(0.11)
	[0.03]	[0.04]	[0.81]	[0.34]	[0.00]	[0.02]	[0.51]	[0.70]
Pre – Post 1 (*p*-value)	0.18	0.24	0.71	0.93	0.10	0.08	0.34	0.29
Pre – Post 2 (*p*-value)	0.01	0.05	0.44	0.96	0.00	0.05	0.49	0.38
Pre – Post 3 (*p*-value)	0.03	0.09	0.88	0.47	0.01	0.09	1.00	0.71
Post 1 – Post 2 (*p*-value)	0.02	0.01	0.26	0.86	0.00	0.01	0.18	0.96
Post 2 – Post 3 (*p*-value)	0.44	0.46	0.47	0.19	0.32	0.50	0.40	0.71
Mean (pre-start)	8.06	3.04	2.39	2.33	1.90	1.04	0.70	0.69
District-years	10632	10632	10632	10632	10632	10632	10632	10632
Districts	1467	1467	1467	1467	1467	1467	1467	1467

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Note. Same notes as Table 1. The dependent variables are the infant mortality rate per 1,000 infants in Columns 1 to 4 and the under-5 mortality rate per 1,000 children under 5 years old in Columns 5 to 8, disaggregated by cause of death. ‘Waterborne’ in Columns 1 and 5 includes deaths by infectious diseases, perinatal complications, diseases of the digestive system, and malnutrition and other nutritional deficiencies; ‘Accidents’ in Columns 2 and 6 are deaths by external causes; ‘Respiratory’ in Columns 3 and 7 includes diseases of the respiratory system; ‘Other’ in Columns 4 and 8 denotes deaths by other diseases and complications that are not transmissible directly from one person to another.

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Table 4
Heterogeneous effects by intensity

Dependent variable:	**All**	**Water-borne**	**Accidents**	**Respiratory**	**Other**
Unit:	Deaths per 1,000 infants or children under 5 years old				
	(1)	(2)	(3)	(4)	(5)
Panel A: IMR					
Implementation	0.33	0.18	0.11	0.19	-0.14
	(0.55)	(0.40)	(0.26)	(0.24)	(0.25)
	[0.55]	[0.65]	[0.68]	[0.45]	[0.56]
Implementation × High intensity	0.76	0.63	0.25	-0.28	0.16
	(0.61)	(0.42)	(0.27)	(0.25)	(0.25)
	[0.21]	[0.14]	[0.36]	[0.27]	[0.51]
Mean (pre-start)	15.82	8.06	3.04	2.39	2.33
Panel B: U5MR					
Implementation	0.03	0.03	0.05	0.05	-0.10
	(0.12)	(0.09)	(0.07)	(0.06)	(0.06)
	[0.80]	[0.78]	[0.44]	[0.44]	[0.11]
Implementation × High intensity	0.24	0.20	0.03	-0.03	0.04
	(0.13)	(0.10)	(0.07)	(0.06)	(0.06)
	[0.07]	[0.04]	[0.64]	[0.64]	[0.48]
Mean (pre-start)	4.32	1.90	1.04	0.70	0.69
District-years	10632	10632	10632	10632	10632
Districts	1467	1467	1467	1467	1467

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Note. Same notes as Table 2. 'High intensity' is an indicator for a district's geographic suitability index for low-cost sewerage projects being at or above the median of the index distribution, a predictor of high intensity of open projects.