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The unintended consequences of infrastructure development

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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)

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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 sewerage ditch' in Colombia (Sanchez Flores, 2017); (ii) 'Children drown in an open ditch from sewerage project' (Serquen, 2018) and

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 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

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'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.

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 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 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 infrastructure. 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

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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.

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 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 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

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

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.

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.

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 (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

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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.

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] 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 imple-

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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.

mentation 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-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 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 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 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 mortality 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 $2\times$ 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]

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]

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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.

[8] In the appendix, Table D2 shows the formal fully dynamic CS estimates presented in Figure 1, and Table D3

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.

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.

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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.

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 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 pointwise 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 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 point-wise 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 socio-demographic 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.

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]

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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).

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 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

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

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 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 abandon-

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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).

ment, 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 H1 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 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 H1 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

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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).

[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 H3 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

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 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

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and Mazzocco (2020)'s estimate of resource misallocation due to politically motivated distortions in Brazilian municipalities (27%).

than grants or royalties, enhances their quality (Gadenne, 2015; Martinez, 2023).

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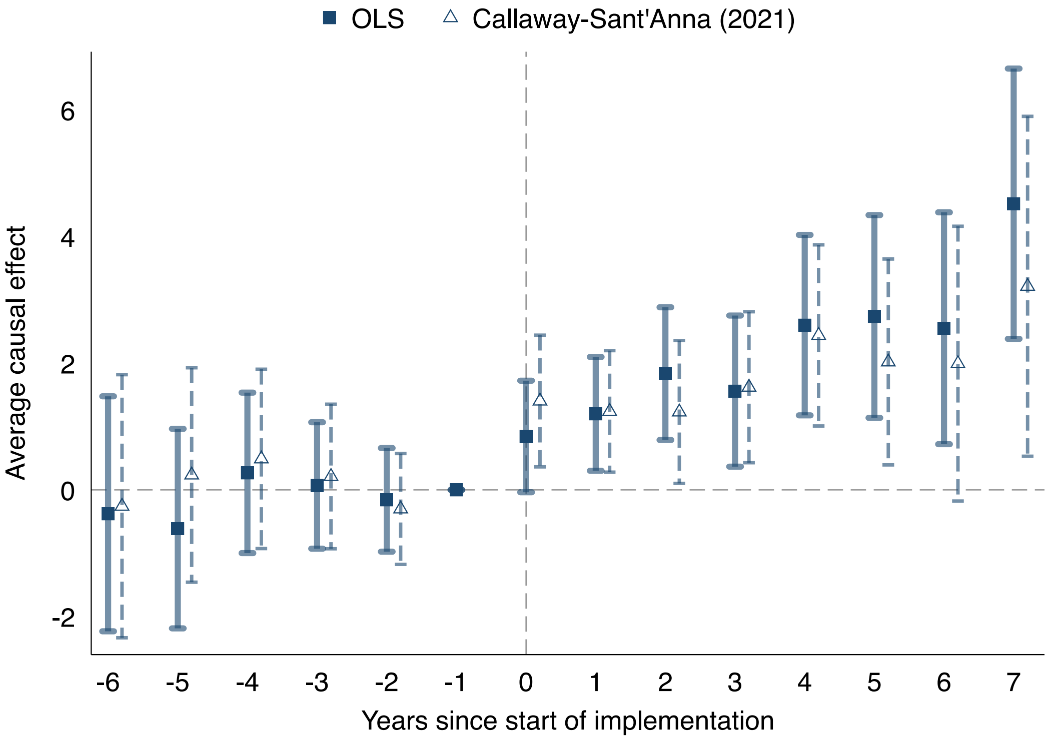
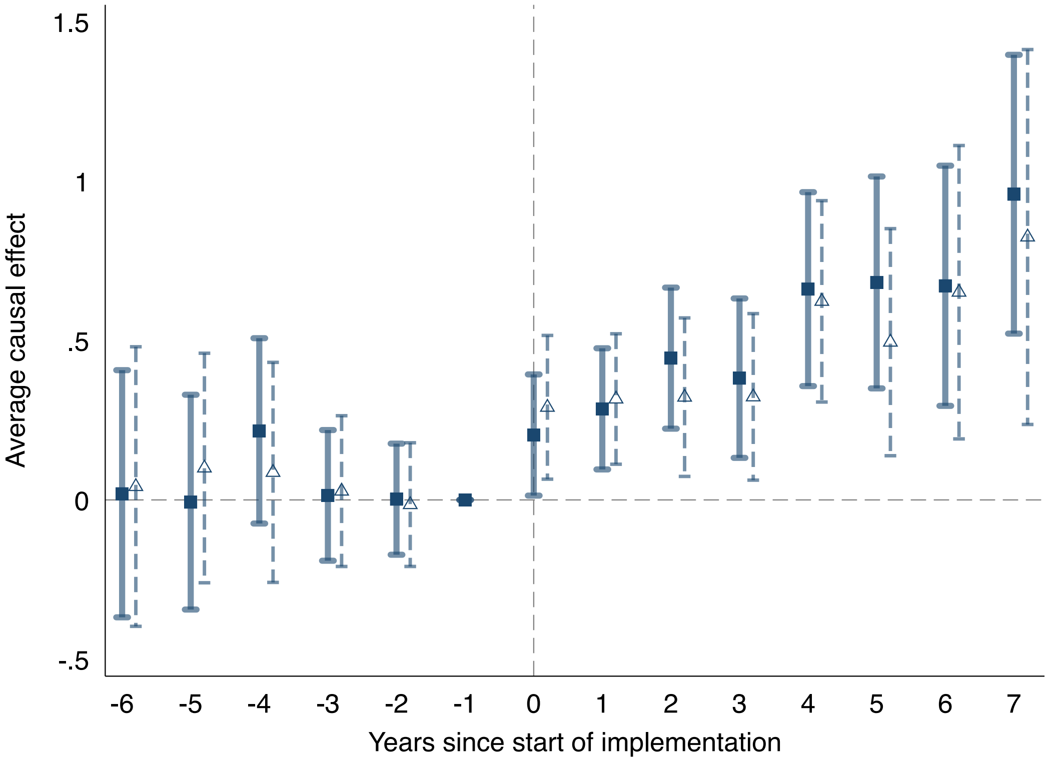


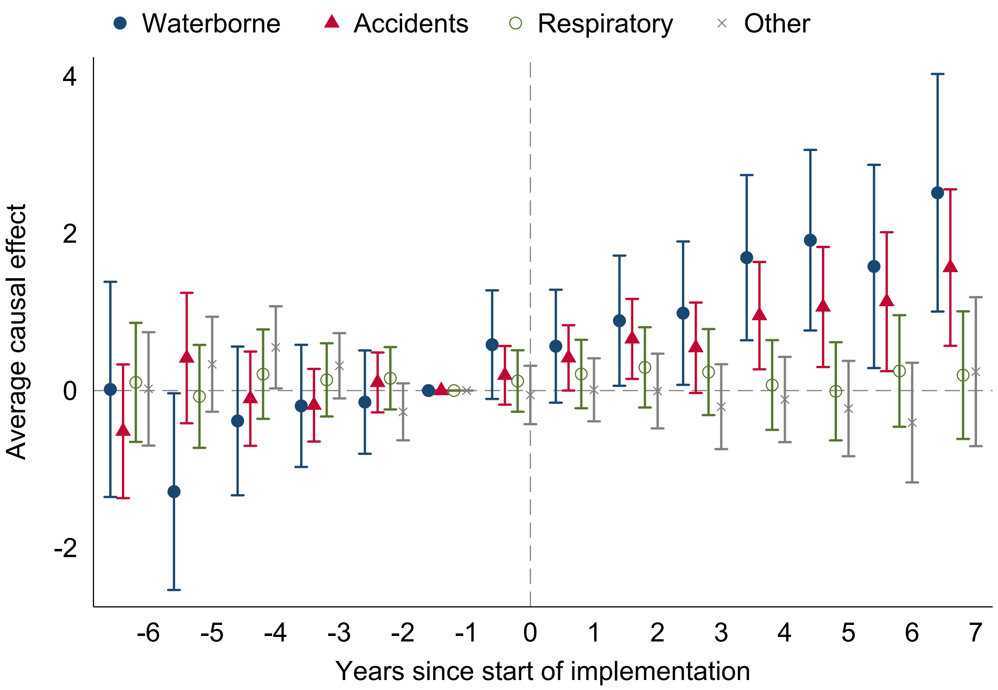
(A) Infant mortality rate



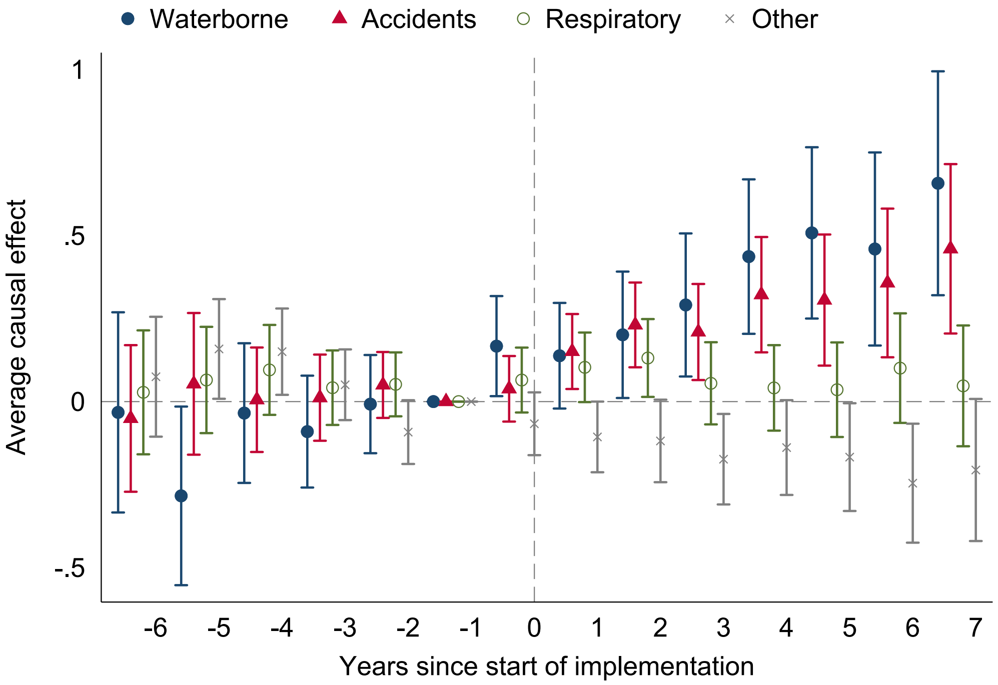
(B) Under-5 mortality rate

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).



(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.

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

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.

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

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, including malformations, neoplasms, congenital malformations, and diseases of the genitourinary system, nervous system, circulatory system, skin and subcutaneous tissue, and musculoskeletal systems and connective tissue. 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.

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

Dependent variable:	**Infant mortality rate**				**Under-5 mortality rate**			
Unit:	Deaths per 1,000 infants				Deaths per 1,000 children under 5 years old			
	Waterborne (1)	Accidents (2)	Respiratory (3)	Other (4)	Waterborne (5)	Accidents (6)	Respiratory (7)	Other (8)
Years since start of implementation								
Pre (–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]
Post 1 (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]
Post 2 (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]
Post 3 (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

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, including malformations, neoplasms, congenital malformations, and diseases of the genitourinary system, nervous system, circulatory system, skin and subcutaneous tissue, and musculoskeletal systems and connective tissue.

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

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.

ONLINE APPENDIX

The Unintended Consequences of Infrastructure Development

Antonella Bancalari

This online appendix provides additional information on the data, methods, and robustness checks, as well as photographic evidence.

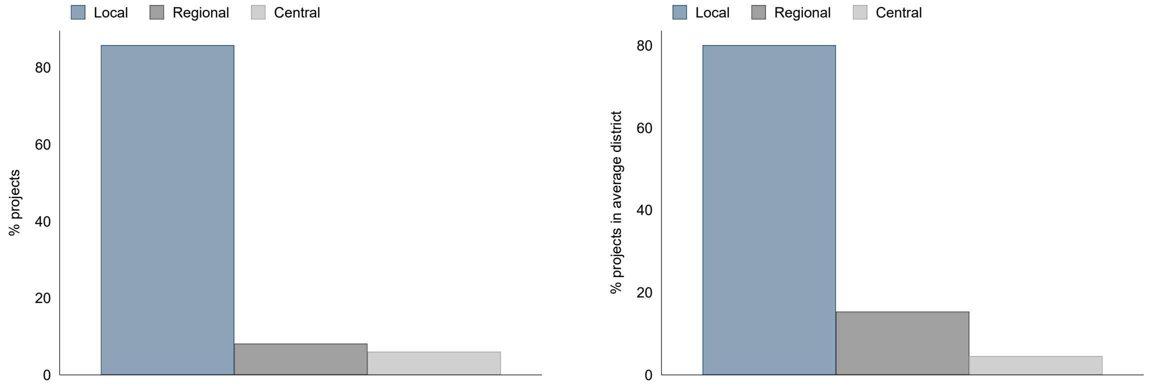
A Additional material for Section I, Background

Districts encompass both urban and rural areas. As outlined in the National Sanitation Plan, the development of sewerage systems is restricted to urban areas with populations exceeding 30,000 residents. The definition of project boundaries varies across projects and districts. In an average district, almost 80% of the projects covered a village, community, or neighborhood.

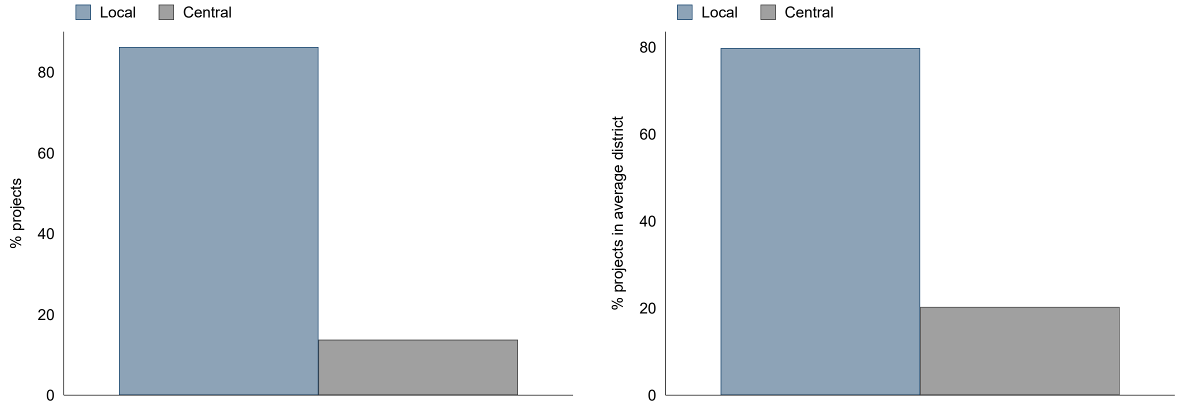
Figure A1 shows the distribution of projects according to the implementation agency (Panels A and B) and according to their funding source (Panels C and D), both as a share of projects (Panels A and C) and as a share of projects in the average district (Panels B and D).

With respect to treatment of effluent, the Plan's ultimate objective is to achieve a 100% rate of effluent treatment by aligning each sewerage system with a corresponding treatment facility, given that 22% of effluent was disposed of in bodies of water without previous treatment in 2005 – a figure consistent with the estimate provided by Fay et al. (2017). However, it is noteworthy that only 11% of sewerage projects explicitly reference 'treatment plants' in their project descriptions.

Furthermore, the National Sanitation Plan dictates that peri-urban areas (with populations ranging from 2,000 to less than 30,000 inhabitants) and rural areas (up to 2,000 inhabitants) will be served by latrines developed under the National Program of Rural Sanitation (PRONASAR). A statistically significant positive correlation of 0.11 exists between the number of sewerage projects and the number of latrine projects implemented within districts, alleviating concerns regarding a trade-off between sewerage expansion and latrine expansion.



(A) Implementation - % projects **(B) Implementation - % in an average district**



(C) Funding - % projects **(D) Funding - % in an average district**

Figure A1
Project characteristics

Note. This figure shows the distribution of projects by government agency formulating the project in Panels (A) and (B) and by funding source in Panels (C) and (D), as a share of projects in Panels (A) and (C) and as a share of projects in an average district in Panels (B) and (D). Sample includes all districts in the analysis that developed sewerage infrastructure during the period of analysis.

Figure A2
Sewerage project under implementation

Note. Photographs taken in Piura from Google Street View in 2013, the year this project was started.

Figure A3
Sewerage project halted

Note. Photograph of a halted project taken in Huánuco (Defensoria del Pueblo, 2015).

B Additional material for Section II, Data

The advantage of using district-level administrative data, as opposed to survey data, is the statistical power gained to detect local effects of infrastructure development. Survey datasets available in Peru are designed to be representative of the population at the level of the 25 regions of Peru. Available surveys in Peru, such as the one from the Living Standards Survey (ENAHO) and the Demographic and Health Surveys (DHS and ENDES), provide data from a non-representative sample of households located in a restricted set of districts. Furthermore, the DHS and ENDES surveys only provide data from a repeated cross-section of women of fertile age, so we cannot leverage panel data for an event-study approach. Moreover, it is not possible to link infrastructure projects to individuals and households because the public works data are not geo-coded, and the geo-codes of DHS and ENDES are displaced for confidentiality purposes.

There are only six sewerage projects categorized as cross-district initiatives, with two operating at the regional level and three at the provincial level. I allocate each respective project to every district within its corresponding province or region. This approach is employed in 3.7% of the district municipalities that implemented sewerage projects.

1 Mortality rates

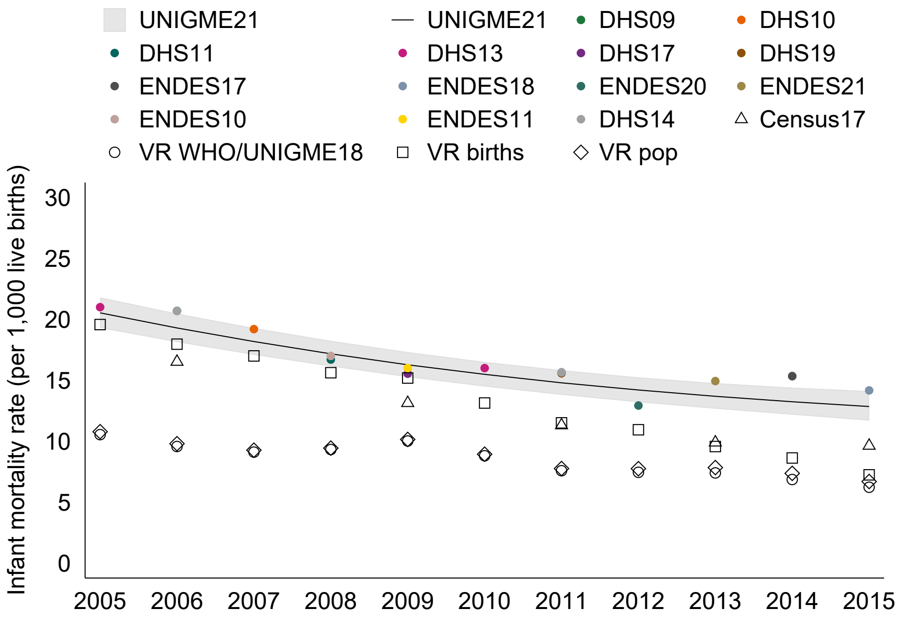
I rely on vital statistics and population forecasts to compute mortality rates at the municipal level, following the approach of previous studies on the topic (Galiani et al., 2005; Alsan and Goldin, 2019). I construct the infant mortality rate (IMR) and the under-5 mortality rate (U5MR) for each district d and calendar year t, using as the denominator the population at risk, multiplied by 1,000:

$$IMR_{dt} = \frac{\text{Deaths of infants aged 0–11 months}_{dt}}{(\text{Population aged 0–59 months / 5})_{dt}} \times 1,000;$$

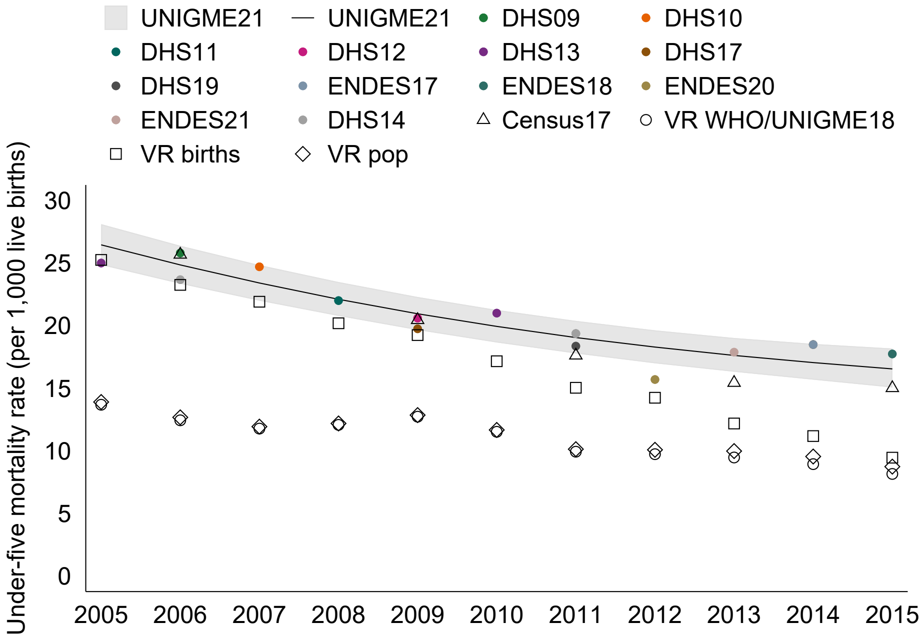
$$U5MR_{dt} = \frac{\text{Deaths of children aged 0–59 months}_{dt}}{\text{Population aged 0–59 months}_{dt}} \times 1,000.$$

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. Figure B1 shows that these data and the approach 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 (UNIGME).

Figure B1 also presents the UNIGME estimates, including confidence intervals, which are computed based on demographic and health surveys collected by the DHS Program and the National Institute of Statistics (ENDES). While this study's mortality rates and the UNIGME estimates exhibit similar trends over time, there is a noticeable difference in their levels. Specifically, mortality rates derived from survey data tend to be higher than those computed using vital records. This observation aligns with the findings of Romero et al. (2021), who suggest that mortality rates estimated from DHS often overestimate actual rates. Mortality rates computed using vital records and births as the denominator are closer in level to the survey data, yet they exhibit a steeper trend over time compared with the UNIGME estimates. Mortality rates calculated using data from the 2017 Census also tend to be lower than those derived from DHS, but still slightly higher than those derived from vital records. Using census data from 2005, it becomes clear that the sample of districts in the analysis, included due to their availability of data on deaths, is positively selected on initial municipal capabilities, as well as their population and sanitation status (see Table B4). It is possible that these municipalities are wealthier and, consequently, have lower mortality rates.



(A) Infant mortality rate



(B) Under-5 mortality rate

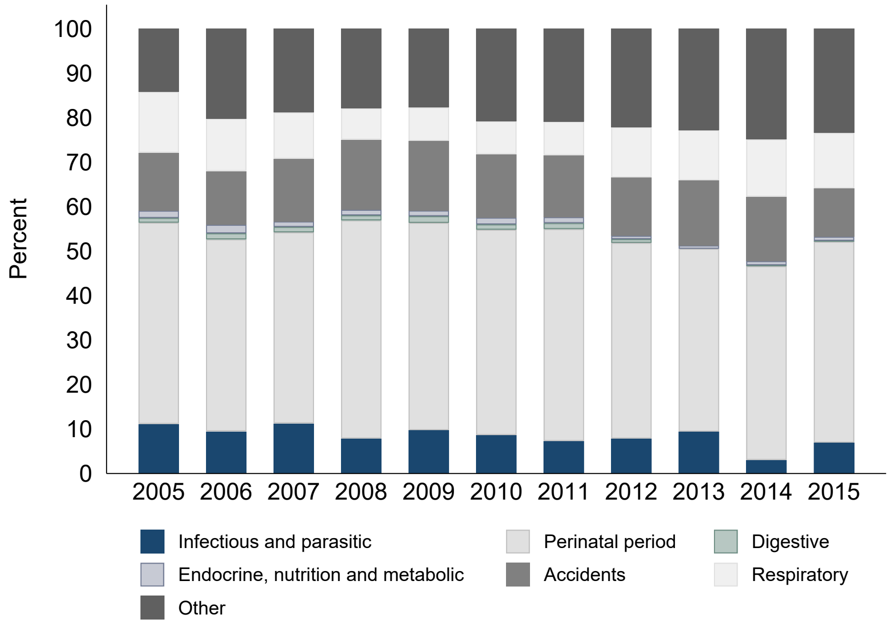
Figure B1
Mortality rates across data sources

Note. Mortality rates per 1,000 births computed from alternative data sources using data compiled by the UN Inter-Agency Group for Child Mortality Estimation, downloaded from https://childmortality.org/data/Peru in 2018. Vital records (VR) is the data utilized in this study for 1,467 districts; 'VR births' uses the number of births as the denominator and 'VR pop' uses the predicted under-5 population divided by five as the denominator. Other data sources include national estimates from Health and Demographic Surveys (DHS), National Survey of Health and Demography (ENDES), and Inter-agency Group for Child Mortality Estimation (UNIGME).

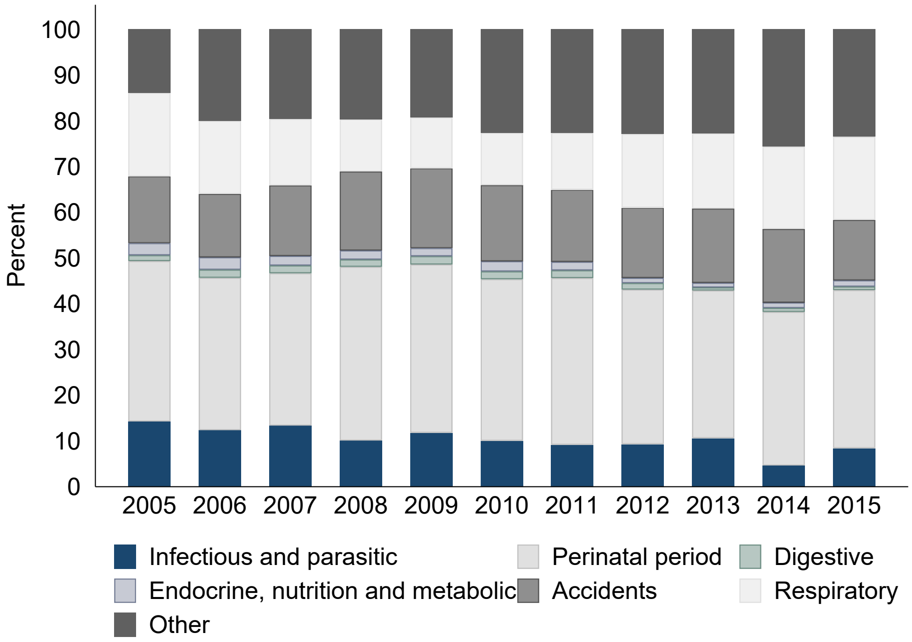
Table B1
Mortality by ICD-10 codes

Cause of death	**Category**
Waterborne-mortality	
Infectious diseases	I
Malnutrition and other nutritional deficiencies	IV
Digestive system	XI
Perinatal period	XVI
Accidents	
Accidents and external causes	XX
Other	
Respiratory system	X
Neoplasms	II
Blood diseases	III
Nervous system	VI
Circulatory system	IX
Skin and subcutaneous tissue	XII
Musculoskeletal systems and connective tissue	XIII
Diseases of the genitourinary system	XIV
Congenital malformations	XVII
Symptoms, signs, and abnormal clinical and laboratory findings, not elsewhere classified	XVIII

Note. There are no deaths by Category V – mental and behavioral disorders; Category VII – diseases of the eye and adnexa; Category XIX – injury, poisoning, and certain other consequences of external causes; nor Category XXI – factors influencing health status and contact with health services. There is only one death caused by Category VIII – diseases of the ear and mastoid process.



(A) Infant mortality rate



(B) Under-5 mortality rate

Figure B2
Distribution of mortality rates by cause of death

Note. Following the World Health Organization's International Classification of Diseases (ICD-10): 'Infectious and parasitic' is Category I; 'Digestive' is Category XI; 'Endocrine, nutrition and metabolic' is Category IV; 'Perinatal period' is Category XVI; 'Accidents' is Category XX; 'Respiratory' is Category X; and 'Other' includes deaths due to neoplasms (Category II), blood diseases (Category III), nervous system (Category VI), circulatory system (Category IX), skin and subcutaneous tissue (Category XII), musculoskeletal systems and connective tissue (Category XIII), diseases of the genitourinary system (Category XIV), congenital malformations (Category XVII), and symptoms, signs, and abnormal clinical and laboratory findings, not elsewhere classified (Category XVIII).

Table B2
Perinatal mortality by ICD-10 codes

Cause of death	**Chapter XVI sub-category**
Maternal and pregnancy	P00-P04
Disorders relared to length of gestation and fetal growth	P05-P08
Birth trauma	P10-P15
Cardio, asphyxia, pneumonia	P20-P29
Infections	P35-P39
Hemorrhage	P50-P61
Endocrine and metabolic	P70-P74
Digestive	P75-P78
Temperature	P80-P83
Other	P90-P96

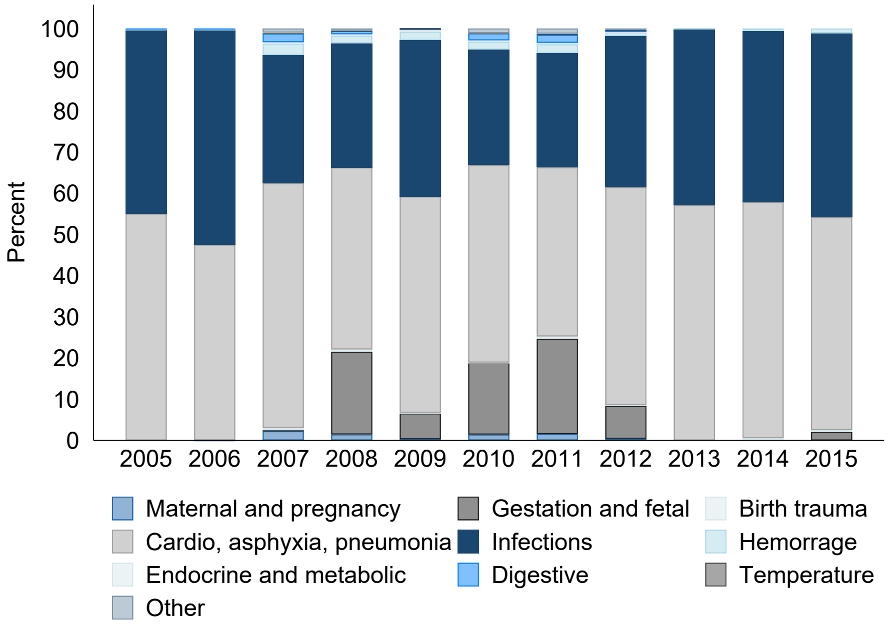


Figure B3
Distribution of perinatal mortality rate (per 1,000 infants) by cause of death

Note. Following the World Health Organization's International Classification of Diseases (ICD-10), Chapter XVI: 'Maternal and pregnancy' is P00-P04; 'Gestation and fetal' is P05-P08; 'Birth trauma' is P10-P15; 'Cardio, asphyxia, pneumonia' is P20-P29; 'Infections' is P35-P39; 'Hemorrage' is P50-P61; 'Endocrine and metabolic' is P70-P74; 'Digestive' is P75-P78; 'Temperature' is P80-P83; and 'Other' is P90-P96.

2 Additional data

I draw on census and administrative data to characterize the districts in the analysis and conduct robustness tests.

I use data from three census rounds (2005, 2007, and 2017) to measure socio-demographic features of districts. All census rounds employed the same methodology with the objective of surveying all households in Peru. However, while the 2005 round gathered information from all household members, the 2007 and 2017 rounds restricted data collection to those present during the interview. This difference is not problematic as I only use data gathered at the household level when using the three census rounds in the analysis presented in Appendix E. The 2007 Census also had more limited scope and covered fewer questions than the censuses conducted in 2005 and 2017. For instance, the 2007 Census did not include questions related to electricity connectivity.

I further use data from the National Register of Municipalities (RENAMU) to measure characteristics of district municipalities, including budget, internet connectivity, whether it receives technical support for the implementation of investment projects, and whether it manages a health center. These data are available only between 2008 and 2014. I also use budget reports from SIAF to identify the level of expenditure on alternative infrastructure, including transportation, energy, and health (available between 2007 and 2014, but 2015 is also available for transportation).

Table B3
Definition of key variables

Variable	**Description**
Infant mortality rate (IMR)	Infant deaths divided by the population of under-5s divided by five (number of infants henceforth), multiplied by 1,000
Under-5 mortality rate (U5MR)	Under-5 deaths divided by the total number of children under 5 years old, multiplied by 1,000
Waterborne	Infant/Under-5 deaths caused by waterborne diseases (including infectious diseases, perinatal complications, diseases of the digestive system, malnutrition, and other nutritional deficiencies) divided by the total number of infants/under-5s , multiplied by 1,000
Accidents	Infant/Under-5 deaths caused by external factors divided by the total number of infants/under-5s, multiplied by 1,000
Respiratory	Infant/Under-5 deaths caused by respiratory diseases divided by the total number of infants/under-5s, multiplied by 1,000
Other	Infant/Under-5 deaths caused by congenital malformations, neoplasms, and diseases of the genitourinary system, nervous system, circulatory system, skin and subcutaneous tissue, and musculoskeletal systems and connective tissue, divided by the total number of infants/under-5s, multiplied by 1,000
Infants	Number of infants below 1 year old
Under-5s	Number of children under the age of 5
Open projects	Number of projects started but not yet completed
Halted project	Indicator variable that equals 1 if project stops receiving funds while still under way
Suitability	Index capturing the district's geographical suitability for sewerage projects, computed based on the share of a district falling in different categories of elevation and gradient, and on river density and area
Population	Total inhabitants
Population density	Total population divided by district area (measured in km^2)
Share HH piped water	Share of households in a district that use piped water for drinking purposes
Share HH sewerage or Sewerage connectivity	Share of households in a district that use a toilet connected to the public sewers as their main sanitation facility
Share HH latrine	Share of households in a district using on-site latrine facilities (either connected to septic tanks or pits)
Share HH open defecation	Share of households in a district that openly defecate
Share HH head secondary	Share of household heads with secondary education completed in a district
Share HH electricity	Share of households in a district connected to the electricity grid
Municipal budget (2010 USD, million)	Total budget of the municipality in real terms
Internet connectivity	Indicator equal to 1 if the municipality has access to the internet, and equal to 0 otherwise
Technical support	Indicator equal to 1 if the municipality is receiving technical support from the Ministry of Economy and Finances for the implementation of investment projects, and equal to 0 otherwise
Manages health centers	Indicator equal to 1 if the municipality is managing at least one health center, and equal to 0 otherwise
Coast	Indicator equal to 1 if the district is located on the coast, and equal to 0 otherwise
Andes	Indicator equal to 1 if the district is located in the Andean region, and equal to 0 otherwise

Table B4
Balance in initial characteristics (2005), by mortality data status

	No mortality data (1)	**Mortality data** (2)	**Difference** (3)
1. Municipal characteristics			
Municipal budget (2010 USD, million)	0.43	2.30	1.87***
	[0.84]	[9.23]	(0.07)
Internet connectivity	0.38	0.65	0.27***
	[0.48]	[0.48]	(0.01)
Technical support	0.65	0.68	0.03***
	[0.47]	[0.46]	(0.01)
Manages health centers	0.14	0.20	0.06***
	[0.34]	[0.40]	(0.01)
2. District characteristics			
Population	1671.92	17862.73	16190.81***
	[1955.66]	[51782.37]	(388.81)
Population density ($\frac{pop}{km^2}$)	10.95	448.25	437.30***
	[14.88]	[2356.57]	(17.60)
Share HH piped water	0.56	0.55	-0.01**
	[0.21]	[0.21]	(0.00)
Share HH sewerage	0.28	0.29	0.01***
	[0.16]	[0.20]	(0.00)
Share HH latrine	0.27	0.37	0.10***
	[0.21]	[0.19]	(0.00)
Share HH open defecation	0.45	0.34	-0.11***
	[0.22]	[0.19]	(0.00)
Share HH head secondary	0.27	0.26	-0.00**
	[0.10]	[0.13]	(0.00)
Share HH electricity	0.69	0.66	-0.03***
	[0.14]	[0.16]	(0.00)

Note. Columns 1 and 2 report sample mean with standard deviation in brackets for the group of districts without mortality data and for the group with mortality data, respectively. Column 3 reports the difference across groups estimated using OLS, with robust standard errors in parentheses.

Looking at the average district-level mortality rates, we can observe a decrease by roughly 40% between 2005 and 2015 (see Table B5). This decrease is also evident in Figure B1, across different sources.

The period of study was a decade of prosperity in Peru (see Table B5). The average district's population and its density, as well as access to public services, increased. Electricity connectivity, piped water and sewerage connectivity, and the share of households in districts that use on-site sanitation facilities all increased by more than 20 percentage points (ppts), while the share practicing open defecation decreased by 27 ppts. Household heads became better educated (measured as the share of heads who had completed secondary education, which increased by 10 ppts). District municipalities became richer. The average budget across district municipalities in the sample of analysis more than doubled between 2005 and 2015 – from 1.3 million to 2.9 million constant USD (2010 prices). This rise coincided with a phase marked by significant resource windfalls, driven by a surge in international mineral prices and the redistribution of these natural resource revenues across all municipalities. Furthermore, a greater share of municipalities had access to the internet (51 ppts more), municipal capabilities improved (measured as the share of municipalities requiring technical support for the implementation of investment projects, which dropped by 8 ppts), and more municipalities managed a health center (the share increased by 9 ppts).

Table B5

Data sources and average values across districts in the analysis

	Beginning		**End**		**Source**
	Mean	SD	Mean	SD	
	(1)	(2)	(3)	(4)	(5)
1. Outcomes					
IMR (per 1,000 infants)	18.01	17.85	10.09	12.75	Vital statistics and population forecasts
U5MR (per 1,000 children)	4.82	4.21	2.89	2.77	
2. District characteristics					
Population	18527.96	49730.92	20768.23	59064.90	Census
Population density ($\frac{pop}{km^2}$)	485.76	2451.16	501.09	2439.53	
Share HH piped water	0.53	0.27	0.70	0.24	
Share HH sewerage	0.22	0.25	0.42	0.27	
Share HH latrine	0.35	0.23	0.42	0.24	
Share HH open defecation	0.42	0.26	0.15	0.15	
Share HH head secondary	0.21	0.14	0.31	0.15	
Share HH electricity	0.55	0.26	0.77	0.16	
3. Municipal characteristics					
Municipal budget (2010 USD, million)	1.31	6.38	2.90	12.27	Municipal reports
Internet connectivity	0.34	0.47	0.86	0.34	
Technical support	0.66	0.46	0.58	0.49	
Manages health centers	0.20	0.39	0.29	0.45	

Note. The beginning period is 2005 and the end period is 2015. Columns 1 and 3 provide the mean for the variables of interest and Columns 2 and 4 provide the standard deviation. Column 5 shows the data source used to compute each of the variables. Census data correspond to the years 2005 and 2017.

C Additional material for Section III, Empirical strategy

Table C1 and the map in Figure C1 highlight the calendar year in which each district municipality started the implementation phase. The distribution of start years across projects exhibits a notable dispersion across various years, when looking at the roll-out at both the district and project level (in Tables C1 and C2, respectively). The time pattern is similar when comparing new systems with projects entailing the expansion and improvement of pre-existing systems (see Table C3).

Table C1

Distribution of start and completion year across districts

	Start		**Completion**	
	Frequency (1)	Percent (2)	Frequency (3)	Percent (4)
Ever	1141	77.78	149	13.06
Never	326	22.22	992	86.94
Total	1467	100.00	1141	100.00
2005	78	6.84		
2006	33	2.89		
2007	137	12.01	1	0.67
2008	148	12.97	1	0.67
2009	189	16.56	3	2.01
2010	100	8.76	10	6.71
2011	90	7.89	12	8.05
2012	137	12.01	14	9.40
2013	104	9.11	26	17.45
2014	64	5.61	32	21.48
2015	61	5.35	50	33.56
Total	1141	100.00	149	100.00

Note. ‘Start’ shows the distribution of the municipalities that ever and never implemented sewerage, representing each the treatment and pure control group, respectively. ‘Completion’ shows the distribution of the municipalities that ever (or never) completed the implementation phase. The distributions of ‘Start’ and ‘Completion’ across calendar years correspond to districts that ever implemented projects (treated) and to districts that ever completed the implementation phase in the period of study.

Table C2

Distribution of start and completion year across projects

	Start		**Completion**	
	Frequency (1)	Percent (2)	Frequency (3)	Percent (4)
Ever			2154	35.32
Never			3945	64.68
Total			6099	100.00
2005	124	2.03		
2006	42	0.69	1	0.05
2007	322	5.28	9	0.42
2008	483	7.92	23	1.07
2009	672	11.02	94	4.36
2010	613	10.05	185	8.59
2011	533	8.74	270	12.53
2012	962	15.77	200	9.29
2013	951	15.59	354	16.43
2014	808	13.25	478	22.19
2015	589	9.66	540	25.07
Total	6099	100.00	2154	100.00

Note. ‘Start’ shows the distribution across start years of projects that were ever started. ‘Completion’ shows the distribution of projects that were started, and were ever (or never) completed, during the period of study.

Table C3

Distribution of start and completion year across projects, by type of project

	New system				**Expansion or improvement**			
	Start		**Completion**		**Start**		**Completion**	
	Freq. (1)	Percent (2)	Freq. (3)	Percent (4)	Freq. (5)	Percent (6)	Freq. (7)	Percent (8)
2005	14	0.48			110	3.48		
2006	19	0.65			23	0.73	1	0.10
2007	138	4.70	5	0.45	184	5.82	4	0.38
2008	255	8.68	8	0.73	228	7.21	15	1.43
2009	352	11.99	45	4.08	320	10.12	49	4.66
2010	324	11.03	101	9.16	289	9.14	84	7.99
2011	282	9.60	146	13.24	251	7.94	124	11.80
2012	464	15.80	97	8.79	498	15.75	103	9.80
2013	429	14.61	183	16.59	522	16.51	171	16.27
2014	396	13.48	247	22.39	412	13.03	231	21.98
2015	264	8.99	271	24.57	325	10.28	269	25.59
Total	2937	100.00	1103	100.00	3162	100.00	1051	100.00

Note. Same as Table C2. Distribution of start and completion years split by type of project.

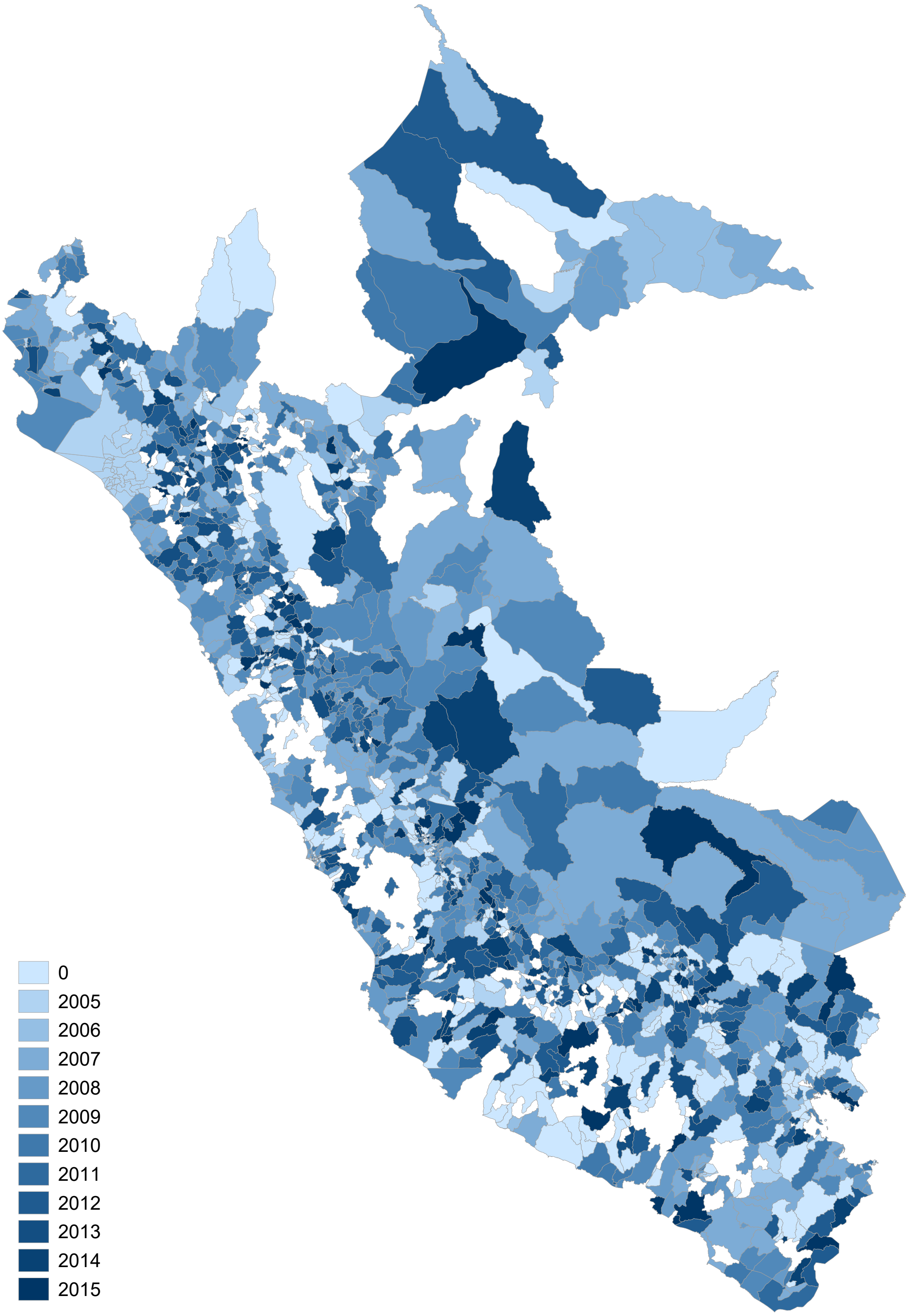


Figure C1
Spatial distribution of start year

Note. Map showing the year in which the development of sewerage infrastructure was started. Lighter-shaded districts started works earlier than darker-shaded districts. The districts that did not develop sewerage in the period of study are denoted as zero. Blank districts are those excluded from the analysis.

Table C4
Treatment status and timing of start

	OLS		**Cox hazard model**	
	Ever started		**Timing of start**	
	(1)	(2)	(3)	(4)
1. Geographical features				
Share district gradient (0.8, 4.19]%	-0.03	-0.00	-0.48	-0.51
	(0.08)	(0.09)	(0.27)	(0.29)
Share district gradient (4.19, 13]%	-0.02	-0.04	-0.90***	-0.92***
	(0.09)	(0.09)	(0.26)	(0.28)
Share district gradient above 13%	-0.02	-0.02	-1.02***	-1.02***
	(0.08)	(0.09)	(0.25)	(0.26)
Share district elevation (250, 500] mamsl	-0.12	-0.11	-0.46	-0.43
	(0.09)	(0.10)	(0.27)	(0.27)
Share district elevation (500, 1000] mamsl	-0.04	-0.03	0.04	0.19
	(0.09)	(0.10)	(0.30)	(0.32)
Share district elevation above 1000 mamsl	-0.13*	-0.12	-0.04	-0.01
	(0.07)	(0.07)	(0.19)	(0.20)
District area (km^2)	-0.00	-0.00	-0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)
River density ($\frac{km}{km^2}$)	0.00	0.00	-0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Coast	-0.03	-0.04	-0.39**	-0.41**
	(0.04)	(0.04)	(0.13)	(0.14)
Andes	-0.02	-0.02	-0.33*	-0.32*
	(0.04)	(0.04)	(0.13)	(0.13)
2. District characteristics				
Population	0.00**	0.00**	0.00**	0.00**
	(0.00)	(0.00)	(0.00)	(0.00)
Population density ($\frac{pop}{km^2}$)	-0.00***	-0.00***	-0.00**	-0.00**
	(0.00)	(0.00)	(0.00)	(0.00)
Share HH piped water	-0.03	-0.03	-0.28	-0.31
	(0.06)	(0.06)	(0.16)	(0.16)
Share HH sewerage	2.32	2.27	1.02	1.63
	(1.53)	(1.60)	(4.38)	(4.57)
Share HH latrine	2.14	2.08	0.33	0.94
	(1.53)	(1.61)	(4.38)	(4.57)
Share HH open defecation	2.09	2.05	0.06	0.66
	(1.53)	(1.60)	(4.37)	(4.57)
Share HH head secondary	-0.12	-0.23	0.44	0.49
	(0.18)	(0.19)	(0.47)	(0.49)
Share HH electricity	-0.03	-0.00	-0.10	-0.05
	(0.07)	(0.07)	(0.19)	(0.20)
3. Municipal characteristics				
Municipal budget (2010 USD, million)	0.00***	0.00***	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Internet connectivity	0.09***	0.09***	0.14	0.15
	(0.03)	(0.03)	(0.07)	(0.08)
Technical support	0.03	0.03	0.03	0.03
	(0.02)	(0.02)	(0.07)	(0.07)
Manages health centers	-0.00	-0.01	-0.06	-0.09
	(0.03)	(0.03)	(0.08)	(0.08)
Re-election rate since 1993		0.05		-0.10
		(0.07)		(0.19)
Observations	1467	1378	1141	1071

Note. For time-varying predictors, I use the initial values (2005). Coefficients of an OLS regression with treatment status capturing ever starting infrastructure in Columns 1 and 2. Cox regression of timing until the events 'Start' in Columns 3 and 4. Robust standard errors reported in parentheses. Statistical significance denoted by *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table C5
Balance in initial characteristics (2005), by 'pure' control and treatment groups

	Control (1)	**Treatment** (2)	**Difference** (3)
1. District characteristics			
Population	13154.66	21497.87	8343.21***
	[39513.77]	[57710.48]	(837.08)
Population density ($\frac{pop}{km^2}$)	1024.01	331.98	-692.03***
	[4091.60]	[1682.70]	(69.95)
Share HH piped water	0.56	0.55	-0.01**
	[0.22]	[0.21]	(0.00)
Share HH sewerage	0.28	0.30	0.02***
	[0.22]	[0.20]	(0.00)
Share HH latrine	0.36	0.38	0.02***
	[0.20]	[0.18]	(0.00)
Share HH open defecation	0.36	0.32	-0.03***
	[0.20]	[0.18]	(0.00)
Share HH head secondary	0.27	0.26	-0.01**
	[0.14]	[0.12]	(0.00)
Share HH electricity	0.66	0.66	-0.00
	[0.18]	[0.16]	(0.00)
2. Municipal characteristics			
Municipal budget (2010 USD, million)	1.73	2.71	0.98***
	[3.99]	[10.79]	(0.12)
Internet connectivity	0.58	0.69	0.11***
	[0.49]	[0.46]	(0.01)
Technical support	0.70	0.68	-0.02***
	[0.46]	[0.47]	(0.01)
Manages health centers	0.19	0.20	0.01
	[0.40]	[0.40]	(0.01)

Note. Columns 1 and 2 report sample mean with standard deviation in brackets for the control and for the treatment group, respectively. Column 3 reports the difference between the 'pure' control group (never treated) and the 'pure' treatment group (treated at some point), estimated using OLS, with robust standard errors reported in parentheses. Statistical significance denoted by *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table C6
Initial IMR levels, by treatment and control groups (dynamic)

	Control (1)	**Treatment** (2)	**Difference** (3)
C vs. T (by 2005)	18.45	10.57	-7.87***
	[18.14]	[9.19]	(1.30)
C vs. T (by 2006)	18.47	12.62	-5.85***
	[18.28]	[10.41]	(1.26)
C vs. T (by 2007)	19.02	13.57	-5.45***
	[18.82]	[11.80]	(1.04)
C vs. T (by 2008)	19.54	14.35	-5.19***
	[19.47]	[12.49]	(0.99)
C vs. T (by 2009)	20.20	15.16	-5.04***
	[19.86]	[14.38]	(1.04)
C vs. T (by 2010)	21.01	15.04	-5.97***
	[20.17]	[14.64]	(1.07)
C vs. T (by 2011)	21.44	15.33	-6.11***
	[20.67]	[14.77]	(1.12)
C vs. T (by 2012)	22.08	15.85	-6.23***
	[21.43]	[15.20]	(1.24)
C vs. T (by 2013)	23.87	15.85	-8.01***
	[22.32]	[15.35]	(1.41)
C vs. T (by 2014)	24.98	15.88	-9.10***
	[23.24]	[15.23]	(1.54)
C vs. T (by 2015)	25.82	16.07	-9.75***
	[23.61]	[15.53]	(1.68)

Note. Columns 1 and 2 report sample mean with standard deviation in brackets for the control and for the treatment group, respectively. Column 3 reports the difference between the control group and the treatment group, estimated using OLS. ‘C’ stands for control group and ‘T’ for treatment group. The control and treatment groups vary in each row. In the first row, the treatment group is those ever treated during the period of study and the control group is those never treated, so the pure control. In subsequent rows, the control group encompasses the pure control group along with districts that were later subjected to treatment, and the treatment group is those treated by the year in parenthesis. Robust standard errors reported in parentheses. Statistical significance denoted by *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table C7
Initial U5MR levels, by treatment and control groups (dynamic)

	Control (1)	**Treatment** (2)	**Difference** (3)
C vs. T (by 2005)	4.93	2.90	-2.03***
	[4.28]	[1.99]	(0.29)
C vs. T (by 2006)	4.95	3.27	-1.67***
	[4.32]	[2.18]	(0.27)
C vs. T (by 2007)	5.10	3.58	-1.52***
	[4.44]	[2.69]	(0.24)
C vs. T (by 2008)	5.24	3.80	-1.44***
	[4.58]	[2.92]	(0.23)
C vs. T (by 2009)	5.37	4.09	-1.28***
	[4.49]	[3.70]	(0.25)
C vs. T (by 2010)	5.57	4.07	-1.50***
	[4.58]	[3.67]	(0.25)
C vs. T (by 2011)	5.69	4.13	-1.56***
	[4.68]	[3.67]	(0.26)
C vs. T (by 2012)	5.86	4.26	-1.60***
	[4.85]	[3.72]	(0.29)
C vs. T (by 2013)	6.26	4.28	-1.98***
	[5.00]	[3.75]	(0.32)
C vs. T (by 2014)	6.55	4.29	-2.26***
	[5.17]	[3.72]	(0.35)
C vs. T (by 2015)	6.79	4.33	-2.46***
	[5.28]	[3.75]	(0.38)

Note. Columns 1 and 2 report sample mean with standard deviation in brackets for the control and for the treatment group, respectively. Column 3 reports the difference between the control group and the treatment group, estimated using OLS. 'C' stands for control group and 'T' for treatment group. The control and treatment groups vary in each row. In the first row, the treatment group is those ever treated during the period of study and the control group is those never treated, so the pure control. In subsequent rows, the control group encompasses the pure control group along with districts that were later subjected to treatment, and the treatment group is those treated by the year in parenthesis. Robust standard errors reported in parentheses. Statistical significance denoted by *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table C8
Cox hazard model: predicting timing of start with pre-start changes

	(1)	(2)	(3)
1. Outcomes			
△ IMR	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)
△ U5MR	-0.03	-0.03	-0.03
	(0.02)	(0.02)	(0.02)
2. District characteristics			
△ Population		0.00	0.00
		(0.00)	(0.00)
△ Population density		0.00*	0.00*
		(0.00)	(0.00)
3. Municipal characteristics			
△ Municipal budget		0.14***	0.14***
		(0.02)	(0.02)
△ Internet connectivity		1.16**	1.46***
		(0.39)	(0.39)
△ Technical support		0.38	0.37
		(0.32)	(0.33)
△ Manages health centers		-0.70	-0.54
		(0.38)	(0.39)
△ Political turnover			-0.36
			(0.35)
Observations	953	953	914

Note. Predictors are computed as the mean of the annual change in the time-varying values, before the start of the implementation phase. Cox regression of timing until the events ‘Start’ in all columns. The lower number of observations are due to missing values of predictors. Robust standard errors reported in parentheses. Statistical significance denoted by *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

D Additional material for Section IV.2, Robustness checks

1 Alternative IMR denominator

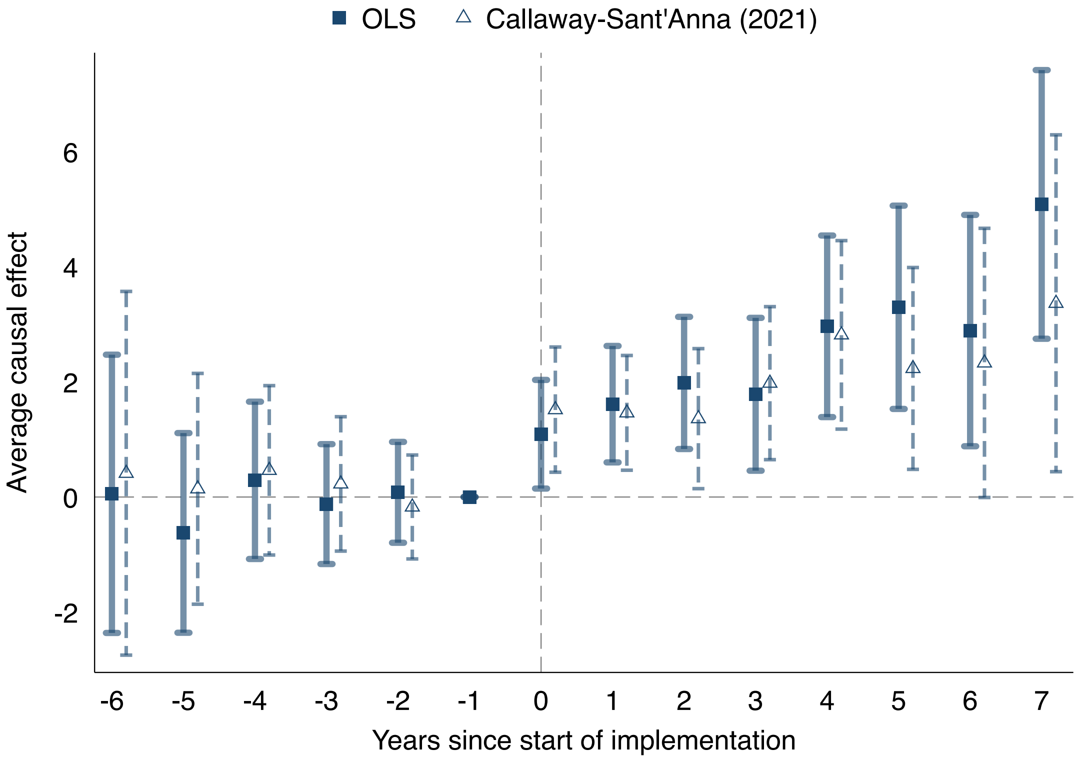


Figure D1
Effect on infant mortality rate (alternative denominator)

Note. Infant mortality rate (per 1,000 infants), computed using as an alternative denominator the forecasted population of under-5s weighted by the share of infants out of under-5s in each district in the 2005 Census. Same notes as Figure 1.

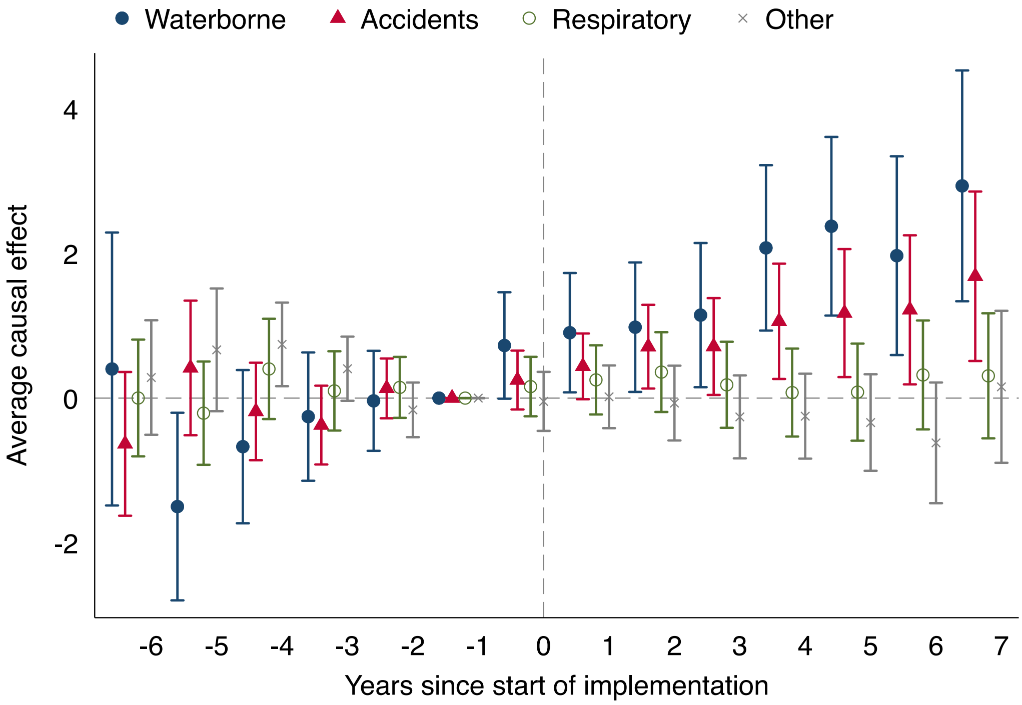


Figure D2
Effect on infant mortality rate (alternative denominator), by cause of death

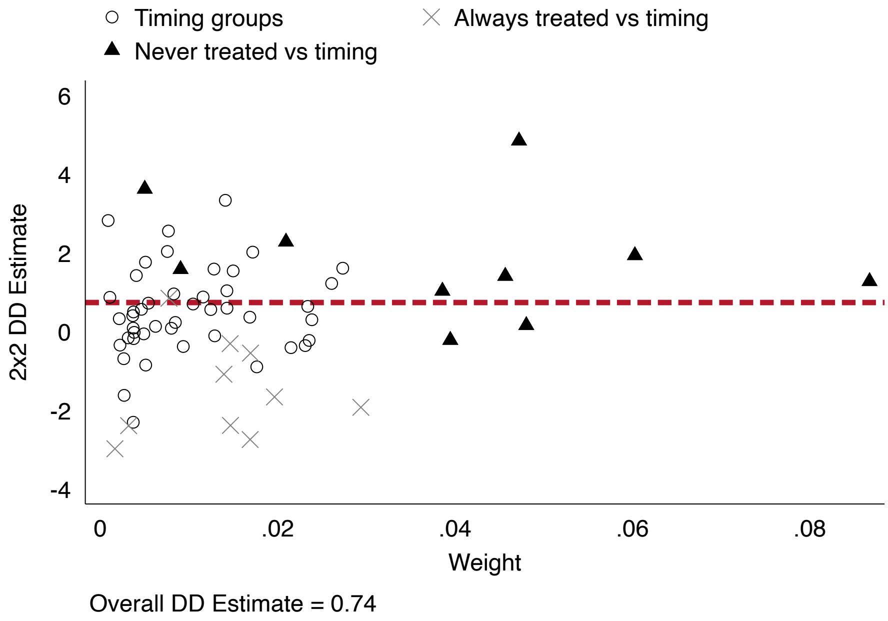
Note. Infant mortality rate (per 1,000 infants), computed using as an alternative denominator the forecasted population of under-5s weighted by the share of infants out of under-5s in each district in the 2005 Census. Same notes as Figure 2.

Table D1
Dynamic effect on infant mortality rate (alternative denominator), by cause of death

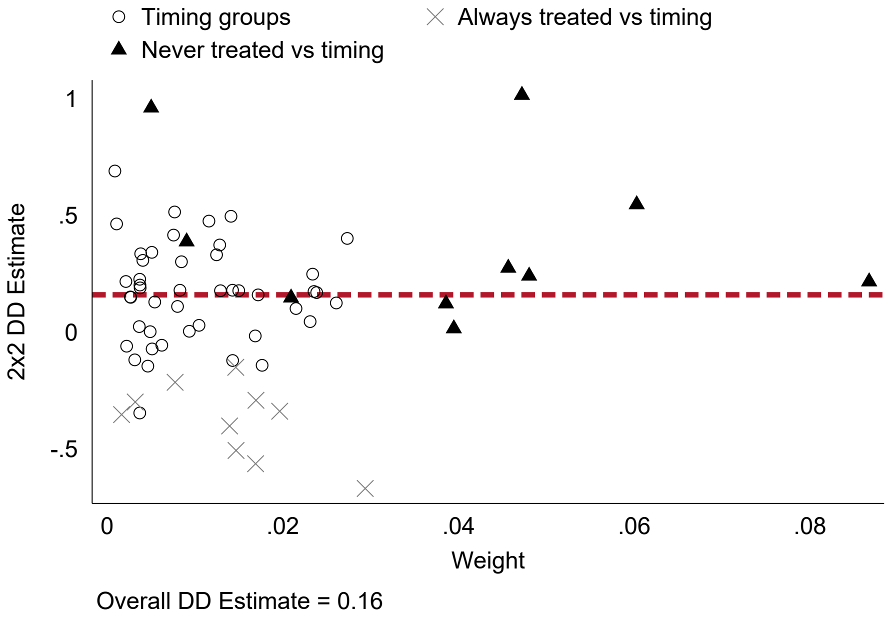
Unit:	Deaths per 1,000 infants				
	All (1)	Waterborne (2)	Accidents (3)	Respiratory (4)	Other (5)
Years since start of implementation					
Pre (–10 to –2)	0.18	-0.21	0.00	0.18	0.21
	(0.52)	(0.40)	(0.23)	(0.24)	(0.22)
	[0.73]	[0.60]	[0.99]	[0.46]	[0.33]
Post 1 (0 to 3)	1.25	0.67	0.38	0.16	0.03
	(0.50)	(0.39)	(0.21)	(0.25)	(0.22)
	[0.01]	[0.08]	[0.07]	[0.51]	[0.88]
Post 2 (4 to 7)	2.52	1.64	0.89	-0.01	0.01
	(0.79)	(0.54)	(0.37)	(0.33)	(0.28)
	[0.00]	[0.00]	[0.02]	[0.98]	[0.98]
Post 3 (8 to 10)	3.48	1.94	0.96	0.19	0.38
	(1.13)	(0.78)	(0.56)	(0.47)	(0.48)
	[0.00]	[0.01]	[0.09]	[0.68]	[0.42]
Pre – Post 1 (*p*-value)	0.04	0.08	0.19	0.72	0.57
Pre – Post 2 (*p*-value)	0.01	0.00	0.06	0.60	0.52
Pre – Post 3 (*p*-value)	0.01	0.01	0.15	0.97	0.74
Post 1 – Post 2 (*p*-value)	0.01	0.00	0.03	0.38	0.89
Post 2 – Post 3 (*p*-value)	0.10	0.50	0.79	0.41	0.24
Mean (pre-start)	16.58	8.33	3.33	2.52	2.40
District-years	10593	10593	10593	10593	10593
Districts	1461	1461	1461	1461	1461

Note. Infant mortality rate (per 1,000 infants), computed using as an alternative denominator the forecasted population of under-5s weighted by the share of infants out of under-5s in each district in the 2005 Census. The lower sample is due to districts having no infants recorded during the 2005 Census, thus setting the infant mortality rate to missing in the sample of study. Same notes as Table 3.

2 Negative weights and alternative TWFE estimators



(A) Infant mortality rate



(B) Under-5 mortality rate

Figure D3
Decomposition of static TWFE estimator

Note. This figure plots the 2 × 2 difference-in-differences (DD) components from the decomposition theorem of Goodman-Bacon (2021) against their weight. The triangles are DD estimates in which one timing group acts as the treatment group and the never-treated districts act as the control group. The crosses are DD estimates in which one timing group acts as the treatment group and the always-treated districts (those treated from 2005 onwards, 6.8% of the treated sample) act as the control group. Hollow circles are DD estimates in which one timing group acts as the treatment group and another treatment group acts as the control group. These include DD estimates using the early-treated as the control group and the later-treated as the treatment group. The dashed horizontal line denotes the average two-way fixed effects estimate, which equals the average of the y-axis values weighted by their x-axis value.

Table D2
Dynamic effect by Callaway and Sant'Anna (2021)

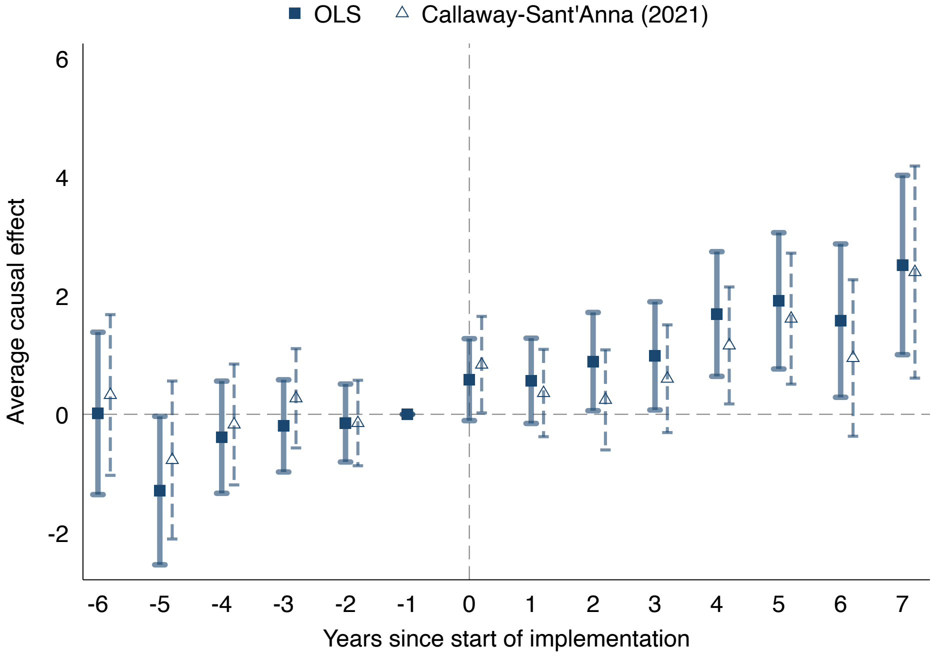
Dependent variable:	**Infant mortality rate**	**Under-5 mortality rate**
Unit:	Deaths per 1,000 infants or children under 5 years old	
	(1)	(2)
Years since start of implementation		
t-6	-0.26	0.04
	(1.26)	(0.27)
	[0.84]	[0.88]
t-5	0.24	0.10
	(1.03)	(0.22)
	[0.82]	[0.65]
t-4	0.49	0.09
	(0.86)	(0.21)
	[0.57]	[0.68]
t-3	0.21	0.03
	(0.69)	(0.14)
	[0.76]	[0.85]
t-2	-0.30	-0.01
	(0.53)	(0.12)
	[0.57]	[0.90]
t+0	1.40	0.29
	(0.63)	(0.14)
	[0.03]	[0.03]
t+1	1.24	0.32
	(0.58)	(0.12)
	[0.03]	[0.01]
t+2	1.23	0.32
	(0.69)	(0.15)
	[0.07]	[0.03]
t+3	1.62	0.32
	(0.72)	(0.16)
	[0.03]	[0.04]
t+4	2.44	0.62
	(0.87)	(0.19)
	[0.01]	[0.00]
t+5	2.02	0.49
	(0.99)	(0.22)
	[0.04]	[0.02]
t+6	1.99	0.65
	(1.32)	(0.28)
	[0.13]	[0.02]
t+7	3.21	0.82
	(1.63)	(0.36)
	[0.05]	[0.02]
Observations	9,151	9,151

Note. Event study estimates using Callaway and Sant'Anna (2021)'s alternative TWFE estimator. The sample is lower because it excludes observations that have missing outcome in the period after the start of the treatment (keeping those with pair balance t+0 and t+1). All regressions include district and year fixed effects. Robust and asymptotic standard errors clustered at the district level are reported in parentheses and p-values in brackets.

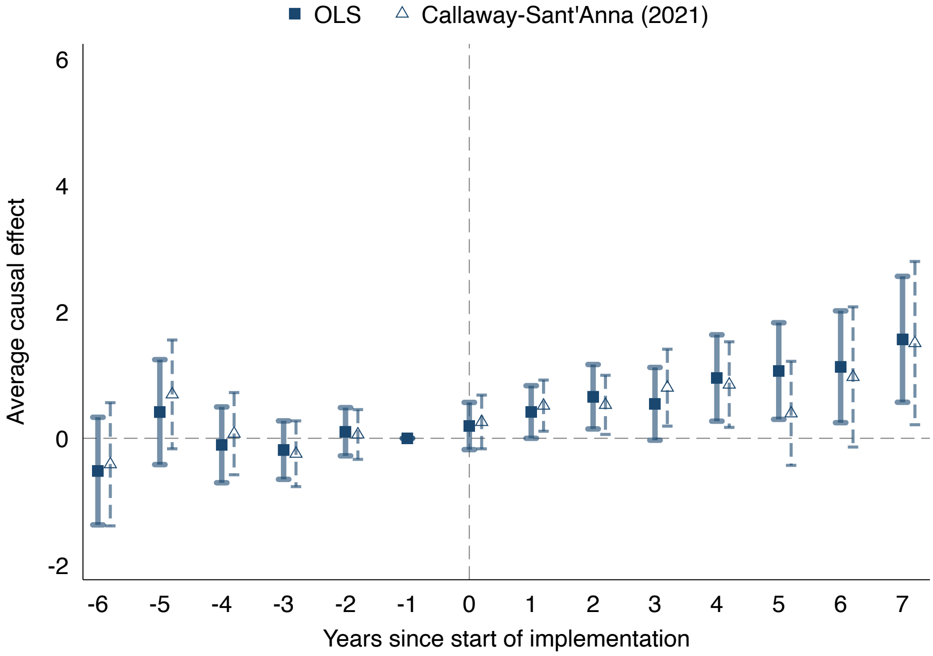
Table D3
Other aggregate estimands by Callaway and Sant'Anna (2021)

Dependent variable:	**Infant mortality rate**	**Under-5 mortality rate**
Unit:	Deaths per 1,000 infants or children under 5 years old	
	(1)	(2)
Panel A: ATT for all groups across all periods		
ATT	1.79	0.45
	(0.60)	(0.13)
	[0.00]	[0.00]
Panel B: ATT for each year, across all groups		
CAverage	1.60	0.44
	(0.58)	(0.13)
	[0.01]	[0.00]
T2006	-1.24	0.12
	(2.19)	(0.55)
	[0.57]	[0.83]
T2007	2.78	0.67
	(1.05)	(0.25)
	[0.01]	[0.01]
T2008	1.66	0.41
	(0.91)	(0.20)
	[0.07]	[0.04]
T2009	2.62	0.57
	(1.05)	(0.22)
	[0.01]	[0.01]
T2010	2.04	0.76
	(0.89)	(0.19)
	[0.02]	[0.00]
T2011	1.71	0.31
	(0.91)	(0.21)
	[0.06]	[0.13]
T2012	2.32	0.48
	(0.98)	(0.21)
	[0.02]	[0.02]
T2013	1.24	0.38
	(0.92)	(0.20)
	[0.18]	[0.06]
T2014	1.09	0.28
	(1.28)	(0.27)
	[0.40]	[0.29]
T2015	1.77	0.42
	(1.34)	(0.27)
	[0.18]	[0.12]

Note. C is control and T is treated. Same notes as Table D2.



(A) Waterborne

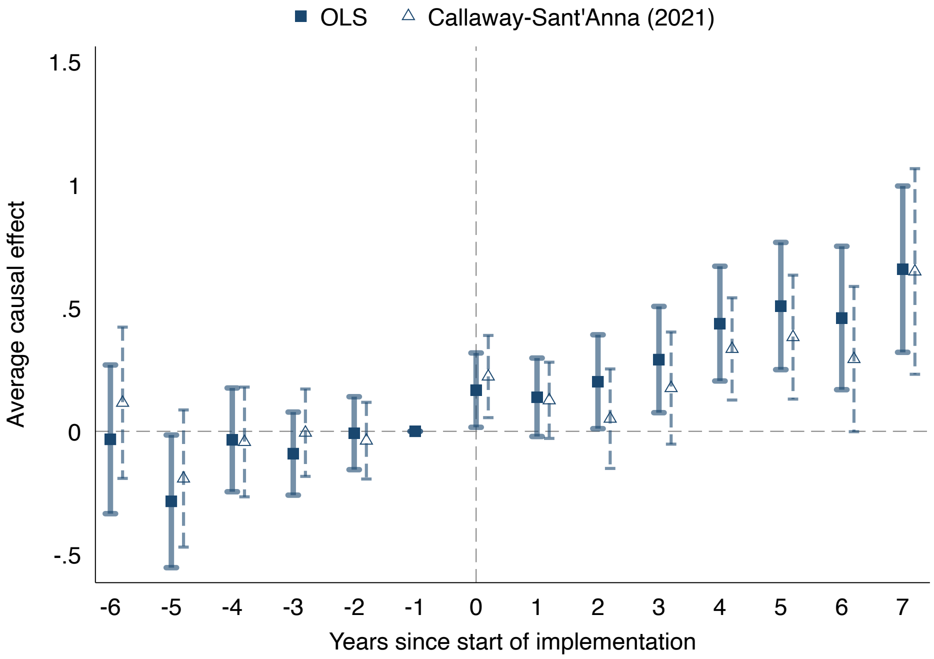


(B) Accidents

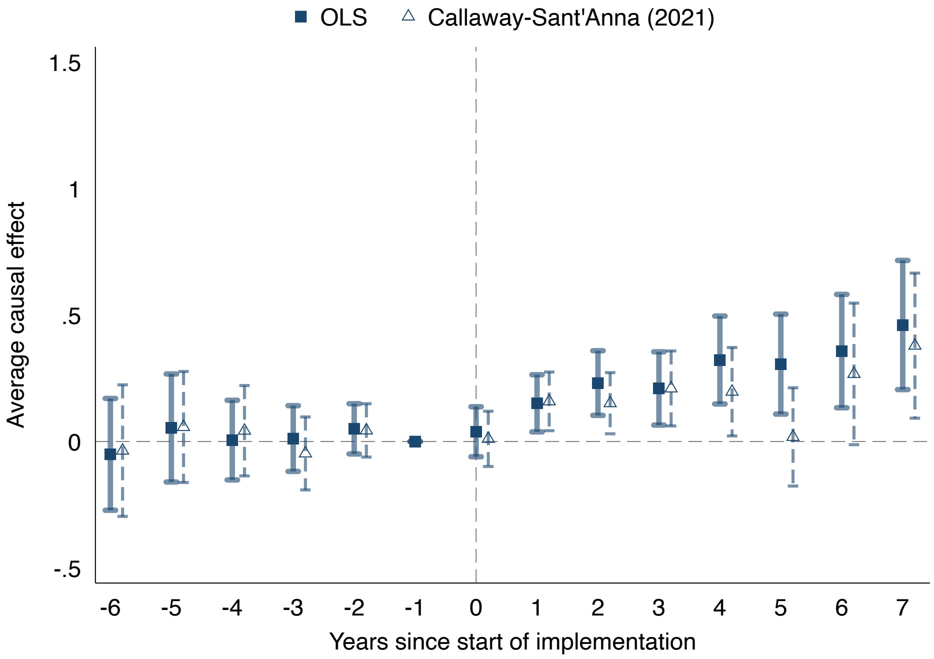
Figure D4

Effect of infrastructure development on infant mortality rate, by cause of death

Note. ‘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. Same notes as Figure 1.



(A) Waterborne

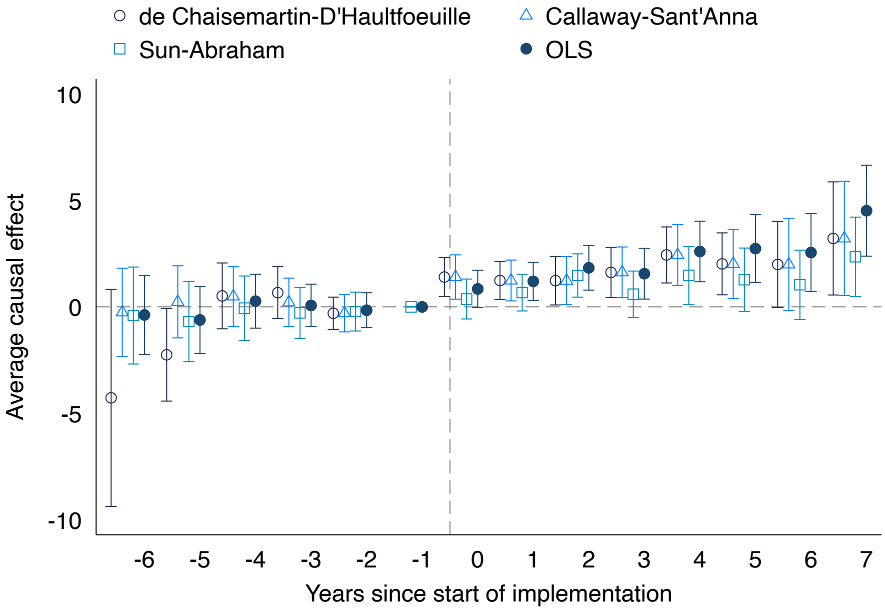


(B) Accidents

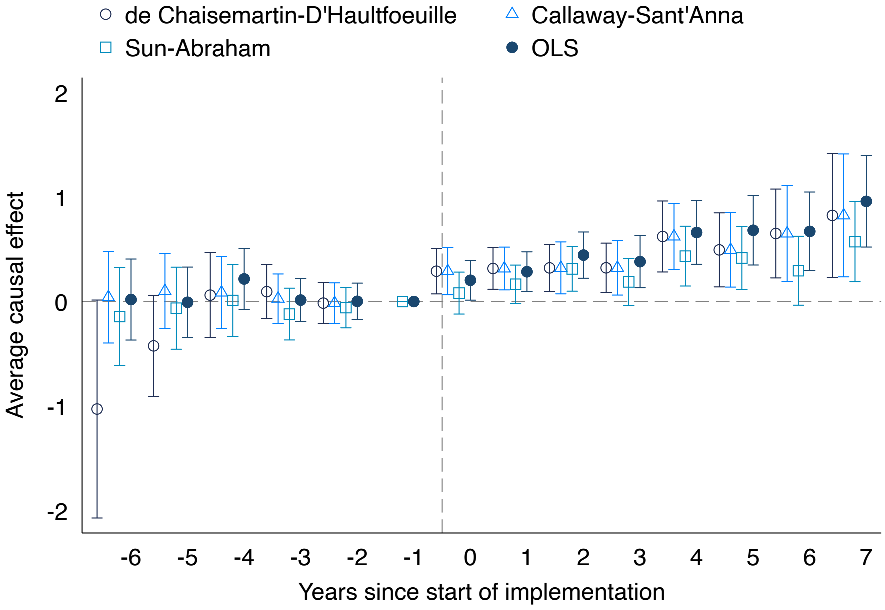
Figure D5

Effect of infrastructure development on under-5 mortality rate, by cause of death

Note. Same notes as Figure D4.



(A) Infant mortality rate



(B) Under-5 mortality rate

Figure D6
Robustness check: alternative TWFE estimators

Note. Event-study plots based on OLS (same notes as Figure 1) and three estimators robust to treatment effect heterogeneity: de Chaisemartin and D'Haultfoeuille (2020), Sun and Abraham (2021), and Callaway and Sant'Anna (2021). For de Chaisemartin-D'Haultfoeuille, the plot shows the maximum number of placebos that is possible with this estimator and the data. Infant mortality rate measured per 1,000 infants and under-5 mortality rate measured per 1,000 children under 5.

3 Adding controls

Table D4
Dynamic effect on infant mortality, additional controls

	(1)	(2)	(3)	(4)	(5)	(6)
Years since start of implementation						
Pre (–10 to –2)	-0.01	-0.01	0.08	0.12	0.08	0.12
	(0.47)	(0.46)	(0.47)	(0.47)	(0.58)	(0.48)
	[0.98]	[0.98]	[0.87]	[0.79]	[0.89]	[0.80]
Post 1 (0 to 3)	0.94	0.93	0.99	0.97	0.91	0.96
	(0.45)	(0.44)	(0.45)	(0.45)	(0.55)	(0.46)
	[0.03]	[0.04]	[0.03]	[0.03]	[0.10]	[0.04]
Post 2 (4 to 7)	1.63	1.51	2.04	2.02	1.80	2.12
	(0.70)	(0.69)	(0.71)	(0.71)	(0.86)	(0.73)
	[0.02]	[0.03]	[0.00]	[0.00]	[0.04]	[0.00]
Post 3 (8 to 10)	1.87	1.50	3.03	2.98	3.43	3.26
	(1.02)	(0.99)	(1.04)	(1.03)	(1.26)	(1.07)
	[0.07]	[0.13]	[0.00]	[0.00]	[0.01]	[0.00]
Pre – Post 1 (*p*-value)	0.08	0.08	0.08	0.09	0.23	0.10
Pre – Post 2 (*p*-value)	0.05	0.06	0.02	0.02	0.10	0.02
Pre – Post 3 (*p*-value)	0.10	0.17	0.01	0.01	0.02	0.01
Post 1 – Post 2 (*p*-value)	0.12	0.18	0.02	0.02	0.10	0.01
Post 2 – Post 3 (*p*-value)	0.67	0.99	0.08	0.09	0.02	0.05
Mean (pre-start)	15.82	15.82	15.82	15.82	16.04	15.82
District-years	10632	10632	10632	10632	7667	9946
Districts	1467	1467	1467	1467	1120	1400
Controls	**Geo × year**	**Region × year**	**Pop**	**Municipal**	**Other investments**	**Political turnover**

Note. Same notes as Table 1. Each column denotes a specification controlling for a different variable: 'Geo × year' is the geographic suitability index interacted with calendar year; 'Region × year' is dummies capturing each of the three geographical regions in Peru (i.e. coast, Andes, and Amazon) interacted with calendar year; 'Pop' controls for total population and population density (per km^2); 'Municipal' includes indicators capturing whether a district municipality has access to the internet, requires technical support for the implementation of investment projects, and manages at least one health center, and municipal budget (logs); 'Other investments' include expenditure on transportation, energy, and health projects (logs); and 'Political turnover' is an indicator capturing whether the municipality mayor, council, and officials changed as a result of the local elections of 2006, 2010 and 2014. Missing observations in 'Municipal' and 'Other investments' are imputed using the province-level average between 2005 and 2015. Differences in the sample are due to missing observations in 'Other investments' for 8 out of 194 provinces in Column 5 and due to unidentified political data for 84 districts in Column 6.

Table D5

Dynamic effect on under-5 mortality, additional controls

	(1)	(2)	(3)	(4)	(5)	(6)
Years since start of implementation						
Pre (–10 to –2)	0.06	0.06	0.08	0.09	0.08	0.10
	(0.10)	(0.10)	(0.10)	(0.10)	(0.12)	(0.10)
	[0.57]	[0.57]	[0.42]	[0.38]	[0.49]	[0.32]
Post 1 (0 to 3)	0.25	0.24	0.26	0.25	0.24	0.26
	(0.10)	(0.09)	(0.10)	(0.10)	(0.12)	(0.10)
	[0.01]	[0.01]	[0.01]	[0.01]	[0.04]	[0.01]
Post 2 (4 to 7)	0.45	0.41	0.55	0.55	0.56	0.56
	(0.15)	(0.14)	(0.15)	(0.15)	(0.18)	(0.15)
	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
Post 3 (8 to 10)	0.45	0.35	0.76	0.75	0.92	0.76
	(0.21)	(0.20)	(0.22)	(0.21)	(0.26)	(0.22)
	[0.03]	[0.08]	[0.00]	[0.00]	[0.00]	[0.00]
Pre – Post 1 (*p*-value)	0.03	0.03	0.03	0.03	0.11	0.03
Pre – Post 2 (*p*-value)	0.02	0.03	0.01	0.01	0.03	0.01
Pre – Post 3 (*p*-value)	0.10	0.20	0.01	0.01	0.00	0.01
Post 1 – Post 2 (*p*-value)	0.03	0.06	0.00	0.00	0.00	0.00
Post 2 – Post 3 (*p*-value)	0.98	0.58	0.08	0.09	0.01	0.10
Mean (pre-start)	4.32	4.32	4.32	4.32	4.43	4.33
District-years	10632	10632	10632	10632	7667	9946
Districts	1467	1467	1467	1467	1120	1400
Controls	**Geo × year**	**Region × year**	**Pop**	**Municipal**	**Other investments**	**Political turnover**

Note. Same notes as Table D4.

E Alternative channels

Could infrastructure development instead have affected mortality through demographic and behavioural changes?

I first examine whether the results could be explained by a drop in the denominator: the number of children under 5 years old. Using panel data formed by population forecasts for every district and year in the study period and the fully dynamic specification in Equation 3, I find no significant effect of infrastructure development on a district's under-5 population, nor pre-trends (see Figure E1).

Next, I investigate whether the observed increase in mortality rates is a result of migration. On the one hand, the prospect of sewerage networks might attract households, and overcrowding is a key determinant of early-life mortality (Marx et al., 2013). On the other hand, selective emigration could also explain the results. Higher-income individuals and the health-conscious, and thus those with lower mortality rates, could have migrated away from disruptive and odiferous sewerage infrastructure works.

Using three census rounds (2005, 2007, and 2017), Table E1 points in the direction that demographic compositional changes are not the main channel explaining increases in mortality rates. I use the static specification of Equation 1, but include a pre-treatment indicator, equal to 1 for treated districts and 0 for control districts in 2005, and a post-treatment indicator, equal to 1 for treated districts and 0 for control districts in 2017. The reference year is 2007. Here, control districts are those where a sewerage project was never developed in the period of study and treated districts are those where the implementation phase started after 2007. The analysis excludes districts treated before or in 2007. With this twist, I also show that there were no pre-trends by comparing the difference in outcomes between treated and control and between 2005 and 2007, before the implementation phase (see Panel A, 'Pre (2005)'). I next compare the difference in outcomes between treated and control in 2017 with that in 2007 (see Panel A, 'Post (2017)'). I also use the static specification of Equation 1 for all treated districts (see Panel B). I find no significant change in the district's total population during the implementation phase. I find suggestive evidence of positively selected migration, meaning that the estimated effect on early-life mortality rates could be downward biased. The share of households with a head who had completed secondary education increased by 0.01 percentage points (ppts), a small effect and hence not concerning. Better-educated households might have found the areas expanding access to sewerage attractive.[2]

Overall, these findings suggest that selective migration cannot explain the estimated increase in early-life mortality during the implementation phase.

Moreover, I rule out that reductions in connectivity to piped-water and sewerage systems can explain the core findings. With the specification in Panel B, I even find a significant increase of 2 ppts in the share of households that report using piped water as their main drinking source during the implementation phase. Potential reasons for this small improvement in water use are threefold. First, it could be explained by the positively selected immigration discussed before. Second, private inputs might have improved in response to poor public health during the implementation. Instead of using the limited sources of safe water to irrigate plots and for livestock, parents might have been more likely to use safe sources as drinking water to protect their children. This idea is in line with that of Jalan and Ravallion (2003), who state that public inputs are substitutes for parentally chosen private inputs. Third, the National Sanitation Plan complemented sewerage works with sensitisation campaigns highlighting the positive health externalities of using both safe water and sanitation (Von Hesse, 2016). Sewerage connectivity also seems to have increased during the implementation phase by 2–3 ppts on average. Although few districts completed all projects by the end of the study, partial completion can explain this estimated increase in sewerage connectivity.

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[2] Data on the share of households that are connected to the electricity network are only available for 2005 and 2017. Because I cannot test for pre-trends, I do not include this as an outcome to measure effects on selective migration.

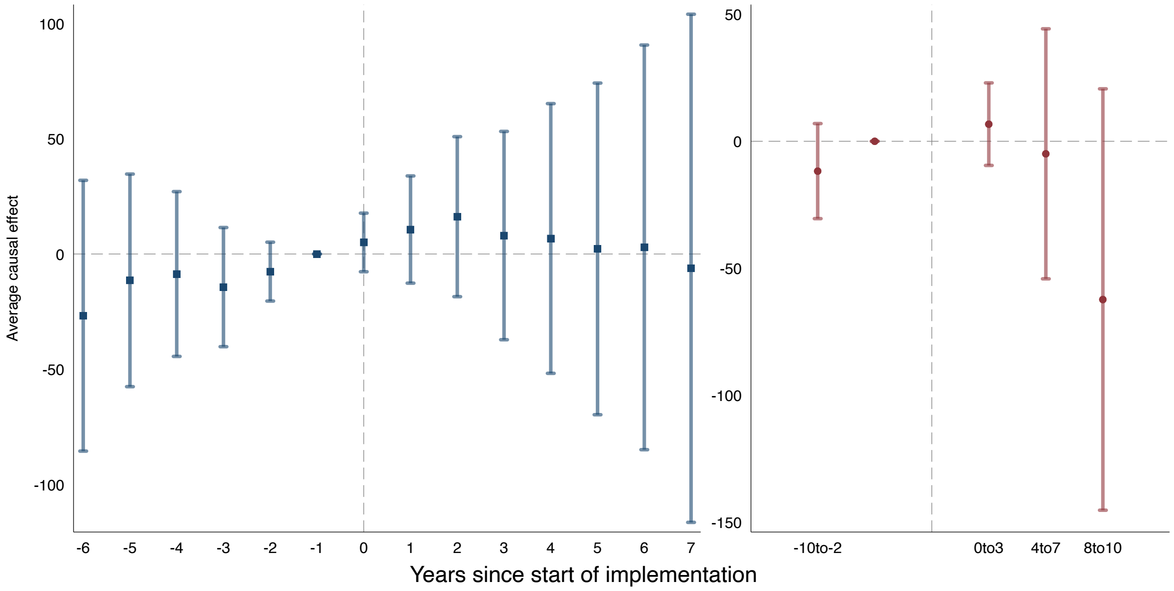


Figure E1
Effect on under-5 population

Note. Same notes as Figure 1.

Table E1
Effect of infrastructure development on demographics and behaviour

Dependent variable:	**Migration**	**Educated head**	**Piped water**	**Sewerage connectivity**
Unit:	Population		Share of households in district	
	(1)	(2)	(3)	(4)
Panel A				
Pre (2005)	-276.20	0.00	-0.02	-0.00
	(254.48)	(0.00)	(0.02)	(0.00)
	[0.28]	[0.12]	[0.38]	[0.51]
Post (2017)	528.12	0.01	0.02	0.03
	(588.46)	(0.00)	(0.02)	(0.01)
	[0.37]	[0.05]	[0.41]	[0.00]
Mean (pre-start)	15405.77	0.23	0.50	0.23
District-years	4064	4064	4064	4064
Districts	1356	1356	1356	1356
Panel B				
Implementation	-216.35	0.00	0.03	0.02
	(443.78)	(0.00)	(0.01)	(0.01)
	[0.63]	[0.06]	[0.01]	[0.00]
Mean (pre-start)	15636.43	0.23	0.50	0.23
District-years	4397	4397	4397	4397
Districts	1467	1467	1467	1467

Note. Estimates based on three census rounds for the years 2005, 2007, and 2017. In Panel A, 'Pre (2005)' is an indicator variable that equals 1 in 2005 for districts that started developing sewerage after 2007 and 0 for districts that never developed sewerage. 'Post (2017)' is an indicator variable that equals 1 for districts that started developing sewerage by 2017 and 0 otherwise. The reference period is 2007. The sample of analysis in Panel A excludes districts that started the implementation phase before 2007. In Panel B, 'Implementation' is an indicator variable that equals 1 after the implementation phase starts in a district that developed sewerage infrastructure and 0 otherwise. The dependent variables are: 'Population' (Column 1) measured as total inhabitants; 'Educated head' (Column 2) which denotes the share of household heads with secondary education completed; 'Piped water' (Column 3) measuring the share of households that use piped water for drinking purposes; and 'Sewerage connectivity' (Column 4) measuring the share of households that use a toilet connected to the public sewers as their main sanitation facility. 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 for variable definitions.

F Additional material for Section IV.4.i, Heterogeneous effects by intensity

1 Intensity of exposure to open projects

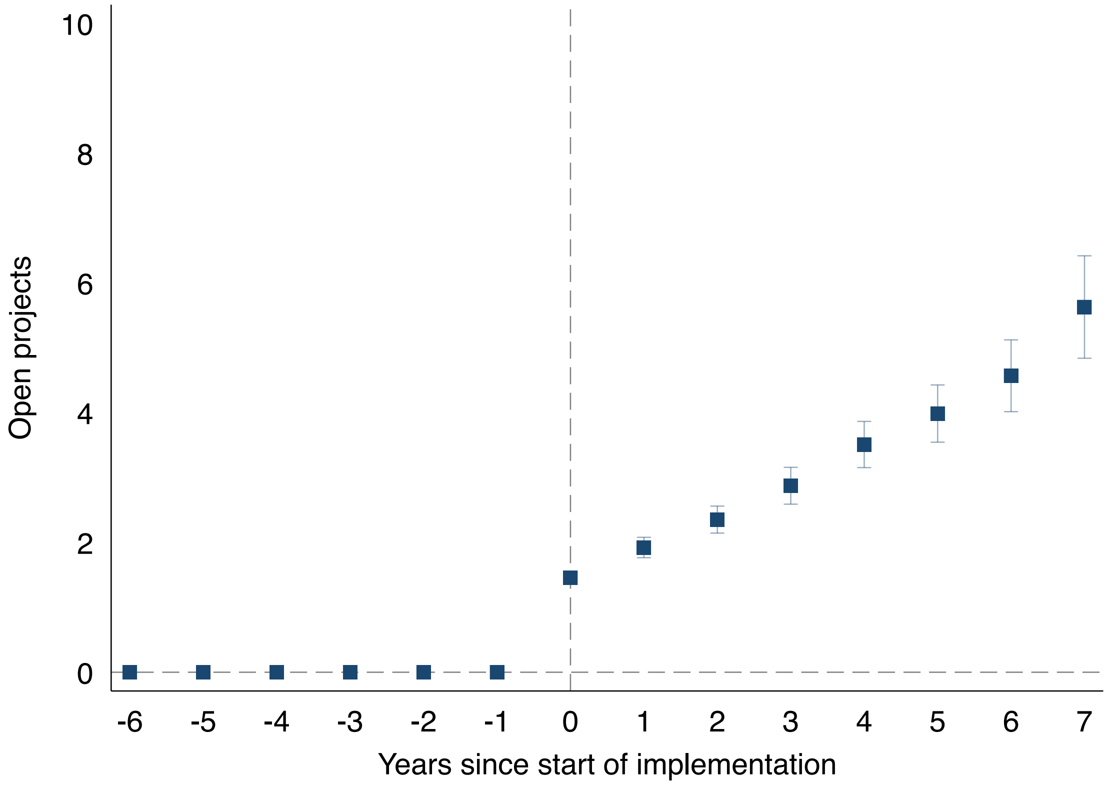


Figure F1
Event study of the number of open projects

Note. Event studies of the effect of infrastructure development on the number of open projects. Estimates of Equation 3, controlling for two-way fixed effects (district and calendar year), and their 90% confidence intervals are presented. $t-7$ is excluded as a normalization, and the periods at the extremes are trimmed.

2 Geographic suitability

To understand how geography affects the implementation of sewerage projects, I first run a regression of the total number of projects developed in a given district between 2005 and 2015 on the following geographic factors: elevation, slope, river density, and area.

I estimate the following ordinary least squares (OLS) regression:

$$S_d = \sum_{k=2}^{4} \beta_{1k} Gr_{dk} + \sum_{k=2}^{4} \beta_{2k} E_{dk} + \beta_4 R_d + \beta_3 A_d + \epsilon_d. \tag{4}$$

Here, S_d is the total number of started projects in district d between 2005 and 2015, Gr_{dk} is the share of area of district d falling into each of the three steep categories k (flat slope is the reference category), E_{dk} is the share of area of district d falling into each of the three elevated categories k (low altitude is the reference category), R_d is the district's river density (river length in km per area in km^2), and A_d is the total area of land within district boundaries.

As predicted by the engineering literature (Hammer, 1986; Romero Rojas, 2000; Panamerican Center of Sanitation Engineering and Environmental Sciences, 2005), I find that steep gradient categories and high river density favor sewerage infrastructure implementation, while elevation and district area are negatively associated with project placement (see Table F1). Steep slope and elevation predict the start of sewerage projects non-monotonically for slope and elevation.

I compute a geographic suitability index for all districts in Peru non-parametrically using principal component analysis, including all the above-described geographic factors. The computed index is the first component with an eigenvalue larger than 1. Peru's geographic diversity provides an ideal source of quasi-random variation. Figure F4 presents the spatial distribution of the suitability index.

The computed geographic suitability index correlates positively with the numbers of started projects and open projects, on average, across districts between 2005 and 2015 (Figure F2). At the project level, start is expedited in more geographically suitable areas, while completion is not correlated with the geographic suitability index (Figure F3).

Table F1
Geographic characteristics affecting sewerage implementation

Dependent variable	Sewerage projects 2005–15 OLS coefficient
Share district gradient {0.8, 4.19]%	-0.23
	(2.23)
	[0.92]
Share district gradient {4.19, 13]%	1.94
	(2.00)
	[0.33]
Share district gradient above 13%	0.98
	(1.71)
	[0.56]
Share district elevation {250, 500] mamsl	-5.55
	(1.62)
	[0.00]
Share district elevation {500, 1000] mamsl	-0.80
	(2.04)
	[0.70]
Share district elevation above 1000 mamsl	-7.19
	(1.33)
	[0.00]
River density ($\frac{km}{km^2}$)	0.00
	(0.00)
	[0.09]
District area (km^2)	-0.00
	(0.00)
	[0.04]

Note. The dependent variable is the number of sewerage projects started between 2005 and 2015. The omitted slope category is the share of district area in the flat category (below 0.8%) and the omitted elevation category is the share of district area in the low-altitude category (below 250 mamsl). Robust standard errors are given in parentheses and *p*-values in brackets.

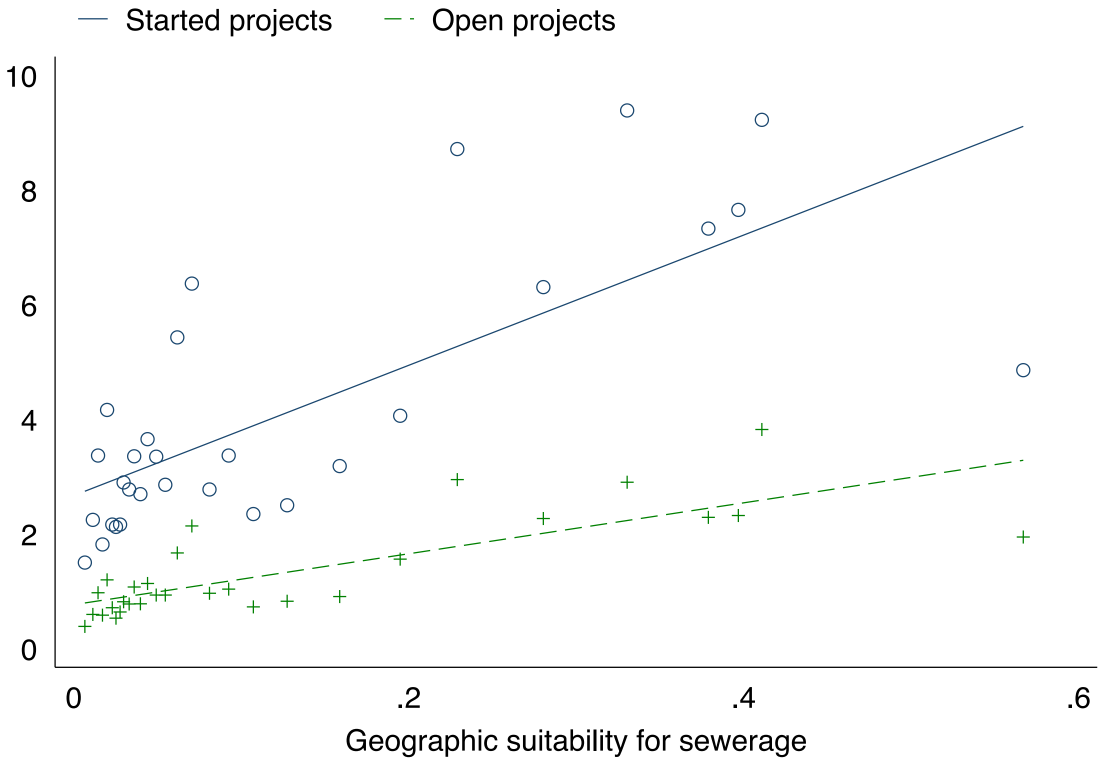


Figure F2
Geographic suitability and projects, district level

Note. ‘Started projects’ is the total number of projects started by 2015. ‘Open projects’ is the average number of projects started but not completed between 2005 and 2015.

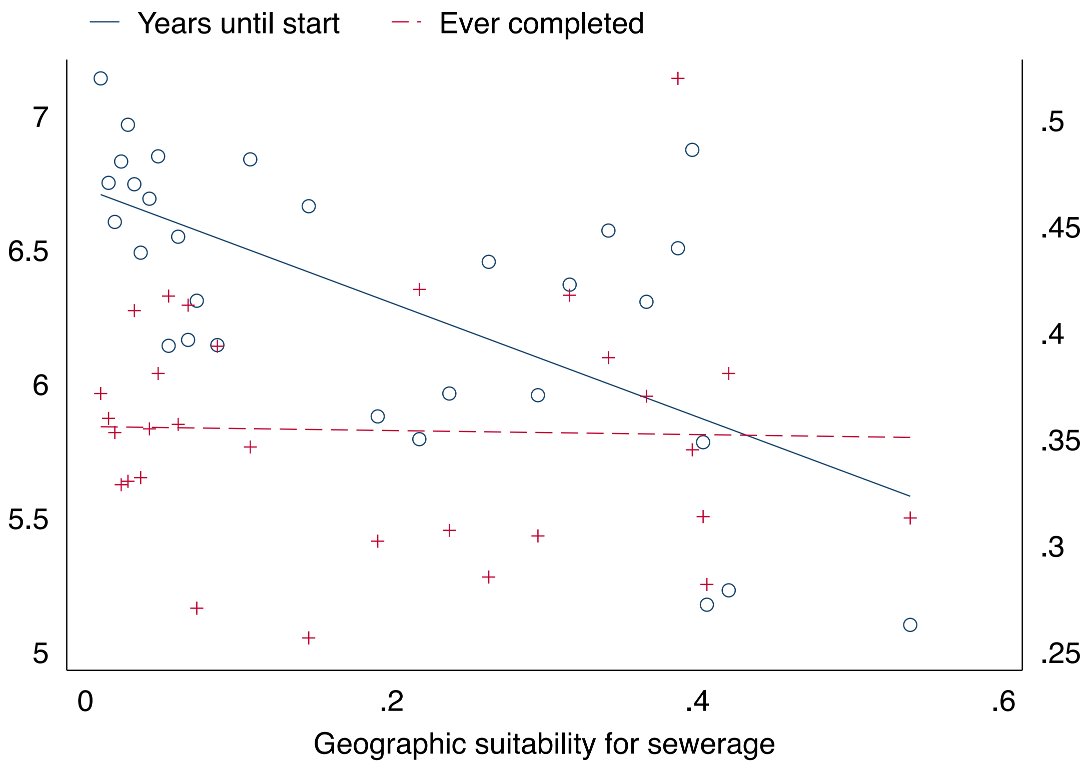


Figure F3
Geographic suitability and projects, project level

Note. 'Years until start' is the average number of years since 2005 until projects were started, measured by the left-hand y-axis. 'Ever completed' is the share of projects that were ever completed, measured by the right-hand y-axis.

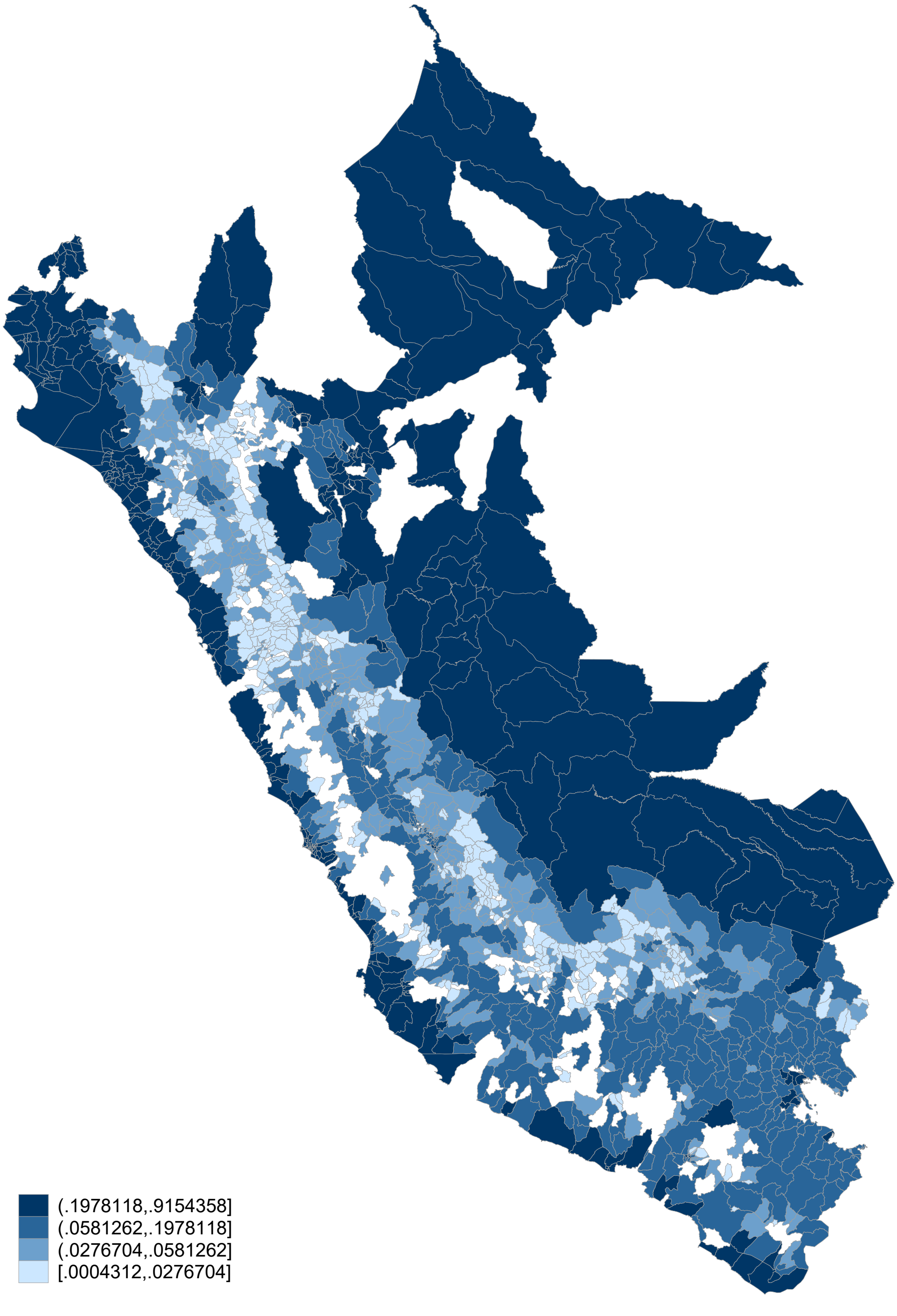


Figure F4
Spatial distribution of geographic suitability

Note. Map showing the distribution of the geographic suitability index. Lighter-shaded districts are less suitable than darker-shaded districts. Blank districts are those excluded from the analysis.

Table F2

Dynamic effect of infrastructure development on early-life mortality, high intensity

Dependent variable:	**Infant mortality rate**					**Under-5 mortality rate**				
Unit:	Deaths per 1,000 infants					Deaths per 1,000 children under 5 years old				
	All (1)	Waterborne (2)	Accidents (3)	Respiratory (4)	Other (5)	All (6)	Waterborne (7)	Accidents (8)	Respiratory (9)	Other (10)
Years since start of implementation										
Pre (–10 to –2)	0.53	0.48	0.13	-0.01	-0.07	0.04	0.07	0.03	-0.02	-0.04
	(0.56)	(0.39)	(0.24)	(0.28)	(0.21)	(0.12)	(0.09)	(0.06)	(0.07)	(0.06)
	[0.34]	[0.21]	[0.59]	[0.96]	[0.75]	[0.73]	[0.41]	[0.58]	[0.75]	[0.47]
Post 1 (0 to 3)	0.88	0.80	0.27	-0.27	0.08	0.21	0.23	0.05	-0.05	-0.02
	(0.53)	(0.40)	(0.22)	(0.29)	(0.21)	(0.12)	(0.09)	(0.05)	(0.07)	(0.06)
	[0.10]	[0.05]	[0.21]	[0.35]	[0.71]	[0.07]	[0.01]	[0.31]	[0.50]	[0.72]
Post 2 (4 to 7)	2.20	1.44	0.88	-0.45	0.33	0.60	0.46	0.20	-0.11	0.04
	(0.90)	(0.60)	(0.39)	(0.40)	(0.29)	(0.19)	(0.13)	(0.09)	(0.09)	(0.07)
	[0.01]	[0.02]	[0.03]	[0.26]	[0.25]	[0.00]	[0.00]	[0.02]	[0.22]	[0.55]
Post 3 (8 to 10)	2.90	1.51	1.01	-0.18	0.55	0.78	0.52	0.25	-0.04	0.06
	(1.28)	(0.84)	(0.59)	(0.55)	(0.45)	(0.27)	(0.19)	(0.13)	(0.12)	(0.11)
	[0.02]	[0.07]	[0.09]	[0.75]	[0.22]	[0.00]	[0.01]	[0.06]	[0.72]	[0.62]
Pre – Post 1 (*p*-value)	0.22	0.11	0.40	0.50	0.81	0.19	0.04	0.56	0.78	0.77
Pre – Post 2 (*p*-value)	0.12	0.17	0.14	0.23	0.22	0.01	0.01	0.14	0.29	0.27
Pre – Post 3 (*p*-value)	0.11	0.28	0.22	0.76	0.19	0.02	0.03	0.16	0.86	0.39
Post 1 – Post 2 (*p*-value)	0.02	0.08	0.02	0.38	0.18	0.00	0.00	0.02	0.17	0.15
Post 2 – Post 3 (*p*-value)	0.30	0.88	0.65	0.33	0.42	0.17	0.54	0.46	0.32	0.86
Mean (pre-start)	15.05	7.76	2.71	2.29	2.28	4.00	1.81	0.92	0.63	0.64
District-years	5951	5951	5951	5951	5951	5951	5951	5951	5951	5951
Districts	734	734	734	734	734	734	734	734	734	734

Note. Same notes as Table 3. Sample restricted to districts that experienced high intensity of construction works, computed as their geographic suitability for low-cost sewerage projects being at or above the median of the distribution.

Table F3
Dynamic effect of infrastructure development on early-life mortality, low intensity

Dependent variable:	**Infant mortality rate**					**Under-5 mortality rate**				
Unit:	Deaths per 1,000 infants					Deaths per 1,000 children under 5 years old				
	All (1)	Waterborne (2)	Accidents (3)	Respiratory (4)	Other (5)	All (6)	Waterborne (7)	Accidents (8)	Respiratory (9)	Other (10)
Years since start of implementation										
Pre (–10 to –2)	-0.43	-1.01	-0.09	0.44	0.24	0.14	-0.17	0.08	0.17	0.06
	(0.77)	(0.65)	(0.36)	(0.35)	(0.36)	(0.17)	(0.15)	(0.10)	(0.08)	(0.09)
	[0.58]	[0.12]	[0.80]	[0.21]	[0.51]	[0.40]	[0.25]	[0.45]	[0.04]	[0.51]
Post 1 (0 to 3)	0.92	-0.16	0.38	0.70	-0.00	0.26	-0.02	0.18	0.22	-0.12
	(0.76)	(0.62)	(0.35)	(0.36)	(0.38)	(0.16)	(0.15)	(0.10)	(0.09)	(0.10)
	[0.22]	[0.80]	[0.28]	[0.05]	[1.00]	[0.09]	[0.89]	[0.07]	[0.01]	[0.20]
Post 2 (4 to 7)	1.15	0.48	0.64	0.34	-0.31	0.36	0.12	0.27	0.16	-0.19
	(1.14)	(0.86)	(0.57)	(0.49)	(0.47)	(0.24)	(0.19)	(0.16)	(0.12)	(0.13)
	[0.31]	[0.57]	[0.26]	[0.49]	[0.50]	[0.14]	[0.53]	[0.09]	[0.16]	[0.13]
Post 3 (8 to 10)	3.29	2.12	0.73	0.18	0.27	0.69	0.40	0.28	0.11	-0.10
	(1.71)	(1.40)	(0.99)	(0.70)	(0.78)	(0.35)	(0.31)	(0.25)	(0.17)	(0.21)
	[0.06]	[0.13]	[0.46]	[0.80]	[0.73]	[0.05]	[0.20]	[0.28]	[0.51]	[0.64]
Pre – Post 1 (*p*-value)	0.25	0.25	0.46	0.15	0.73	0.24	0.42	0.18	0.02	0.13
Pre – Post 2 (*p*-value)	0.24	0.13	0.27	0.86	0.32	0.43	0.17	0.30	0.93	0.09
Pre – Post 3 (*p*-value)	0.05	0.04	0.45	0.73	0.97	0.16	0.08	0.49	0.74	0.49
Post 1 – Post 2 (*p*-value)	0.75	0.28	0.47	0.30	0.41	0.53	0.27	0.36	0.42	0.44
Post 2 – Post 3 (*p*-value)	0.04	0.10	0.90	0.67	0.28	0.12	0.18	1.00	0.63	0.52
Mean (pre-start)	16.59	8.35	3.38	2.48	2.38	4.65	1.99	1.16	0.78	0.73
District-years	4681	4681	4681	4681	4681	4681	4681	4681	4681	4681
Districts	733	733	733	733	733	733	733	733	733	733

Note. Same notes as Table 3. Sample restricted to districts that experienced low intensity of construction works, computed as their geographic suitability for low-cost sewerage projects being below the median of the distribution.

Table F4
'Horse-race'-like heterogeneous effects

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	-0.76	-0.70	-0.52	0.52	-0.06
	(1.10)	(0.74)	(0.55)	(0.50)	(0.53)
	[0.49]	[0.34]	[0.34]	[0.30]	[0.92]
Implementation × High intensity	0.60	0.74	0.11	-0.30	0.05
	(0.69)	(0.46)	(0.33)	(0.29)	(0.29)
	[0.39]	[0.11]	[0.73]	[0.29]	[0.86]
Mean (pre-start)	15.83	8.06	3.05	2.39	2.33
Panel B: U5MR					
Implementation	-0.13	-0.23	-0.04	0.12	0.01
	(0.24)	(0.19)	(0.13)	(0.13)	(0.13)
	[0.59]	[0.21]	[0.78]	[0.33]	[0.92]
Implementation × High intensity	0.26	0.24	-0.01	-0.01	0.04
	(0.14)	(0.11)	(0.08)	(0.07)	(0.07)
	[0.07]	[0.03]	[0.93]	[0.87]	[0.53]
Mean (pre-start)	4.33	1.90	1.04	0.70	0.69
District-years	10602	10602	10602	10602	10602
Districts	1464	1464	1464	1464	1464

Note. Same notes as Table 4. I control for the interaction 'Implementation' by the following initial characteristics: district being above the median of population, population density, share HH piped water, share HH sewerage, share HH head secondary, share HH electricity, and municipal budget; as well as indicators for municipality internet connectivity, technical support, and managing a health center. The lower sample size is due to missings in the additional heterogeneity dimensions.

3 Effect of open projects

To visualize pre-treatment effects in the first-stage regression, I first leverage the dynamic event study used in the main analysis. This empirical strategy is akin to that of Nunn and Qian (2011) and the first-stage equation is denoted by:

$$N_{d,t=h} = \sum_{\substack{h=-a \\ h\neq -1}}^{b} \alpha_h (1[K_{dt} = h] \times H_d) + \sum_{\substack{h=-a \\ h\neq -1}}^{b} \tau_h 1[K_{dt} = h] + \phi_d + \lambda_t + \mu_{dt} \tag{5}$$

where $N_{d,t=h}$ measures the number of open projects in district d and years since event h. H_d is an indicator for the geographical suitability index being at or above the median of the distribution, which is captured in levels by the district fixed effects ϕ_d. All other variables are defined as in Equation 3. The estimated coefficients α_h measure the increase in open projects experienced by districts that are suitable for sewerage infrastructure (relative to those that are not suitable) after the implementation phase was started (relative to before).

Figure F5 shows that there are no indications of pre-trends, and that the number of open projects increases consistently in every additional year of exposure for districts that are geographically suitable.

Next, to estimate the effect of the number of open projects on early-life mortality, I use an adapted version of the static specification in Equation 1. The first stage is given by:

$$N_{dt} = \tau^{static} D_{dt} + \alpha D_{dt} \times H_d + \phi_d + \lambda_t + \nu_{dt} \tag{6}$$

I then estimate the following specification using two-stage least squares (2SLS):

$$Y_{dt} = \beta N_{dt} + \phi_d + \lambda_t + \nu_{dt} \tag{7}$$

where N_{dt} is the number of open projects in district d and year t. All other parameters are the

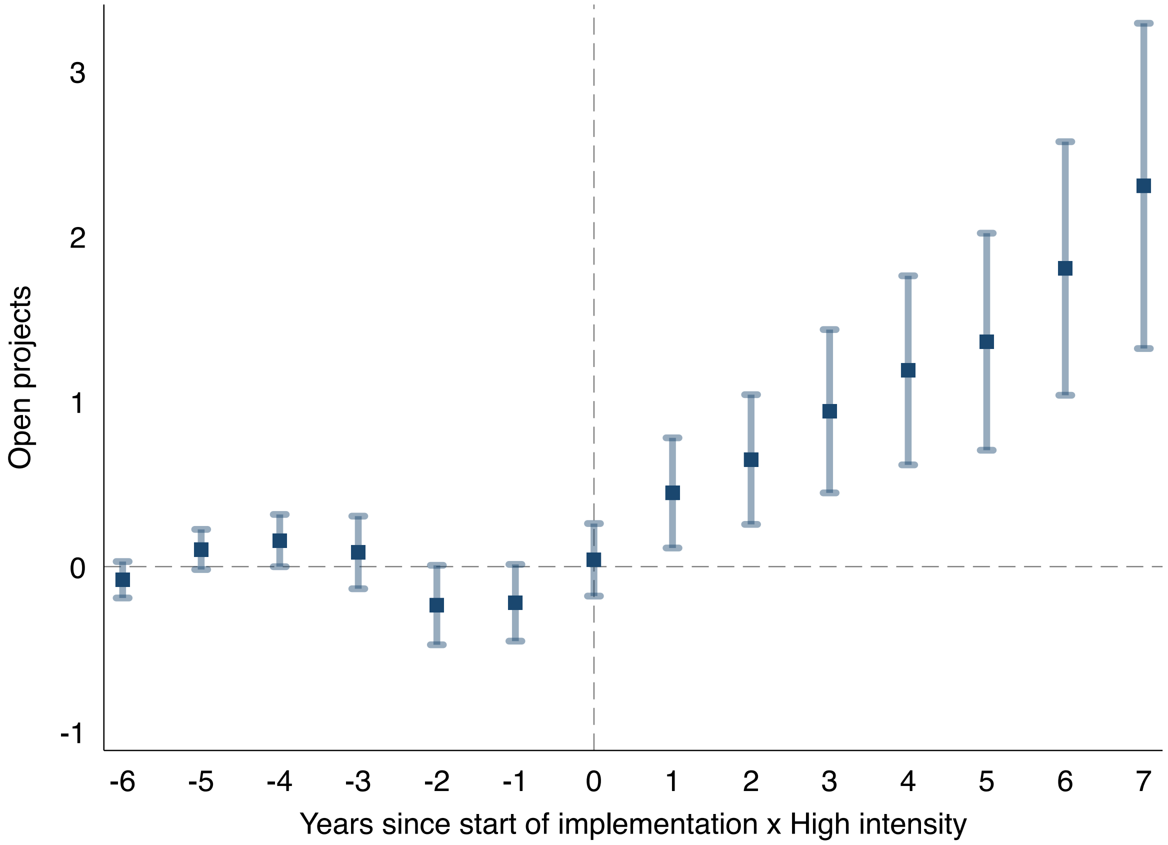


Figure F5
Dynamic effect on open projects

Note. OLS estimates of Equation 5, controlling for fully dynamic event-study estimates and two-way fixed effects (district and calendar year), and their 90% confidence intervals (clustering standard errors by districts) are presented. The first lead is excluded as a normalization. The plot shows the estimates of the interaction between event indicators and the suitability index, trimming the periods at the extremes where fewer than 35% of treated districts experienced event h.

same as specified in Equation (1).

The coefficient of interest is β, which captures the estimated impact on early-life mortality of an additional unfinished project after the start of the implementation phase. The instrument is likely to comply with the monotonicity assumption, as all suitable districts are more likely to start projects (and thus have open projects), as opposed to being less likely to start projects due to their geographical advantages ('defiers').

The 2SLS estimation is a weighted average of the unit causal responses along the length of the number of open projects. There is more than one causal effect for a given district: the effect of going from 0 to 1 open project, from 1 to 2 projects, and so on. Thus, there are $n_{\max}$ causal effects, because n takes on values in the set $\{0, 1, \ldots, n_{\max}\}$. The unit causal response is the average difference in potential mortality rates in districts between n and $n-1$.

More specifically, the 2SLS estimates capture the 'local (weighted) average treatment effect' of the unit causal responses in districts that implemented more sewerage projects (or not) only driven by their geographic suitability for sewerage projects. These districts are known as 'compliers'. What the 2SLS estimates do not capture is the effect of projects started in specific districts for, say, political reasons, even if they are not geographically suitable. These districts are known as 'always-takers'.

Table 4 shows the reduced-form estimates, as it presents the effect of D_{dt} and $D_{dt} \times H_d$ on mortality. Table F5 presents the 2SLS estimations for overall early-life mortality and mortality disaggregated by cause of death. Following the recommendation of Lee et al. (2020), I also report the p-values of the Anderson and Rubin (1949) test that is robust to weak instruments. The t-ratio inference procedures have been proven by Lee et al. to yield distortions in size and coverage rates in instrumental variable (IV) strategies. They recommend using the Anderson–Rubin test, as it is known to have correct size and coverage and attractive optimality properties, while also being robust to arbitrarily weak instruments. The test rejects the null hypothesis that the estimated effects are equal to zero for overall mortality and mortality caused by waterborne diseases and accidents.

The Kleibergen–Paap F-statistic of excluded instruments is 72.96, way higher than the Stock and Yogo (2002) weak instrumental variable test critical value for the 10% maximal IV size (19.93). This means that the bias of the IV estimator, relative to the bias of OLS, is below 10% for a 5%-level test.

Table F5
Effect of open projects on early-life mortality, 2SLS

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					
Open projects	0.49	0.37	0.16	-0.04	0.01
	(0.22)	(0.16)	(0.10)	(0.09)	(0.08)
	[0.02]	[0.02]	[0.10]	[0.63]	[0.91]
AR p-values	0.08	0.07	0.24	0.54	0.80
Mean (pre-start)	15.82	8.06	3.04	2.39	2.33
Panel B: U5MR					
Open projects	0.12	0.10	0.04	0.01	-0.02
	(0.05)	(0.04)	(0.02)	(0.02)	(0.02)
	[0.01]	[0.00]	[0.12]	[0.69]	[0.23]
AR p-values	0.03	0.01	0.28	0.73	0.22
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

Note. Estimates based on district-level panel data spanning the years 2005–15. Coefficients correspond to estimates of Equation 7 using 2SLS and D_{dt} and $D_{dt} \times H_d$ as instruments. 'Open projects' measures the number of projects that were started but not yet completed in district d and calendar year t. The dependent variables are the infant mortality rate (IMR) per 1,000 infants in Panel A and the under-5 mortality rate (U5MR) per 1,000 children under 5 in Panel B. All regressions include district and year fixed effects. Standard errors clustered by district are reported in parentheses and p-values in brackets. The table also reports the weak-instrument-robust Anderson–Rubin (AR) p-values.

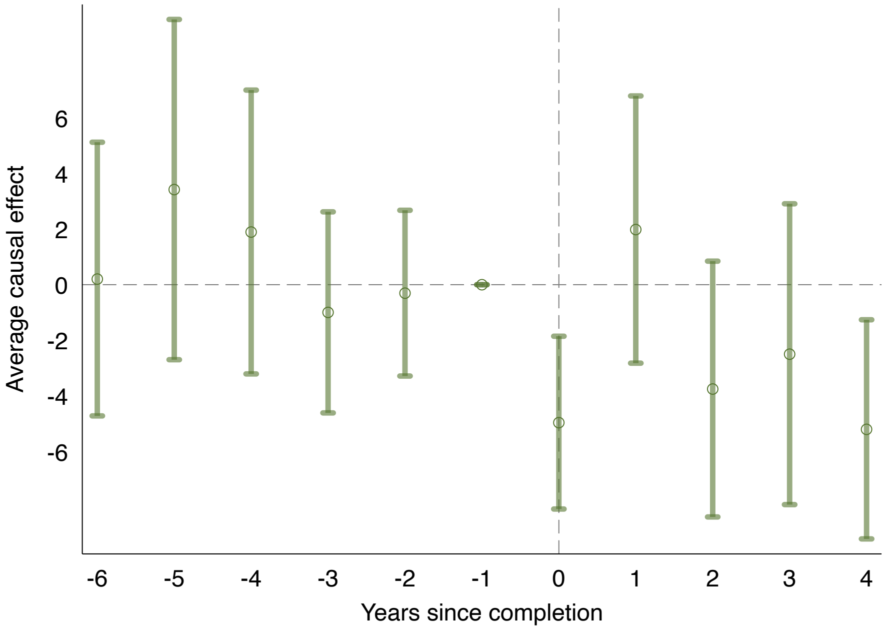
G Additional material for Section IV.4.ii, Completion

Initial district and municipal characteristics are balanced across district municipalities that completed and did not complete sewerage works that were started during the period of study (see Columns 1 and 2 of Table G1). Also, a Cox hazard model shows that the timing of completion is expedited in municipalities having access to the internet and located at the coast or in the Andean region, and delayed in districts with greater population density and a larger share of households with a head who attained completed secondary education (see Columns 3 and 4 of Table G1).

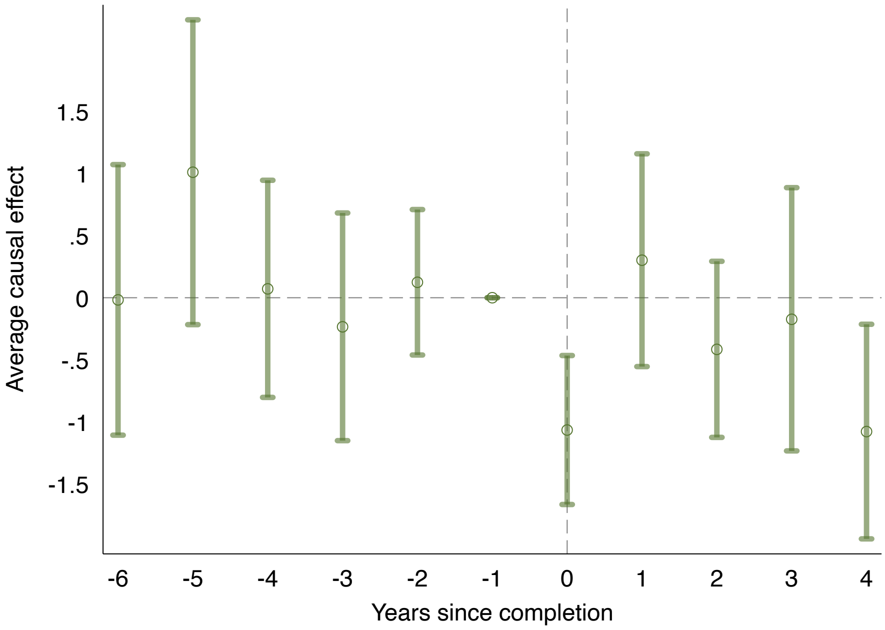
Table G1
Treatment status and timing of completion

	OLS **Ever completed**		**Cox hazard model** **Timing of completion**	
	(1)	(2)	(3)	(4)
1. Geographical features				
Share district gradient (0.8, 4.19]%	0.15	0.12	-0.04	-0.09
	(0.12)	(0.12)	(0.82)	(0.86)
Share district gradient (4.19, 13]%	0.13	0.17	0.29	0.31
	(0.11)	(0.11)	(0.69)	(0.71)
Share district gradient above 13%	0.12	0.13	0.32	0.20
	(0.10)	(0.11)	(0.67)	(0.69)
Share district elevation (250, 500] mamsl	-0.34**	-0.31*	-0.96	-0.84
	(0.13)	(0.14)	(0.83)	(0.85)
Share district elevation (500, 1000] mamsl	-0.10	-0.11	0.05	0.05
	(0.12)	(0.12)	(0.75)	(0.77)
Share district elevation above 1000 mamsl	-0.17*	-0.17*	0.28	0.35
	(0.08)	(0.08)	(0.56)	(0.58)
District area (km^2)	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
River density ($\frac{km}{km^2}$)	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Coast	-0.02	0.01	-0.84**	-0.74*
	(0.05)	(0.06)	(0.31)	(0.32)
Andes	-0.00	0.00	-0.67*	-0.63*
	(0.05)	(0.05)	(0.28)	(0.28)
2. District characteristics				
Population	0.00*	0.00*	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)
Population density ($\frac{pop}{km^2}$)	-0.00*	-0.00	0.00***	0.00*
	(0.00)	(0.00)	(0.00)	(0.00)
Share HH piped water	-0.00	0.01	0.45	0.45
	(0.07)	(0.07)	(0.35)	(0.36)
Share HH sewerage	-0.86	-1.91	2.32	-2.80
	(1.98)	(2.06)	(10.97)	(11.26)
Share HH latrine	-1.06	-2.06	5.34	0.32
	(1.98)	(2.06)	(10.97)	(11.25)
Share HH open defecation	-1.07	-2.10	6.05	0.95
	(1.97)	(2.06)	(10.95)	(11.24)
Share HH head secondary	0.12	0.14	4.13***	4.08***
	(0.22)	(0.23)	(1.11)	(1.16)
Share HH electricity	-0.15	-0.16	-0.73	-0.74
	(0.09)	(0.09)	(0.43)	(0.45)
3. Municipal characteristics				
Municipal budget (2010 USD, million)	0.00	0.00	0.01	0.01
	(0.00)	(0.00)	(0.01)	(0.01)
Internet connectivity	0.04	0.05	-0.59**	-0.66**
	(0.03)	(0.04)	(0.22)	(0.23)
Technical support	-0.00	-0.00	-0.05	-0.07
	(0.03)	(0.03)	(0.16)	(0.16)
Manages health centers	-0.04	-0.05	-0.53*	-0.51*
	(0.04)	(0.04)	(0.23)	(0.24)
Re-election rate since 1993		-0.10		0.11
		(0.09)		(0.47)
Observations	1340	1251	1340	1251

Note. Initial characteristics are from 2005. Coefficients of an OLS regression with treatment status capturing ever completing infrastructure in Columns 1 and 2. Cox regression of timing until the events 'Completion' in Columns 3 and 4. Robust standard errors reported in parentheses. Statistical significance denoted by *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Sample in Columns 2 and 4 reduced due to missings in the 'Re-election rate since 1993' variable.



(A) Infant mortality rate



(B) Under-5 mortality rate

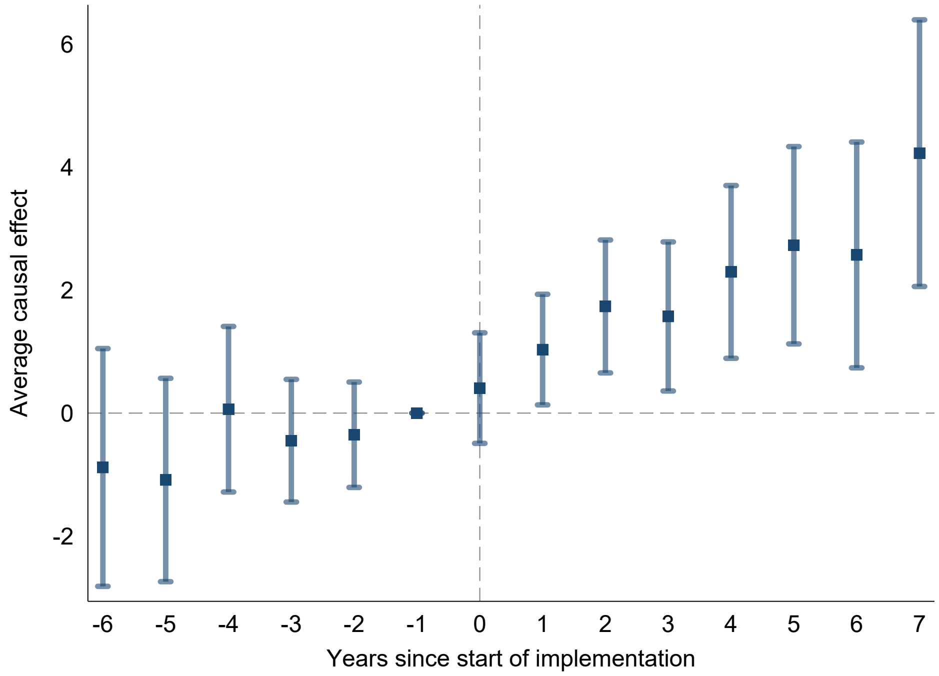
Figure G1
Effect of completion on early-life mortality

Note. Controlling for two-way fixed effects (district and calendar year) and clustering standard errors at the district level. The first lead is excluded as a normalization. Only 13% of districts that started a project completed all during the period of study. Sample restricted to districts that developed sewerage infrastructure between 2005 and 2015.

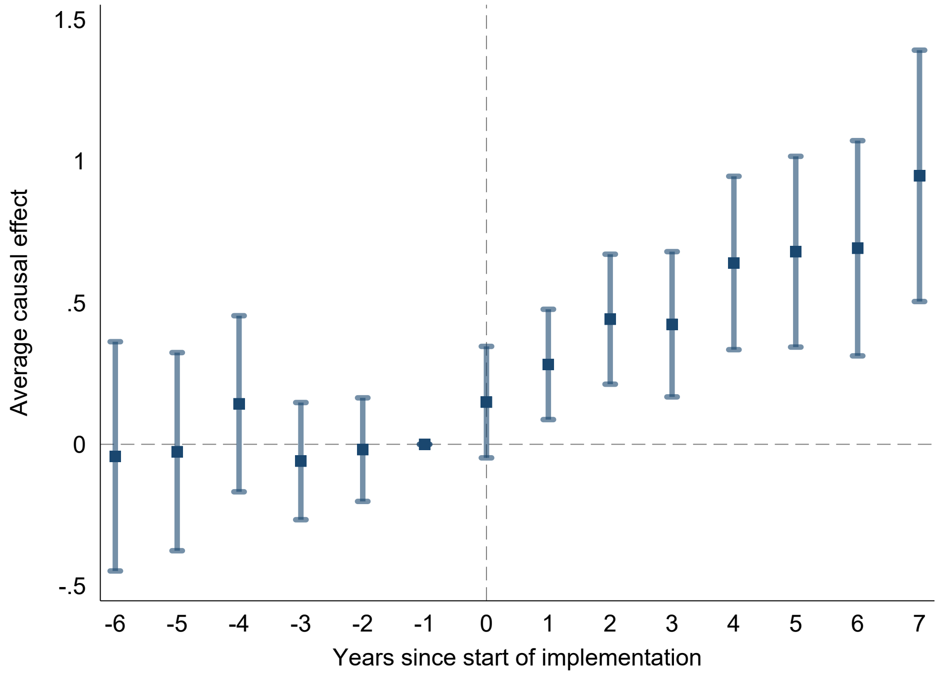
Table G2
Static effect of infrastructure completion on early-life mortality

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					
Completion	-2.67	0.18	-1.16	-1.02	-0.67
	(1.37)	(0.97)	(0.76)	(0.77)	(0.60)
	[0.05]	[0.85]	[0.13]	[0.19]	[0.26]
Mean (pre-start)	11.07	5.61	1.63	1.79	2.04
Panel B: U5MR					
Completion	-0.57	0.18	-0.35	-0.26	-0.14
	(0.26)	(0.21)	(0.18)	(0.15)	(0.14)
	[0.03]	[0.40]	[0.06]	[0.09]	[0.34]
Mean (pre-start)	3.02	1.30	0.62	0.53	0.58
District-years	4748	4748	4748	4748	4748
Districts	884	884	884	884	884

Note. Same notes as Table 2, but with the completion of the implementation phase as the treatment. The lower sample size is due to the exclusion of district-years in which no project was started. The number of districts is below the 1,141 districts that were treated due to singleton groups dropped when using district fixed effects.



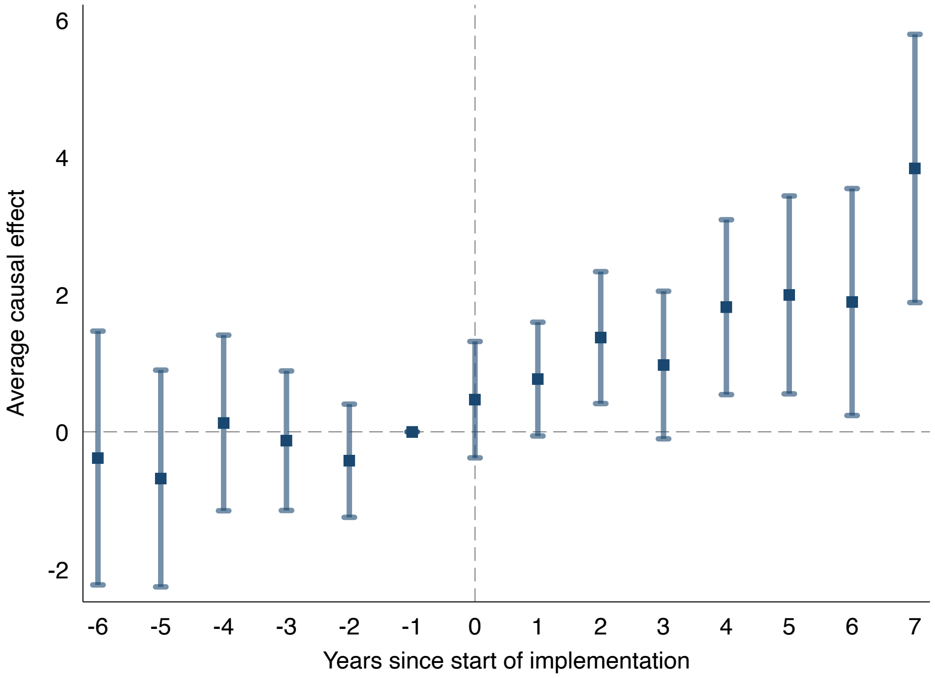
(A) Infant mortality rate



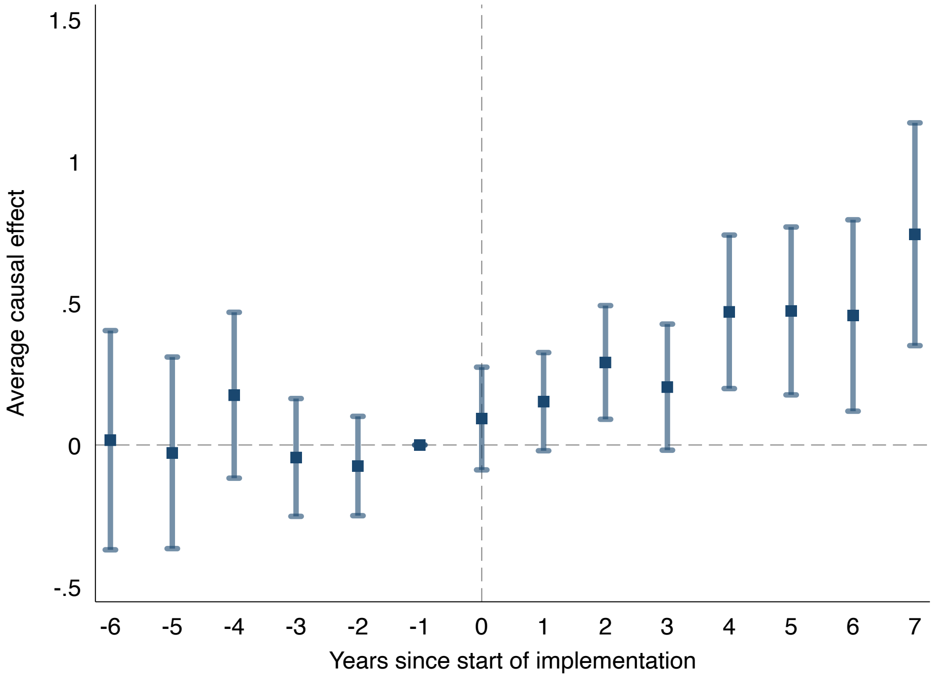
(B) Under-5 mortality rate

Figure G2
Effect of infrastructure development, excluding districts that completed works

Note. Same notes as Figure 1. Sample restricted to districts that were permanently exposed to the implementation phase. Recall that only 13% of districts that started projects completed all.



(A) Infant mortality rate



(B) Under-5 mortality rate

Figure G3
Effect of infrastructure development, setting as control in-between periods

Note. Same notes as Figure 1. Setting as control the in-between periods, where no project is occurring, but later on new projects are implemented (6% of treated district for an average of 2.5 years).

H Additional material for Section V1, Policy implications

To understand what happened during the implementation phase, Figure H1 presents a pair-wise correlation matrix across project characteristics by 2015. The number of years until a project starts is negatively correlated with duration, being completed, and having been halted at least one year, likely driven by the censoring of the data by 2015. Duration is positively correlated with having been halted and negatively correlated with being completed. No other project characteristics are correlated with start, duration, or completion, including cost overruns, the type of project (construction, expansion or improvement), the implementing agency, the investment amount, and the targeted population.

On average, projects took two years to complete but doubled in duration if halted. There was significant variation in the duration of project halts, ranging from one year to indefinitely. Older projects had a higher chance of being halted by 2015 due to data censorship. On average, projects were halted for 2.5 years. By 2015, 40% of projects initiated were halted and could be considered abandoned if not resumed and completed (see Figure H1, upper panel).

It is noteworthy that nearly 85% of district municipalities initiating sewerage projects halted them for at least a year. In more than 30% of these districts, all projects were halted at some point. These halts delayed infrastructure completion and prolonged the implementation phase. Treated districts were, on average, 3.6 years under project halts. 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) (see Figure H1, lower panel).

A natural question to ask is whether halting projects makes the implementation phase more dangerous, e.g. because health and safety measures depreciate more if projects are halted. Leveraging variation in the timing that halting started, I find no statistical difference in early-life mortality before and after the first halt of projects (see Figure H3).

However, halting projects exacerbates the lethal effects of the implementation phase in two ways: because of the delays entailed and the risk of abandonment.

Delays

Halting projects delays the completion of the implementation phase. With back-of-the-envelope calculations, I show that the social cost–benefit ratios of infrastructure projects are typically underestimated, and that these are even higher when the implementation phase experiences unnecessary delays. Because there are no data on expected completion, I deduce the average delay by comparing the time that the implementation phase took in districts where projects were halted and in districts where they were never halted. Figure H2 shows that the share of projects halted out of those open in a district is positively correlated with the duration of the implementation phase.

Calculating social cost–benefit ratios is a difficult task since there might be other social costs and I focus on just one in this study. For instance, morbidity must have increased and quality of life was jeopardised for all. Even for children who survive, early-life illness can have long-term negative consequences in terms of cognitive development, adult health, productivity, and earnings (Case and Paxson, 2008).

I estimate the monetary value for children under 5 who died due to hazards while projects were implemented and compare this with the monetary value of children who survived as a result of greater access to sewerage infrastructure. This exercise requires several assumptions. First, I follow a typical assumption that the survival of children today is worth more than the survival of children in the future, using a discount rate of 5%. Second, I assume that a surviving child would live a healthy life for another 70 years – life expectancy in Peru was 75 years in 2015 (World Bank, 2020). Third, I assume that the value of a healthy life year is about USD 75,000, a lower-bound estimate in economic studies (typically USD 75,000–150,000) (Watson, 2006). Furthermore, I convert this study's estimates to be measured per 1,000 children under 5 for ease of comparison with other studies' estimates.

I use the estimated effect of completed sewerage infrastructure on child mortality from two scenarios: (1) the estimated effect on child mortality in Argentina between 1990 and 1999 in Galiani et al. (2005), which is similar to the estimated static effect on under-5 mortality from full completion (according to Table G2); and (2) the estimated effect on child mortality in Massachusetts between 1880 and 1920 from Alsan and Goldin (2019). The estimated effects of completed sewerage on child mortality are –0.334 per 1,000 children for Scenario 1 and –4.037 per 1,000 children for Scenario 2. The latter scenario is very optimistic and stems from a context in which the initial sanitation and disease environment in Massachusetts in 1880 was worse than the case of Peru in the early 2000s. For both scenarios, I assume that the negative effect on mortality rates accrues in perpetuity without growing in magnitude. The net present value of these benefits accrued in perpetuity for each scenario is (1) USD 35 million and (2) USD 424 million.[3]

I estimate the social costs of two cases. Case A corresponds to the pathway of infrastructure development in districts where no project was halted, which have a mean of 2.6 years of exposure to construction works. I take the estimates from Table 2 (Column 1 of Panel B shows an increase of 0.16 deaths per 1,000 under-5s per year and per district), which are comparable to the static estimates of Galiani et al. (2005) and Alsan and Goldin (2019). The total social cost amounts to USD 2.2 million per 1,000 children and district. This cost corresponds to 6% of the social benefit in Scenario 1 and less than 1% of the benefit in the optimistic scenario (2).

In contrast, in Case B, I consider districts where at least one project was halted, which is the case for 85% of districts. The mean duration of the implementation phase for these districts is 5.3 years. The total social cost amounts to USD 4.5 million per 1,000 children and per district. This cost corresponds to 13% of the benefit in Scenario 1 and 1% of the benefit in the optimistic scenario (2). The estimated cost–benefit ratio for Case B is twice as much as the estimated cost–benefit ratio for Case A. Table H2 shows all figures used in the crude calculation.

Mid-construction abandonment

The second way in which halting projects exacerbates the effects on mortality is by increasing the probability of abandonment, which exposes the population to hazards indefinitely. Completion costs increase with halting due to interest payments, physical decay in exposed works, and relocation of staff and machinery. If the projects that were halted by the end of the study are never restarted and completed, they would only yield a negative social surplus. As I show that halting at least one project is as dangerous as implementing projects uninterruptedly (see Figure H3), one could use the estimated effect of an additional year spent implementing

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[3] The net present value of an infinite stream of social benefits (in perpetuity) is calculated using the formula $NPV = FV/i\%$, where FV is the future value per year of lives saved and i is the discount rate.

projects (regardless of halting status) to predict the social cost of abandonment. Besides the private sunk cost of abandoned projects, a back-of-the-envelope calculation suggests that districts would perpetually face an annual social loss equivalent to USD 840,000 per 1,000 children if there is mid-construction abandonment.

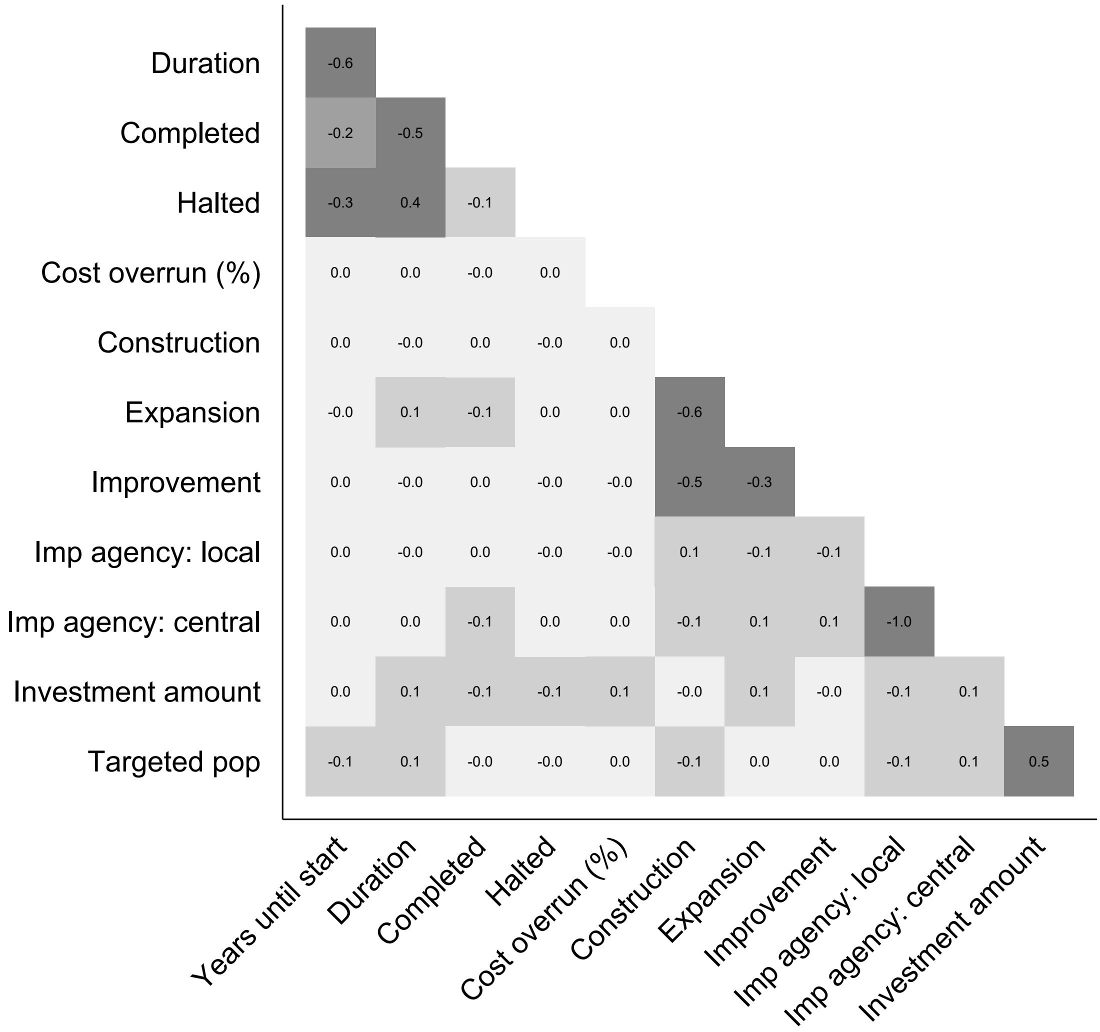
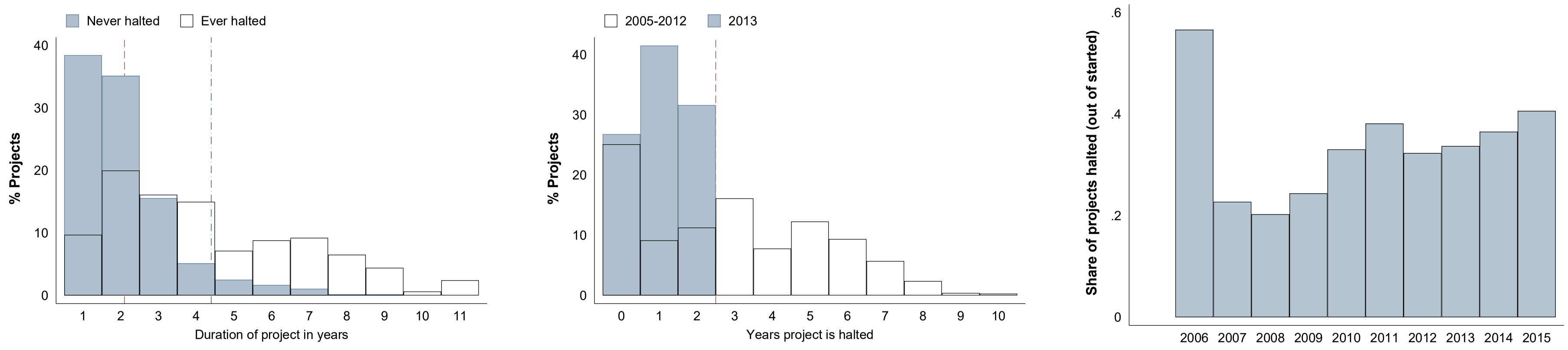


Figure H1

Pair-wise correlation matrix across project characteristics

Note. ‘Cost overrun (%)’ is set as the cost differential between planned and actual investment, as a percentage of the planned investment. ‘Imp agency’ captures the level of government of the implementation agency, where ‘local’ corresponds to the regional government and municipalities and ‘central’ to the central government. ‘Targeted pop’ is the estimated population to be targeted and to benefit from the project.

Project-level

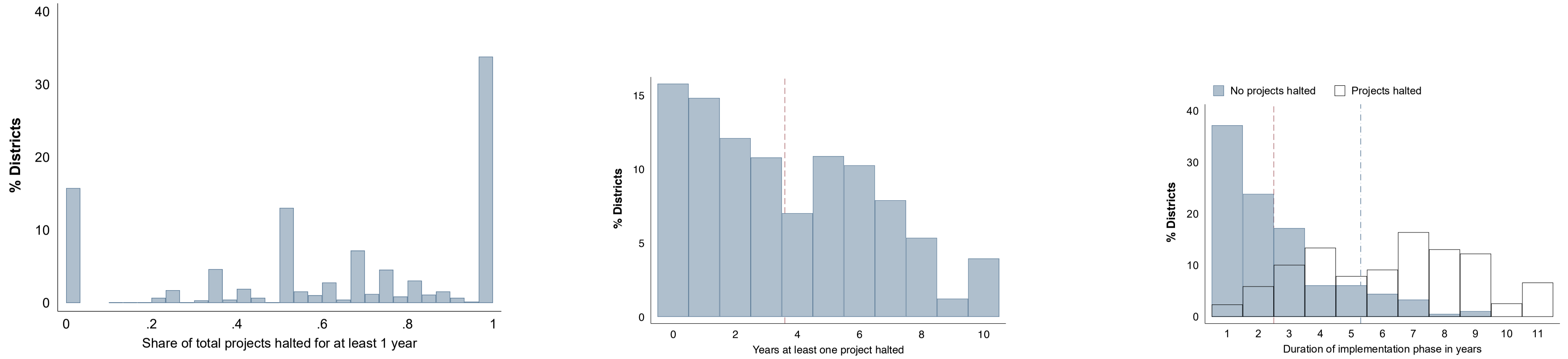


(A) Project duration, by halting status

(B) Years projects are halted

(C) Share projects halted by year

District-level



(D) Share of projects halted

(E)Years projects are halted

(F) District implementation duration

Table H1
Duration and halting

Note. Panel A presents the distribution of duration by whether or not a project was ever halted. Panel B shows the distribution of the years a project is halted, measured as the years that no additional funds are disbursed although a project is not completed, split by period in which the project was started. Panel C shows the share of projects halted out of those started by each calendar year. Panel D shows the distribution of the share of total projects halted (for at least one year) by the end of the study period in 2015. Panel E shows the distribution of the years at least one project is halted in a district. Panel F shows the duration of the implementation phase, at the district level, by whether or not a district ever had a halted project.

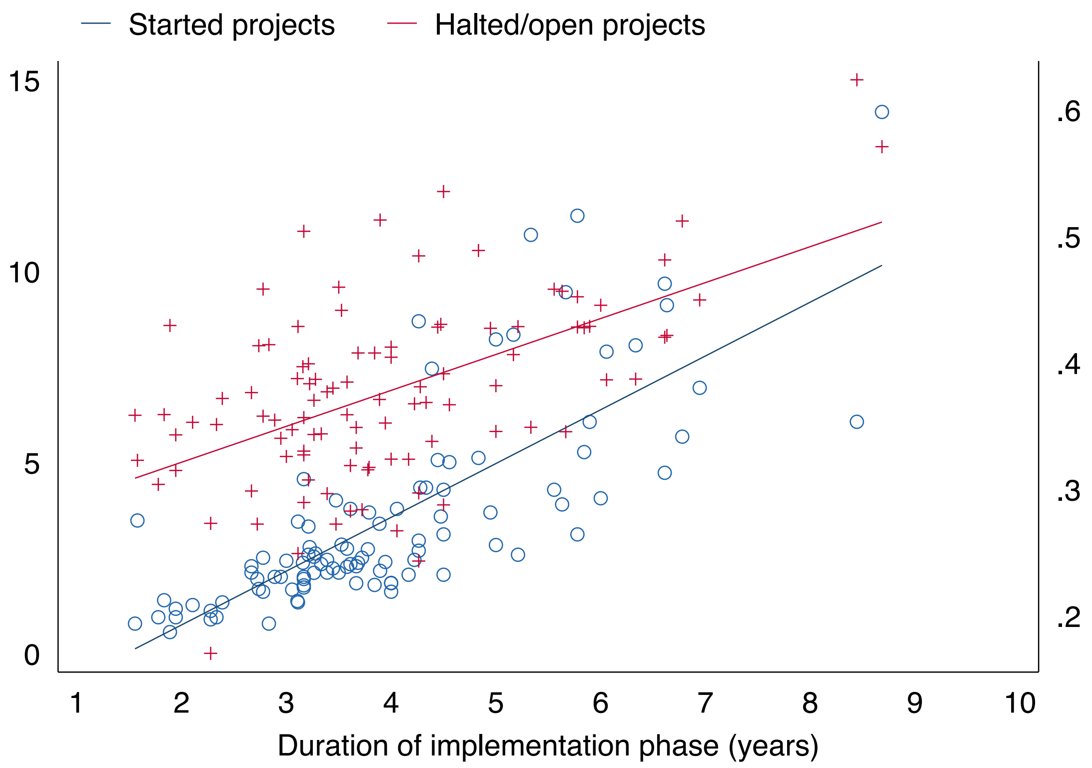
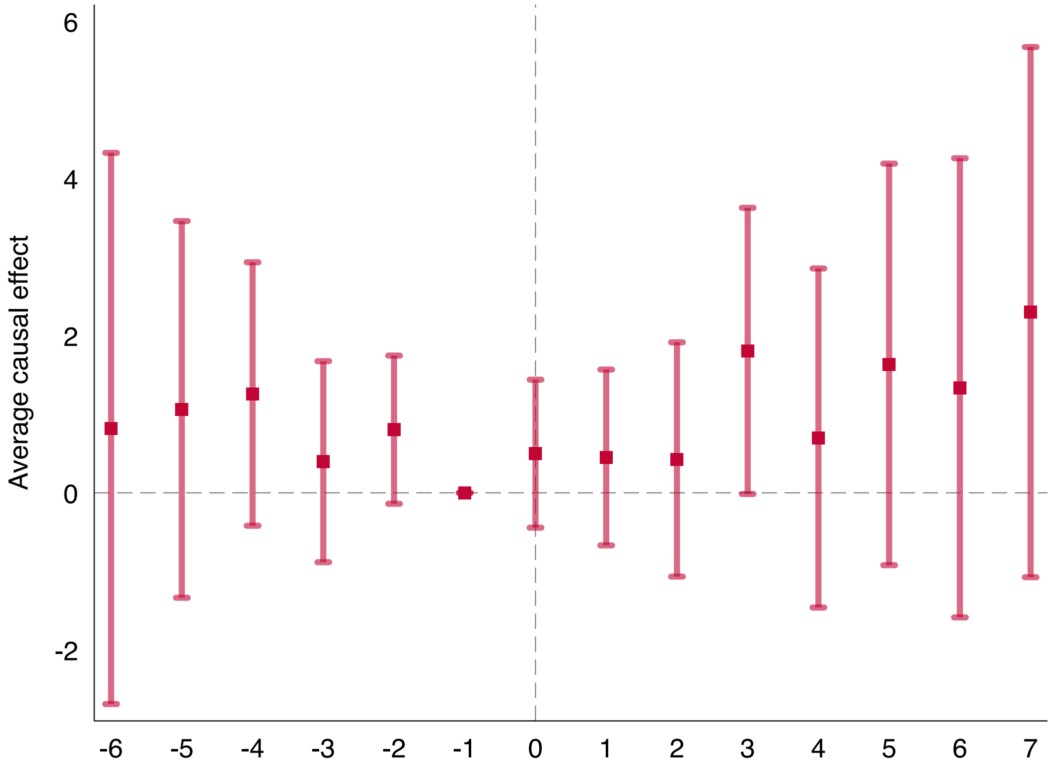
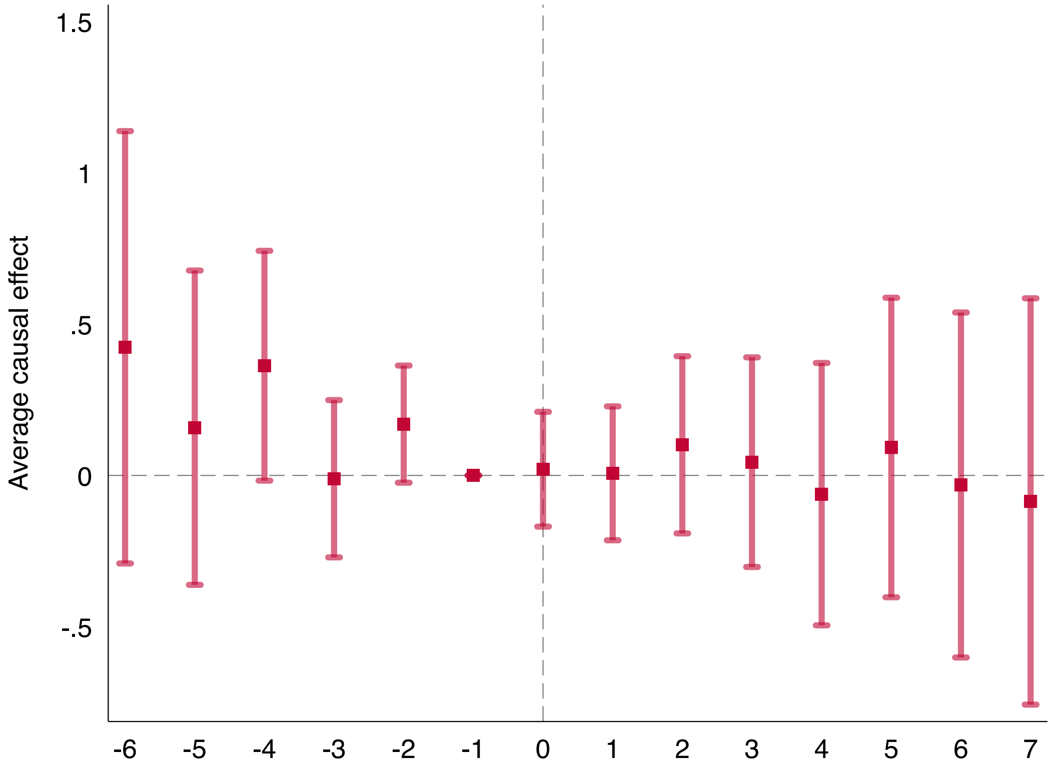


Figure H2
Correlation between duration and halting, district level

Note. ‘Started projects’ is the total number of projects started by 2015 and ‘Halted/open projects’ is the average ratio of projects halted to projects open between 2005 and 2015. Sample restricted to districts that developed sewerage infrastructure between 2005 and 2015.



(A) Infant mortality rate



(B) Under-5 mortality rate

Figure H3

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

Note. Event is the first year after halting at least one project. Effects of halting 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. OLS estimates of Equation 3, controlling for two-way fixed effects (district and calendar year), and their 90% confidence intervals (clustering standard errors by districts) are presented. The first lead is excluded as a normalization. Plots show the fully dynamic event-study estimates, trimming the periods at the extremes where fewer than 35% of 'treated' districts experienced h.

Table H2
Social cost/benefit of sewerage infrastructure

	Scenario 1 Galiani et al., 2005	**Scenario 2** Alsan and Goldin, 2019
Life expectancy	70	70
Value of a healthy life year (USD)	75,000	75,000
Completion (perpetuity)		
Years of analysis	10	40
Change in U5MR per year	-0.334	-4.037
Social benefit (USD)	1,753,500	21,194,250
Discount rate	0.05	0.05
Growth rate U5MR	constant	constant
NPV social benefit per 1,000 children	35,070,000	423,885,000
Implementation		
Change in U5MR per year	0.16	0.16
Social cost (USD) per 1,000 children per year	-840,000	-840,000
Case A: Implementation without halting		
Years	2.6	2.6
Social cost (USD) per 1,000 children	-2,184,000	-2,184,000
Cost/benefit	0.06	0.005
Case B: Implementation with halting		
Years	5.3	5.3
Social cost (USD) per 1,000 children	-4,452,000	-4,452,000
Cost/benefit	0.13	0.01

Note. The following assumptions are reflected in the table: (i) the survival of children today is worth more than the survival of children in the future, using a discount rate of 5% as used in the calculations by Watson (2006); (ii) a child surviving as a result of sewerage systems would live a healthy life for another 70 years – life expectancy in Peru was 75 years in 2015 (World Bank, 2020); and (iii) the value of a healthy life year is about USD 75,000, a lower bound in the estimates of economic studies (Cutler and Meara, 2000).

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