IFS
Institute for Fiscal Studies

Antonella Bancalari

Working paper
22/27

Can white elephants kill? Unintended consequences of infrastructure development

UKRI
Economic and Social Research Council

Can White Elephants Kill? Unintended Consequences of Infrastructure Development[*]

Antonella Bancalari [†]

Abstract

I provide evidence of the severe social costs imposed by infrastructure projects that are being implemented (i.e., projects started but not yet completed) in the context of sewerage in Peru. Using a counterfactual implementation predicted from geography-based cost considerations as an instrument, I show that implemented projects increase infant and under-five mortality. These results are driven by hazards, poor hygienic conditions and unsafe behavior, which increase deaths by waterborne diseases and accidents. Delays and mid-construction halting are common, and exacerbate the lethal effects of projects. Failing to take the implementation phase into account could severely bias the welfare evaluation of infrastructure. (JEL: C36, H54, I15, J18, N36, O18)

Keywords: Infrastructure, Implementation, Public Expenditure, Mortality, Instrumental Variable.

---

[*] This project has benefited from data and discussions with individuals from numerous institutions in Peru, including the Ministry of Sanitation, Health, and Economics, and the World Bank. I am grateful to Alex Armand, Britta Augsburg, Oriana Bandiera, Robin Burgess, Claudio Ferraz, Joan Costa-i-Font, Sebastian Galiani, David A. Jaeger, Berkay Ozcan, Rohini Pande, Juan Pablo Rud, Martin Rossi, and Sandra Sequeira for their useful comments. I also thank participants at BREAD/CEPR/STICERD/TDC Development Economics, NEUDC, LACEA, CSAE Oxford, RES and PAA conferences, and at the seminars in numerous institutions such as LSE, IFS-UCL, Oxford University, World Bank and Inter-American Development Bank. All work and opinions in this paper are my own and do not represent the views of the Government of Peru nor other institutions. This work was supported by the London School of Economics Doctoral Scholarship.

[†] University of St. Andrews, School of Economics and Finance, and Institute for Fiscal Studies. Castlecliffe, The Scores, St Andrews KY16 9AZ, United Kingdom. Email: antonella.bancalari@st-andrews.ac.uk

Investing in infrastructure has long been deemed a driver of economic growth and development (Aschauer, 1989; Isham and Kaufmann, 1999). In 2019 alone, the total investment in infrastructure projects amounted to about 1.2 trillion US dollars (USD), almost 5% of the global GDP (Fay et al., 2019). Economic research has identified high social benefits accruing from *completed* infrastructure (e.g. Dinkelman, 2011; Rud, 2012; Lipscomb, Mobarak, and Barham, 2013; Donaldson, 2018; Alsan and Goldin, 2019; Asher and Novosad, 2020; Banerjee, Duflo, and Qian, 2020), but it is important to understand the consequences of infrastructure projects that are being *implemented* (i.e., projects started but not yet completed). Traditional policy analysis evaluates the welfare effect of infrastructure by weighting the welfare gain of completed projects and the loss in private surplus associated with the construction works. When doing so, it typically ignores the potential social benefits or costs that arise during the implementation phase.

The implementation of infrastructure is plagued by inefficiencies: delays, cost overruns, halting of projects, and abandonment of projects mid-construction. For instance, in OECD countries, cost overruns on transportation projects range between 20% and 45%, driven mostly by delays (Flyvbjerg, Holm, and Buhl, 2004). In low- and middle-income countries (LMICs), studies suggest that over one-third of the public infrastructure projects started are halted and their completion is not guaranteed (Williams, 2017; Rasul and Rogger, 2018). These inefficiencies prolong the duration of infrastructure projects, exposing the population to hazards and disruptions for longer. Failing to take into account these potential social costs could severely bias the welfare evaluation of infrastructure projects.

In this paper, I first provide stark evidence that projects that are being implemented generate social costs as severe as early-life deaths in the context of sewerage infrastructure in Peru. I then document that the majority of the projects suffered from being halted mid-construction and that this inefficiency magnified the social costs of infrastructure implementation. Health-related infrastructure, like water-pipes and sewers, once completed and in use, is considered to be the greatest technological advance in public health in high-income countries (Cutler and Miller, 2005; Watson, 2006; British Medical Journal, 2018; Kesztenbaum and Rosenthal, 2017; Alsan and Goldin, 2019), and in LMICs, it has been found to prevent 1.1 million early-life deaths annually (Prüs-Ustün et al., 2014; Bhalotra et al., 2018). With back-of-the-envelope calculations, I show that the social costs associated with failed implementation (i.e., projects suffering from delays and being halted) can largely offset the social benefits of completed sewerage infrastructure.

Similar to the implementation of other large infrastructure projects, the installation of sewerage systems requires extensive excavation works that leave open ditches, which become full of stagnant water or turn into landfills and generate pools of infection. Furthermore, large building sites frequently divert traffic chaotically and create accidents due to poor signaling. Water cuts required to install sewerage pipes force the local population to rely on unsafe sources of water; the collection of water outside their premises also increases the prevalence of vector-borne diseases, and leads them to rely on sanitation practices associated with large negative health externalities (Geruso and Spears, 2018). All of these hazards, which have attracted media attention in Peru, are exacerbated when projects are halted and abandoned mid-construction (RPP Noticias, 2018; Serquen, 2018; Malpartida Tabuchi, 2018).

Between 2005 and 2015, the Government of Peru invested over 3 billion USD to implement more than 6,000 sewerage projects nationwide. Districts in Peru accumulated implemented sewerage projects over time because the rate of completion was very low.[1] I estimate the effects of implemented projects on early-life mortality using novel administrative datasets and relying on an instrumental variable (IV) strategy that exploits geographical features and national availability of funding.

I combine several sources of administrative and fine-grain spatial data, and I leverage budgetary reports to identify the cumulative number of implemented projects in each district and year. District-level mortality rates are then matched to these data to generate a panel of 1,379 districts for every year between 2005 and 2015. The implementation phase, in which no projects were yet completed, is isolated by restricting the sample of analysis to district–year observations before the completion of at least one project in a given district. Thus, the counterfactual scenario is that there is no project implemented.[2]

The main challenge in estimating the effects of implemented projects on mortality rates is that the placement of projects and their development are endogenous to district characteristics that also affect mortality trends. Richer and better-connected districts were more likely to implement more projects and earlier on, and these districts experienced steeper trends in mortality compared with low-treatment-intensity districts.

To address these endogeneity concerns, I rely on an IV strategy. The instrument is a counterfactual implementation of projects had investments been based solely on minimizing costs while maximizing coverage. I rely on the fact that a unique combination of geographic characteristics (i.e. terrain slope, elevation, river density and area) affects a district's technical suitability for low-cost sewerage projects. I predict a time-variant project implementation with an iterative approach, subject to a nationwide budget constraint and maximum threshold implementation per district. Variation in geography combined with a time-variant dimension has frequently been used to predict the allocation of

---

[1] Districts are the lowest jurisdictional level in Peru. Peru had 1,830 districts belonging to 196 provinces and 25 regions in 2005, with an average population of 23,000 inhabitants per district.

[2] A project-level analysis is not feasible because mortality would be measured as repeated nested values for all projects in the same district and year, meaning that the outcome would also be affected by the implementation and completion of other projects in the same district.

infrastructure projects (e.g., Duflo and Pande, 2007; Dinkelman, 2011; Rud, 2012; Lipscomb et al., 2013).

I predict the evolution of implemented projects following closely the strategy of Lipscomb et al. (2013). First, each district in Peru is ranked based on its geographic suitability for low-cost sewerage projects. Second, every year, a project is predicted in the highest-ranking (i.e., most suitable) districts until the national budget for sewerage infrastructure is exhausted. Finally, a maximum threshold of total projects implemented in a given district is imposed, which opens up capacity to predict projects in less geographically suitable districts in later years. The budget and the maximum threshold implementation create discontinuities in the prediction of projects along the ranking of districts each year. For instance, the ten most suitable districts are predicted to implement projects in the first year of study, whereas the eleventh most suitable district "waits" for the next year. I aggregate this prediction to construct an IV that measures the cumulative number of predicted implemented projects, assuming that none was completed during the period of study.

The key identification assumption is that no other factors that affect mortality changed over time along the same spatial lines: from the most suitable districts in terms of low-cost sewerage (i.e., robust water flow with a steep gradient and low altitude) in the early years to slightly more expensive (i.e., less water-rich, flatter, and higher altitude) districts in later years. The panel dimension of the data allows the inclusion of district and year fixed effects, which control for time-invariant district characteristics (e.g., geography) and nationwide shocks, respectively. Still, one might be concerned if new settlements or municipal capabilities for public works followed the same pattern as the predicted implementation of sewerage projects. I provide evidence that such concerns are likely to be minimal. Lagged values of population density and municipal revenue, human resources, and Internet connectivity do not predict the simulated implementation of sewerage projects. Also, the results remain robust when controlling for the contemporaneous values of these indicators.

Moreover, I show that pre-trends in mortality across low and highly suitable districts are paralell and that the instrument had no effect on mortality rates prior to the start of projects. In addition, several robustness checks support the validity of the exclusion restriction and the causal interpretation of the results. For instance, I control for time-varying trends in geographic suitability, showing that the results are ultimately driven by discontinuities in the predicted implementation along the ranking generated by year-specific budgetary variation and the maximum threshold of project implementation per district. I also show that the results are robust to controlling for expenditure on public works in the transportation, energy, and health sectors, alleviating concerns that the instrument is predicting investment (or underinvestment) in other types of infrastructure.

I answer, first, the following research question. In contrast to projects not being started, did implemented projects affect early-life mortality? I find that with every additional sewerage project implemented per year in a district, infant and under-five mortality rates increased by 0.003 deaths per 1,000 infants and 0.660 per 1,000 children, which translates into a 17% and 14% increase, respectively, relative to the initial average district mortality rates.

Rather than pollution, which has been identified as the main channel behind mortality effects from completed infrastructure and in use (Cesur et al., 2017; Mettetal, 2019; Alexander and Schwandt, 2022), the main mechanisms behind the results are hazards, poor hygienic conditions and unsafe behaviour. The estimated mortality effects are driven by water-borne diseases and accidents, in line with hazards posed by the open ditches that result from the construction works (e.g. deep pools of stagnant water where infectious diseases breed and children can drown). An additional sewerage project implemented per year increased the infant and under-five mortality rate caused by water-borne diseases by 0.002 deaths per 1,000 infants and by 0.410 deaths per 1,000 children ($\approx$ 20% and $\approx$ 18% increases from the initial mean rates, respectively). Furthermore, an additional project implemented increased the under-five mortality rate caused by accidents by 0.277 deaths per 1,000 children ($\approx$ 33% increase from the initial mean rate). I find no effect on the infant mortality rate caused by accidents, which is consistent with the notion of older and more mobile children being more exposed to outdoor hazards. There are no effects on the mortality caused by other diseases and complications unrelated to health and safety risks from construction works, such as congenital malformations and non-communicable diseases.

An additional mechanism behind the results is the lack of availability of safe water, in line with water cuts required to install sewerage pipes. Lower availability of water led preexistent on-site sanitation facilities to collapse and forced households to rely on sanitation practices that are unsafe for public health.[3] Implemented projects increased a district's share of households relying on unsafe sources of water by 2.8 percentage points (ppts; $\approx$ 6% increase relative to the initial mean) and decreased the share of households using latrines by 5.1 ppts ($\approx$ 14% decrease relative to the initial mean), while they increased the share of those practicing open defecation by 4.1 ppts ($\approx$ 9.8% increase relative to the initial mean). Finally, I show that alternative channels, such as changes in fertility, migration, and selective migration, cannot explain the increase in early-life mortality caused by implemented projects.

---

[3] On-site sanitation is a technology that stores excreta *in situ*, typically in septic tanks or pits. These facilities require water to flush down the excreta, and the storage space must be emptied regularly to remain functional (WHO, 2017).

The second set of research questions I answer are the following. How bad was the management of these projects? Did inefficiencies in the implementation exacerbate the lethal effects? I document the fact that delays were generated often because projects were halted. More than 70% of projects were halted at some point, increasing the average implementation time from three to five years, and 40% of projects started during the first half of the study period (2005–2010) were abandoned mid-construction by 2015. I unbundle heterogeneity in the effects by stratifying the sample of district-years depending on whether all projects are halted or not (keeping also the district-years in which no project is implemented). The effect on mortality of an additional halted project is more than twice as large as the effect of an additional project that is underway.

A back-of-the-envelope calculation suggests that the social benefits of completed projects (based on Alsan and Goldin (2019) and Galiani et al. (2005) studies) are seven times as much as the estimated social cost of projects implemented without problems. These benefits, nevertheless, are just a fraction of the social costs associated with delayed and halted projects. Of course, if projects are abandoned mid-construction and are never completed, the social benefits will never manifest and the social costs will be perpetual.

The paper proceeds as follows. In Section I, I describe the context in which sewerage projects were implemented in Peru. In Sections II and III, I describe the data and the empirical strategy, respectively. In Section IV, I present the main results and document mechanisms. I discuss the implications of the main results for welfare analysis in Section V, I conclude in Section VI.

I Background

I start with an overview of the implementation of sewerage infrastructure projects in Peru and the factors that drove the allocation and development of projects. I then document the quality of the management of these projects and the potential hazards that the implementation phase, and its failures, posed for the local population.

By 2005, only 25% of households in an average district were using a sanitation facility connected to the public sewers in Peru. Households mostly relied on their on-site sanitation facilities (34% of households), either latrines connected to septic tanks or pit latrines, or open defecation (41% of households) (see Table B1 in the Appendix). To remedy the poor access to safe sanitation facilities, the National Sanitation Plan set out the first nationwide effort towards expanding sewerage access in Peru by 2015. In the period between 2005 and 2015, the Government of Peru invested approximately 3 billion USD to start more than 6,000 sewerage projects all over the country.

Half of these projects entailed the construction of a brand new sewerage system, 30%

consisted of an expansion of piped networks from existing systems in the district, and 20% were to improve existing systems (see Panel A of Figure A1 in the Appendix). Each project covered a fraction of a district, but the definition of project boundaries was not set in a thorough manner, and it varied across projects and districts.[4] An average project was intended to benefit 24% of the 2005 population of the district in which it was located (see Figure A2 in the Appendix). By 2015, more than four projects had been implemented in an average district (see Figure A3 in the Appendix), meaning that, on average, almost all of the initial population of a district was served.

Between 2005 and 2015, most projects were implemented directly by district municipalities (56% of projects) (see Panel C of Figure A1 in the Appendix).[5] District municipalities could only implement sewerage projects if they were incorporated into the National System of Public Investment (SNIP, Spanish acronym), which requires the following: (i) an annual budget above one million soles (approximately 250,000 USD); (ii) access to the IT network; and (iii) approval from the municipal council to receive technical assistance in the implementation of investment projects from the Ministry of Economy and Finance. The largest sources of funding were district municipal funds: 39% of sewerage projects were funded by royalties, earmarked for social infrastructure, and 23% were funded by local tax revenue (see Panel D of Figure A1 in the Appendix). District municipalities have full discretion over the use of these sources when developing a public infrastructure project.

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 health and safety guidelines that include adequate signaling and removal of harmful waste in a safely manner, these are not clearly determined nor respected (Defensoria del Pueblo, 2015).[6]

A report from the Ministry of Construction, Housing 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 an unorganized manner when it comes to the implementation of 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 assess in a rigorous way the potential health and environmental risks that projects pose.

---

[4] Note that 80% of the projects covered areas delimited by streets and roads within the district, but the exact perimeter was not specified, 17% of the projects provided access to sewerage to institutions such as schools and health centers, and only 4% of the projects covered whole communities (see Panel B of Figure A1 in the Appendix).

[5] The district municipality is the local government body of a district.

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

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 the physical progression of projects and health and safety measures lack capabilities, and that communities are not involved in the supervision either (World Bank, 2015).

Moreover, interviews with engineers working for the Government and the Senior Specialist of the World Bank's Sanitation Programme in Peru reveal how the implementation of sewerage projects often poses the following hazards: (i) excavation works release pollutants into the environment; (ii) the works leave open ditches that propagate infectious diseases if they are filled with stagnant water or they become landfills; (iii) water cuts required to install sewerage pipes force the local population to rely on unsafe sources of water for drinking purposes; (iv) the lack of water access can lead to the collapse of existing on-site sanitation facilities; and (v) large building sites frequently divert traffic chaotically and create accidents due to poor signaling.

These risks are dangerous for young children, who are still developing an awareness of hazards and whose immune systems are not yet fully developed, and in particular for children who are starting to crawl and walk freely outdoors. All of these hazards have attracted media attention, and there has been a dramatic case of children drowning in an open ditch that had become a two-meter deep pool (RPP Noticias, 2018; Serquen, 2018; Malpartida Tabuchi, 2018).

The implementation of sewerage projects was faulty during the period of study, generating delays that exacerbated the hazards imposed to the local population. Cost overruns were common in these projects, regardless of project complexity (see Appendix B, and Figure A4 for the distribution by potential project beneficiaries).[7] Cost increases can render further work on contracts unprofitable for contractors after even relatively short delays (Williams, 2017). A report from the World Bank's office in Peru, which evaluated 14 sanitation projects implemented between 2010 and 2014, highlights that while cost overruns became more common, the pace of physical progression was reduced over time. These delays increase the average project duration, while making projects more expensive (World Bank, 2015).

These faulty conceptions of public investment create mid-project delays that further increase the cost of completion due to interest payments and physical decay in exposed works. They can even result in the relocation of the contractor's staff and plant. Indeed, projects were frequently halted in all regions of Peru for several reasons. The Ministry of Construction, Housing and Sanitation in Peru estimates that, from a random sample of 100

---

[7] Cost overruns are calculated as the difference between actual and planned costs, divided by the planned cost.

halted sewerage projects by 2015, 47% were halted because of mid-project delays, works abandoned by contractors, and insufficient funds; 32% because property rights were not secured in the area where works were conducted; 11% because of low-quality technical planning; 5% because of lack of water availability; and 5% due to social conflicts (Von Hesse, 2016). Appendix A, Figures A5 and A6, show how sewerage works lack health and safety measures while underway and abandoned, respectively.

II Data

In this section, I describe the data used in the analysis and I explain how the main variables are measured. I also present descriptives about the implementation of sewerage projects and the link to mortality.

A Measurement

I construct a panel dataset by combining several novel sources of data. I match project-level administrative data to district-level data from vital statistics, municipal registries, census data, and spatial grided data.

1 Project implementation

The focus of this paper is the implementation of infrastructure projects. To measure this, I rely on viability studies from 6,173 sewerage projects implemented between 2005 and 2015 in Peru, and I combine them with budget reports from the Integrated System of Financial Administration (SIAF, Spanish acronym) of the Ministry of Economy and Finance. 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 by at least 90%).[8] With these data, I can also identify when a project is halted (i.e., no disbursements while still underway) and the nationwide budget spent on sewerage projects each year. A project is implemented if it has already been started, but has not been concluded. If a project is not completed during the period of study, it is considered as being implemented until 2015.

At the district level, I construct a variable capturing the cumulative number of *implemented projects* in a given district and year by aggregating the project-level data.[9] By

---

[8] Interviews with bureaucrats indicated that construction works are completed at the 90% accrued budget level, where only paperwork is pending.

[9] A limitation of this dataset is that sanitation projects are formulated in a sub-area of districts (the smallest jurisdictional level in Peru), but this is not easily identifiable (i.e., no exact address or geo-codes) and there is no early-life mortality data at the same level. For projects formulated at a higher governmental

2015, an average district has approximately started four and completed one sewerage project. The low rate of completion lead districts to accumulate implemented projects every year (see Appendix B and Figure A3). The cumulative number of implemented projects does not decrease in a given district before the completion of at least one project.

2 Outcomes

The main outcome variables are *infant and under-five mortality rates* per 1,000 infants and children below five years old, respectively, at the district level. I compute these rates using vital records provided by the Ministry of Health of Peru and population forecasts built by the National Institute of Statistics and Informatics (INEI, Spanish acronym), both of which are only available at the district level.

Infant (under-five) mortality is computed as the number of dead infants (children under five years old) over total infants (children under five years old) for each district and year, multiplied by 1,000 as conventionally computed.[10] Between 2005 and 2015, both infant and under-five mortality rates fell by 35% (see Table B1).

Mortality data are disaggregated for general pathological groups following the World Health Organization's International Classification of Diseases (ICD-10). I compute infant and under-five mortality rates by cause of death per 1,000 infants or children, respectively, for two main categories. First, I compute the rates by conditions related to the health and safety hazards explained in Section I, including deaths by infectious diseases (ICD-10 category I), perinatal complications (ICD-10 category XVI), diseases of the digestive system (ICD-10 category XI), malnutrition and other nutritional deficiencies (ICD-10 category IV), diseases of the respiratory system (ICD-10 category X), and by external causes which mostly include deaths caused by falls, drowning, and traffic-related accidents (ICD-10 category XX).[11] Second, I construct mortality rates by deaths unrelated to sanitation and external hazards, including deaths due to congenital malformations (ICD-10 category XVII), neoplasms (ICD-10 category II), diseases of the genitourinary system (ICD-10 category IV), nervous system (ICD-10 category VI), circulatory system

---

level that lacks data on the number of projects per district, I assign one project to each district within the corresponding province or region. This approach does not capture the intensity of sewerage implementation within each of the districts, but it is done in only 3.7% of the districts that had ever implemented projects.

[10] Because of the incompleteness of birth registries in Peru (93% coverage by 2005; UNICEF, 2005), I use the population of under-fives divided by five, assuming that the distribution across ages is similar, to measure infants. I verify the validity of the vital registers by comparing the computed nationwide mortality trends with those computed from several nationally representative surveys (see Figure B1).

[11] All deaths that occurred during the first 28 days of life are placed into the perinatal deaths category, regardless of the cause. Thus, even if the death occurred from an infectious or parasitic disease, it is assigned to the perinatal deaths during the first 28 days of life, and not to the infectious and parasitic diseases category. Therefore, I also include this category as one related to health and safety hazards of implemented projects, following Galiani, Gertler, and Schargrodsky (2005).

(ICD-10 category IX), skin and subcutaneous tissue (ICD-10 category XII), and musculoskeletal systems and connective tissue (ICD-10 category XIII).[12]

3 Additional variables

I also draw on Census and administrative data to explore mechanisms and conduct robustness and sensitivity tests. I use data from three Census rounds (2005, 2010, and 2017) to measure demographic features and composition of districts, as well as water use and sewerage connectivity. Data from 2017 are used to impute the year 2015 and the missing years are imputed with the latest value available. I further draw on data from the National Register of Municipalities (RENAMU, Spanish acronym) to measure characteristics of district municipalities (available only between 2008 and 2014), and I use budget reports from SIAF to identify the level of expenditure on alternative infrastructure projects, including transportation, energy, and health (available between 2007 and 2014, but 2015 is also available for transportation). See Appendix B for details of the data sources and variables used in the analysis.

District municipalities became richer during the period of study, sewerage connectivity increased, and mortality decreased (see Table B1 and Figure B1 in the Appendix). The average revenue of a district municipality quadrupled—from 4 million to 15 million soles ($\sim$ USD 4.5 million)—and many municipalities gained access to the Internet. Municipal capabilities improved (measured as the share of municipalities requiring technical assistance for the implementation of investment projects, which dropped) and more municipalities managed a health center. Districts improved their access to public services greatly in the decade of analysis. Sewerage connectivity increased, as well as the share of households in districts that rely on on-site sanitation facilities, while the share practicing open defecation decreased. Likewise, the share of households relying on unsafe sources of water decreased. Electricity connectivity also increased. Household heads became better educated (measured as the share of heads who had completed secondary education, which increased). Public expenditure increased over the period of analysis in the transportation, energy, and health sectors.

I exploit variation in *geographical features* to instrument for projects implemented (as explained in Section III). For this, I use spatial data provided by the Ministry of Environment of Peru measuring terrain and river flow for multiple cells (1×1 km^2), matched to district boundaries for 2015. I compute the area of districts and their share in different parts of the distribution of elevation and gradient, and river density.[13] Districts in Peru

---

[12] Deaths by diseases of the musculoskeletal and genitourinary systems and of the skin and subcutaneous tissue are very rare for both infants and children under five years old.

[13] 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,

have rugged terrains (see Figure B2 and Table B1): on average, the largest share of district area is highly elevated (74%) and very steep (37%). River density is, on average, 53 km per km^2 and there is substantial variation across districts (124 standard deviations). The Ministry of Environment of Peru also provided data on mining production between 2005 and 2015.

B Descriptive statistics

Because of low completion rates, over time districts accumulated projects that were being implemented. The implementation phase was often prolonged because projects were halted. Panel A of Figure 1 shows the distribution of years in which projects started between 2005 and 2013 were being implemented, regardless of whether they were completed.[14] The distribution of the years in which projects were implemented is skewed to the right for projects that were never halted. From those projects that were ever halted, less than 10% were being implemented for a year, and almost half were being implemented for more than five years. On average, projects were being implemented for 4.7 years, and those that were ever halted were being implemented for 5.3 years, while those not halted were being implemented for 2.8 years. Approximately 75% of projects were halted at some point. Panel B of Figure 1 shows that there is also large variation in the number of years in which projects were halted, ranging from one year to indefinitely, and the older a project, the higher the chance of observing it was halted, given the right-censoring of the data by 2015. On average, projects were halted for 2.5 years (three years for projects started before 2013).

From the pool of projects started during the first half of the study period (2005–2010), which potentially had enough time to be completed by 2015: (i) 23.0% were completed and never halted; (ii) 2.2% were never halted, but completion not observed; (iii) 20.6% were halted but restarted and completed; (iv) 10.1% were halted and restarted, but completion not observed; (v) 44.1% were halted and abandoned (no restart or completion observed). These figures suggest that the path of almost half of the projects is to end up in mid-construction abandonment.

[Figure 1 here]

4.19]%, {4.19–13]%, and above 13 %. The first category captures flat areas below or equal to 0.8% in which sewerage construction is costliest, as determined by technical guidelines (Panamerican Center of Sanitation Engineering and Environmental Sciences, 2005).

[14] The sample in these plots is restricted to projects started between 2005 and 2013 given the right-censoring nature of the data (i.e., by 2015, there are at least two years to observe the completion of these projects).

III Empirical strategy

I conduct a district-level analysis in which I estimate the effect of projects on early-life mortality using panel data for every district and year between 2005 and 2015. I also use the following specification,

$$MR_{dt} = \beta_1 S_{dt} + \gamma_d + \delta_t + \xi_{dt}, \tag{1}$$

where MR_{dt} denotes infant (IMR) or under-five (U5MR) mortality rates, and S_{dt} is the cumulative number of sewerage projects being implemented (i.e., projects started, but not yet completed) in district d and year t. The panel dimension of the data allows the inclusion of district (γ_d) and year (δ_t) fixed effects that control for time-invariant unobservables and nationwide shocks, respectively, that can affect both health and project implementation. Standard errors are clustered at the district level to deal with serial correlation due to the panel characteristics of the data and because the intra-cluster correlation is the highest at this level.

An advantage of a district-level analysis is that districts are the jurisdictional level at which public investment strategies and portfolios of projects are set. Hence, this unit of observation means that dependences between projects of the same portfolio can be taken into account. Furthermore, this is the lowest jurisdictional level at which vital statistics are measured in Peru. Districts accumulated implemented projects over time because the rate of completion was lower than the rate of starting new projects (see Figure A3 in the Appendix). Finally, a district-level analysis allows isolation of the implementation phase, in which no projects were yet completed at the same level at which the outcome is measured.

The main challenge to estimating the effects of implemented projects on mortality rates is that the placement of projects and their development are endogenous to district characteristics that also affect mortality rates. Relatively richer and better-connected districts implemented more projects, but also had initially lower mortality (see Figures A5 and C4 in the Appendix). While the difference in levels is controlled by the inclusion of district fixed effects, the district characteristics mentioned above can also affect trends in mortality rates. In fact, Panels A and B in Figure C4 in the Appendix show that high-implementation-intensity districts experienced steeper secular trends that low-intensity districts before the start of projects, in line with greater investment in population health and economic development in the former over time.[15] Hence, naive estimates of the effect

---

[15] Due to lack of historical data on mortality rates, the trends are plotted in Figure C4 based on the years relative to the start of the first project in a district. The sample is restricted to districts that implemented at least one project and to the years before the completion of the first project. Given the presence of pre-trends and that the start date of project was not random, an event study design would be a weak identification

of implemented projects on mortality rates based on the roll-out of project across districts in Peru is likely to be biased. I use an IV strategy to deal with these endogeneity concerns.

A Instrumental variable

In this subsection, I motivate and describe the empirical strategy I use for addressing the above-mentioned endogeneity concerns.

I use the cumulative number of "predicted" sewerage projects being implemented as an instrument for the "actual" cumulative number of sewerage projects implemented in each district-year. The prediction combines district-level exposure given by the geographical suitability of districts (based on land slope, elevation, and river density) to implement low-cost sewerage projects, with country-level changes in funds for sewerage projects. Ranking districts based on its geographic suitability and predicting projects accordingly until the budget is exhausted, and imposing a maximum threshold of total projects implemented per district, the instrument mimics a social planner that implements projects based solely on cost minimization while maximizing coverage. The instrument is likely to comply with the monotonicity assumption, as all suitable districts predicted to implement more, and earlier, sewerage projects are more likely to do so, as opposed to being less likely due to its geographical advantages ("defiers").

This identification strategy is akin to Duflo and Pande (2007), Lipscomb et al. (2013), Burgess et al. (2015), and Nunn and Qian (2014), whose counterfactual simulations exploit cross-sectional variation in the pre-treatment periods interacted with a time-variant predictor. Local geography has been frequently used as quasi-random variation to predict the allocation of infrastructure projects (e.g., Duflo and Pande, 2007; Dinkelman, 2011; Rud, 2012; Lipscomb et al., 2013). In particular, the estimation strategy is similar to Lipscomb et al. (2013) who rank locations in Brazil by their geographic suitability and predict hydropower plants accordingly until the budget is exhausted, and to Duflo and Pande (2007) who uses slope interacted with a time-varying state budget variable to predict irrigation dam placement in India.

The key identification assumption is that no potential confounders, such as population settlement, political will, municipal capabilities and policies, and other types of infrastructure, independently moved over time along the same spatial lines as the predicted implementation of projects. It is unlikely that those unobservables moved from the

---

strategy in this setting. After project completion, mortality trends become flatter. The reversal in trends is steeper for low-treatment-intensity districts, perhaps because of works exposing the population to greater hazards in these poorer areas and/or resources being relocated to high-intensity districts. I restrain, however, from making any causal claim based on these plots about the effect of project implementation on mortality given that the sample of districts dramatically drops for years after the start of the first project in a given district.

lowest-cost districts in terms of sewerage technology (i.e., with robust water flow, a steep gradient, and low elevation) in the early years to slightly more expensive districts(i.e., flatter, less water-rich, and higher altitude) in later years.

To directly examine the validity of the exclusion restriction, I test whether the simulated implementation of sewerage projects can be predicted by development indicators from earlier years. Table 1 shows that the point estimates on five-year-lagged values of population density, which serves as a proxy for population settlement, municipal revenues, which serve as a proxy for political will to collect and attract funds, and municipal human resources and Internet access, which serve as a proxy for capabilities to implement public works, are all close to zero and statistically insignificant. These findings suggest that the lagged development indicators do not predict the spatial and over-time variation of the cumulative number of predicted projects, and provides some confidence that the prediction following cost-minimization is orthogonal to these potential confounders. In addition, I show in Section A that the results remain robust when controlling for the present values of these district and municipal characteristics.

Moreover, I present a falsification test of the instruments' orthogonality in Table 2, columns 1 and 2. Following equation (1), I regress the infant and under-five mortality rates on the predicted number of sewerage projects (instead of the actual number of implemented projects), restricting the sample to the district-years in which no actual project has yet been started in each district.[16] It is reassuring to find that, prior to actual project implementation, the instrument has no statistically significant effect on mortality rates. Once project implementation is started, and in district-years before the completion of at least one sewerage project, the instrument does have a positive and statistically significant effect on mortality rates, as shown by the reduced-form estimates in columns 3 and 4. These results serve as additional evidence that the predicted implementation of projects only affects mortality through the actual implementation of projects.

The validity of the instrument relies on additional considerations. First, the nationwide variation in funds for sewerage projects is plausibly exogenous to district-level mortality conditional on year fixed effects that purges year-specific unobservables (e.g. elections or natural disasters). Second, the geographical component is plausibly exogenous conditional on the inclusion of district fixed effects that capture time-invariant effects of geography on public health. Still, one may worry that the instrument is picking up non-random-related differences in mortality trends across districts with different geographic characteristics. Figure C4 in the Appendix shows that, while the mortality trends across low- and high-treatment-intensity districts diverge, the mortality trends across low- and

---

[16] Note that 7% of districts are dropped from this sample because they have no period without projects being implemented, as projects were started in the initial year of the study (2005).

high-geographically suitable districts were parallel before the start of projects.[17] Even when controlling for trends in geographical suitability, and relying only on discontinuities in the prediction of projects along the suitability ranking (due to the nationwide budget constraint and given the maximum threshold of project implementation, the instrument retains strong predictive power to produce robust results.

The instrument is built in two main steps, which I discuss in turn (see Appendix C for more details).

(1) **Geographic suitability for low-cost sewerage projects**

I first compute, non-parametrically, a measure of a district's geographical suitability for low-cost sewerage projects. A combination of factors, unique to sewerage infrastructure, affects the cost of implementing sewerage projects. While elevation increases the cost of projects (i.e., complex treatment plants that inject oxygen and chemicals at altitude), gradient decreases the cost (i.e., steepness allows waste water to flow through pipes from houses to disposal areas without the need for installing expensive electrical bombs). The cost decreases with river density (i.e., water availability enables the discharge of effluent with a short network of pipes) and increases with a district's area (e.g., the need to instal a longer sewerage network) (Hammer, 1986; Romero Rojas, 2000; Panamerican Center of Sanitation Engineering and Environmental Sciences, 2005). Sewerage projects that leverage on the considered geographic characteristics (i.e., steeper gradients, low altitude, high water flow, and shorter pipe networks) tend to be less complex, and hence cheaper (Panamerican Center of Sanitation Engineering and Environmental Sciences, 2005).

As predicted by the engineering literature, I find that steep gradient categories and river density favor sewerage implementation, while elevation and area are negatively associated with project implementation (see Appendix C and Table C1). I construct an index including all geographic features and keeping the first component with an eigenvalue larger than one in a principal component analysis.[18]

(2) **Time-variant counterfactual implementation**

A counterfactual project implementation that varies across districts and over time is predicted with an iterative approach, subject to two restrictions: (i) nationwide

---

[17] The mortality trends in Panel C and D in Figure C4 also show a trend reversal after the start of projects. This evidence suggests that during the implementation of projects an otherwise steep decrease in mortality rates flattened in both low and highly suitable districts that started at least one project. Again, I restrain from making causal claims based on these plots because the sample of districts dramatically drops for years after the start of projects.

[18] I conduct a sensitivity analysis in which I vary the way the geographic suitability is modeled. I alternatively use lasso linear and lasso Poisson models to predict the relationship between projects implemented, the geographic variables, its squares and interactions (see Table D4 in the Appendix).

budget for sewerage; (ii) maximum threshold implementation per district. Ranking all districts in Peru based on the geographic suitability index, a project is allocated to each district until the nationwide budget is exhausted. The same procedure is followed for the following years until a district implements a maximum of five projects, which is the mean implementation of projects between 2005 and 2015 (and the 75th percentile of the distribution of projects).[19] Imposing a threshold of maximum project implementation generates greater variation over time in the prediction, by opening up capacity to predict projects in less geographically suitable districts in later years.

The instrument is built as the cumulative number of projects predicted to be implemented, assuming that they are not completed during the period of analysis. The instrument is hence capturing variation in the marginal predicted project per district-year. The counterfactual implementation of projects is predicted as the following underlying function:

$$P_{dt} = min(5, P_{dt-1} + I(fundrank_d \leq maxfund_t)). \tag{2}$$

Here, P_{dt} is the cumulative number of predicted projects implemented in district d and year t, which cannot decrease, $I(.)$ is the indicator function, $fundrank_d$ is the funding rank of district d based on its geographic suitability, $maxfund_t$ is the maximum fundable projects given the nationwide budget in year t, P_{dt} takes on values in the set $\{1, 2, 3, 4, 5\}$ given the maximum threshold of project implementation, and P_{d0} is equal to zero because the analysis focuses on a new batch of projects implemented from 2005.

The highest-ranking districts are predicted to implement sewerage projects earlier and to have more projects across the years. For instance, for 2005, each of the 20 highest-ranking districts is predicted to implement one project each because the maximum number of fundable projects is 20, given the nationwide budget available for 2005. In subsequent years, projects that would have been allocated to higher-ranked districts that already hit the maximum threshold are now allocated to lower-ranked districts. Therefore, by 2015, the highest-ranked districts would have implemented up to five sewerage projects, while the lower-ranked districts would have implemented fewer than five projects. This creates a counterfactual implementation roll-out that provides variation across districts and years.

Figure 2 shows a "snapshot" of the actual (Panel A) and counterfactual (Panel B) implementation of sewerage projects in 2005, 2010, and 2015. The early implementation of sewerage projects was focused on the affluent and populous north coast as well as on the

---

[19] I conduct a sensitivity analysis in which I vary this threshold. I alternatively use the 25th percentile and the 90th percentile of the distribution of implemented projects between 2005 and 2015 (see Table D4 in the Appendix).

relatively less affluent center region of the Andes. The intensity of sewerage implementation increases in these regions and expands eastward every year, until the Amazon region is covered. By 2015, there is substantial variation in the number of sewerage projects across districts. The regions that implemented relatively fewer projects are the north-east region of the Amazon and the south of Peru. Ignoring the demands of the population or political will of municipal mayors (demand-side factors) to implement sewerage projects leads the prediction to over-allocate projects to unattended places, such as the north-east Amazon area and the south coast. Water-rich districts with steeper gradients and lower altitudes are predicted to implement sewerage infrastructure earlier, but the dynamics are mediated by the budget and maximum threshold implementation constraints. These restrictions weaken the relevance of the instrument but allow the extraction of time-varying exogenous variation linked to geographical characteristics.

[Figure 2 here]

B Specification

The predicted counterfactual implementation exploits two sources of variation: differences in nationwide budget for project implementation across years in Peru, and differences across districts that are driven by their geographic suitability for low-cost sewerage projects. The first-stage equation is

$$S_{dt} = \alpha P_{dt} + \gamma_d + \delta_t + \xi_{dt}, \tag{3}$$

where P_{dt} denotes the cumulative number of predicted implemented projects. The first stage attempts to isolate the portion of the variation in project implementation that is attributable to these exogenous cost considerations. Table 2 (column 5) shows the first-stage estimates from equation (3). The cumulative number of "predicted projects" is a relevant instrument for the cumulative number of "implemented projects". On average, an additional project predicted to be implemented in a district is associated with 0.151 implemented projects.

I estimate the following specification using a two-stage least-squares (2SLS) estimator

$$MR_{dt} = \beta_2 \hat{S}_{dt} + \gamma_d + \delta_t + \xi_{dt}, \tag{4}$$

where $\hat{S_{dt}}$ is the instrumented cumulative number of implemented sewerage projects in district d and year t. I restrict the sample of analysis to district-years prior to project completion to set as the counterfactual district-years with no projects implemented. The final sample is a panel dataset of 1,379 districts for every year between 2005 and 2015.

This sample includes all districts in Peru with available data that never implemented a project or that implemented projects, but with at least one year in which no project was yet completed. Thus, β_1 can be interpreted as the effects of implemented projects before completion compared with not implementing any project at all. $\hat{S_{dt}}$ does not decrease, and so it is capturing variation in the marginal implemented project per district–year.

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

More specifically, the 2SLS estimates capture the "local (weighted) average treatment effect" of the unit causal responses in districts that implemented sewerage projects (or not) only driven by their geographic suitability for low-cost projects. These districts are known as "compliers". What the 2SLS estimates do not capture is the effect of projects implemented in specific districts for, say, political reasons, even if they are not geographically suitable for low-cost sewerage projects. These districts are known as "always-takers". The 2SLS estimates are thus close to a "best case scenario" because I am measuring the effect of the implementation of technologically appropriate sewerage projects.

IV Results

I present the main results in this section. I use a panel dataset of 1,379 districts for every year between 2005 and 2015 before the completion of the first project in each district. This sample of analysis only excludes less than 1% of districts in Peru with available data because these districts started and completed a project on the first year of analysis (2005).[20] The panel data include in total 8,555 district-year observations.

I find that implemented projects increased early-life mortality, an unintended consequence of the developmental phase of infrastructure. Table 3 presents the estimated effect of the cumulative number of implemented sewerage projects on a district's infant and under-five mortality rate. Columns 1 and 2 in Panel A present ordinary least-squares (OLS) estimates. The association between implemented projects and early-life mortality is positive in the naive OLS model. Columns 3 and 4 present 2SLS estimates, instrumenting "implemented projects" with "predicted projects" using equation (4). In Panel A, the 2SLS estimates reveal that, on average, an additional implemented sewerage project per

---

[20] The inclusion of district fixed effects also excludes 2% of districts from the sample because they have only one year of observation.

year increased the infant mortality rate (IMR) by 0.003 deaths per 1,000 infants and the under-five mortality rate (U5MR) by 0.660 deaths per 1,000 children under five years old. These results translate into approximately a 17% increase over the initial district average infant mortality rate and 14% increase over the initial district average under-five mortality rate, respectively.

On average, districts have accumulated 2.3 projects implemented and have experienced three years of project implementation before the completion of the first project. Thus, the effects during the implementation period in an average district, without projects being completed, are 0.02 additional infants deaths per 1,000 infants and 4.31 additional under five deaths per 1,000 children.

[Table 3 here]

Following the recommendation of Lee et al. (2020), I report the p-values of the Anderson and Rubin (1949) test that is robust to weak instruments.[21] The test rejects the null hypothesis that the estimated effects are equal to zero at the 5% significance level. The estimated confidence sets from the Anderson–Rubin Wald test are slightly wider and shifted towards a higher magnitude than the 2SLS confidence intervals. The Anderson–Rubin Wald test confidence intervals are [0.001, 0.006] for the IMR and [0.132, 1.485] for the U5MR, both consistent with a positive effect of implemented projects on early-life mortality.

Table 3 also reports the Sanderson–Windmeijer F-statistic of excluded instruments to understand the 2SLS distortion compared with the OLS estimates (Sanderson and Windmeijer, 2016). The F-statistic is close to the Stock and Yogo (2002) weak ID test critical value for the 10% maximal IV size (16.38), meaning that the bias of the IV estimator, relative to the bias of OLS, is between 10% and 15% for a 5% level test.

The 2SLS estimates are larger than the OLS estimates likely because the compliers (as explained above, the districts that implemented projects driven by their geographic suitability for low-cost sewerage) in the IV strategy are different from the average district. Districts that implemented sewerage projects due to demand-side factors rather than technical factors may have greater incentives to mitigate risks associated with the construction works. Furthermore, the 2SLS specification may be correcting for measurement error and the attenuation bias associated with it. While the actual cumulative number of implemented projects constructed using a combination of administrative records likely suffers from classical measurement error (i.e. underreporting or misreporting of project

---

[21] The t-ratio inference procedures have been proven by Lee et al. (2020) to yield distortions in size and coverage rates in IV strategies. They recommend using the Anderson and Rubin (1949) test, as it is known to have correct size and coverage and attractive optimality properties, while also being robust to arbitrarily weak instruments.

implementation in poorer areas), the geographical variables used to compute the predicted implementation of projects are measured precisely (based on 1×1 km^2 satellite maps).

These results hide meaningful heterogeneity with respect to the developmental pattern that projects followed. As discussed in Section B, the majority of projects were halted for at least one year, generating unnecessary delays and potentially exacerbating the negative consequences of project implementation. In Panel B of Table 3, I present heterogeneous effects by whether or not projects are halted in a district-year, estimating equation (4) with 2SLS and stratifying the sample. Columns 1 and 2 restrict the sample of analysis to district-years in which either no project is implemented or none of the implemented projects is halted in a district. In turn, columns 3 and 4 restrict the sample of analysis to district-years in which either no project is implemented or all projects under implementation in a district are halted. Interestingly, the effect on mortality of an additional halted project is more than twice as large as the effect of an additional project that is underway (i.e., “business-as-usual”). With the counterfactual scenario being no projects implemented, an additional halted project per year, on average, increased the infant mortality rate by 0.006 deaths per 1,000 infants and the under-five mortality rate by 1.707 deaths per 1,000 children. The latter effect is statistically significant at the 5% level and represents an increase equivalent to 35% with respect to the average U5MR in 2005.

Although the distinction between the effect of projects while underway and while halted is important, I lose statistical power because the sample of analysis drops by almost half when stratifying observations by project development. Hence, the remainder of the analysis presented is based on the original sample, regardless of the developmental pattern that projects in the district follow, as presented in Panel A of Table 3.

A Robustness checks

A variety of checks support the validity of the exclusion restriction of the IV strategy and bolster the robustness of the 2SLS estimates presented in Table 3.

First, I find that the effects are not driven by trends in mortality rates that are specific to the geographical characteristics that favor low-cost sewerage projects or that might drive the nationwide budget for sewerage projects. Table 4 shows that the results remain robust when controlling for calendar year interacted with the geographic suitability index (Panel 1).[22] This test shows that the variation of the instrument comes mainly from the discontinuities introduced by the order in which new projects are implemented based on suitability rankings, the budget constraint and the maximum threshold implementation per district. Because the Amazon is a fundamentally different region compared with the rest

---

[22] Table D1 in the Appendix also shows that the estimated effects remain robust when adding each individual geographical component as controls, either in isolation or jointly.

of Peru, and it plays an important role when predicting project implementation (as seen in Figure 2), one might be concerned if the results are driving by Amazon-specific trends in mortality. Panel 2 in Table 4 shows that the results remain robust when additionally controlling for calendar year interacted with an Amazon location dummy. Another concern is if the instrument is capturing the effects of local mining activities, as geography is correlated with it and a large share of projects were funded by royalties, predominantly from the mining sector (i.e. 39% of projects funded by royalties, and almost half of royalties come from mining activities). Panel 3 in Table 4 shows that the point estimate remains similar in magnitude and statistically significant when additionally controlling for mining production (in constant USD, using 2010 as the base year). This test proves that no unobserved shocks to this industry affects health outcomes through the same mixture of geographical characteristics.

Second, I demonstrate that the results are not driven by investments in other types of infrastructure across districts. A threat to the identification strategy is the delivery of other infrastructure, such as roads, energy plants and health centers, that could affect early-life mortality, and that follow the same spatial and temporal patterns as the instrument, if these also pose health hazards to the local population. The results can also be explained by other types of infrastructure that are beneficial for early-life health, but developed following the opposite pattern to the instrument. Furthermore, investment in sewerage systems could crowd-out investment in other types of infrastructure that are beneficial for public health. Encouragingly, Table D2 in the Appendix shows that the main 2SLS estimates remain robust when controlling for district expenditure on transportation, energy, and health. The results are less precisely estimated when controlling for energy expenditure, but this is likely because we lose 24% of the sample of districts. Furthermore, the instrument is weakly correlated with these other infrastructure expenditures and none of these alternative expenditures explains the increase in mortality rates.

Third, Table D3 in the Appendix shows that the results remain robust to several sensitivity tests, including: controlling for municipal characteristics correlated with the implementation of projects and mortality (i.e., indicators capturing whether district municipality has access to the Internet, needs technical assistance to formulate investment projects, and manages at least one health center, and municipal income (ln)); controlling for an Amazon location indicator because of the peculiarities of this region (e.g., isolation, greater precipitation, vector-borne diseases) and the important role it plays when predicting implemented projects; restricting the sample of analysis to districts that implemented projects; excluding the capital of Peru, Lima, given how different it is from the rest of the country (e.g., richest area, best access to public services, highest initial sewerage connectivity); and transforming the independent variable to a top-coded version to deal with outliers.

Finally, I use 11 alternative IV strategies by introducing variations in how the main instrument is computed (see Table D4 in the Appendix). I first vary how the geographic suitability is modeled. Recall that in the main strategy I compute the geographic suitability index non-parametrically using principal component analysis. I alternatively predict a district's geographic suitability using machine learning (i.e. lasso linear and lasso Poisson models based on the relationship between projects implemented and all geographical variables, their squares and interactions). Next, I vary the threshold used to predict the time-varying counterfactual project implementation. Recall that in the analysis I use the mean number of projects implemented, which is the same as the 75th percentile of the distribution of projects implemented between 2005 and 2015. Alternatively, I use the 25th percentile and the 90th percentile of the distribution. Finally, I vary how I estimate the time-variant counterfactual project implementation. I use as an alternative instrument the interaction between geographic suitability and the annual nationwide budget available for sewerage projects.[23] The results remain in the same direction and the point estimates similar in magnitude. While the predictive power of the instrument is reduced with the alternative modeling of districts' geographic suitability and alternative thresholds, it is improved when building the instrument as an interaction term. Overall, the effect of an additional implemented project per year on IMR ranges between 0.000 and 0.004 deaths per 1,000 infants, and on U5MR the effect ranges between 0.160 and 1.197 deaths per 1,000 children under five years old.

B Mechanisms

1 Mortality by cause of death

To shed light on mechanisms, I estimate the effects of implemented projects on mortality rates disaggregated by cause of death. I first focus on mortality caused by conditions related to the health and safety hazards explained in Section I. One would expect deaths by infectious diseases, diseases of the digestive system, malnutrition, and other nutritional deficiencies to be the most responsive to the implementation of sewerage projects due to the fecal–oral transmission pathways that characterize these conditions, including diarrhea, gastroenteritis, typhoid, paratyphoid, and cholera. Tuberculosis is also included in this category, which is generally transmitted through airborne droplets, though contaminated dairy products might have played a role in disease transmission during this period (Watson, 2006). Furthermore, we would expect to see increases in deaths caused by falls,

---

[23] This alternative methodology resembles "shift-share" instruments, widely used in empirical fields in economics, which introduce spatial or other forms of cross-sectional variation to leverage over-time analyses.

drowning, and traffic-related accidents if construction works during the implementation of sewerage projects posed hazards to children. The effect of implemented projects on mortality rates could also operate through diseases of the respiratory system given that pollutants are released into the air during excavation works. Among others, this category includes pneumonia, influenza, whooping cough, and bronchitis.

While older children are more likely to be exposed to outdoor risks, younger children were likely to be affected through faecally contaminated water. Most infants are not exclusively breastfed, but are instead often fed a gruel that contains water. By 2015, only 63% of infants under six months were exclusively breastfed in Peru (World Bank, 2020).

Next, I focus on congenital malformations and non-communicable diseases, both of which are unrelated to health and safety hazards from construction works. The latter group includes deaths by neoplasms, diseases of the genitourinary system, nervous system, circulatory system, skin and subcutaneous tissue, and musculoskeletal systems and connective tissue.

Table 5 presents the estimated effect of the number of implemented sewerage projects on a district's infant and under-five mortality rate by cause of death, before the completion of projects. The dependent variables are the infant mortality rate per 1,000 infants in Panel A and the under-five mortality rate per 1,000 children under five years old in Panel B, disaggregated by cause of death: water-borne diseases (column 1), accidents (column 2), respiratory diseases (column 3), malformations (column 4), and other non-communicable diseases (column 5). All columns present 2SLS estimates, instrumenting "implemented projects" with "predicted projects" using equation (4).

On average, an additional project implemented increased the mortality caused by water-borne diseases by 0.002 deaths per 1,000 infants and by 0.410 deaths per 1,000 children ($\approx$ 20% and $\approx$ 18% increases from the mean initial rates, respectively). Furthermore, an additional project implemented increased the under-five mortality rate caused by accidents by 0.277 deaths per 1,000 children ($\approx$ 33% increase from the initial rate). I find no effect on the infant mortality rate caused by accidents, which supports the notion that outdoor hazards from the large building sites affected only older children. Both infants and older children were, however, affected by infectious diseases and nutritional deficiencies, likely generated by the construction works. As discussed in Section I, the implementation of sewerage projects often leaves open ditches, which become full of stagnant water or become landfills, and also requires water cuts that force the local population to rely on sources of water that are unsafe for drinking purposes because they are faecally contaminated (Fay et al., 2017). I find no effect on mortality caused by respiratory diseases, meaning that airborne pollutants are not the main channel explaining the results.

Notably, I find no effect of an additional project implemented on mortality rates caused by congenital malformations and non-communicable diseases unrelated to health and safety hazards posed by infrastructure projects. This evidence bolsters the claim that the instrument is not picking up systematic differences in mortality trends by all causes of death.

[Table 5 here]

2 Water and sanitation behavior

In addition, I examine the effects on water and sanitation use. As discussed in Section I, interviews with local experts revealed that water cuts are required in order to install or improve existing sewerage networks. Lack of water availability can increase early-life mortality through the following channels. First, municipalities might be discouraged to invest in piped water treatment (i.e., adding chemicals such as chlorine to remove contamination before distributing water to houses) if the service is disrupted. Once the service is resumed, untreated water would arrive through pipe networks, posing health risks to households that do not treat water in their premises to make it safe to drink (e.g., boiling or filtering water).

Second, interruptions in the piped water networks force the local population to rely on unsafe sources of water for drinking purposes. As indicated by the 2005 Census, the alternative sources available in these districts in Peru were public taps, water trucks, unprotected spring and surface water, none of which is considered safely managed by the standards of the WHO-UNICEF Joint Monitoring Program. Drinking water from a water source that is not accessible on the premises requires water collection, and stagnant water is the main transmission pathway of vector-borne infections (WHO, 2017).

Third, lack of water availability for hygienic purposes might lead to the collapse of on-site sanitation facilities, which most of the population relied on before connecting to public sewers. Latrines connected to septic tanks and pits require water to flush the fecal effluent, otherwise they overflow and can even release black waters (i.e., effluent with fecal matter) into the local environment (Bancalari and Martinez, 2018). With the collapse of existing sanitation facilities, households are forced to practice open defecation. This unsafe sanitation practice jeopardizes the local environment (i.e., introducing disease) and increases early-life mortality (Geruso and Spears, 2018).

Table 6 presents the estimated effect of the number of implemented sewerage projects on water and sanitation behavior. The coefficients correspond to 2SLS estimates of the effect of “implemented projects” instrumented by “predicted projects” using equation (4), but replacing the dependent variable with the following dependent variables: an indicator variable for whether the district municipality treats water to make it safe to drink

("Treated", column 1); the share of households that rely on unsafe sources of water ("Unsafe", column 2); the share of households that use an on-site latrine facility ("On-site", column 3); the share of households that openly defecate ("OD", column 4).

On average, an additional project implemented per year decreased the likelihood of municipalities treating piped water by 11 ppts ($\approx 13\%$ compared to the initial share treating it), although not precisely estimated. I also find that an additional project implemented per year increased the share of households relying on unsafe sources of water by 2.8 ppts ($\approx 6\%$ increase relative to the initial mean), and decreased the share of households using latrines by 5.1 ppts ($\approx 14\%$ decrease relative to the initial mean), while it increased the share of those practicing open defecation by 4.1 ppts ($\approx 9.8\%$ increase relative to the initial mean). All together, these results support the notion that during the implementation phase of sewerage projects, the local population drank unsafe sources of water, whose collection also increases the prevalence of vector-borne diseases, and relied on hygiene and sanitation practices that generate large negative health externalities.

[Table 6 here]

3 Alternative mechanisms

Could the implementation of sewerage projects instead have affected mortality rates through demographic changes? The observed increase in mortality rates could be a result of a decrease in the denominator: infants and children under five years old. A decrease could be a result of families moving away from disruptive infrastructure works, while an increase could be a response to lower infant survival and families trying to attain their desired fertility. Infrastructure works might have generated migration and, more importantly, selected migration. Higher-income individuals and the health-conscious could have emigrated to districts that were not experiencing disruptions and were less odiferous.

To examine the possibility of a district's composition effect, in Table 7 I modify equation (4) and replace mortality rates with the following outcomes: number of children under 12 months ("Infants", column 1); number of children under five years old ("Under-5" , column 2); total population ("Population", column 3); population density in km^2 ("Density", column 4); district share of household heads with secondary education completed ("Education", column 5); and district share of households connected to electricity grids ("Electricity", column 6).

There does not appear to have been an immediate fertility response to implemented projects, consistent with a fairly stable fertility rate during the period of study (World Bank, 2020). Moreover, there is no statistically significant effect on the number of children under the age of five. There is a positive effect on the total population in districts that translates into an increase by 15% over the average initial population. It is possible that the works attracted households keen to gain access to the public sewers. This effect, however, appears not to be a major explanation for an increase in mortality rates, given that there was no change in population density. The literature has mostly attributed increases in mortality to overcrowding (Marx, Stoker, and Suri, 2013; Hathi et al., 2017).

The analysis in columns 5 and 6 is estimated on a limited sample because of the availability of the dependent variable only in the quinquennial censuses.[24] Nevertheless, the results point in the direction that compositional changes are not the main channel explaining increases in mortality rates. In fact, an additional implemented project increased by 0.4 ppts the share of households with a head who had completed secondary education (1.8% over the initial average share). There is no statistically significant effect in the share of households connected to the electricity network. If anything, the implementation of sewerage projects encouraged an immigration flow that was positively selected, meaning that the estimated effect in Table 3 could be downward biased. The estimated effects of implemented projects on mortality, however, remain robust when controlling for mortality trends specific to 'Education' and 'Electricity' in 2005 (see Appendix Table D5).

V Discussion: the real cost of sewerage

In this section, I present a back-of-the-envelope calculation of how much the social costs of infrastructure projects are typically underestimated. In particular, I estimate the monetary value for under-five children 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 systems.

This exercise requires several assumptions. First, I assume that 2.3 projects are launched per district. Second, I assume that the survival of children in the future is worth somewhat less than the survival of those during the 10 years around project completion, using a discount rate of 5%, as used in the calculations by Watson (2006). Third, I assume that a surviving child would live a healthy life for another 70 years—the life expectancy in Peru was 75 years in 2015 (World Bank, 2020). Finally, I make the conservative assumption that the value of a healthy life year is about 75,000 USD, following the calculation of Cutler and Meara (2000).

I estimate the social costs of four scenarios. I first consider a case in which districts follow the average development pathway of projects in Peru between 2005 and 2015, implementing 2.3 projects in 4.7 years. Taking the estimates from Panel A, column 4, of

---

[24] For these two outcomes, data from 2017 are used to impute the year 2015 and the missing years are imputed with the latest value available.

Table 3 (+0.625 deaths per 1,000 children), the social cost during implementation amounts to 35.5 million USD per district. This case, nevertheless, hides meaningful heterogeneity in terms of how well projects are implemented. Hence, I next consider a scenario in which projects are implemented without being delayed or halted for only one year, which is the minimum project implementation time found in the period of analysis. Taking the estimates from Panel B, column 2, of Table 3 (+0.633 deaths per 1,000 children) for districts without projects halted, the social cost would be only 7.6 million USD per district. If projects are delayed for 1.8 years, which is the average additional years that projects that were never halted take to be implemented, there is an additional 13.8 million USD in social costs. An average delay can more than double the estimated effect in mortality, and so the social costs. Lastly, I consider the case in which all started projects are halted for 2.5 years, the average halting time in the period of study. Taking the estimates from Panel B, column 4, of Table 3 (+1.71 deaths per 1,000 children) for districts with all projects halted, the social costs increase by 51.5 million USD. This estimate highlights the huge costs associated with leaving projects halted (see Table D6 in the Appendix).

To put these social costs in context, I compare it to the monetary benefit of averted deaths resulting from completed projects. I use the estimated effect of completed sewerage on early-life mortality from two scenarios: (1) estimated effect per municipality in Argentina and per year during 10 years (1990–1999) from the study of Galiani et al. (2005); and, (2) estimated effect per municipality in Massachusetts and per year during 40 years (1880–1920) from the study of Alsan and Goldin (2019). The estimated effects of completed sewerage on child mortality are 0.334 for scenario (1), and 0.149 for scenario (2). I assume that, after the period of analysis, the annual effect accrues in perpetuity without growing in magnitude.

Table D7 in the Appendix shows all figures used in the crude calculation. I first estimate the monetary value of lives saved between $k+1$ and $k+f$, where k is the year of completion and f is the years relative to completion for each study. I multiply the annual effect in each district municipality by the remaining years of healthy life and the value of a healthy life. The social benefit from the study period for each scenario is: (1) 17.535 million USD; and (2) 31.290 million USD. Next, I estimate the monetary value of lives saved per year after the period of study. The net present value of these benefits accrued in perpetuity for each scenario is: (1) 35.070 million USD; and, (2) 15.645 million USD.[25] Thus, the total benefit after project completion per district in each scenario is: (1) 52.605 million USD; and, (2) 46.935 million USD.

Sewerage projects are highly beneficial if implemented in a short period of time and

---

[25] Net present value of a 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.

without suffering from delays and mid-construction halting. In this case, the social benefits would be around six times as much the estimated social costs. This ratio, however, drops substantially when projects suffer from delays, as in this case the social benefits are only twice as much the costs. Finally, the social costs completely offset the benefits if all projects in a district are halted for the average halting time (2.5 years). The social benefits would be only a fraction of the costs, ranging between 0.72 and 0.64 (see Table D7 in the Appendix). The back-of-the-envelope calculation reinforces the notion that social costs in the implementation phase must be taken into account in cost–benefit analyses. It also highlights the detrimental consequences of halting projects and the importance of completing them.

VI Conclusions

Public infrastructure is a driver of development, but its implementation can generate negative social costs. This is the first paper to provide robust empirical evidence of the large detrimental mortality effects that occur in the process of infrastructure development. I end by emphasizing the relevance of my results. First, we learn about the social costs of implemented projects relative to not starting projects. There is sufficient evidence in the literature that completed (and utilized) sewerage infrastructure decreases early-life mortality (e.g., Galiani et al., 2005; Kesztenbaum and Rosenthal, 2017; Alsan and Goldin, 2019). Hence, the take-away message is that while sewerage infrastructure is welfare-improving after completion, its implementation poses high social costs that must be taken into account. Putting in place measures to minimize risks to the local population might increase the implementation costs, but can prevent whole projects ending up as net social losses. Traditional policy analyses evaluating the welfare effects of infrastructure projects have long overestimated the benefits of such projects, as the social costs generated during the implementation phase are often not incorporated in the calculations.

Second, I prove that mismanagement of infrastructure projects magnifies the social costs from the implementation phase, putting at risk the cost-effectiveness of a welfare-improving infrastructure such as sewerage. I find that halted projects exacerbate the estimated lethal effects. A back-of-the-envelope calculation shows that the social benefits of deaths averted, accrued in perpetuity, might not be enough to offset the social costs from the failed implementation phase. And, of course, the social benefits of sewerage would not fully materialize if projects are never completed. At the end of my analysis period, more than 40% of the projects were abandoned mid-construction. Abandoned projects also have a high opportunity cost, as these projects had an average of 40% of the contractual sum disbursed. If these projects are never completed, the sunk cost would be a waste equal to one-third of the public expenditure on tertiary education in 2015 in Peru (World Bank, 2020). These results highlight how pervasive waste in government spending is and emphasize the complementarity between infrastructure and institutions that is central to improving living standards (Bandiera et al., 2009; Ashraf et al., 2016).

There are many other costs associated with the implementation of projects, which opens up a research agenda. Morbidity must have increased and the quality of life was jeopardized 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; Case, 2010). Averted morbidity and deaths from completed projects, of course, may offset these negative consequences, but there might be additional costs associated with the construction phase that require further investigation, such as disruptions in commuting that restrict labor market opportunities.

It is equally vital to understand how to improve infrastructure provision. While this literature stream is growing (see, for example, Robinson and Torvik (2004), Olken (2007), Lewis et al. (2016), Rasul and Rogger (2018)), it is unclear whether "white elephants" are mainly a result of lack or misallocation of resources, bureaucratic capacity or political will.

My new policy-relevant focus on the implementation phase is an important first step towards understanding how infrastructure affects living standards throughout all stages of the developmental process, how the effects can be measured, and the magnitude of the social costs generated.

SUPPLEMENTARY MATERIAL

An Appendix for this article is attached.

References

Agüero, Jorge M., Carlos Felipe Balcazar, Stanislao Maldonado, and Hugo Nopo. 2021. “The Value of Redistribution: Natural Resources and the Formation of Human Capital under Weak Institutions”. *J. Develop. Econ.* 148: 102581.

Alexander, Diane and Hannes Schwandt. 2022. “The Impact of Car Pollution on Infant and Child Health: Evidence from Emissions Cheating.” *Review of Economic Studies* 0: 1–39.

Alsan, Marcella, and Claudia Goldin. 2019. “Watersheds in Child Mortality: The Role of Effective Water and Sewerage Infrastructure, 1880 to 1920.” *J. Political Economy* 127: 586–638.

Anderson, Theodore W., and Herman Rubin. 1949. “Estimation of the Parameters of a Single Equation in a Complete System of Stochastic Equations.” *Annals of Mathematical Statistics* 20: 46–63.

Aschauer, David Alan. 1989. “Is Public Expenditure Productive?” *J. Monetary Econ.* 23: 177–200.

Asher, Sam, and Paul Novosad. 2020. “Rural Roads and Local Economic Development.” *American Econ. Rev.* 110 (3): 797–823.

Ashraf, Nava, Edward L. Glaeser, and Giacomo A. M. Ponzetto. 2016. “Infrastructure, Incentives, and Institutions.” *American Econ. Rev.: Papers & Proceedings* 106 (5): 77–82.

Bancalari, Antonella, and Sebastian Martinez. 2018. “Exposure to Sewage from On-site Sanitation and Child Health: A Spatial Analysis of Linkages and Externalities in Peri-urban Bolivia.” *J. Water Sanitation and Hygiene for Development* 8 (1): 90–99.

Bandiera, Oriana, Andrea Prat, and Tommaso Valletti. 2009. “Active and Passive Waste in Government Spending: Evidence from a Policy Experiment.” *American Econ. Rev.* 99 (4): 1278–308.

Banerjee, Abhijit, Esther Duflo, and Nancy Qian. 2020. “On the Road: Access to Transportation Infrastructure and Economic Growth in China.” *J. Development Econ.* 145: 102442.

Bhalotra, Sonia R., Alberto Diaz-Cayeros, Grant Miller, Alfonso Miranda, and Atheendar S. Venkataramani. 2021. “Urban Water Disinfection and Mortality Decline in Developing Countries.” *American Economic Journal: Economic Policy* 13 (4): 490-520.

Borusyak, Kirill, Peter Hull, and Xavier Jaravel. 2021. “Quasi-Experimental Shift-Share Research Designs.” *Rev. Econ. Studies* forthcoming (`https://doi.org/10.1093/restud/rdab030`).

British Medical Journal. 2007. “BMJ Readers Choose the ‘Sanitary Revolution’ as Greatest Medical Advance since 1840.” *BMJ News* 334: 111.

Burgess, Robin, Remi Jedwab, Edward Miguel, Ameet Morjaria, and Gerard Padró Miquel. 2015. “The Value of Democracy: Evidence from Road Building in Kenya.” *American Econ. Rev.* 105 (6): 1817–51.

Case, Anne. 2010. “Causes and Consequences of Early-Life Health.” *Demography* 47(S): S65–S85.

Case, Anne, and Christina Paxson. 2008. “Stature and Status: Height, Ability, and Labor Market Outcomes.” *J. Political Econ.* 116: 499–532.

Cesur, Resul, Erdal Tekin, and Aydogan Ulker. 2017. “Air Pollution and Infant Mortality: Evidence from the Expansion of Natural Gas Infrastructure.” *Economic Journal* 127 (600): 330–62.

Cutler, David and Grant Miller. 2005. “The Role of Public Health Improvements in Health Advances: The Twentieth-Century United States.” *Demography* 42: 1–22.

Cutler, David M., and Ellen Meara. 2000. “The Technology of Birth: Is It Worth It?” *Frontiers in Health Policy Research* 3: 33–67.

Defensoria del Pueblo. 2015. “Why Are There So Many Sanitation Projects Abandoned? This Affects Your Rights.” *Defensoria del Pueblo*, 9 June. `https://www.defensoria.gob.pe/blog/obras-de-agua-paralizadas/`.

Dinkelman, Taryn. 2011. “The Effects of Rural Electrification on Employment: New Evidence from South Africa.” *American Econ. Rev.* 101 (7): 3078–108.

Donaldson, Dave. 2018. “Railroads of the Raj: Estimating the Impact of Transportation Infrastructure.” *American Econ. Rev.* 108 (5): 899–934.

Duflo, Esther and Rohini Pande. 2007. “Dams.” *Quarterly Journal of Economics* 122: 601–46.

Fay, Marianne, Luis Alberto Andres, Charles Fox, Ulf Narloch, Stephane Straub, and Michael Slawson. 2017. “Rethinking Infrastructure in Latin America and the Caribbean: Spending Better to Achieve More.” World Bank Technical Report.

Fay, Marianne, Hyoung Il Lee, Massimo Mastruzzi, Sungmin Han, and Moonkyoung Cho. 2019. “Hitting the Trillion Mark: A Look at How Much Countries Are Spending on Infrastructure.” World Bank Policy Research Working Paper No. 8730.

Flyvbjerg, Bent, Mette K. Skamris Holm, and Soren L. Buhl. 2004. “What Causes Cost Overrun in Transport Infrastructure Projects?” *Transport Reviews: A Transnational Transdisciplinary Journal* 24: 3–18.

Galiani, Sebastian, Paul Gertler, and Ernesto Schargrodsky. 2005. “Water for Life: The Impact of the Privatization of Water Services on Child Mortality.” *J. Political Econ.* 113: 83–120.

Geruso, Michael, and Dean Spears. 2018. “Neighborhood Sanitation and Infant Mortality.” *American Econ. J.: Appl. Econ.* 10: 125–62.

Hammer, Mark. 1986. *Water and Wastewater Technology* (2nd edn). New York: Wiley.

Hathi, Payal, Sabrina Haque, Lovey Pant, Diane Coffey, and Dean Spears. 2017. “Place and Child Health: The Interaction of Population Density and Sanitation in Developing Countries.” *Demography* 54: 337–60.

Isham, Jonathan, and Daniel Kaufmann. 1999. “The Forgotten Rationale for Policy Reform: The Productivity of Investment Projects.” *Quarterly Journal of Economics* 114: 149–84.

Kesztenbaum, Lionel, and Jean-Laurent Rosenthal. 2017. “Sewers’ Diffusion and the Decline of Mortality: The Case of Paris, 1880–1914.” *J. Urban Economics* (2017), 98: 174–86.

Lee, David S., Justin McCrary, Marcelo J. Moreira, and Jack Porter. 2020. “Valid t-ratio Inference for IV.” Cornell University Working Paper, https://arxiv.org/pdf/2010.05058.pdf.

Lewis-Faupel, Sean, Yusuf Neggers, Benjamin A. Olken, and Rohini Pande. 2016. “Can Electronic Procurement Improve Infrastructure Provision? Evidence from Public Works in India and Indonesia.” *American Econ. J.: Econ. Policy* 8: 258–83.

Lipscomb, Molly, A. Mushfiq Mobarak, and Tania Barham. 2013. “Development Effects of Electrification: Evidence from the Topographic Placement of Hydropower Plants in Brazil.” *American Econ. J.: Appl. Econ.* 5: 200–31.

Malpartida Tabuchi, Jorge. 2018. “Mosquitoes due to Abandoned Sewerage Project in Asia, Lima.” *El Comercio*, 17

February. https://elcomercio.pe/lima/sucesos/criadero-zancudos-asia-obra-paralizada-noticia-497970-noticia/.

Marx, Benjamin, Thomas M. Stoker, and Tavneet Suri. 2013. “The Economics of Slums in the Developing World.” *J. Econ. Perspectives* 4: 187–210.

Mettetal, Elizabeth. 2019. “Irrigation Dams, Water and Infant Mortality: Evidence from South Africa.” *J. Development Econ.* 138: 17–40.

Nunn, Nathan, and Nancy Qian. 2014. “US Food Aid and Civil Conflict.” *American Economic Review* 104 (6): 1630–66.

Olken, Benjamin A. 2007. “Monitoring Corruption: Evidence from a Field Experiment in Indonesia ” *J. Political Economy* 115(2): 200–249.

Panamerican Center of Sanitation Engineering and Environmental Sciences. 2005. “Guia para el Diseno de Tecnologias de Alcantarillado.” Technical report, Organizacion Panamericana de la Salud (OPS/WHO) and Cooperacion Suiza para el Desarrollo (COSUDE), Lima, Peru.

Prüs-Ustün et al. 2014. “Burden of Disease from Inadequate Water, Sanitation and Hygiene in Low- and Middle-Income Settings: A Retrospective Analysis.” *Tropical Medicine Internat. Health* 19: 894–905.

Rasul, Imran, and Daniel Rogger. 2018. “Management of Bureaucrats and Public Service Delivery: Evidence from the Nigerian Civil Service.” *Economic Journal* 128 (608): 413–46.

Robinson, James A., and Ragnar Torvik. 2004. “White Elephants.” *J. Public Econ.* 89: 197–210.

Romero Rojas, Jairo Alberto. 2000. *Treatment of Waste Water: Theory and Principles of Design*. Bogota: Editorial Escuela Colombiana de Ingenieria.

RPP Noticias. 2018. “In Lambayeque, 55 Abandoned Sewerage Projects.” *RPP*, 11 January. https://rpp.pe/peru/lambayeque/en-lambayeque-55-obras-de-saneamiento-estan-paralizadas-noticia-10991

Rud, Juan Pablo. 2012. “Electricity Provision and Industrial Development: Evidence from India.” *J. Development Econ.* 97: 352–67.

Sanderson, Eleanor, and Frank Windmeijer. 2016. “A Weak Instrument F-Test in Linear IV Models with Multiple Endogenous Variables.” *J. Econometrics* 190: 212–21.

Serquen, Walter. 2018. “Children Drown in an Open Ditch from Sewerage Project.” *Correo*, 9 February. `https://diariocorreo.pe/edicion/lambayeque/lambayeque-dos-hermanitos-mueren-ahogados-al-caer-una-zanja-de-una-ob`

Stock, James H. and Motohiro Yogo. 2002. “Testing for Weak Instruments in Linear IV Regression.” NBER Technical Working Paper No. 284.

UNICEF. 2005. “State of the World’s Children.” Technical report. Geneva: UNICEF.

Vega, Ysela. 2015. “Treatment Plant EPSEL is a Source of Infection.” *La Republica*, 30 June. `https://larepublica.pe/sociedad/199549-planta-de-tratamiento-de-epsel-es-un-foco-contaminante`.

Von Hesse, Milton. 2016. “Guidelines for a National Sanitation Policy.” Technical report, Peruvian Ministry of Housing, Construction and Sanitation, Lima.

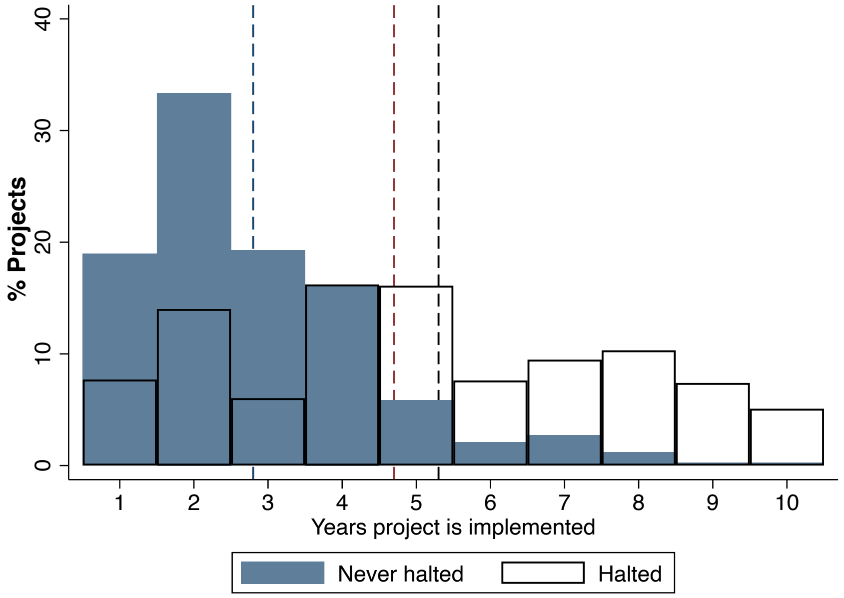
Watson, Tara. 2006. “Public Health Investments and the Infant Mortality Gap: Evidence from Federal Sanitation Interventions on U.S. Indian Reservations.” *J. Public Econ.* 90: 1537–60.

Williams, Martin J. 2017. “The Political Economy of Unfinished Development Projects: Corruption, Clientelism, or Collective Choice?” *American Political Sci. Rev.* 111: 705–23.

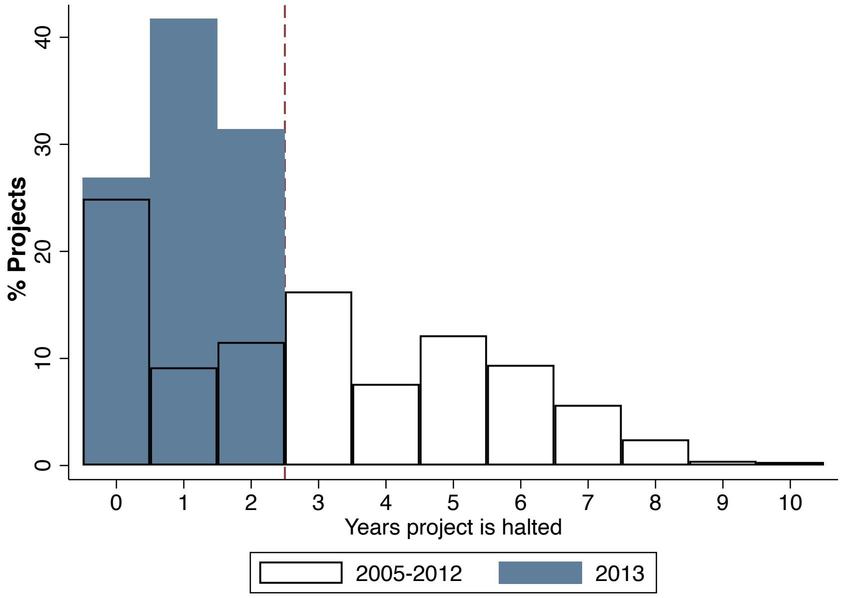
WHO-UNICEF Joint Monitoring Program. 2017. “Safely Managed Drinking Water.” Thematic report on drinking water. Geneva, Switzerland: World Health Organization.

World Bank. 2015. “Pilot Study of Public Investment for Water and Sanitation Projects in Urban and Rural Areas.” Technical report. Lima, Peru: World Bank.

World Bank. 2020. *World Development Indicators*. Washington DC: World Bank.



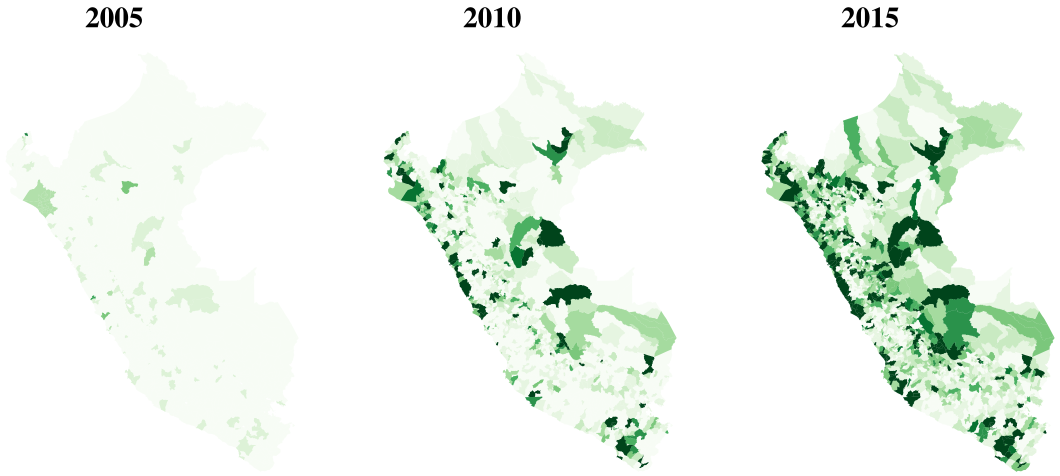
(A) Duration of implementation



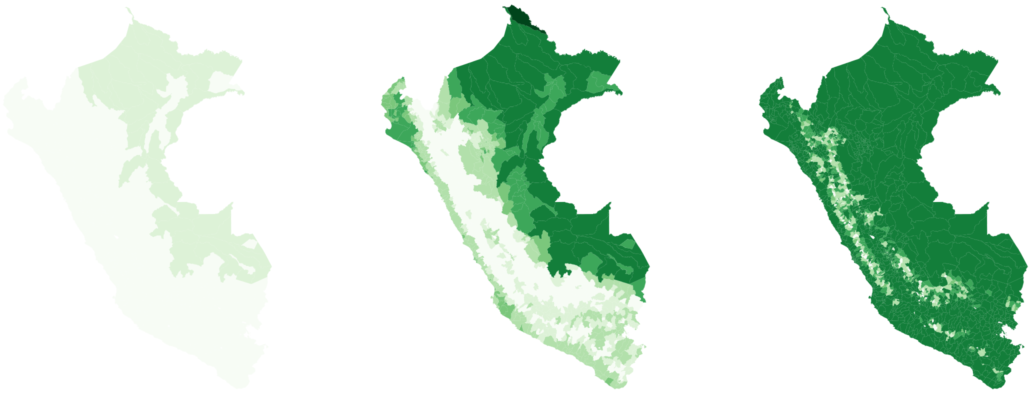
(B) Duration of halting

Figure 1
Years projects are implemented and halted

Note. Distribution of projects by years implemented and halted. “Years project is implemented” is computed as the number of years a project is under construction, regardless of whether or not it was ever completed. “Years project is halted” is computed as the number of years that no additional funds are disbursed although a project is not completed. The sample is restricted to projects started between 2005 and 2013 given the right-censoring nature of the data (i.e., by 2015, there are at least two years to observe the completion of these projects). In Panel A, the blue dashed line denotes the mean implementation time for projects that were never halted (2.8 years), the dashed black line denotes projects that were halted at some point (5.3 years), and the red dashed line is for all projects (4.7 years) in the sample. In Panel B, the red dashed line denotes the mean of the distribution of years that projects in the sample were halted (2.5 years). See Online Appendix D for variable definitions and see the text for further details.



(A) Actual



(B) Predicted

Figure 2
Actual and predicted projects implemented across districts

Note. Spatial distribution of the actual and predicted number of sewerage projects implemented, in Panels A and B respectively, for the years 2005, 2010, and 2015. The district boundary is given in the maps in black. Light-shaded districts are those in which no or few sewerage projects were implemented, and dark-shaded districts are those in which several sewerage projects were implemented.
Source. Author's calculations using data on the number of sewerage projects implemented between 2005 and 2015.

Table 1
Effect of development indicators on predicted projects

Dependent variable:	Instrument for implemented sewerage projects			
Unit:	Projects			
	(1)	(2)	(3)	(4)
Population density (t-5)	0.000			
	(0.000)			
	[0.937]			
Revenues (t-5)		0.029		
		(0.037)		
		[0.434]		
Human resources (t-5)			-0.000	
			(0.000)	
			[0.245]	
Internet access (t-5)				0.038
				(0.030)
				[0.210]
District-year	8448	6889	8345	8414
Districts	1,408	1,408	1,408	1,408

Note. Estimates based on district-level panel data spanning the years 2005–2015. The dependant variable is the cumulative number of "predicted projects". The regressors are the five-year-lagged values of: population density (population per km^2) in column 1; municipal revenues (hyperbolic syne transformation) in column 2; municipal total human resources in column 3; and an indicator equal to one if the municipality has Internet access, and zero otherwise, in column 4. All coefficients are estimated with ordinary least-squares (OLS), including district and year fixed effects. Standard errors clustered by district are reported in parentheses and p-values in brackets. See Online Appendix D for variable definitions and see the text for further details.

Table 2
Effect of predicted projects on mortality and projects implemented

	Placebo test		Reduced-form		1st stage
Dependent variable:	IMR	U5MR	IMR	U5MR	Implemented
Unit:	Deaths per 1,000 infants or children				Projects
	(1)	(2)	(3)	(4)	(5)
Predicted projects	0.000	0.071	0.000	0.100	0.151
	(0.000)	(0.064)	(0.000)	(0.041)	(0.039)
	[0.156]	[0.266]	[0.034]	[0.014]	[0.000]
Mean (initial)	0.018	4.818	0.018	4.818	0.086
District-year	5,630	5,630	8,555	8,555	8,555
Districts	1,283	1,283	1,379	1,379	1,379

Note. Estimates based on district-level panel data spanning the years 2005–2015. The dependant variables are: infant mortality rate (IMR) per 1,000 infants in columns 1 and 3; under-five mortality rate (U5MR) per 1,000 children under five years old in columns 2 and 4; and the number of implemented projects in column 5. Columns 1 and 2 present the reduced-form regression of the mortality rates on the cumulative number of "predicted projects" before the start of the first actual "implemented project" in each district, which serves as a Placebo test in support of the exclusion restriction. Columns 3 and 4 present the reduced-form regression of the mortality rates on the cumulative number of "predicted projects", following equation (1). Column 5 presents the first-stage regression of the cumulative number of "implemented projects" on the cumulative number of "predicted projects", following equation (3). In all regressions, the sample of analysis is restricted to years prior to the completion of at least one sewerage project in a given district. The sample in columns 2 and 3 is lower because it is further restricted to the years prior to the start of at least one sewerage project (districts that started projects in the initial year of the study are dropped because they have no period in which projects were not yet started). 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 mean of each outcome in the initial year of the study (2005). See Online Appendix D for variable definitions and see the text for further details.

Table 3
Effect of projects implemented on mortality

Dependent variable:	IMR	U5MR	IMR	U5MR
Unit:	Deaths per 1,000 infants or children			
	(1)	(2)	(3)	(4)
Panel A				
	OLS		2SLS	
Implemented projects	0.000	0.057	0.003	0.660
	(0.000)	(0.016)	(0.001)	(0.312)
	[0.000]	[0.000]	[0.058]	[0.034]
Anderson–Rubin p-value			0.034	0.014
Mean (initial)	0.018	4.818	0.018	4.818
F-stat (SW)			14.716	14.716
District-year	8,555	8,555	8,555	8,555
Districts	1,379	1,379	1,379	1,379
Panel B				
	2SLS		2SLS	
	No halting in district		All halted in district	
Implemented projects	0.003	0.633	0.006	1.707
	(0.002)	(0.455)	(0.004)	(0.930)
	[0.107]	[0.165]	[0.138]	[0.066]
Anderson–Rubin p-value	0.083	0.140	0.119	0.044
Mean (initial)	0.018	4.818	0.018	4.818
F-stat (SW)	16.070	16.070	16.504	16.504
District-year	5,236	5,236	4,346	4,346
Districts	1,009	1,009	968	968

Note. Estimates based on district-level panel data spanning the years 2005–2015. The dependant variables are the infant mortality rate (IMR) per 1,000 infants in columns 1 and 3, and under-five mortality rate (U5MR) per 1,000 children under five years old in columns 2 and 4. In Panel A, columns 1 and 2 show OLS estimates following equation (1). Columns 3 and 4 in Panel A and columns 1–4 in Panel B show 2SLS estimates of the effect of "implemented projects" instrumented by "predicted projects" using equation (4). The sample of analysis is restricted to years prior to the completion of at least one sewerage project in a given district. The samples columns 1 and 2 in Panel B are further restricted to district-year observations in which no project is halted, and in columns 3 and 4 to district-year observations in which all projects are halted or no project has been started. 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, the Sanderson–Windmeijer (SW) F-statistic and the mean of each outcome in the initial year of the study (2005). See Online Appendix D for variable definitions and see the text for further details.

Table 4
Robustness checks by controlling for geographic-specific trends

	IMR (1)	U5MR (2)	F-stat (SW) (3)
1. Suitability index x year	0.003	0.684	29.359
	(0.001)	(0.235)	
	[0.013]	[0.004]	
AR p-value	0.006	0.001	
2. Suitability index x year +			
Amazon x year	0.003	0.674	24.856
	(0.001)	(0.254)	
	[0.025]	[0.008]	
AR p-value	0.014	0.002	
3. Suitability index x year +			
Amazon x year +			
Mining production	0.003	0.673	24.861
	(0.001)	(0.254)	
	[0.025]	[0.008]	
AR p-value	0.014	0.002	
District–year	8555	8555	
Districts	1379	1379	

Note. Estimates based on district-level panel data spanning the years 2005–2015. The dependant variables are the infant mortality rate (IMR) per 1,000 infants in column (1) and the under-five mortality rate (U5MR) per 1,000 children under 5 years old in column (2). Column (3) reports the Sanderson–Windmeijer (SW) F-statistic. Coefficients correspond to 2SLS estimates of the effect of the number of 'implemented projects' instrumented by 'predicted projects' using equation 4. The sample of analysis is restricted to years prior to the completion of at least one sewerage project. 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. The different specifications controlling for geography interacted with year dummies in each row are reported in the left-hand column. Geographic control variables are as follows: 'Suitability index' is a normalized index ranging between zero and one that captures the geographical suitability for low-cost sewerage projects. 'Amazon' is an indicator equal to one if the district is located in the Amazon region, and zero otherwise. 'Mining production' is the monetary value of mining production in USD at 2010 constant prices, transformed using a hyperbolic syne transformation.

Table 5
Effect of projects implemented on mortality, by cause of death

Dependent variable:	Water-borne	Accidents	Respiratory	Malformation	Non-commun.
Unit:	Deaths per 1,000 infants or children under five years old				
	(1)	(2)	(3)	(4)	(5)
Panel A: IMR					
Implemented projects	0.002	0.001	-0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)
	[0.089]	[0.226]	[0.646]	[0.319]	[0.671]
Anderson–Rubin p-value	0.067	0.210	0.645	0.306	0.670
F-stat (SW)	15.861	15.861	15.861	15.861	15.861
Mean (initial)	0.010	0.002	0.003	0.002	0.005
District-year	8,555	8,555	8,555	8,555	8,555
Districts	1,379	1,379	1,379	1,379	1,379
Panel B: U5MR					
Implemented projects	0.410	0.277	-0.007	0.064	-0.062
	(0.214)	(0.151)	(0.127)	(0.094)	(0.159)
	[0.056]	[0.067]	[0.959]	[0.497]	[0.697]
Anderson–Rubin p-value	0.035	0.044	0.959	0.491	0.697
F-stat (SW)	15.861	15.861	15.861	15.861	15.861
Mean (initial)	2.268	0.820	0.731	0.388	1.299
District-year	8,555	8,555	8,555	8,555	8,555
Districts	1,379	1,379	1,379	1,379	1,379

Note. Estimates based on district-level panel data spanning the years 2005–2015. The dependant variables are the infant mortality rate per 1,000 infants in Panel A and the under-five mortality rate per 1,000 children under five years old in Panel B, disaggregated by cause of death. "Water-borne" (column 1) includes deaths by infectious diseases, perinatal complications, diseases of the digestive system and malnutrition and other nutritional deficiencies; "Accidents" (column 2) are deaths by external causes; "Respiratory" (column 3) includes diseases of the respiratory system; "Malformation" (column 4) includes deaths due to congenital malformations; and 'Non-commun.' (column 5) denotes deaths by disease that are not transmissible directly from one person to another, including neoplasms, congenital malformations, diseases of the genitourinary system, nervous system, circulatory system, skin and subcutaneous tissue, and musculoskeletal systems and connective tissue. Coefficients correspond to 2SLS estimates of the effect of "implemented projects" instrumented by "predicted projects" using equation (4). The sample of analysis is restricted to years prior to the completion of at least one sewerage project. 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, the Sanderson–Windmeijer (SW) F-statistic and the mean of each outcome in the initial year of the study (2005). See Online Appendix D for variable definitions and see the text for further details.

Table 6
Effect of projects implemented on water and sanitation use

	Water		Sanitation	
Dependent variable:	Treated	Unsafe	On-site	OD
Unit:	Indicator	Share of households in district		
	(1)	(2)	(3)	(4)
Implemented projects	-0.111	0.028	-0.051	0.041
	(0.084)	(0.017)	(0.013)	(0.011)
	[0.183]	[0.097]	[0.000]	[0.000]
Anderson–Rubin p-value	0.130	0.086	0.000	0.000
F-stat (SW)	7.743	25.739	25.666	25.666
Mean (initial)	0.834	0.471	0.353	0.418
District-year	8,430	12,750	12,746	12,746
Districts	1,300	1,379	1,379	1,379

Note. Estimates based on district-level panel data spanning the years 2005–2015. The dependant variables are: an indicator variable of whether the district municipality treats water to make it safe to drink ("Treated", column 1); the share of households that rely on unsafe sources of water ("Unsafe", column 2); the share of households that use an on-site latrine facility ("On-site", column 3); the share of households that openly defecate (OD; column 4). For the outcomes in columns 2–4, data from 2017 are used to impute the year 2015 and the missing years are imputed with the latest value available. Coefficients correspond to 2SLS estimates of the effect of "implemented projects" instrumented by "predicted projects" using equation (4). The sample of analysis is restricted to years prior to the completion of at least one sewerage project. The sample in column 1 is lower due to missing data for 79 districts on this outcome. 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, the Sanderson–Windmeijer (SW) F-statistic and the mean of each outcome in the initial year of the study (2005). See Online Appendix D for variable definitions and see the text for further details.

Table 7
Effect of projects implemented on the demographic features and composition of districts

Dependent variable	Fertility		Migration		Selective	
	Infants	Under-five	Population	Density	Education	Electricity
Unit:	Population in age subgroup		Total population	Population per km^2	Share of households	
	(1)	(2)	(3)	(4)	(5)	(6)
Implemented projects	0.173	0.864	3513.991	12.323	0.004	−0.003
	(12.510)	(62.551)	(1210.377)	(29.233)	(0.002)	(0.004)
	[0.989]	[0.989]	[0.004]	[0.673]	[0.091]	[0.386]
Anderson–Rubin p-value	0.989	0.989	0.000	0.674	0.063	0.380
Mean (initial)	495.913	2479.565	23472.257	645.086	0.219	0.557
F-stat (SW)	15.861	15.861	15.861	15.861	15.812	15.635
District-year	8,555	8,555	8,555	8,555	8,551	8,528
Districts	1,379	1,379	1,379	1,379	1,379	1,376

Note. Estimates based on district-level panel data spanning the years 2005–2015. The dependent variables are the number of infants (“Infants”, column 1); under-five population (“Under-five”, in column 2); total population (“Population”, column 3); population density in km^2 (“Density”, column 4); share of household heads with secondary education completed (“Education”, column 5); and share of households connected to electricity grids (“Electricity”, column 6) in a given district. Data for the outcome in column 5 are only available for the years 2005, 2010, and 2017, and for the outcome in column 6 only for the years 2005 and 2017 and for fewer districts out of the total sample. For these two outcomes, data from 2017 are used to impute the year 2015 and the missing years are imputed with the latest value available. Coefficients correspond to 2SLS estimates of the effect of “implemented projects” instrumented by “predicted projects” using equation (4). The sample of analysis is restricted to years prior to the completion of at least one sewerage project. 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, the Sanderson–Windmeijer (SW) F-statistic and the mean of each outcome in the initial year of the study (2005). See Online Appendix D for variable definitions and see the text for further details.

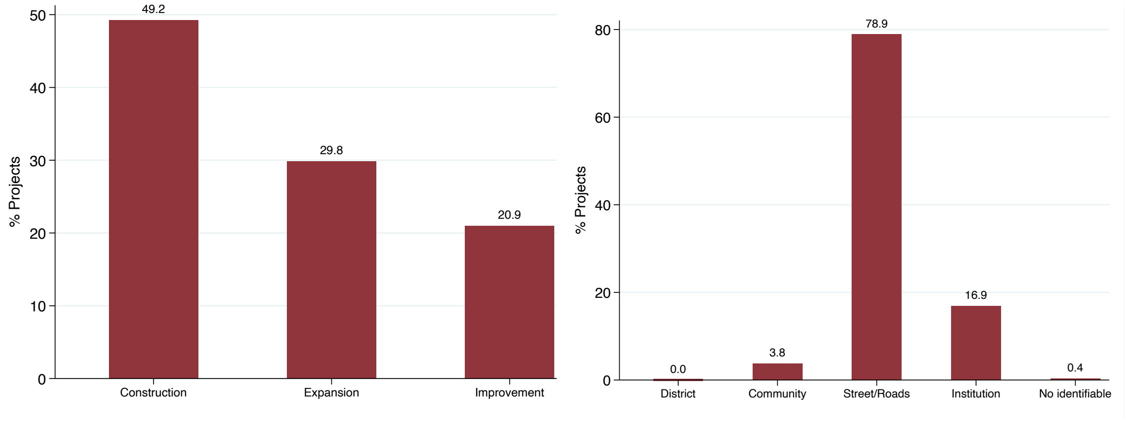
FOR ONLINE PUBLICATION:
APPENDIX

Can White Elephants Kill?
Unintended Consequences of Infrastructure Development

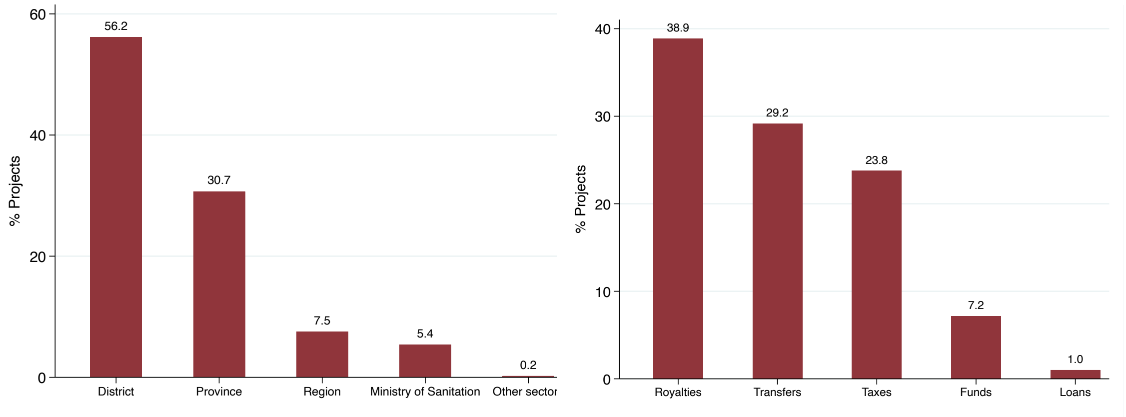
Antonella Bancalari

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

A Details about the implementation of sewerage projects



(A) Type **(B) Area**



(C) Implementing agency **(D) Funding source**

Figure A1
Project characteristics, started between 2005 and 2015

Note. These figures show in Panel (A) the distribution of sewerage projects by type of project, in Panel (B) by area covered, in Panel (C) by government agency formulating the project, and in Panel (D) by funding sources. Sample includes the pool of projects declared viable and started between 2005 and 2015.
Source: Author's calculations using data from the SNIP and SIAF.

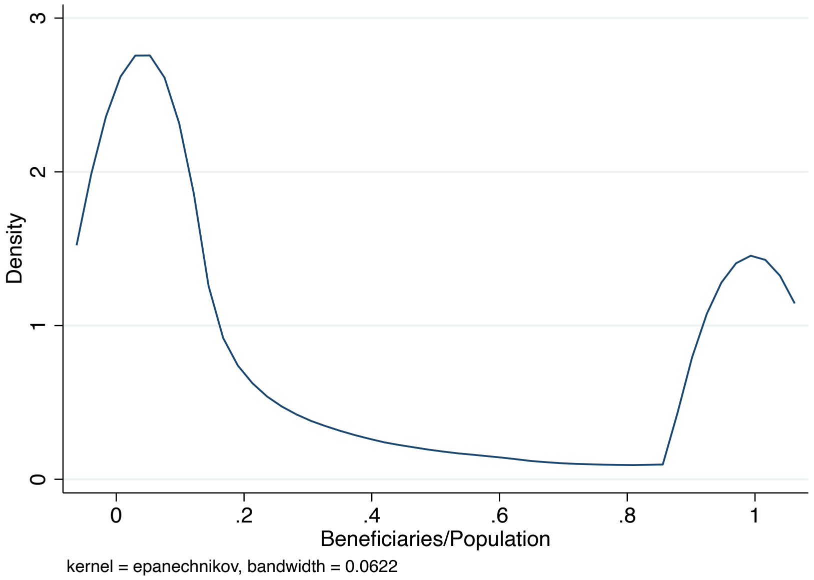


Figure A2
Distribution of Project Beneficiaries/Population in 2005

Note. This figure shows the distribution of the share of planned beneficiaries per project out of the initial population in a district. It is capped at a maximum of 100% of the initial population. The mean is 0.17 and the median 0.05.

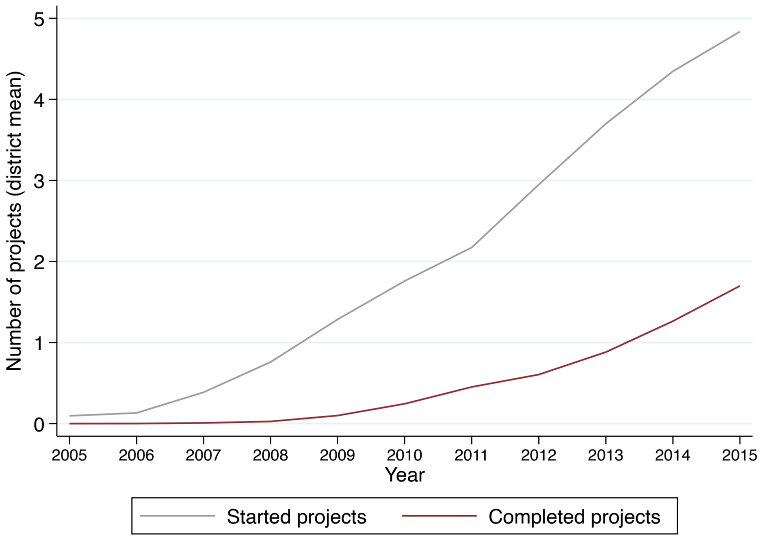


Figure A3
Projects Implemented Between 2005 and 2015 (District Average)

Note. The blue line shows the cumulative number of projects started and the red line shows the cumulative number of projects completed.

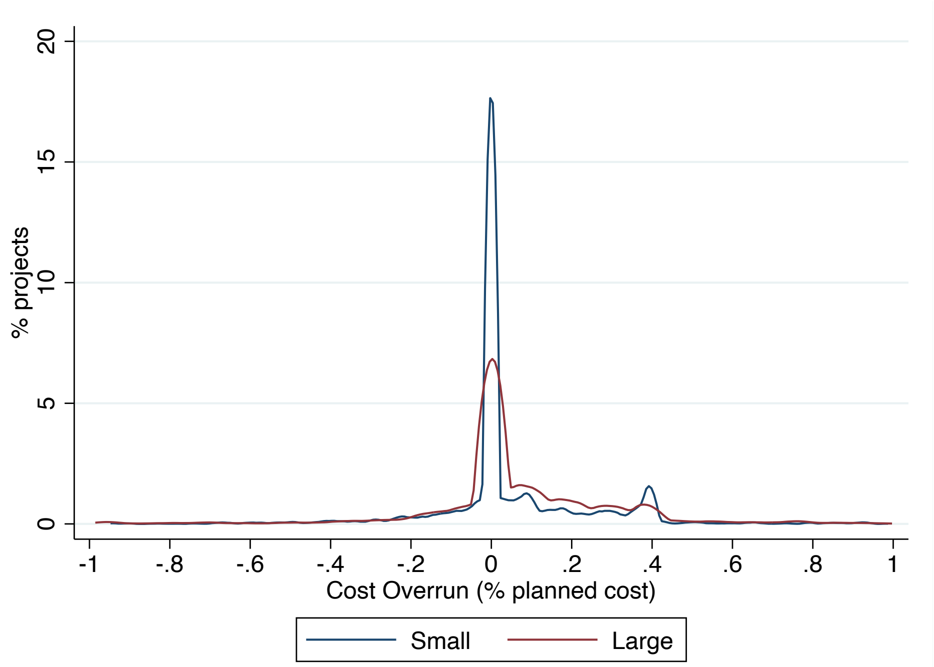
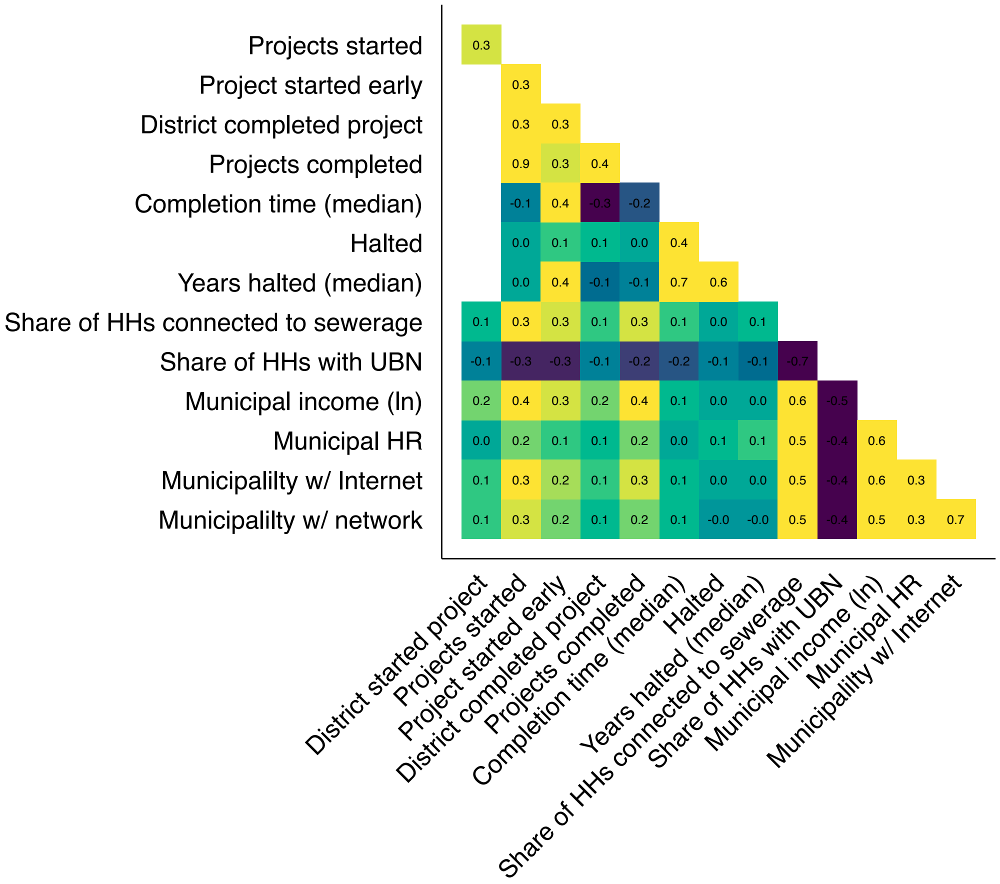


Figure A4
Distribution of Cost Overrun for Sewerage Projects, 2005–2015

Note. This figure shows the distribution of cost overruns as a percentage of the planned cost. It is calculated as the difference between actual and planned costs, divided by the planned cost. It is capped at a maximum of 100 % of projects costs, though some outliers have a cost overrun up to 5 times the project costs. 'Small' projects are those below the median of potential beneficiaries and 'Large' otherwise.

Figure A5 show that the likelihood of implementing projects (starting and completing projects), early on (before 2010) and a greater number of them, is positively correlated with the income and staff of municipalities, as well as their access to the Internet and communication networks in 2005. While the National Sanitation Plan states that previously unattended and poor districts should have been prioritized when expanding access to sewerage, in practice, this criterion was not followed. Implementation is negatively correlated with the share of households with unmet basic needs and positively correlated with the share of households connected to the sewerage network by 2005 (as pre-existent systems facilitate the expansion of sewerage networks. During the period of study, the median project completion time in a district is negatively correlated with the number of projects completed, but positively correlated with the years in which projects are halted (district median). The likelihood of halting projects is higher when projects were started earlier, likely because of the longer period available to observe this event. The likelihood of halting projects does not correlate with any initial district and municipality characteristic.



	District started project	Projects started	Project started early	District completed project	Projects completed	Completion time (median)	Halted	Years halted (median)	Share of HHs connected to sewerage	Share of HHs with UBN	Municipal income (ln)	Municipal HR	Municipalilty w/ Internet
Projects started	0.3												
Project started early		0.3											
District completed project		0.3	0.3										
Projects completed		0.9	0.3	0.4									
Completion time (median)		-0.1	0.4	-0.3	-0.2								
Halted		0.0	0.1	0.1	0.0	0.4							
Years halted (median)		0.0	0.4	-0.1	-0.1	0.7	0.6						
Share of HHs connected to sewerage	0.1	0.3	0.3	0.1	0.3	0.1	0.0	0.1					
Share of HHs with UBN	-0.1	-0.3	-0.3	-0.1	-0.2	-0.2	-0.1	-0.1	-0.7				
Municipal income (ln)	0.2	0.4	0.3	0.2	0.4	0.1	0.0	0.0	0.6	-0.5			
Municipal HR	0.0	0.2	0.1	0.1	0.2	0.0	0.1	0.1	0.5	-0.4	0.6		
Municipalilty w/ Internet	0.1	0.3	0.2	0.1	0.3	0.1	0.0	0.0	0.5	-0.4	0.6	0.3	
Municipalilty w/ network	0.1	0.3	0.2	0.1	0.2	0.1	-0.0	-0.0	0.5	-0.4	0.5	0.3	0.7

Figure A5
Correlation Matrix: District Characteristics

Note. This figure shows the pairwise correlation of project implementation with initial district and district municipality characteristics, as well as levels and trends in district-level mortality. Yellow and green blocks denote positive correlations, while blue and purple blocks denote negative correlations.

A Examples of implemented sewerage projects

Figure A6

Implemented Sewerage Project with a Completion Rate ≤ 60 %

Note. Photograph taken in Piura from Google streets on 2013, the year this project was started.

Figure A7
Abandoned Sewerage Project

Note. Photograph taken in Huanuco for the technical report of the Defensoria del Pueblo (Vega Luna, 2015) exploring mid-construction abandonment of sewerage projects.

B Details about additional data sources

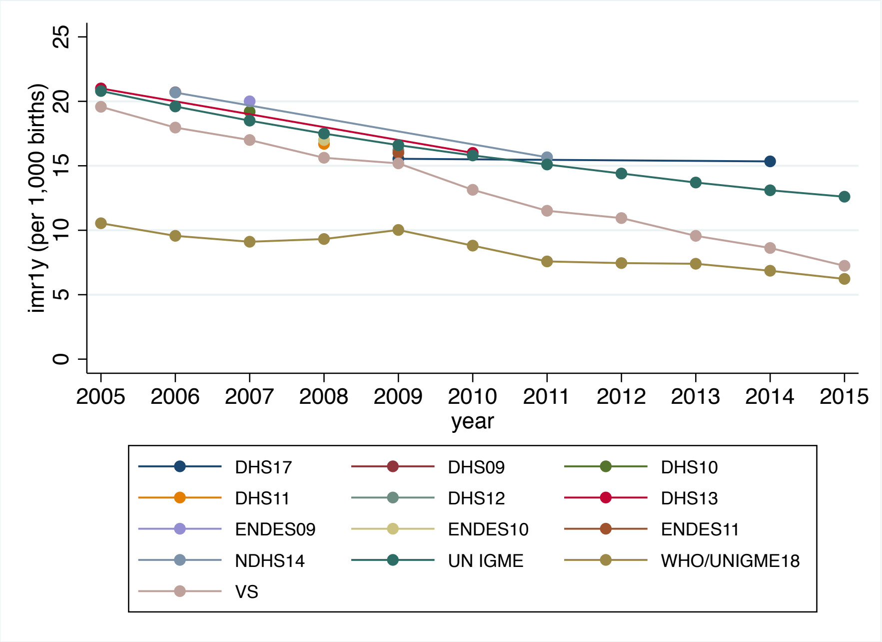
A Mortality rates

I construct the infant mortality rate (IMR) and the under-five mortality rate (U5MR) for each district d and year t, using as the denominator the population at risk, multiplied by 1,000 as conventionally computed:

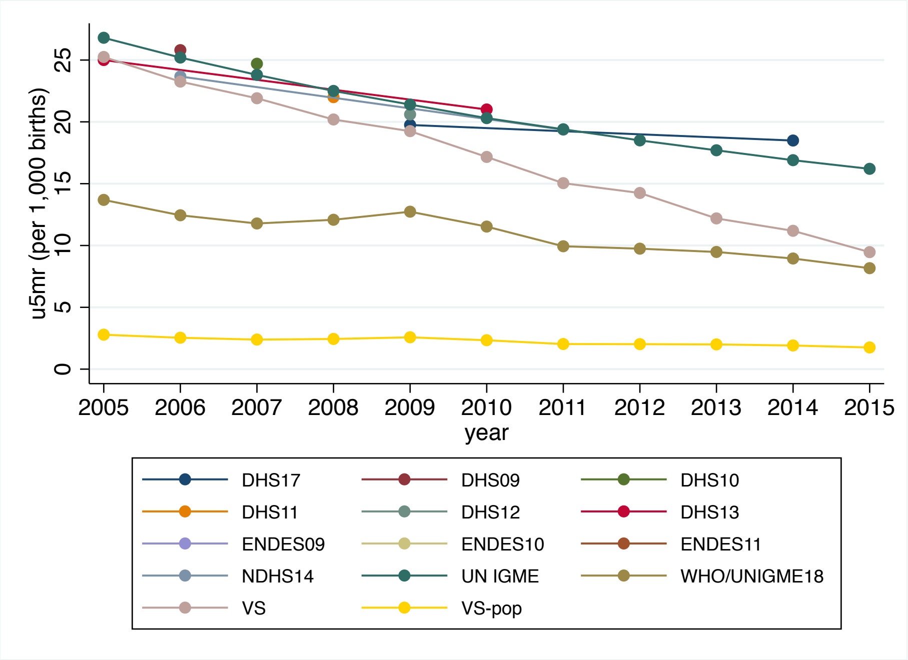
$$IMR_{dt} = \frac{\text{Deaths of infants aged 0–11 months}_{dt}}{\text{Population aged 0–59 months/5}_{dt}} \times 1,000;$$

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

Figure B1 compares nationwide mortality trends using the vital statistics data versus data from several nationally representative surveys.



Panel A. Infant Mortality Rate

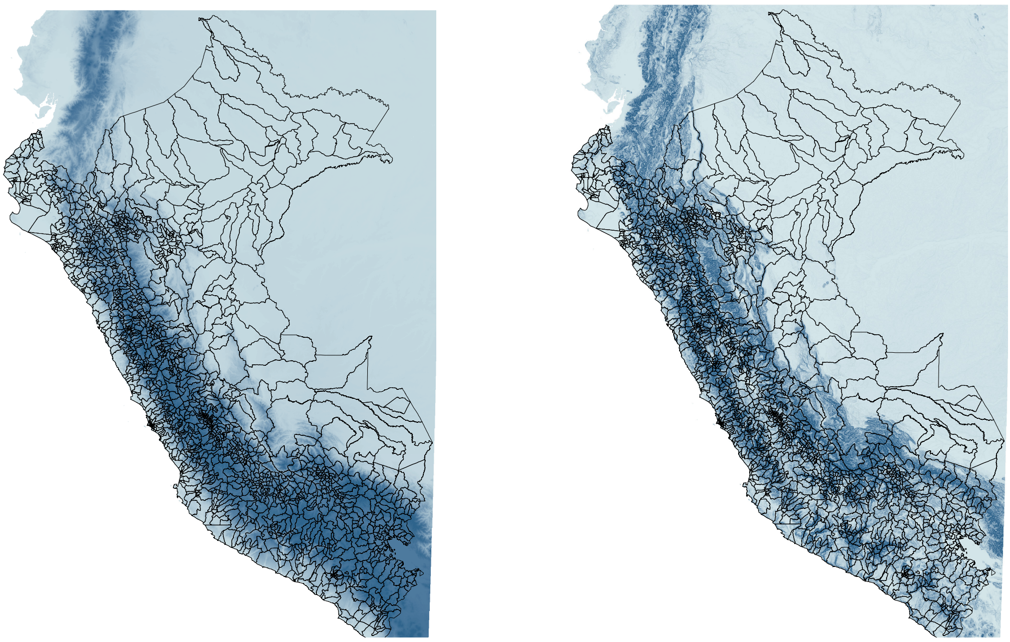


Panel B. Under-five Mortality Rate

Figure B1
Mortality Rates across Data Sources

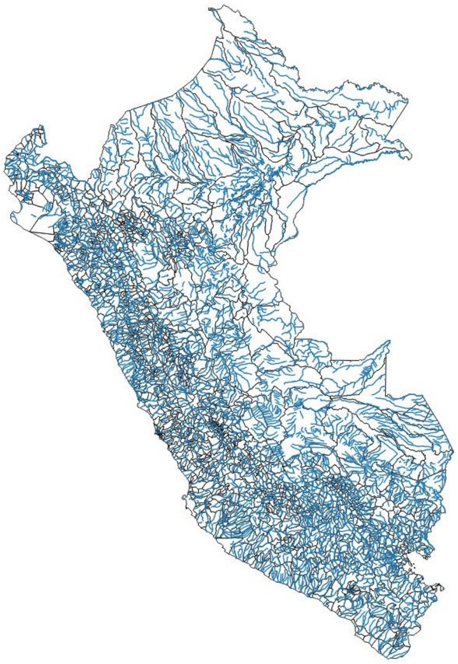
Note. Mortality rates computed from alternative data sources, including: vital statistics (VS, main source used in this paper), Health and Demographic Surveys (DHS), National Survey of Health and Demography (ENDES) and Inter-Agency Group for Child Mortality Estimation (UN IGME).

B Geographic characteristics



Panel A. Elevation

Panel B. Slope



Panel C. Rivers

Figure B2
Geography in Peru

Note. Darker shaded grid cells are at a higher altitude. The borders in black represent the districts' borders.
Source: Digital elevation maps provided by the Peruvian Ministry of Environment with information on multiple cells (1×1 km^2).

C Summary

Table B1
Summary Statistics and Data Sources

	(1)	(2)	(3)	(4)	(5)
	Beginning period		End period		Source
	Sum		Sum		
1. Outcomes					
Deaths under 1y	6,404		3,820		Vital records
Deaths under 5y	8,256		4,987		
Population under 5y	2,672,357		2,481,908		INEI Pop forecast
Infant mortality (per 1,000 infants)	11.98		7.70		
Under-five mortality (per 1,000 children)	3.08		2.01		
2. Sewerage diffusion					
Cumulative started projects	101		4823		SNIP and SIAF reports
Cumulative completed projects	0		1732		
	Mean	SD	Mean	SD	
2. District characteristics					
Population density (pop/sq km)	642.91	2837.77	847.34	3188.96	Census and Spatial data
Population	23,403.32	57,020.49	32,947.11	75,973.03	Census
Municipal revenue (millions)	4.84	21.82	15.50	55.47	Municipal Registry
Internet access	0.38	0.48	0.93	0.26	
TA in formulation of investment projects	0.66	0.46	0.58	0.49	
Manages health centers	0.22	0.41	0.32	0.47	
Water treated	0.85	0.36	0.99	0.10	
Share HH unsafe water	0.46	0.27	0.28	0.23	Census
Share HH sewer	0.25	0.27	0.46	0.29	
Share HH on-site	0.34	0.23	0.40	0.25	
Share HH open defecation	0.41	0.26	0.13	0.13	
Share HH head secondary	0.22	0.15	0.34	0.16	
Share HH electrified	0.56	0.26	0.79	0.16	
Transport expenditure (millions)	1.50	7.62	1.92	7.94	SIAF reports
Energy expenditure (millions)	0.04	0.22	0.19	1.13	
Health expenditure (millions)	0.71	2.53	0.36	1.49	
3. Geography					
Share district gradient ≤ 0.8%	0.10	0.23			Spatial data
Share district gradient {0.8-4.19]%	0.19	0.22			
Share district gradient {4.19-13]%	0.34	0.20			
Share district gradient above 13%	0.37	0.29			
Share district elevation ≤ 250 mamls.	0.15	0.33			
Share district elevation {250-500] mamls.	0.05	0.14			
Share district elevation {500-1000] mamls.	0.06	0.15			
Share district elevation above 1000 mamls.	0.74	0.41			
River density (km/sq km)	53.32	124.30			
District area (sq. km)	635.93	1,655.50			

Note. The beginning period is 2005 and the end period is 2015. Columns (1) and (3) provide the sum for the variables of interest and the mean for the geographical and control variables for 2005 and 2015, respectively. Columns (2) and (4) provide the standard deviation for control variables for 2005 and 2015, respectively, and column (2) also provides the standard deviation for the cross-sectional geographical variables. Column (5) shows the data source used to compute each of the variables. SIAF reports on expenditures in transportation only available between 2007–2015, and on energy and health between 2007–2014. Census data only available for the years 2005, 2007 and 2017, but data on the share of HHs electrified only available for the years 2005 and 2017.

D Definition of key variables

Variable	**Description**
Infant mortality rate (IMR)	Infant deaths divided by the total number of infants, multiplied by 1,000, in a given district and year.
Under-five mortality rate (U5MR)	Under-five deaths divided by the total number of children under 5 years old, multiplied by 1,000, in a given district and year.
Implemented projects	Number of projects started, but not yet completed in a given district and year.
Predicted projects	Number of predicted projects implemented in a given district and year.
Halted project	Indicator variable that equals one if project stops receiving funds while still underway in a given year.
Waterborne	Infant/under-five deaths caused by water-borne diseases (including infectious diseases, peri-natal complications, diseases of the digestive system, malnutrition and other nutritional deficiencies) divided by the total number of infants/under-fives in a given district and year, multiplied by 1,000
Accident	Infant/under-five deaths caused by external factors divided by the total number of infants/under-fives in a given district and year, multiplied by 1,000
Respiratory	Infant/under-five deaths caused by respiratory diseases divided by the total number of infants/under-fives in a given district and year, multiplied by 1,000
Malformation	Infant/under-five deaths caused by malformations divided by the total number of infants/under-fives in a given district and year, multiplied by 1,000
Non-communicable	Infant/under-five deaths caused by non-communicable diseases (including neoplasms, congenital malformations, diseases of the genitourinary, nervous, circulatory, skin and subcutaneous tissue, and musculoskeletal systems and connective tissue) divided by the total number of infants/under-fives in a given district and year, multiplied by 1,000
Water – Treated	Indicator variable that equals one if the municipality treats the piped-water for drinking purposes in a given district and year.
Water – Unsafe	Share of households that use unsafe sources of water (including public tap, water truck, unprotected spring and surface water) for drinking purposes in a given district and year.
Sanitation – On-site	Share of households using on-site latrine facilities (either connected to septic tanks or pits) in a given district and year.
Sanitation – OD	Share of households that openly defecate in a given district and year.
Geography	Index capturing the district's technical suitability for low-cost sewerage projects, computed based on the share of a district falling in different categories of elevation, gradient, river density and area.
Infants	Number of infants below 1 year old in a given district and year.
Under-5	Number of children under the age of 5 in a given district and year.
Population	Forecasted total population in a given district and year.
Population Density	Forecasted total population divided by district area (measured in km^2) in a given district and year.
Education	Share of household heads with secondary education completed in a given district and year.
Electricity	Share of households connected to electricity grids in a given district and year.

C Instrumental Variable Strategy

A Further details about the construction of the IV

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, gradient, river density and area. I estimate the following ordinary least-squares (OLS) regression:

$$S_d = \sum_{k=2}^{4} \beta_{1k} Gr_{dk} + \sum_{k=2}^{4} \beta_{2k} E_{dk} + \beta_4 R_d + \beta_3 A_d + \epsilon_d. \tag{5}$$

Here, S_d is the total number of implemented projects in district d between 2005 and 2015, Gr_d is the share of area of district d falling in each of the three steep categories k (flat gradient is the reference category), E_d is the share of area of district d falling in 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 (Panamerican Center of Sanitation Engineering and Environmental Sciences, 2005; Romero Rojas, 2000; Hammer, 1986), I find that steep gradient categories and river density favour sewerage implementation, while elevation and district area are negatively associated with project placement (see Table C1). Steep gradient and elevation predicts the implementation of sewerage projects non-monotonically: the largest coefficient is the lower-middle ({0.8, 4.19] percent) gradient category and the highest elevation category (above 1,000 mamsl).

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.

I identify the nationwide budget for projects constructing new sewerage systems and expanding and improving existing systems based on the total disbursement made to all sewerage projects in a given year. The average cost of a sewerage project is calculated from the cost of all sewerage projects. The nationwide budget for sewerage projects increased year to year and this generates variation over time on the funds available for predicted sewerage projects (see Figure C1).

The over-time variation in the nationwide budget for sewerage projects is not driven by a single district. Figure C2 shows the number of districts per year with positive expenditures, as well as those with expenditure above the median of each year. Even during the initial years, the nationwide budget is driven by more than 100 districts. Over time, the

Table C1
Geographic Characteristics affecting Sewerage Implementation

Dependent variable	Sewerage projects 2005–2015	
	OLS coeff.	Beta coeff.
	(1)	(2)
Share district gradient {0.8-4.19]%	0.833	0.022
	(2.047)	
	[0.684]	
Share district gradient {4.19-13]%	2.315	0.064
	(1.785)	
	[0.195]	
Share district gradient above 13%	0.903	0.038
	(1.542)	
	[0.558]	
Share district elevation {250-500] mamls	-5.015	-0.103
	(1.475)	
	[0.001]	
Share district elevation {500-1000] mamls	-1.425	-0.029
	(1.818)	
	[0.433]	
Share district elevation above 1000 mamls	-6.710	-0.369
	(1.233)	
	[0.000]	
River density (km/sq km)	0.005	0.096
	(0.003)	
	[0.090]	
District area (sq. km)	-0.001	-0.134
	(0.000)	
	[0.016]	
Observations	1832	

Note. The dependent variable is the number of sewerage projects started between 2005 and 2015. Column (1) shows the coefficients of an OLS regression and column (2) shows the standardized beta coefficients. The omitted gradient category is the share of district area in the flat category (below 0.8 percent) 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.

number of districts driving the nationwide budget for sewerage increases to 800 districts, out of 1,408 districts, and number of districts with positive expenditure above the median increased to 400 districts by 2015.

Ranking all districts in Peru based on the geographic suitability index, the counter-

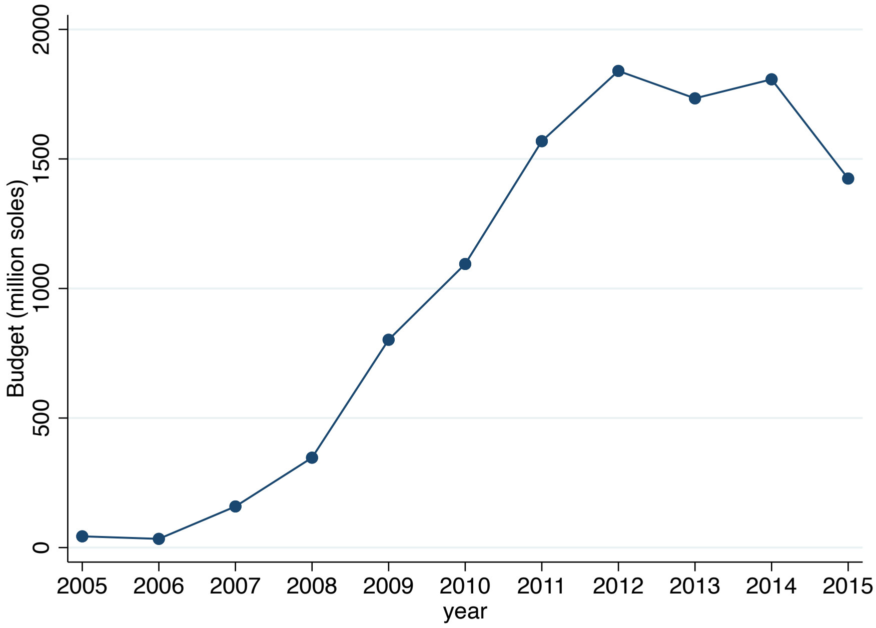


Figure C1
Nationwide Budget Spent in Sewerage Projects

Note. Author's calculation using data from the National System of Public Investment (SNIP for its Spanish acronyms) and the Integrated System of Financial Administration (SIAF for its Spanish acronyms).

factual implementation predicts one project in each district until the nationwide budget is exhausted (considering the average cost of a sewerage project). The highest-ranking districts implement sewerage projects earlier and more projects across the years. For instance, for 2005, the prediction allocates one project for each of the 20 highest-ranking districts because the budget spent that year amounts to the average cost of 20 projects. The prediction follows the same procedure for the following years until a district implements a maximum of five projects, which is the median of the distribution of projects implemented by districts between 2005 and 2015. This threshold of maximum project implementation leaves extra generation capacity that is subsequently relocated to other districts further down the ranking (see Table D4 for a sensitivity analysis using different thresholds and alternative methodologies). Projects that would have been placed in higher-ranked districts that already hit the maximum are placed in lower-ranked districts. Therefore, by 2015, the highest-ranked districts would have implemented up to five sewerage projects, while the lowest-ranked districts would have implemented none. This creates an implementation roll-out that provides variation across districts and years.

The following plots show that the distribution of sewerage projects implemented differed by initial (2005) district characteristics, while the distribution of predicted sewerage projects does not differ by initial district characteristics.

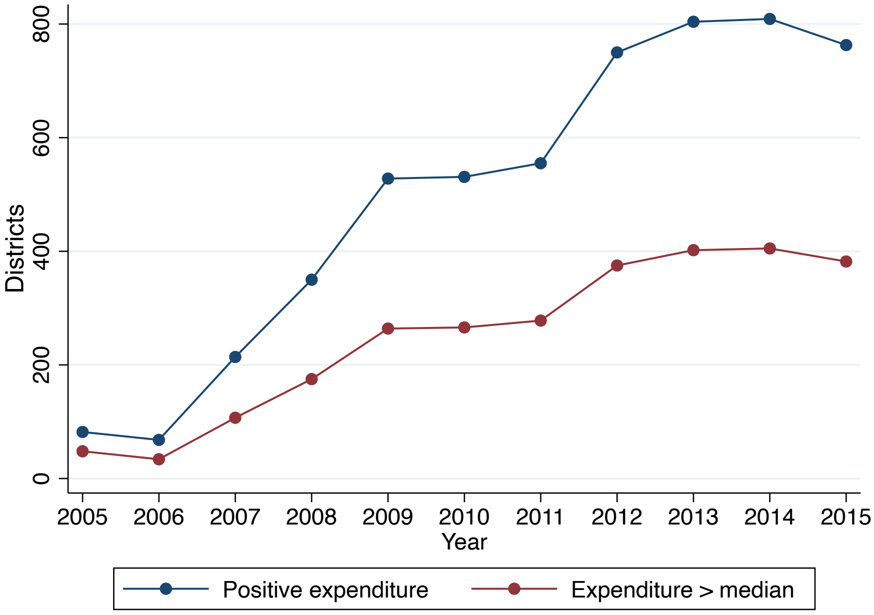
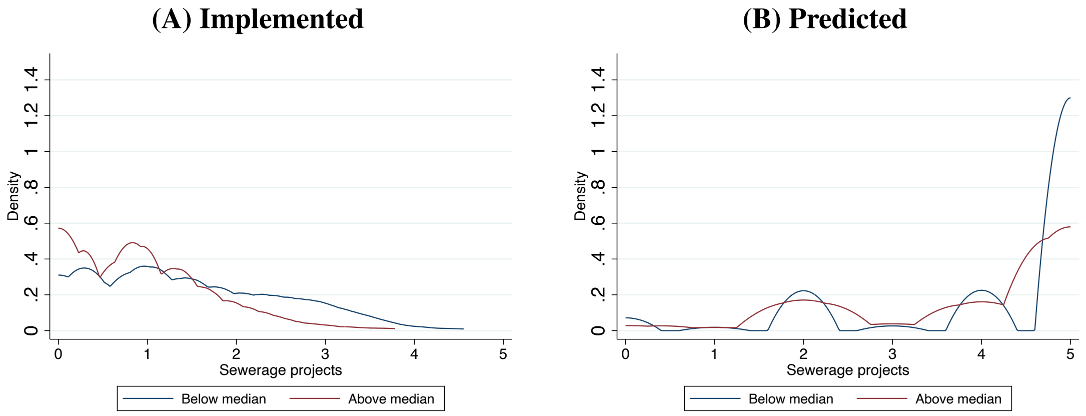


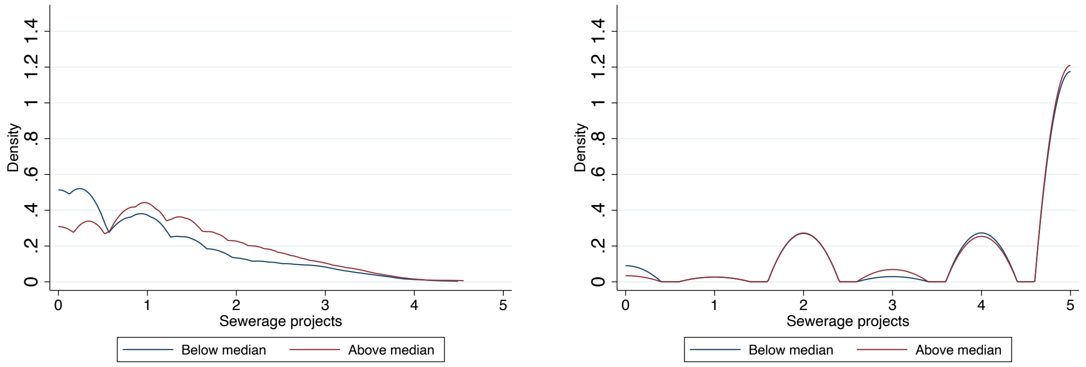
Figure C2
Districts with high expenditure, per year

Note. Author's calculation using data from the National System of Public Investment (SNIP for its Spanish acronyms) and the Integrated System of Financial Administration (SIAF for its Spanish acronyms).

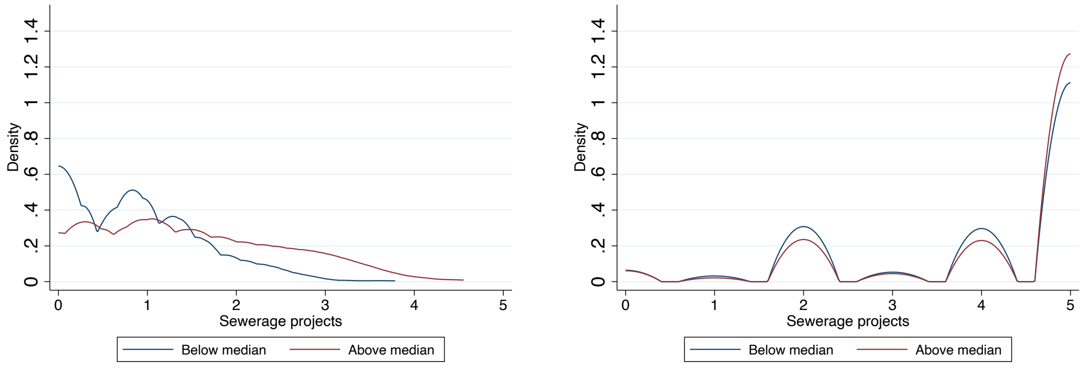
Differences in initial district characteristics are controlled by the inclusion of district fixed effects, but these characteristics can also predict differences in trends. Indeed, Panels A and B in Figure C4 show that the mortality trends of districts implementing fewer projects (low intensity) is higher in levels but also diverges over time from those that implemented more projects (high intensity). Panels C and D, in turn, show that the mortality trends of districts with low geographic suitability for sewerage projects are parallel during the years before the start of the first project in the district. The trends coverage after the start of projects when looking at the under-five mortality rate in Panel D.



by Share of HHs with Unmet Basic Needs



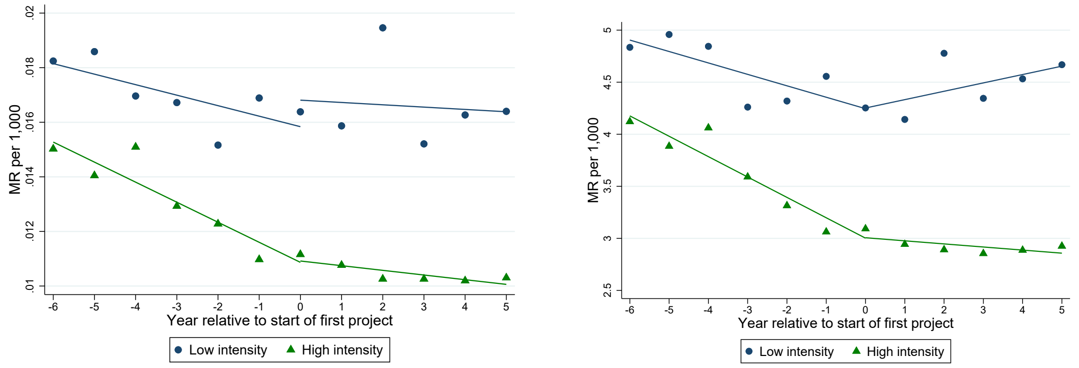
by Share of Rural Population



by Share of HHs Connected to Sewerage

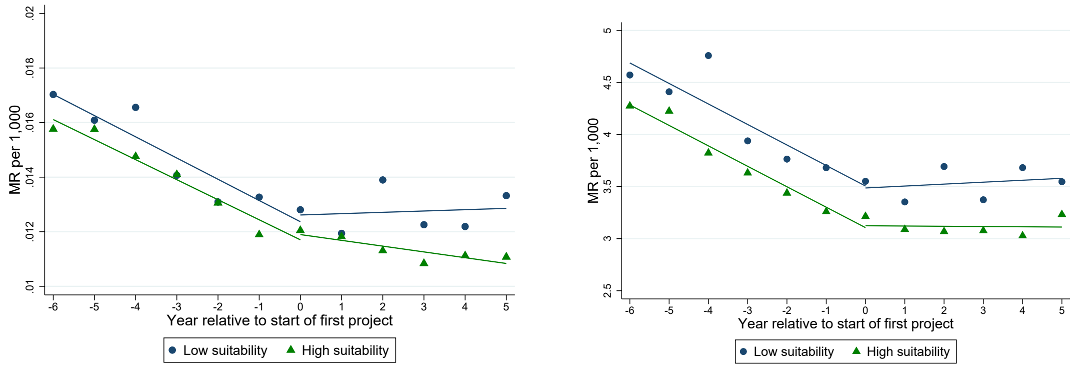
Figure C3
Distribution of Projects by Initial District Characteristics

Note. These figures show the distribution of implemented in Panel (A) and predicted in Panel (B) sewerage projects by initial (2005) characteristics of the districts' population. The blue distribution corresponds to districts with a percentage of population below the median and the red distribution corresponds to districts above the median of the distribution of each characteristic in 2005.



(A) IMR by Actual Projects

(B) U5MR by Actual Projects



(C) IMR by Geographic Suitability

(D) U5MR by Geographic Suitability

Figure C4
Mortality Trends, by Projects Implemented and Geographic Suitability

Note. These figures show in Panels (A) and (B) the trends in infant and under-five mortality, respectively, for districts below (low intensity) and above (high intensity) the median of the maximum number of actual projects implemented. Panels (C) and (D) present the trends in infant and under-five mortality, respectively, for districts below (low suitability) and above (high suitability) the median of the geographic suitability index underlying the instrumental variable. Due to lack of historical data on mortality rates, the trends are set based on the years relative to the start of the first project in a district. The sample is restricted to districts that implemented at least one project and to the years before the completion of the first project. I restrict the plot to 6 years prior to the start of the first project, where at least 40% of the sample of districts that started a project remains, and 5 years after, where at least 25% of the sample remains.

D Validity of the instrument

To interpret the results as the causal effect of unfinished projects on early-life mortality, the exclusion restriction must hold. In other words, the counterfactual implementation of projects across districts and years must affect early-life mortality only through actual implementation of projects. In this section, I provide evidence that supports the validity of the exclusion restriction and, hence, the internal validity of the results.

I first show that the instrument is not capturing variation driven by trends in geographic characteristics with greater suitability for low-cost sewerage projects. In Table D1, I test the robustness of the estimated effect of unfinished projects on early-life mortality when controlling for geographic characteristics interacted with year.

The estimated effects of implemented sewerage projects on IMR in column (1) and U5MR in column (2) remain robust. The Sanderson–Windmeijer F-stats also remain similar in all specifications and the Anderson-Rubin p-values, robust to arbitrarily weak instruments, confirm that the effects are statistically significant in all alternative estimations.

Next, I demonstrate that investments in other types of infrastructure are not driving the results. As infrastructure is frequently developed as a bundle, the results could be driven by other types that are developed following the same spatial and temporal pattern as my instrument. Mostly if these other types also pose health hazards, such as pollution from roads and energy plants. Furthermore, my results could be explained by other types of infrastructure that are beneficial for early-life health, but developed following the opposite pattern to my instrument. Another concern could be if investing in sewerage systems crowds out investment in other type of infrastructure beneficial for early-life health. To alleviate these concerns, I first control for district expenditure on transportation, energy and health. Next, I explore if the alternative infrastructure investments can explain the direct effect of the instrument on early-life mortality. In other words, I test whether my instrument is a strong predictor of variation in other infrastructure expenditure and, if so, whether the predicted variation can explain the increase in mortality rates.

Table D2 presents the estimates of the effect of implemented projects on IMR (column 1) and U5MR (column 2) when controlling for expenditure in transport, energy and health projects (specifications 1–3). This exercise confirms the main results: the magnitude of the estimates remain positive and qualitative similar in magnitude. The Anderson-Rubin test confirms the statistical significance of the estimated effects when controlling for Transport and Health expenditures. The coefficients are not precisely estimated when controlling for Energy expenditures, likely due to the drop in sample in Table 3 to only 6,247 district-years. This drop in sample in specification 3 and 5 is due to the available of Energy expenditure data for only 1,032 districts out of those used in the original estima-

Table D1
Robustness checks by controlling for geographic-specific trends

	IMR (1)	U5MR (2)	F-stat (SW) (3)
1. Gradient x year	0.002	0.611	27.866
	(0.001)	(0.205)	
	[0.007]	[0.003]	
AR p-value	0.002	0.000	
2. Gradient x year +			
Area x year	0.003	0.668	22.854
	(0.001)	(0.235)	
	[0.010]	[0.004]	
AR p-value	0.002	0.000	
3. Gradient x year +			
Area x year +			
River density x year	0.003	0.655	23.210
	(0.001)	(0.229)	
	[0.010]	[0.004]	
AR p-value	0.002	0.000	
4. Gradient x year +			
Area x year +			
River density x year +			
Elevation x year	0.006	1.486	7.524
	(0.003)	(0.680)	
	[0.041]	[0.029]	
AR p-value	0.003	0.001	

Note. Estimates based on district-level panel data spanning the years 2005–2015. The dependant variables are the infant mortality rate (IMR) per 1,000 infants in column (1) and the under-five mortality rate (U5MR) per 1,000 children under 5 years old in column (2). Column (3) reports the Sanderson–Windmeijer (SW) F-statistic. Coefficients correspond to 2SLS estimates of the effect of the number of 'implemented projects' instrumented by 'predicted projects' using equation 4. The sample of analysis is restricted to years prior to the completion of at least one sewerage project. 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 and the Sanderson–Windmeijer (SW) F-statistic. The different specifications controlling for geography interacted with year in each row are reported in the left-hand column. Geographic control variables are as follows: 'Gradient' is the district's % of area falling in the different gradient categories (reference category: below or equal 0.8% percent) ; 'Area' is the district's area measured as km^2; 'River density' is the district's river density measured as km/km^2; 'Elevation' is the district's % of area falling in the different elevation categories (reference category: between 500 and 1,000 mamsl).

tion and only for the years 2007–2014.

Table D2 also presents 2SLS estimates of transport, energy and health expenditure on mortality rates using the counterfactual implementation of sewerage projects as an instrument (specifications 4–6). None of the three alternative infrastructure developments explains the estimated positive effects in mortality in a robust way. The energy expenditure channels is not statistically significant. The AR p-value for the transportation and health channel is statistically significant, but the SW F-stat in specification 4. is very low (0.305) and the sign of the effect in specification 6. is negative. Because this latter effect is opposite to the one estimated, my results would be downward biased. Yet, in all cases, the first stage is weaker than the originally estimated, as shown by the low

Sanderson–Windmeijer F-statistic of excluded instruments.

Moreover, a variety of checks bolster the robustness of the main results. I estimate the 2SLS specification using Equation 4 with a series of modifications.

First, I control for municipal characteristics that were correlated with the implementation of projects (as discussed in Section A). These include indicators that capture whether the district municipality has access to the Internet and requires technical assistance from the Central government to develop infrastructure projects, and municipal revenue (in logs). I also add as a covariate an indicator for whether the municipality manages at least one health center, in order to control for political will on health policy.

Second, I control for an indicator capturing whether the district is located in the Amazon region. The instrument over-allocates projects in the east of Peru, which overlaps with this region characterized with peculiar factors (e.g. isolation, greater precipitation, vector-borne diseases).

Third, I restrict the sample of analysis to districts that started at least one sewerage project, in order to make the sample of study more comparable.

Fourth, I exclude the capital and main region of Peru, Lima, which is more economically developed (i.e. richest, best access to public services, highest initial sewerage connectivity).

Finally,I replace the independent variable with a version top-coded at the 90th percentile of the distribution of sewerage projects to ensure that the results are not driven by outliers.

If the instrument is as good as random when predicting implemented projects, then I expect that these changes in the specification will not affect greatly the point estimates. Table D3 confirms this. The magnitude and precision of the estimated effects of implemented projects on IMR in column (1) and U5MR in column (2) remain robust and statistically significant. The Sanderson–Windmeijer F-statistics of excluded instruments remain similar in most cases (it drops to 8.755 for the project top-coded transformation in specification 5). In addition, the Anderson-Rubin test, robust to arbitrarily weak instruments, confirms that the effects are statistically significant in all alternative estimations (marginally significant when excluding the region Lima, but the lower precision could be due to the lower sample, as it drops to 7,804 district-year observations out of the 8,400 observations in the Table 3).

Table D2
Expenditure in Infrastructure Projects in Other Sectors

Dependent variable:	IMR (1)	U5MR (2)
Expenditure controls		
1. Transportation	0.003	0.687
	(0.002)	(0.431)
	[0.131]	[0.111]
AR p-value	0.081	0.060
F-stat (SW)	7.865	7.865
2. Energy	0.001	0.289
	(0.002)	(0.358)
	[0.420]	[0.419]
AR p-value	0.409	0.408
F-stat (SW)	7.964	7.964
3. Health	0.003	0.654
	(0.002)	(0.425)
	[0.143]	[0.124]
AR p-value	0.096	0.074
F-stat (SW)	7.850	7.850
Alternative endogenous variable		
4. IV for Transportation	0.010	2.345
	(0.017)	(3.985)
	[0.558]	[0.556]
AR p-value	0.080	0.059
F-stat (SW)	0.400	0.400
District–year	7287	7287
Districts	1190	1190
5. IV for Energy	0.001	0.218
	(0.001)	(0.271)
	[0.422]	[0.421]
AR p-value	0.378	0.375
F-stat (SW)	3.996	3.996
District–year	6335	6335
Districts	1047	1047
6. IV for Health	-0.002	-0.472
	(0.001)	(0.322)
	[0.167]	[0.143]
AR p-value	0.097	0.072
F-stat (SW)	6.323	6.323
District–year	7298	7298
Districts	1191	1191

Note. Estimates based on district-level panel data spanning the years 2005–2015. The dependant variables are the infant mortality rate (IMR) per 1,000 infants in column (1) and the under-five mortality rate (U5MR) per 1,000 children under 5 years old in column (2). Rows 1. to 3. show 2SLS estimates of the effect of the number of 'implemented projects' instrumented by 'predicted projects' using equation 4. Rows 4. to 6. show 2SLS estimates of the effect of each expenditure type instrumented by 'predicted projects'. The sample of analysis is restricted to years prior to the completion of at least one sewerage project. 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 and the Sanderson–Windmeijer (SW) F-statistic. Specifications are as follows: 1. Controls for district's expenditure in transportation projects (log); 2. Controls for district's expenditure in energy projects (log); 3. Controls for district's expenditure in health projects (log); 4. Uses the alternative endogenous variable "district's expenditure in transportation projects (log)"; 5. Uses the alternative endogenous variable "district's expenditure in energy projects (log)"; 6. Uses the alternative endogenous variable "district's expenditure in health projects (log)".

Table D3
Sensitivity Checks

Dependent variable:	IMR (1)	U5MR (2)
Additional controls		
1. Municipal characteristics	0.003	0.746
	(0.002)	(0.357)
	[0.042]	[0.037]
AR p-value	0.014	0.010
F-stat (SW)	11.307	11.307
District–year	6920	6920
Districts	1327	1327
2. Amazon location dummy	0.003	0.625
	(0.001)	(0.290)
	[0.049]	[0.031]
AR p-value	0.028	0.013
F-stat (SW)	15.861	15.861
District–year	8555	8555
Districts	1379	1379
Changing sample		
3. Intervened districts	0.002	0.531
	(0.001)	(0.237)
	[0.048]	[0.025]
AR p-value	0.028	0.010
F-stat (SW)	17.970	17.970
District–year	6639	6639
Districts	1076	1076
4. Lima excluded	0.002	0.427
	(0.001)	(0.275)
	[0.187]	[0.121]
AR p-value	0.173	0.103
F-stat (SW)	16.021	16.021
District–year	7938	7938
Districts	1289	1289
Transformation		
5. Projects top-coded	0.002	0.485
	(0.001)	(0.243)
	[0.066]	[0.046]
AR p-value	0.028	0.013
F-stat (SW)	10.038	10.038
District–year	8555	8555
Districts	1379	1379

Note. Estimates based on district-level panel data spanning the years 2005–2015. The dependant variables are the infant mortality rate (IMR) per 1,000 infants in column (1) and the under-five mortality rate (U5MR) per 1,000 children under 5 years old in column (2). All columns show 2SLS estimates of the effect of the number of ‘implemented projects’ instrumented by ‘predicted projects’ using equation 4. The sample of analysis is restricted to years prior to the completion of at least one sewerage project. 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 and the Sanderson–Windmeijer (SW) F-statistic. Each row represents a different sensitivity test on the specifications reported in columns (3) and (4) in Table 3. Specifications are as follows: 1. Controls for municipal characteristics, including indicators capturing whether district municipality has access to the Internet, needs technical assistance to formulate investment projects, and manages at least one health center, and municipal income (ln), where missing values are replaced by the district’s average value; 2. Controls for a dummy capturing whether the district is located in the Amazon region; 3. Restricts the sample of analysis to those districts that ever had an intervention (at least one sewerage project ever started); 4. Excludes the region of the capital of Peru, Lima, from the sample of analysis; 5. Transforms endogenous variable (implemented projects) to a version top-coded at the top 10 percentile.

Moreover, I use 11 alternative instrumental variable strategies by introducing variations in how the main instrument is computed. The results are presented in Table D4.

I rule out that the effects of unfinished sewerage projects on mortality are driven mainly by selected migration. I show in Table D5 that the results remain robust to controlling for the district's initial (2005) share of educated households and those connected to the electricity grid multiplied non-parametrically by year.

Table D4
Effect of Project Implementation on Mortality, using different IVs

Threshold:	Mean / Percentile 75^{th}		Percentile 25^{th}		Percentile 90^{th}		No threshold	
Dependent variable:	IMR (1)	U5MR (2)	IMR (3)	U5MR (4)	IMR (5)	U5MR (6)	IMR (7)	U5MR (8)
Panel A: PCA								
Implemented projects	0.003	0.625	0.002	0.311	0.003	0.812	0.004	1.197
	(0.001)	(0.290)	(0.001)	(0.246)	(0.002)	(0.395)	(0.001)	(0.236)
	[0.049]	[0.031]	[0.138]	[0.205]	[0.056]	[0.040]	[0.000]	[0.000]
Anderson-Rubin p-value	0.028	0.013	0.123	0.195	0.025	0.012	0.000	0.000
F-stat (SW)	15.861	15.861	19.824	19.824	12.311	12.311	36.437	36.437
Panel B: Lasso linear								
Implemented projects	0.001	0.336	0.002	0.470	0.002	0.439	0.003	0.856
	(0.001)	(0.291)	(0.002)	(0.447)	(0.001)	(0.321)	(0.001)	(0.176)
	[0.416]	[0.249]	[0.393]	[0.294]	[0.228]	[0.170]	[0.000]	[0.000]
Anderson-Rubin p-value	0.410	0.231	0.372	0.259	0.210	0.148	0.000	0.000
F-stat (SW)	11.667	11.667	5.709	5.709	11.899	11.899	27.616	27.616
Panel C: Lasso poisson								
Implemented projects	0.001	0.199	0.000	0.160	0.001	0.236	0.003	0.730
	(0.001)	(0.293)	(0.002)	(0.327)	(0.001)	(0.305)	(0.001)	(0.163)
	[0.486]	[0.497]	[0.810]	[0.624]	[0.437]	[0.439]	[0.000]	[0.000]
Anderson-Rubin p-value	0.484	0.496	0.810	0.624	0.433	0.436	0.000	0.000
F-stat (SW)	11.173	11.173	7.899	7.899	11.884	11.884	24.381	24.381
Mean (initial)	0.018	4.818	0.018	4.818	0.018	4.818	0.018	4.818
District-year	8,555	8,555	8,555	8,555	8,555	8,555	8,555	8,555
Districts	1,379	1,379	1,379	1,379	1,379	1,379	1,379	1,379

Note. Estimates based on district-level panel data spanning the years 2005–2015. The dependant variables are the infant mortality rate per 1,000 infants in odd columns, and the under-five mortality rate per 1,000 children under 5 years old in even columns. Coefficients correspond to 2SLS estimates of the effect of the number of ‘implemented projects’ using different instruments. Columns (1)–(6) use an instrument computed by a maximum threshold implementation per district derived from the distribution of all projects implemented between 2005 and 2015. The threshold in columns (1) and (2) is the ‘mean’ of the distribution (equivalent also to the ‘percentile 75^{th}’); in columns (3) and (4) it is the ‘percentile 25^{th}’; and in columns (5) and (6) it is the ‘percentile 90^{th}’. Columns (7) and (8) use an instrument computed as the interaction between the geographic suitability index and the nation-wide budget (hence ‘no threshold’ is used in computing this instrument). I also present variations of the way the geographic suitability is computed. In Panel A, it is an index constructed using principal component analysis. In Panel B (Panel C), a lasso linear (poisson) model (given that the number of projects implemented is a count) is used to predict the geographic suitability based on all geographic variables, their squares and interactions. The sample of analysis is restricted to years prior to the completion of at least one sewerage project. 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, the Sanderson–Windmeijer (SW) F-statistic and the mean of each outcome in the initial year of the study (2005).

Table D5
Robustness Check: Socio-Demographic Trends

Specification	(1) IMR	(2) U5MR	(3) F-stat (SW)
1. Education x year dummies	0.002	0.541	
	(0.002)	(0.346)	
	[0.172]	[0.118]	
AR p-value	0.141	0.083	
F-stat (SW)	10.157	10.157	
2. Electrification x year dummies	0.002	0.561	
	(0.002)	(0.413)	
	[0.193]	[0.174]	
AR p-value	0.154	0.133	
F-stat (SW)	8.132	8.132	

Note. Each row represents a different sensitivity test on the specifications reported in columns (3) and (4) in Table 3. Columns (2) and (3) in this table report the coefficient and standard error on unfinished projects where the dependent variable is the infant mortality rate (1) and under-five mortality rate (2). Column (3) reports the associated first-stage F-statistic (Sanderson–Windmeijer). The different specifications in each row are reported in column (1). Coefficients correspond to 2SLS estimations. All regressions include district and year fixed effects. Clustered standard errors by district are given in parentheses and p-values in brackets. Weak-instrument-robust Anderson-Rubin (AR) p-values reported in curly brackets. 1, controls for the share of households with the head having completed secondary education x year dummies. 2, controls for the share of households connected to the electricity grid x year dummies.

Table D6

Estimated social costs of the implementation of sewerage projects

Projects implemented	2.3
Case A: Average project pathway	
Years	4.7
Change in U5MR per project and year	0.625
Social cost (USD)	-35,470,313
Case B1: projects underway w/o problems	
Implementation years	1.0
Change in U5MR per project and year	0.633
Social cost (USD)	-7,643,475
Case B2: projects underway w/ delays	
Extra years	1.80
Change in U5MR per project and year	0.633
Social cost (USD)	-13,758,255
Case C: projects halted	
Years halted	2.50
Change in U5MR per project and year	1.71
Social cost (USD)	-51,530,063

Notes. The following assumptions are reflected in the table: (i) districts implemented 2.3 projects; (ii) an average project is implemented for 4.7 years; (iii) the average delay is 1.8 additional years; and, (iv) projects are halted for an average 2.5 years. These numbers are obtained from Figure 1.

Table D7

Estimated social benefit of sewerage infrastructure

Parameters	**Scenario 1**	**Scenario 2**
	Galiani et al. (2005)	**Alsan and Goldin (2019)**
Life expectancy	70	70
Value of a healthy life year	75,000	75,000
Completion k+1 – k+f		
Years	10	40
Change in U5MR per year	(0.334)	(0.149)
Social benefit (USD)	1,753,500	782,250
Social benefit for study years (USD)	17,535,000	31,290,000
Completion k+f to infinite		
Years	perpetual	perpetual
Discount rate	0.05	0.05
Growth rate U5MR	constant	constant
NPV social benefit (k+f until forever)	35,070,000	15,645,000
Total social benefit	52,605,000	46,935,000
Benefit/Cost		
Case A: average project pathway	1.48	1.32
Case B1: projects underway w/o problems	6.88	6.14
Case B2: projects underway w/ delays	2.46	2.19
Case C: projects halted	0.72	0.64

Notes. The following assumptions are reflected in the table: (i) the lives of children in the future are worth less than of those during the 10 years around project completion, using a discount rate of 5 percent as used in Watson (2006)'s calculations; (ii) a child surviving as a result of sewerage systems would live a healthy life for another 70 years (the life expectancy in Peru was 75 years in 2015) (World Bank, 2020); and, (iii) the value of a healthy life year is about 75,000 USD, as per Cutler and Meara (2000)'s calculation. The year a project is completed is denoted by k; $k + f$ denote the years after project completion.