Unintended Consequences of Infrastructure Development: Sewerage Diffusion and Early-life Mortality in Peru[*]

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Preliminary Draft

Abstract

Little is known about the effectiveness of sewerage diffusion initiatives from middle-income country governments. Although the aim of such public intervention is to increase access to improved sanitation facilities and ensure a healthier environment, there are risks to infrastructure development that have been overlooked. This paper studies the effect of a nation-wide spread of sewerage that took place in Peru between 2005 and 2015 on infant and under-five mortality rates. I use original administrative and geographical data and rely on an instrumental variable approach exploiting the fact that gradient affects a district's technical suitability for sewerage within provinces. My study finds that in districts that experienced greater sewerage diffusion, infant and under-five mortality rates increased. The adverse effects are sustained over time. These unintended lethal consequences seem to be linked to the construction works required to install sewerage lines, which exposed the population to hazards. The results are driven by deaths from infectious and respiratory diseases, as well as accidents. Taken together, my results suggest adverse effects resulting from failures on public infrastructure provision and raise the need for better environmental assessment and stricter health and safety measures when developing sanitation projects and in general, for government capacity building on urban planning.

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1. Introduction

Access to safely managed sanitation infrastructure has been acknowledged as one of the key UN Millennium Development Goals and Sustainable Development Goals (United Nations 2016). The existence of public health externalities linked to inadequate sanitation provides a justification for government intervention: the average cost of safe sanitation infrastructure is lower than the total social benefits, but greater than the private willingness to pay. During the last decades, governments from low- and middle-income countries (LMICs) have made efforts to expand access to improved sanitation, which resulted in a worldwide increase in the percentage of the population using these services by 9 percentage points during the last decade (World Bank 2016). Sewerage is considered the optimal sanitation solution if sludge is properly treated (JMP WHO-UNICEF 2017), but little is known about the effectiveness of sewerage diffusion led by LMIC governments.

While the sewerage-based sanitary revolution of previous centuries in nowadays high-income countries (HICs) is widely considered the greatest advance on public health and life expectancy (British Medical Journal 2007), causal evidence supporting this in LMICs is thin (Norman et al. 2010). In light of anecdotal evidence of hazards posed to the population during the installation of sewerage lines (Correo 2018; El Comercio 2018; Peru 21 2016), it is striking how policy and academic debates have largely ignored potential unintended consequences from this phase. This may well offset future benefits of sewerage systems if not properly mitigated. While sewerage removes faecal matter away from residential areas and has the potential to improve the sanitation environment if sludge is properly treated, the construction works required to install this system are highly disruptive and may pose adverse health consequences. Open ditches release dust particles and can become pools of infectious diseases and can pose drowning risks if filled with nearby sources of water. Furthermore, cuts in the water supply required to conduct the works may force the population to rely on unimproved sources of water. The manipulation of old sewerage pipes can also contaminate the environment and sources of water with sludge. Even when sewerage works are completed, without universal adoption it is not guaranteed that the benefits of this system will manifest. This is known as the “last-mile” problem—the inability to connect the infrastructure to the final user (Ashraf, Glaeser, and Ponzetto 2016).

The aim of this paper is to analyse the effects of sewerage diffusion on early-life mortality not only after the infrastructure is completed, but also during its construction phase. I focus on Peru, which has recently experienced a nation-wide expansion in public sewerage lines pushed by the Peruvian National Sanitation Plan 2006-2015. This public effort led to substantial variation in sewerage infrastructure development across years and districts within provinces[1], providing a potential tool for identifying the causal effect of sewerage diffusion on mortality rates. This paper relies on both a fixed

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[1] Peru is a decentralized unitary nation with four levels of government: nation, regions, provinces and districts. On average, provinces have 13 districts, the maximum and minimum are 43 and 1, respectively.

effects and instrumental variable approach exploiting the fact that, as documented in the sanitary engineering literature (Panamerican Center of Sanitation Engineering and Environmental Sciences (CEPIS) 2005), land gradient affects a district's technical suitability for sewerage[2]. Steeper gradients decrease sewerage installation costs and hence, flat districts are less likely to experience sewerage diffusion. The interaction between the fractions of district area in different gradient categories and sewerage diffusion at the province level is assumed to be exogenous. I exploit three sources of variation on sewerage diffusion: differences across years in Peru, differences in the contribution of each province to this diffusion and differences across districts within a province driven by technical suitability. I use several sources of administrative data matched to detailed spatial data on terrain elevation that allowed constructing gradient categories at the district level. I first document the relationship between gradient and sewerage diffusion (first stage) and mortality rates (reduced form). I subsequently present the main results and robustness checks to alleviate important concerns regarding the empirical strategy, namely the validity of the exclusion restriction.

Results show that IMR and U5MR increased by 2.1 and 0.08, respectively, with each extra started sewerage project. These unintended mortality consequences seem to be linked to the construction works required to install sewerage lines. IMR and U5MR increase by 4.29 and 0.11, respectively, for each additional sewerage project in construction, translated into a 10 percent and 2 percent increase from initial average mortality rates. While the results suggest a short-term impact on IMR, the increase in U5MR is sustained over time until the benefits of sewerage systems kick-in 6 years after project completion.

There are several possible explanations for the observed rise in IMR and U5MR and I perform additional tests to shed lights on possible mechanisms. The first hypothesis is that a lack of technical rigor during the construction works exposed the population to hazards. Open ditches resulting from excavation works required to install sewerage pipes, release of sludge from old pipes into local areas and cuts on piped water provision can expose the local population to hazards. Consistent with this hypothesis, I find that the increase in IMR and U5MR is driven by deaths from accidents as well as infectious and respiratory diseases. The second hypothesis is that these adverse mortality consequences could be exacerbated due to delays and mid-construction abandonment. I find evidence that 25 percent of the projects remain incomplete even 10 years after started. Consistent with the hypothesis, I find that infant and under-five deaths increased with each extra year that the district is exposed to sewerage projects in construction. The third hypothesis is that, even after sewerage projects are completed, universal adoption is not ensured, and even if so, the quality of these systems is overlooked. In line with this hypothesis, I find that sewerage diffusion does not increase sewerage connectivity nor the probability of the district to treat its sludge and water. I also investigates whether

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[2] The use of gradient as an instrument has gained credit in the development economics literature when analyzing the effects of infrastructure development (Duflo and Pande 2007; Dinkelman 2011).

IMR and U5MR impacts could be driven by fertility or migration changes in response to sewerage diffusion. Census data reveals that these alternative channels do not appear to explain the mortality increase observed.

This paper contributes to the literature on the consequences of sanitation coverage expansion on morbidity and mortality. On the one hand, dating back to McKeown's thesis (1976), this stream has focused on evidence from the 19th and early 20th centuries in North America and Europe (Watson 2006; Kesztenbaum and Rosenthal 2016; Alsan and Goldin 2018), which cannot be transferrable to present-day LMICs because the context differs greatly (population density, institutional quality, political dynamics, social polarization, disease burden, nutritional values, among others). On the other hand, recent studies in nowadays LMICs have mainly focused on the effectiveness of solutions in lower levels of the sanitation ladder (i.e. open defecation and on-site sanitation) (e.g. Duflo et al. 2015; Geruso and Spears 2018). Most evidence in LMICs linked to sewerage comes from policy reforms rather than the impact of the infrastructure development per se. Galiani, Gertler, and Schargrodsky (2005) estimate the impact of the privatization of local water and sewerage services on child mortality. The study found that privatization decreased child mortality rates caused by infectious and parasitic diseases. In contrast to these findings, Granados and Sanchez (2014) found that Colombian municipalities that reformed and allowed private participation on the provision of water and sewerage services exhibited a slower reduction of child mortality rates driven by lower increases in service coverage. It is important to highlight that, although the authors argue that there is a link between privatization and coverage expansion, neither of the two studies provide estimates on the effects of coverage expansion and child mortality. Contrary to my study, both studies treat water and sewerage coverage and child mortality as different outcomes.

This paper also adds to the growing literature analysing the effects of large infrastructure projects in low- and middle-income countries, which has notably exploited geographical characteristics as instruments. This stream of the literature provides large evidence of the positive effects of electrification, as it increases manufacturing output (Rud 2012), female employment (Dinkelman 2011) and housing value (Lipscomb, Mobarak, and Barham 2013) and decreases poverty (Dinkelman 2011; Lipscomb, Mobarak, and Barham 2013). Duflo and Pande (2007) move beyond local effects and analyse the spatial distributional effects of irrigation dams, finding that while dams increase agricultural production and decrease poverty in districts downstream from the dams, poverty increases in districts where dams are located. Relevant to my study, Mettetal (2019) finds that irrigation dams increased infant mortality in Sout Africa due to water pollution and a reduction in water availability. Also relevant, Cesur, Tekin and Ulker (2015) find that the adoption of natural gas infrastructure resulted in a reduction of IMR attributable to improvements in air pollution. In line with these findings, Gupta & Spears (2017) find that the expansion of coal plants worsen child respiratory health. A distinguishing feature of my approach is that, in addition to estimating the effects of project allocation and completion as in the existing literature, I estimate the effects of the infrastructure development phase.

The paper begins by describing the sewerage construction process in Peru and the health and survival-related costs and benefits linked to sewerage diffusion. Section 3 explains the sources of data and Section 4 describes the empirical strategy. Section 5 presents and discusses the results and Section 6 concludes.

2. Background

1.1. Link between sewerage diffusion and early-life mortality

It is well documented in the epidemiological literature that poor a sanitation environment leads to mortality due to faeco-orally transmitted diseases (Wagner and Lanoix 1958). The most affected age group is the one below five years old due to the impair immune system of infants and young children. Children suffering water-borne diseases are at risk of severe dehydration and death (Prüss-Ustün et al. 2014). Surviving children have impaired cognitive ability and physical development, and are more susceptible to relapses and other diseases (Ngure et al. 2014). Furthermore, water-borne diseases experienced during early childhood have long-lasting health and economic consequences. Children suffering from chronic conditions during childhood experience worse health, lower productivity and income during adulthood (Case, Lubotsky, and Paxson 2002; Case and Paxson 2008). Considering the high global prevalence of preventive water-borne diseases, access and adoption of adequate sanitation facilities is a public health matter of outmost importance. It is estimated that 5.5 percent of the global deaths from children under 5 years old could be prevented by improvements in water, sanitation and hygiene (Prüss-Ustün et al. 2014).

According to JMP-WHO-UNICEF (2017), sewerage is the optimal sanitation solution when adequately connected to functional treatment plants, as the system moves away faecal matter from residential areas in a hygienic way (i.e. no contact with the local population). A lower rug on the sanitation ladder is on-site sanitation solutions (i.e. septic tanks and pit latrines), which are prone to faecal spillages if sludge is not properly treated (Bancalari and Martinez 2018). Therefore, sewerage systems may prevent neighbourhoods from being flooded with dark waters that expose children to infectious diseases. Furthermore, compared to on-site sanitation solutions in which maintenance depends on each household, transaction costs to ensure a sustainable operation of sewerage systems are lower. In general, its operation and maintenance is delivered by government agencies that provide these services in a centralized manner and take advantage of economies of scale. Thus, an effective operation and maintenance of sewerage systems could ensure substantial improvements in the disease environment.

However, there are a few factors that may prevent or delay the health benefits of sewerage from manifesting. There are two phases in which this could happen. During the construction phase, deep ditches are excavated in order to install sewerage pipes and old ditches with sludge and pipes water are manipulated. Poor technical rigor in this phase expose the population to hazards, especially infants and children with impair immunity and poor risk assessment. Once projects are completed, the benefits of sewerage systems may only kick-in depending on the adoption rates and the treatment of sludge. First, if the neighbourhood adoption rate is less than universal, children may still be exposed to sludge licking from neighbours' on-site sanitation facilities. Second, even when adoption rates are universal, improvements in the sanitation environment are only ensured if the sewerage system is connected to a functional treatment plant. If sludge and water are not appropriately treated, an accumulation of sludge may be released to nearby open waters which are most likely a source of drinking water.

Causally identified evidence of the impact of nation-wide sewerage diffusion on early-life mortality is surprisingly thin (Norman et al. 2010). Most of the evidence of the effectiveness of sewerage systems in the public health literature is based on historical population studies in nowadays HICs. In one of the earliest and most influential papers in the public health literature, Watson (2006) found that providing in-house access to improved sanitation infrastructure reduced the IMR from gastrointestinal and infectious respiratory diseases among Native American infants in the USA during the early 1960s. In an attempt to disentangle the effect of piped water and sewerage systems, Alsan and Goldin (2018) found a small positive effect of sewerage diffusion alone on child mortality in the US between 1880 and 1920, but a large complementary effect –a decrease of 22 percent in infant mortality and 33.6 percent for child mortality. While Watson (2006) and Alsan and Goldin (2018) do not find evidence of a lead effect of the diffusion of water and sewerage on infant and child mortality rates, both find that the positive effects of sewerage only manifest more than two years after the completion of projects and conditional on households connecting to the sewerage lines. In line with this, Kesztenbaum & Rosenthal (2016) finds an increase in life expectancy at birth from an increase in sewerage connectivity in Paris neighbourhoods between 1880 and 1914. Given that these results cannot be directly transferrable to present-day LMICs due to great contextual differences and the fact that institutions play a great role in determining technical rigor during the construction works and the quality of sewerage systems, whether sewerage diffusion is effective at reducing early-life mortality in LMICs is an empirical question yet to be answered.

1.2. Sewerage diffusion in Peru

The National Sanitation Plan for 2006-2015 set the target of increasing sewerage coverage in urban areas, representing the first national goal of sewerage diffusion in Peru. During this period, investment in sewerage systems increased in the intensive and extensive margin, as both the number of sewerage projects started (received at least one disbursement of funds) and districts in which at least one sewerage project was started grew rapidly. As shown in Figure 1, almost 5,000 projects to construct, expand or improve sewerage systems were started during this decade in almost 1,500 districts. Each year the largest share of projects (around 80 percent) correspond to those that constructed new sewerage systems or expanded pipe networks from the existing infrastructure. The remaining share corresponds to projects that improved sewerage lines already in place.

After the decentralization process of the early 2000s, the Ministry of Housing, Construction and Sanitation (MVCS), as well as regional and local government[3] —district and provincial municipalities— have the faculty to formulate and execute sanitation-related investment projects. Local governments can formulate projects only if they are incorporated into the National System of Public Investment (SNIP)[4] which requires having at the time: (i) access to Internet, (ii) approval of the municipal council to support the development of capabilities in formulation and evaluation of investment projects and (iii) an annual budget above one million soles (approximately 200,000 sterling pounds[5]). The formulation of infrastructure projects consists of a pre-investment technical report. Sewerage projects can be either for construction of new sewerage systems, expansion of sewerage lines or improvement of existing systems. Between 2005 and 2015, 45 percent of the formulated sewerage projects were construction, 31 percent expansion and 25 percent improvements (Figure 2 Panel A). More than 50 percent of sewerage projects developed between 2005 and 2015 were formulated and executed by district municipalities and almost 30 percent by province municipalities (Figure 2 Panel B). Only 12 percent correspond to projects formulated by the central government.

Evaluation units (OPI for its Spanish acronyms) subscribed to the corresponding regional and local government, but depending on the Ministry of Economy and Finance (MEF), are in charge of declaring the technical and economic viability of infrastructure projects and should operate in accordance to the SNIP norms[6]. These are conducted by professional public servants, whose hiring and transferring is managed by the MEF. The economic and technical viability of sewerage

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[3] Since the decentralization, Peru has four levels of government: central, regional government (25), provincial municipalities (196) and district municipalities (1874). Peru is a decentralized, but unitary State, meaning that regional and local government have autonomy, but within the boundaries of the central policy.

[4] Law 27293: General Law of the National System of Public Investment (SNIP).

[5] Ibid.

[6] Ibid.

infrastructure projects depend crucially on the design and direct project costs. Between 2005 and 2015, sewerage projects were evaluated by OPIs located in the same government level that formulated the investment project (Figure 2 Panel C).

Now what happens when you have limited resources and a large portfolio of viable projects? The National Sanitation Plan 2006-2015 states that the prioritization of projects should be in accordance with the following criteria: 1) economic and technical viability, 2) social inclusion, 3) expansion of coverage and 4) universality[7]. The economic and technical viability is explained above. The social inclusion, expansion of coverage and universality criteria is related to increasing sewerage coverage in poor unattended areas. This means that not all projects declared economic and technically viable have guaranteed resources to be executed. Different public resources could finance projects that were declared viable[8]. Between 2005 and 2015, 38 percent of sewerage projects were planned to be financed by transfers from the national government, including special local funds and international aid, 34 percent with local royalties (mostly from mining), and 26 percent with local tax revenue (Figure 2 Panel D). Project selection is conducted by an annual budgeting process in which actors with different incentives interact. For projects financed by the MVCS or through transfers made by the MVCS to local municipalities, funds are allocated through an annual budgeting process conducted in conjunction with the MEF and approved by the Parliament[9]. For projects financed by local revenues, funds are allocated from the budgeting process done by Municipal Councils[10], which are chaired by the Mayor and council members[11]. In both cases, budget proposals are presented and debated to the Parliament or Municipal Councils, where political negotiations take place to select projects and ultimately approve the list as part of the final budget.

Once projects are selected for funds, the government agency that formulated the project sets the form through which the project will be implemented. The SNIP normative establishes that infrastructure projects can be implemented either direct by the government or through private agents. According to the SNIP normative, the first step in the investment phase is the formulation of a technical report that should include engineering and technological details, the final investment amount, executive chronogram, execution modality (direct or through private agents) and risk assessment. The first disbursement of funds therefore goes to the elaboration of this technical report. During its construction phase, the Enterprises of Provision of Sanitation Services (EPS) are in charge of supervising and evaluating the technical quality of the development works. Once public sewers are

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[7] Norm D.S. N007-2006-VIVIENDA: National Plan of Sanitation 2006-2015.
[8] Norm DS N 102-2007-EF: Regulation of the National System of Public Investment.
[9] Elected to five-year terms in the general elections that also include the presidential election.
[10] Elected to five-year terms in the regional and municipal elections that occur simultaneously nationwide.
[11] Law 27972- Municipalities Organic Law.

installed, it is compulsory for landlords to connect the dwelling's wastewater pipes to the public sewerage lines[12]. The EPS are in charge of regulating and supervising the connectivity of dwellings to the public sewerage lines.

1.3. The role of gradient

The gradient of the terrain plays a major role in determining the costs of sewerage projects. The most popular sewerage system in Peru is the conventional gravity system, which consists on a network of pipes installed in the middle of streets and roads in a sloped fashion. This allows wastewater to flow from houses to disposal areas, ideally treatment plants. The sanitary engineering literature provides several reasons as to why gradient is favourable for sewerage construction. First, according to Romero Rojas (2000), in conventional sewerage systems water velocity increases with gradient, which is necessary to guarantee self-cleanliness and limit the sedimentation of sand, faeces and other waste that clogs pipes. Hence, higher gradient enables optimal engineering design, guarantees sustainability and reduces maintenance costs. The Peruvian normative establishes a minimum water flow of 1.5 litres per second (l/s)[13] and the Panamerican Center of Sanitation Engineering and Environmental Sciences (CEPIS for its spanish acronyms) (2005) suggests a minimum gradient of 0.8 percent. Second, according to Hammer (1986), sewerage systems installed in steeper gradients require lower depths to install the pipe network and thus reduces dramatically the length and diameter of pipes and excavation costs, which are a large share of the total construction cost. According to CEPIS (2005), the installation of electric bombs may be necessary in very flat areas, increasing dramatically both construction and operation costs.

Given cost minimization, land gradient influences two important steps in sewerage diffusion: project allocation and project implementation. On the one hand, the technical advantage of steep districts leads them to experience greater allocation of sewerage projects. As discussed above, because land gradient decreases the cost of sewerage diffusion it helps to achieve the technical as well as the economic feasibility of a project. Because of the lack of technical rigour in the implementation of sewerage projects, infants and children from steeper districts that receive more projects are also at greater risk. On the other hand, the technical advantage of steeper districts can also accelerate project completion. As a result, fewer budgeting process are needed to secure funds to finalize sewerage projects. Hence, the likelihood of delays and mid-construction abandonment in steeper districts is lower, which reduces the lethal hazards linked to half-done sewerage systems.

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[12] Law 26338: General Law of Sanitation Services.

[13] Ministry of Construction, Housing and Sanitation. Norm OS.O70.

3. Data

This study exploits detailed Peruvian district panel data on several sources of administrative records available between 2005 and 2015. First, the outcome variables are constructed using the vital statistics registry[14] of the Ministry of Health and the National Institute of Statistics and Informatics (INEI for its Spanish acronym) Population Forecast. The former provides annual birth records of infants born alive and death records of infants under 1 year and children under 5 years disaggregated by cause of death (following the International Classification of Diseases - ICD10) and the latter on the number of children under 5 years old. I construct infant mortality (IMR) and under-5 mortality (U5MR) rates for each district (d) and year (t), following Preston, Heuveline, and Guillot's (2001) methodology[15]:

$$IMR_{dt} = \frac{\#\ deaths\ of\ infants\ aged\ 0-11\ months\ \ in\ d\ and\ t}{\#\ live\ births\ in\ d\ and\ t}\ x\ 1{,}000,$$

$$U5MR_{dt} = \frac{\#\ deaths\ of\ children\ aged\ 0-59\ months\ \ in\ d\ and\ t}{\#\ \ population\ aged\ 0-59\ months\ \ in\ d\ and\ t}\ x\ 1{,}000,$$

Figure 3 shows the trends of IMR and U5MR between 2005 and 2015. The initial IMR and U5MR for districts ever intervened was 18 per 1,000 births and 2.8 per 1,000 under 5 children, respectively. In both cases, the mortality rates of intervened districts are lower than of those districts that never received a sewerage project during this period. The graphs suggest that until 2010, the decrease in mortality rates of both groups of districts followed a fairly similar trend. Yet from 2011 onwards, the decrease in IMR and U5MR flattens out and the levels seem to converge with those of the districts never intervened. Notably, the years in which this trends reversal occur are those in which sewerage diffusion is greater, as observed in Figure 1.

Sewerage diffusion indicators are constructed relying on data from the National System of Public Investment (SNIP for its Spanish acronym) and the Integrated System of Financial Administration (SIAF for its Spanish acronym). These sources provide data on the number of sewerage projects declared viable between 2005 and 2015, including details such as type –construction, expansion or improvement—, budgeted investment and investment accrued by years. Using data on accrued investment, I set the starting year as the year in which the projects received the first disbursement. Sanitation projects are formulated at the neighbourhood or community level, which is a fraction of a

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[14] To alleviate concerns linked to the quality of the vital registers in Peru, I plot the IMR and U5MR trends computed using different surveys and find that these do not differ from those computed using vital statistics (See Appendix Figure 11).

[15] Because completeness of birth registrations in Peru was only 93 percent by 2005 (UNICEF 2005) due to imperfect utilization of institutional delivery services, I apply the winsorizing procedure to IMR observations above the 90th percentile of the IMR distribution for each cause of death. This consists of replacing values above the 90th percentile by the next non-missing higher value below the 90th percentile counting inwards. This procedure also alleviated concerns linked to outliers driving the results.

district –the smallest jurisdictional level in Peru. For projects formulated at a higher level (5 projects at the regional level and 4 at the province level) that lack of data on the number of projects per district, I assign one project to each district within the corresponding province or region. This approach is not capturing the intensity of sewerage diffusion within each of the districts, but it is done in only 3.7 percent of the districts were a sewerage project was ever started.

Households can only connect to public sewers once projects are liquidated and its operation transferred to the EPS. Because the MVCS does not keep a record of the year that a sewerage project is liquidated, I follow the MVCS's advice[16] to set the year of completion as the year in which the accrued investment achieves its maximum, but only for projects in which the budgeted investment is accrued by 90 percent or more. A limitation from this approach is that a few projects were completed using private funds and this is not recorded in the SNIP and SIAF nor the MVCS's records[17]. I set the years in which projects are under construction as the years between the start and completion of projects. Projects without completion year but with start year are defined as in construction until the end year of the dataset.

I construct three indicators of sewerage diffusion at the district level to capture sewerage diffusion not only once the infrastructure is completed, but during its construction phase: (i) cumulative number of sewerage projects started; (ii) number of sewerage projects in construction; and (iii) cumulative number of sewerage projects completed. Indicators (i) and (iii) are constructed as cumulative given that sewerage infrastructure is a long-lasting investment whose access persists across years, entailing complementarities across systems.

The final dataset of analysis is an unbalanced panel data of 10,032 district-year observations for IMR and 10,519 district-year observations[18] (1 408 districts) for U5MR spanning 2005-2015.

In addition, I rely on geographical data provided by the Peruvian Ministry of Environment (MINAM for its Spanish acronym), including information on surface elevation for multiple cells (1x1 km) and district area (squared kilometers). I construct a measure of gradient using surface elevation at each cell and neighboring cells[19]. I compute the fraction of district area falling into four gradient categories: (i) [0-0.8] percent, (ii) {0.8, 4.19] percent, (iii) {4.19-13] percent, and (v) above 13 percent. The first category captures flat areas (below or equal 0.8 percent) in which sewerage construction is more costly as determined by technical guidelines (CEPIS 2005). The remaining categories are created

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[16] Daniel Camacho. Director of the General Office of Statistics and Informatics of MVCS. Interview on the 6th of December 2016 at the Ministry of Housing, Construction and Sanitation. Lima, Peru.

[17] Edy Patricio Alvarez. Specialist of the Planning, Budget and Systems Office of MVCs. Email exchanged on 03 Jan 2017.

[18] Singleton districts not included in the analysis due to the inclusion of district fixed effects.

[19] Calculated with ArcMap®

considering quintiles of the gradient distribution, which ensures an adequate prevalence of each category. I additionally use the information on surface elevation at each cell to compute the fraction of district area in four different elevation categories: 0-250 meters, 250-500 meters, 500-1,000 meters, and above 1,000 meters.

I use additional data from the National Register of Municipalities (RENAMU for its Spanish acronym) including dummy variables indicating when the district municipality manages at least one health center, when it needs technical assistance to formulate investment projects and when it has access to Internet and municipal income (ln). Unfortunately, this dataset is only available for 85 percent of districts included in the analysis. In addition, I rely on data from the National Election Jury (JNE for its Spanish acronym) indicating the political affiliation of district mayors to construct a dummy variable indicating if the mayor is affiliated to the government party. I also use INEI forecasts as a measure of district total population and compute with this data population density.

Moreover, I use data from the Peruvian 2005 Census as a measure of initial status, including sewerage and piped-water connectivity and share of households with unmet basic needs[20].

Finally, I use child-level data from pooled rounds of the Demographic and Health Survey (DHS) spanning 2005-2015. This data is ideal to capture morbidity because it includes anthropometric measures for children below 5 years old, including height-for-age, weight-for-age and weight-for-height computed as z-scores from the WHO population reference. It also includes caregiver reports of whether the child suffered from diarrhoea the two weeks preceding the survey for all children in sampled households below 5 years old.

4. Empirical strategy

Figure 4 depicts district-wise sewerage diffusion (measured as started projects) between 2005 and 2015 and shows great variation in sewerage diffusion across districts and provinces. My identification strategy exploits this variation and relies on within-province differences in sewerage diffusion, particularly differences across districts within a province.

Consider the following panel regression:

$$MR_{dpt} = \beta_1 S_{dpt} + \alpha_d + \delta_{pt} + \epsilon_{dpt}, \qquad (1)$$

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[20] Measured as households with at least one of the following: living in weak dwellings, overcrowded with more than 3 people per bedroom, without access to sanitation facilities, with children 6-12 years old not attending school and whose household head has incomplete primary.

where MR_{dpt} denotes infant ($1q_o$) or under-5 mortality ($5q_o$) rates and S_{dpt} the number of sewerage projects in the district d, province p and year t. α_d is a district fixed effect that allows controlling for time-invariant characteristics and δ_{pt} is a province-year interaction effect to control for differential trends across provinces that could endogenously affect the allocation of sewerage projects. Standard errors are clustered at the province level due to the correlation across district mortality rates within the same jurisdiction[21]. In some models I add as covariates municipal characteristics, including indicators of whether the district municipality manages at least one health centre (proxy for health-caring municipality), needs technical assistance to formulate investment projects, has access to Internet and municipal income (ln) (to capture public investment capabilities), whether the mayor is affiliated to the government party (proxy for political preference), and total district population (to capture demographic differences).

OLS estimates on the impact of sewerage diffusion of district IMR and U5MR (β_1) are unlikely to be consistent. Richer and fast growing districts are expected to build relatively more sewerage lines, meaning that the estimates would be downward biased. Table 1 presents initial characteristics of all districts in the sample with available data (column 1). An average district has a population of approximately 23 thousand, with 640 people per km^2 and an area of 636 km^2. Column 2 presents the initial characteristics of districts that never started a sewerage projects (not intervened) compares them with districts that did (intervened). The remaining columns compare districts in which the first sewerage project started after 2014 (later) with those starting before (early) (columns 4 and 5), and districts in which fewer than 2 projects (low) were started with those starting more (high) (columns 6 and 7). I set both cut-offs following the median of the sample of districts intervened. We can see significant differences in 2005 characteristics across districts with different intervention status. Districts that were ever intervened had lower population density and their municipalities were more likely to have access to Internet, higher resources and less likely to have a mayor affiliated to the government's political party (likely pivotal districts). Among intervened districts, the differences between early and late intervened districts seem to be comparable to those between low and high intervened districts. Early and high intervened districts had greater population and density and land area, their municipalities were more likely to have access to Internet and had higher income than their counterparts, had higher sewerage and piped-water connectivity, lower share of households living overcrowded and slightly higher share of household heads with education above secondary school. Overall, there are substantial initial differences across districts by intervention status likely affecting mortality trends beyond sewerage diffusion.

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[21] The intra-cluster correlation is 0.07 for IMR and 0.2 for U5MR. The OLS results remain robust and if anything, more precisely estimated when using spatial heteroskedastic and autocorrelation consistent (HAC) standard errors.

To address this endogeneity problem, I rely on an instrumental variable strategy based on the geography of sewerage diffusion. The relationship between sewerage diffusion and land gradient, as described in Section 2, forms the basis of my identification strategy. Figure 5 shows the distribution of the four gradient categories, as explained in Section 3: (i) gradient [0-0.8%]; (ii) gradient [0.8-4.19%}; (iii) gradient [4.19-13%}; and (iv) gradient above 13%. Figure 4 and 5 together illustrate my identification strategy. Despite its economic disadvantage, we can observe in Figure 4 that the central area of Peru experienced substantial sewerage diffusion. Interestingly, Figure 5 shows that a large proportion of this land falls in the steep gradient categories since it is where the Andes Mountains are located. Similarly, we can see in the northeast of Peru (the Amazon jungle) that districts with a larger share of area in the flat gradient category received substantially fewer sewerage projects.

To formally evaluate the relationship between sewerage diffusion and district gradient, I estimate the following first-stage regression:

$$S_{dpt} = \sum_2^4 \beta_{4k}(S_{pt}^p * Gr_{dk}) + \beta_5(S_{pt}^p * E_d) + \sum_2^5 \beta_{6k}(l_t * Gr_{dk}) + \alpha_d + \delta_{pt} + \epsilon_{dpt}, \quad (2)$$

where Gr_{dk} is the fraction of district area in gradient category k interacted with cumulative number of sewerage projects in the province (S_{pt}^p). The omitted gradient category is the proportion of district area in the flat category. E_d denotes a set of geographical district-specific time-invariant characteristics, including elevation and land area, that enter the regression interacted with cumulative number of sewerage projects in the province (S_{pt}^p). Furthermore, I include gradient-year interactions ($l_t * Gr_{dk}$) to alleviate concerns of the instrument picking up non-sewerage related differences in growth patterns across districts with different gradient characteristics.

Table 2 shows the first-stage and reduced form results for the cumulative number of *started* sewerage projects. I columns (1) to (3) I formally examine the relationship between the number of sewerage projects started by 2015 and district land gradient. The omitted gradient category is the proportion of land area in the flat gradient category (0-0.8%). These results confirm the importance of geography for sewerage diffusion: both the fraction of district area on steep gradient categories alone and interacted with the cumulative number of started sewerage projects at the province level predicts sewerage diffusion at the district level. Whenever there is sewerage expansion at the province level, the likelihood of a district starting an additional sewerage project increases monotonically with its share of area in a non-flat gradient category. The F-statistic for the gradient variables interacted with province sewerage diffusion are above the usual rule of thumb of at least 10 (Stock, Yogo, and Wright 2002), which confirms the relevance of the instruments. Columns 4 and 5 correspond to the reduced form estimates, which suggest a positive impact of the instruments on both IMR and U5MR. I observe the same relationship between gradient and sewerage diffusion when the latter is computed as the number of projects in construction and the cumulative number of completed sewerage projects (see Appendix, Tables 21 and 22, respectively). Together with sufficiently high F-statistics, these results confirm that the instruments comply with the relevance condition.

My empirical strategy relies on estimating equation (1) with two-stage least squares using the interaction between gradient categories and provincial sewerage diffusion as instruments. I thus exploit variation in sewerage diffusion from three sources: differences in sewerage diffusion across years, differences in the contribution of each province to this increase and differences across districts within a province that are driven by the geographic suitability of districts. A similar instrumental variable strategy is used in other studies widely credited for their internally valid estimates (e.g. Duflo and Pande 2007; Dinkelman 2011). The identifying assumption underlying my analysis is that absent sewerage diffusion, the evolution of early-life mortality across districts located in the same province but with different gradient would not have systematically differ across provinces with greater sewerage diffusion and with fewer sewerage diffusion. Figure 4 help illustrate this point. I am assuming that the difference in mortality rates between a steep and flat district in Chiclayo province (centre-west high sewerage diffusion) would have been similar to the difference in mortality rates between a steep and flat district in Iquitos province (north-east low sewerage diffusion), absent sewerage diffusion at the provincial level.

5. Results

5.1. Main results

I estimate the impact of sewerage diffusion on IMR and U5MR following Equation (2). Table 3 presents the main results estimating the effects on IMR and U5MR from the cumulative number of started sewerage project, the number of sewerage projects in construction and the cumulative number of completed sewerage projects. Columns (1) to (4) provide OLS estimates and column (5) to (8) 2SLS estimates. While the OLS estimates suggest that sewerage diffusion is associated with a reduction in IMR, the 2SLS estimates are positive and more precisely estimated. Naïve estimates of the impact of sewerage diffusion on early-life mortality would have led to the misleading conclusion that these projects actually improved the population's living standards. The estimates are downwards biased, most likely because intervened districts were those richer, with better living standards and initially lower mortality rates.

The 2SLS results remain robust and, if anything, more precisely estimated when including municipal characteristics and total district population. On average, an extra sewerage project started increases by 2.08 the IMR and 0.07 the U5MR, a 4 percent and 2 percent increase, respectively, from initial average mortality rates. The coefficient of the impact on U5MR is more precisely estimated –at a 5 percent significant level. These unintended mortality consequences seem to be linked to the construction works required to install sewerage lines. IMR and U5MR increase by 4.29 and 0.11, respectively, for each additional sewerage project in construction, translated into a 10 percent and 2 percent increase from initial average mortality rates. The results further suggest that IMR and U5MR increase by 2.56 and 0.15, respectively, for each additional completed sewerage project[22]. This is equivalent to a 6 percent and 3 percent increase from IMR and U5MR baseline levels, respectively. Yet, the effect of an extra project completed on IMR is not significant. Curiously, the increase in U5MR is larger in magnitude when a new sewerage project is completed. This could be reflecting lingering effects from the construction phase.

5.2. Lead and lagged effect of completed sewerage diffusion

The 2SLS estimates of Tables 3 suggest a short-term positive significant impact on IMR and U5MR resulting from an extra sewerage project completed. This may be reflecting lingering effects on morbidity from the construction phase that can translate into future deaths due to complications of the immune system

Tables 4 and 5 show leads and lags of the effect of the completed sewerage projects. Encouragingly, I find no effects on IMR and U5MR two years prior to the completion and a spike one year prior to completion, exactly the phase in which construction works are likely to be more disruptive. Table 4 shows a short-term positive effect on IMR and a negative effect from year t+3 onwards, although the lagged effects are not precisely estimated. The story for U5MR is different. Table 5 shows that an extra sewerage project completed has lasting effects in U5MR for up to 4 years after. On average, U5MR increases between 0.3 and 0.4 during the second, third and fourth year following project completion. These results are in line with lingering effects from the construction phase. Interestingly, I find evidence that the benefits from sewerage systems appear down the line. The results suggest that sewerage reduces U5MR by 0.19 only 6 years after project completion. Although the sample size is reduced dramatically down the line, the result is significant at a 5 percent level and the instrument is relevant (F-stat of 11). This result suggests that if hazards to child survival can be avoided during the

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[22] Because one may worry that these effects are actually driven by piped-water diffusion, I estimate the impact of piped-projects (including sewerage and piped-water projects and those that include both). The results in the Appendix Table 23 show that indeed IMR and U5MR increased, but with lower magnitude and precision. This suggests that most of the effect is driven by sewerage.

infrastructure works, sewerage systems are actually beneficial in the long run. However, we cannot rule-out that this estimate is reflecting pre-existing trends in mortality rates since it may not be capturing the exposed cohort. Figures 6 and 7 illustrate these findings and show that the effects of completed sewerage projects follow different trajectories for IMR and U5MR.

Table 6 and 7 show the leads and lags of the effect of sewerage projects in construction. The results confirm several hypotheses. First, there is a short-term adverse effect of the construction works on IMR and U5MR. Second, while there are no lagged effects of sewerage construction on IMR, the effects are persistent for U5MR even 4 years after the construction period. Third, the positive results are not driven by pre-existing conditions; if anything, there was a reduction in mortality rates in the years prior to the sewerage works.

5.3. **Robustness checks**

A variety of specifications bolster the robustness of the main results. These include: (i) restricting the sample of analysis to districts that started at least one sewerage project to make districts more comparable; (ii) excluding the capital and main province of Peru, Lima, given that fundamental differences can affect the results; (iii) adding population density as a control due to the confounding effect of overcrowding; (iv) replacing the independent variable with a version top-coded at the 90th percentile of the distribution to ensure that the results are not driven by outliers; and (v) considering only projects constructing new sewerage systems or expanding sewerage lines rather than improving existing infrastructure. Tables 8 and 9 show that the results remain robust across all five specification. The magnitude and precision of the estimated effects, as well as the relevance of the instruments, increase in most specifications. This is more evident for the estimated effect of sewerage diffusion on IMR (Table 8). The precision in some estimates is compromised, but this is expected in cases in which the sample size is reduced dramatically, such as restricting the analysis to only intervened districts.

Nevertheless, to interpret these results as the causal effect of sewerage diffusion on early-life mortality, the exclusion restriction must hold. In other words, the interaction between steep gradient and province-level sewerage diffusion must affect IMR and U5MR only through district sewerage diffusion. To alleviate concerns, I first explore alternative channels and then use an alternative instrument.

5.4. **Alternative channels as controls**

It is possible that the measure of sewerage diffusion at the province level is strongly correlated with other province outcomes that are actually driving the increase in mortality rates, conditional on gradient. I therefore explore whether the sewerage diffusion channel holds when including as covariates other observable province characteristics. The literature has underlined a series of mechanisms that are important in the process of child survival. First, population density may be confounding the estimated effects. Although there are survival gains linked to high population density due to the benefits from urbanization, Hathi et al. (2017) show that overcrowding can exacerbate any health hazards linked to inadequate housing and environmental quality. Provinces that experienced greater sewerage diffusion are those with higher population density and it can be argued that gradient affects residential sorting. If this is the case, then differences in mortality rates between steep and flat districts could differ across provinces even in the absence of sewerage diffusion. Flatter areas with greater population density may experience higher mortality rates due to overcrowding, in which case my estimates would be downward biased. The opposite is the case if we consider improvements in living standards linked to urbanization. To check this, I compute population density at the province level using population forecasts spanning 2005-2015 and province area in square kilometers.

Second, it might be that provinces with greater sewerage diffusion are also those with greater access to other services. Infrastructure is sometimes delivered as a package and political economy may play a great role. As noted by Laffont (2005), government inefficiencies and corruption increases the marginal costs of raising funds and constraints the ability of the executive to invest in infrastructure. Alternatively, the power of lobbies and unions may explain the allocation of resources across provinces. Therefore, sewerage diffusion at the province level may be capturing the province ability and willingness of the local government to invest in infrastructure. The fact that gradient decreases sewerage costs and deters other infrastructure development is particularly helpful. If infrastructure development in general imposes hazards, then other types of infrastructure delivered to flatter districts at the same time would have increase its mortality rates, and my estimates would be downward biased. However, one could argue that sewerage diffusion has particular short-term negative externalities that do not exist in the development of other infrastructure. As Dinkelman (2011) and Lipscomb et al. (2013) show that electrification allocated mostly in flatter districts decreased poverty, it could be argued that provinces that experienced sewerage diffusion also experienced greater electrification and poverty reduction, and that the difference in mortality rates across steep and flat districts was driven by it. To check this, I use the share of population connected to the electricity network in the province. I use the two-year lead of this variable to capture the development of the electrification network. This data is only available for two census rounds.

Furthermore, it could be argued that it is easier to develop roads, other energy projects (i.e. natural gas) and construct health centres in flatter districts. The literature has pointed the relevance of public infrastructure to ensure that infants and children have access to preventive and curative health care, adequate nutrition and overall better living standards (Cesur, Tekin, and Ulker 2015; Kramer et al. 2017). Therefore, the adverse mortality effects observed could be driven by decreases in mortality in flatter districts, rather than increases in steeper districts due to sewerage diffusion. The opposite may be the case considering the air pollution adverse effects linked to roads and other infrastructure such as coal plants (Marcus 2017; Gupta and Spears 2017). To address this concern, I use province expenditure data on transportation and energy spanning 2007-2015 and the number of public health centres available for the years 2010, 2011, 2014 and 2014.

In Tables 10 and 11 I progressively include the above-described variables as controls in both stages of the IV specification and check if the sewerage diffusion channel holds. In all specifications (columns 1 to 5) the coefficient of district sewerage diffusion remains positive and similar in magnitude. The estimate of the impact of an extra sewerage project in construction on IMR increases in magnitude and becomes more precise (compared to the estimated effect of sewerage construction on IMR without adding covariates in Table 3) when controlling for province population density and transport and energy expenditure. For U5MR, the inclusion of province level population density and transport expenditure and electricity connectivity increases the explanatory power of the sewerage construction story (Table 7 columns 1, 2 and 5). For both IMR and U5MR, the coefficient of the effect of sewerage in construction is slightly smaller and less precisely estimated when including the number of health centres, which is likely attributable to the significant decrease in sample size (from 1150 to 652 for IMR and from 1203 to 688 districts for U5MR). The coefficients on these additional covariates do not provide much additional information. The results only suggest that greater population density at the province level is positively associated with U5MR, in line with Hathi et al.'s (2017) findings. When measuring sewerage diffusion as cumulative number of completed projects, the estimated effect on IMR is no longer statistically significant, but the results remain robust for U5MR (see Appendix Tables 24 and 25).

5.5. **Gradient as an instrument for alternative channels**

I further explore if some of the alternative stories discussed in the previous section could explain the reduced form results. In other words, I test whether the interaction between the number of sewerage projects in construction at the province level and land gradient is a strong predictor of variation in the alternative channels identified, and if so, if the predicted variation can explain the increase in mortality rates observed in the main results. Table 12 presents IV results of the alternative channels from which district data is available. The main conclusion is that none of these channels could explain the estimated effects in mortality rates. In all cases the first-stage is weak, as all F-statistics are below

10—the rule of thumb. Moreover, most estimates are not statistically significant. Only the coefficient of the effect of population density on U5MR is statistically significant at the 5 percent significance level, but it has a negative sign, when a positive one was expected to rule out the sewerage construction channel. I find similar results when using the cumulative number of completed projects at the province level interacted with gradient as instruments (see Appendix Table 28).

5.6. **Reverse causality**

Another potential concern is reverse causality because local shocks in mortality, namely spikes in water-borne diseases, may pressure district municipalities to expand access to sewerage systems. If the demand for sewerage in a single district drives sewerage diffusion in the province, then the number of sewerage projects conducted in the province is itself endogenous to outcomes in that district. To address this concern, I use as an alternative instrument the interaction between gradient categories and the number of sewerage projects conducted in adjoining districts. By construction, this instrument is independent of district specific mortality shocks. The exclusion restriction of this instrument is satisfied if sewerage diffusion in adjoining districts does induce sewerage diffusion in the own district, conditional on gradient, but is not related to mortality shocks there. This spatial correlation is expected to happen through the supply-side. Installing sewerage lines in neighboring districts may increase the probability of a given district to experience the same due to economies of scale. Conditional on having the appropriate gradient, equipping several adjacent districts with sewerage lines reduces materials and transaction costs. It also enables a given district to take advantage of treatment plants constructed to serve neighboring districts. One might worry that sewerage diffusion in a given district was a response to shocks in adjacent district mortality rates due to contamination fears. This is less likely to hold when the effect is conditional on gradient, but I cannot rule out this possibility.

Table 13 shows the 2SLS estimates of the effect of sewerage diffusion on IMR (columns 1 and 2) and U5MR (columns 3 and 4) using the alternative instrument. We can see that this instrument is also relevant and it even increases the explanatory power of sewerage diffusion at the district level. The F-stats in all models are well above the rule of thumb to reject weak instruments. The estimates remain robust and, if anything, more precisely estimated and slightly larger in magnitude. On average, an extra sewerage project started increases by 3.06 the IMR and 0.05 the U5MR. Again, these unintended mortality consequences seem to be linked to the construction works required to install sewerage lines. IMR and U5MR increase by 6.23 and 0.08, respectively, for each additional sewerage project in construction, although the estimated effect on U5MR is less precisely estimated. Moreover, when using this alternative IV strategy, the estimated effects of an extra project completed on IMR and U5MR are not anymore statistically significant.

6. Mechanisms

How could the lives of young children be affected by the diffusion of sewerage in their districts? Isn't the aim of such interventions to improve living standards? There are several possible explanations for the observed rise in IMR and U5MR and I perform additional tests to shed lights on possible mechanisms. The first hypothesis is that lack of technical rigor during the construction works exposed the population to dangers. The second hypothesis is that any hazards during the construction period could be exacerbated due to delays and high mid-construction abandonment. The third hypothesis is that, even after sewerage projects are completed, universal adoption is not ensured, and even if so, the quality of these systems is overlooked

6.1. Sewerage and early-life mortality by cause of death

The effects presented in the previous section suggest that there is an unintended adverse impact of sewerage diffusion on IMR and U5MR. The first hypothesis of the study is that this is due to the risks associated with inadequate management of the infrastructure development works. Opening larger ditches to install the pipe network releases dust particles into the air, creates sources of infections, generates risks of falling and drowning and diverts traffic chaotically. If this is the case, the impact of sewerage diffusion on early-life mortality should mainly operate by affecting deaths from pathogen-related diseases as well as accidents.

Tables 14 and 15 investigate the impact of sewerage diffusion on IMR and U5MR, respectively, by cause of death. Each column presents coefficients from separate estimates using different measures of mortality depending on diseases and related health problems that caused the death. The mortality data was aggregated for 7 general pathology groups following the WHO International Classification of Diseases (ICD 10). Column (1) uses the infectious and parasitic (ICD-10 category I) mortality rate as the outcome, which includes a number of infectious diseases likely to be affected by the sanitation environment such as intestinal infections, typhoid, paratyphoid and cholera (Watson 2006). The outcome in column (2) is the mortality rate resulting from certain conditions originating in the perinatal period (ICD-10 category XVI). All deaths that occurred during the first 28 days of life are classified in the perinatal death group regardless of the cause. The outcome in column (3) in the mortality rate resulting from diseases of the respiratory system (category X), which include acute respiratory infections, including influenza and pneumonia, linked to bacteria transmitted through the faecal-oral pathway such as Klebsiella Pneumoniae (Aiello et al. 2008) as well as lung diseases caused by air pollutants. The outcome in column 4 is the mortality rate linked to external causes (ICD-10 category XX), which mostly include deaths caused by falls, drowning and traffic-related accidents. The outcome in column 5 is the congenital malformations mortality rate (ICD-10 category XVII). In addition, I estimate the impact of sewerage diffusion on U5MR for two more outcomes: U5MR linked to diseases of the nervous system (column 6) and diseases of the circulatory system (column 7). There are very few cases of infant deaths falling in these two categories.

The 2SLS results in Table 14 suggest an extra started sewerage project increases by 0.18 the IMR caused by respiratory infections and by 0.15 the IMR caused by accidents, although the latter coefficient is less precisely estimated[23]. The results are reassuring since both death categories can be linked to the sanitation environment and construction works. The estimated effect on mortality caused by respiratory infections remains robust and larger in magnitude when testing the effect of an extra sewerage project in construction and completed. With each additional project, there is an average increase of 0.28 in the IMR. Each additional project in construction also increases the IMR caused by malformations by 0.15, although less precisely estimated. These could suggest adverse effects of sewerage diffusion while in utero. An additional project completed also causes an increase by 0.31 in the IMR caused by accidents.

The results presented in Table 15 are also supportive of my identification strategy. The findings indicate that sewerage diffusion increases by 0.02 the U5MR caused by infectious diseases, respiratory infections and accidents. These estimates remain robust and increase in magnitude when testing the effect of an extra sewerage project in construction and of an extra sewerage project completed. It is encouraging to find nil effects on deaths from causes not linked to environmental hazards, such as malformations and diseases from the nervous and circulatory systems. In line with the main hypothesis of this study, I find that the impact of sewerage diffusion on early-life mortality mainly operates by increasing deaths from diseases related to the quality of the environment and risks linked to infrastructure works.

To make sense of these results, it is important to provide further background. In Peru, the SNIP normative establishes that the EPSs should evaluate and monitor technical reports and construction works. Yet, there is ample evidence of their ineptness[24]. Therefore, there is a high prevalence of low quality technical reports that result in engineering failures and environmental risks. There is

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[23] It may be puzzling for infants to die from accidents due to their limited mobility, but the initial average IMR is not low relative to other causes – 5 infants died due to accidents compared to 4 that died from respiratory diseases per 1,000 live births.

[24] A diagnose of the institutional quality of the EPS revealed that more than 80 percent perform poorly, measured by its management transparency, customer support, institutional management, financial and operational sustainability and work environment (Von Hesse 2016).

anecdotal evidence of government agencies and contractors copying and pasting technical reports and changing the title of projects (Apoyo Consultoria 2014). A random check of five technical reports revealed that even when the environmental risk assessment raises dangers, no mechanisms are put forward to mitigate these risks. Open ditches resulting from the excavation works to install sewerage pipes pose a number of hazards to children. Environmental dangers documented in Peru are linked to dust particles, stagnated ground water that created sources of vector-borne diseases or the use of open ditches as landfill sites (El Comercio 2018). Shockingly, there is evidence of children falling and drowning into open ditches from sewerage works that can be as deep as two meters and get filled with water from nearby sources or heavy rain (Correo 2018). An important risk linked to open ditches is traffic diversion into previously quite residential areas. An interview with an engineer expert on sewerage systems[25] revealed that contractors frequently divert traffic in an unorganized matter –they do not put in place effective signalling systems and this can result in greater traffic accidents. Another example of precarious technical implementation is how contractors handle old pipe networks when expanding the sewerage network from systems already in place. Safely handling wastewater coming from old pipes is costly and thus contractors lack incentives to prevent sewage from running into residential areas. An interview with the Leader of the World Bank's Water and Sanitation Programme in Peru[26] revealed that in areas where drinking piped-water supply is intermittent and in the presence of cracks in water pipes, sewage leaks can be absorbed by the water pipes once water provision is resumed. Ingesting faecal matter present in drinking water causes infectious diseases and these can entail fatal consequences for the exposed young children.

To further understand how young lives are threatened by the diffusion of sewerage in their districts, I explore how child health is affected. It is well established in the epidemiological literature that poor sanitation affects childhood nutritional status and impairs growth via at least three pathways: repeated bouts of diarrhoea, environmental enteric dysfunction and soil-transmitted helminthic infections (Humphrey 2009; Ngure et al. 2014). Besides water-borne diseases, any illness experienced during the early years of life consumes the nutrients and energy that the body would have otherwise used for its physical and cognitive growth (Deaton 2007). We would, therefore, expect child morbidity to be affected by infrastructure development works that expose the population to hazards. To test this, I match DHS data from children below 5 years old to the number of sewerage projects in construction on the year that morbidity was measured. Table 17 presents the estimated effect of sewerage diffusion on child anthropometrics in columns 1-3, for each of the following outcomes: (i) height-for-age; (ii) weight-for-age; and (iii) weight-for-height. Each outcome is measured as z-scores

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[25] Ponz, Fernando. Interview on 17 May 2018. Apoyo Consultoria. Lima, Peru.

[26] Marmanillo, Iris. Interview on 16 May 2018 at the World Bank Regional Office. Lima, Peru.

computed from the WHO reference group. The last column presents the effects on the incidence of diarrhea reported for the two weeks preceding the interview. We can see that, on average, the incidence of diarrhea increases by 0.002 percentage points, meaning a 1.4 percent from the prevalence in 2005, for each additional started sewerage project. This finding is in line with the hypothesis that sewerage diffusion exposed the population to pathogens, either directly in the environment or through the local sources of drinking water, which are the main cause of diarrheal diseases. Notably, we can also observe that height-for-age decreases by 0.01 standard deviations with each additional completed sewerage work, translated into a 0.4 percent decrease in height-for-age from its initial mean. These results help explain how, given their impaired immunity, children can die even after sewerage projects are completed.

6.2. Delays and project non-completion

A second mechanisms that can help explain the results is the fact that delays and/or mid-construction abandonment of projects can exacerbate the hazards that the implementation of sewerage projects pose to infants and children. Interviews with local engineers indicate that an average sewerage construction project should take one year to be completed, but delays are frequent. For projects started and completed between 2005 and 2015, the mode and median completion time were two years and it took more than four years to complete 10 percent of the projects. Strikingly, between 2005 and 2015, only half of projects that ever received funds were completed[27] (see Figure 8). This reveals that a large share of started sewerage projects is currently paralyzed. From the pool of projects started after 2005, 25 percent were not completed even 10 years after started (Figure 9). Several unfinished projects had a significant amount of work done on them: projects that remain unfinished by 2015 have seen 41 percent of the contract sum disbursed to the contractor. Overall, 13 percent of the expenditure in sewerage systems between 2005-2015 was allocated to projects that were never finished. A back-of-the-envelope calculation suggests that this waste equals 1/5 of the expenditure in Education in 2015 (World Bank 2016). Hence, the social opportunity cost of project non-completion is substantial. All together, this is evidence of frequent delays and high mid-construction abandonment of sewerage projects in Peru. Delays put at risk the chance of a sewerage project to be ever completed, as they increase the costs of completion due to physical decay of exposed works and reallocation of contractor's machinery and staff, among others. Cost adjustments may cause further delays due to the need to reformulate technical reports. Severe delays in project implementation and mid-construction abandonment of sewerage projects have attracted media attention in Peru (Peru 21 2016).

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[27] A project is declared completed when it has accrued up to 90 percent of the budgeted investment, following the threshold indicated by bureaucrats of the MVCS.

I formally evaluate the effect of time exposed to construction works on early-life mortality. To do so, I compute the total years that each district is exposed to a sewerage project in construction. I then estimate this time-invariant effect on the average annual change in IMR and U5MR using the steep gradient categories as instruments. Table 17 Panel A shows that an extra year that a district is exposed to sewerage works increased IMR by 33 percent and U5MR by 5 percent, on average, over a period of 10 years. To alleviate the concerns that these results are not driven by changes in fertility nor under-5 population, I estimate the effect on infant and under-five deaths. Table 17 Panel B shows that an extra year that a district is exposed to sewerage works increased infant deaths by 9 percent and under-five deaths by 5 percent, on average, over a period of 10 years. While the results are in line with the hypothesis of delays and mid-construction abandonment driving the estimated results, the limitation is that gradient is not a sufficiently relevant instrument for time exposed to sewerage works (F-stats below 10).

To shed lights on the determinants of project non-completion, I formally estimate a discrete-time hazard model of the probability of completing sewerage projects using a sample of all started sewerage projects (4,220 projects and 16,277project-year observations) and controlling non-parametrically for duration. The results of a linear probability model of the likelihood of project completion are reported in Table 18, which show several interesting results. First, I find that the likelihood of project completion increases if the district municipality executes the project and the likelihood is even larger if the mayor is affiliated to the central government political party (columns 1 and 2). Second, I find that the likelihood of project completion increases if the district municipality executes the project with its own funds (i.e. mining royalties and/or tax revenue) and the mayor is affiliated to the central government political party (columns 3 and 4). This association remains robust when I restrict the analysis to projects executed by the district municipality (column 5 and 6). This findings are consistent with Williams' (2017) theory of project non-completion modelled as a dynamic inconsistent outcome of a collective choice process in the context of limited funds. The technical and contractual process of infrastructure development involves a phase of project selection and budgeting and an iterated process of construction followed by payment throughout the life of the project. In the budgeting phase, a group of political actors with different distributive preferences select a set of projects to allocate funds to. Vote-trading coalitions are formed, but these require intertemporal bargains that are difficult to maintain because legislators whose projects were favoured may violate the promise ex-post. These commitment failures make any coalition vulnerable to an alternative proposal during the next budgeting process. Political negotiations over expenditure priorities are ongoing throughout the year, as plans and budgets are not strictly executed. These ongoing negotiations occur frequently through informal channels. There is evidence in Peru that informal lobbying in an attempt to influence expenditure decisions is common[28]. In the construction process, assuming that contractors have no power over the government to ensure contractible payment, the non-payment of a tranche forces the contractor to stop working until the payment is made. This can result in long litigation processes that leave construction halfway done. The more unstable the collective choice from the budgeting phase is, the more likely a project is interrupted with no guarantee of completion. Technical and contractual characteristics can aggravate this situation. In line with Williams' (2017) model, projects funded by central government transfers are more likely to be completed, perhaps because local councils suffer from more unstable collective choices.

Third, I find that the likelihood of project completion decreases in electoral years, both general (presidential and parliamentarian) as well as local elections (regional, province and municipal). This is consistent with a clientelistic model of politicians deliberately leaving projects incomplete before elections to tie the continuation utility of a voter to their political success (Robinson and Verdier 2013). Credit-claiming dynamics make the incumbent more likely than a challenger to complete a project started by the incumbent and thus, leaving unfinished projects could increase voters' incentives to re-elect the incumbent.

Finally, I find evidence that project completion is associated with various project and municipal characteristics. The likelihood of project completion decreases with the project budget, likely a proxy for project complexity; the number of other sewerage projects in construction, perhaps due to resource dispersion and population density, although it increases with total population. Interestingly, the likelihood of project completion decreases when the district is classified as needing technical assistance in the formulation of infrastructure investment projects. This is in line with Rasul and Rogger's (2018) that the quality of management matter for completion rates.

6.3. Connectivity and quality of systems

Even when projects are completed, the health benefits associated with sewerage systems may not materialize in practice in the short-term due to two main reasons. First, expanding access to sewerage systems does not ensure universal connectivity. Poorer landlords may not be able or willing to pay the connection fees that could bring sewerage services directly to their homes. This is known as the "last-mile problem" –the inability to connect expensive infrastructure to its final user. This happens when the average cost of health-related infrastructure is lower than the social benefits, but greater than the private willingness to pay (Ashraf, Glaeser, and Ponzetto 2016). In line with this prediction,

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[28] Anonymous. Interview on the 06 December 2016 at the Ministry of Housing, Construction and Sanitation. Lima, Peru.

Table 19 shows that sewerage diffusion did not increase sewerage connectivity, neither in levels (column 1) nor as a change in 10 years (column 2).

Second, even if universal connectivity is ensured, the sustainability of sewerage systems depends on the effectiveness of government agencies in its operation and maintenance. Although the Peruvian norm establishes that it is compulsory for landlords to connect to public sewers when available, the enforcement is selective. This results in a skewed composition of connectivity rates towards those that are able to afford so or have the willingness-to-do so (e.g. tenants willing to pay higher rents, interested landlords, families with better information about sanitation risks and preferences for health outcomes). Due to the negative health externalities linked to inadequate sanitation, achieving less than universal connectivity to sewers may not ensure short-term improvements in the disease environment. Table 19 shows that sewerage diffusion did not change the likelihood of the system treating water nor sludge. These results are not surprising, since there is evidence that in Latin American and particularly in Peru only about 30 percent of the wastewater is treated (Fay et al. 2017), with the remaining sludge ending up in open waters used as drinking water sources or for irrigation purposes. Furthermore, a diagnose of the institutional quality of the EPS in charge of the operation and maintenance of sewerage systems in Peru revealed that more than 80 percent perform poorly, measured by its management transparency, customer support, institutional management, financial and operational sustainability and work environment (Von Hesse 2016). There is evidence that the bad performance of EPS led to inoperative treatment plants that resulted in a focus of infection, affecting local sources of water and agricultural fields and deteriorating the disease environment of the population (La Republica 2015).

6.4. Alternative story: fertility and selective migration

Finally, I investigate whether sewerage diffusion affected early-life mortality rates through demographic channels other than the technical rigor of the construction works. Basically I estimate the effect of sewerage diffusion on different outcomes. First, the observed increase in mortality rates could be a result of a decrease in the denominator, namely the number of live births for IMR and the number of children under 5 years old for U5MR. Columns 1 and 2 in Table 20 show that this is not the case – the estimated effects on live births and under-5 population are not statistically significant. Second, the increase in mortality rates could be a result of overcrowding due to migration. People may be attracted to areas with greater sewerage diffusion because of the expectation of greater access to public services. Columns 3 and 4 in Table 20 show that sewerage diffusion did not result in an increase in the total population nor population density. Third, the adverse mortality consequences could also reflect selective emigration of the most well off households and immigration of poorer households, which creates larger regional disparities. Disruptive sewerage works may create incentives for well-off household to move away, reducing rent and attracting poorer households. Table 20 columns 5-7 shows that there is no evidence of within district sorting. The effect of sewerage diffusion on the urbanization rate and electricity connectivity is not statistically significant. Although there is a negative and statistically significant effect at the 1 percent level on the number of people with completed secondary education, the effect is too small (a 0.09 percent increase from the initial mean) to account for the estimated increase in IMR and U5MR.

7. Conclusions

In low- and middle-income countries, infant and child mortality is high and caused mainly by easily preventable diseases, largely associated with sanitation quality. Sewerage systems are in theory the optimal sanitation solution and it is widely accepted that sewerage-based sanitary revolution played an important role in the decrease of early-life mortality rates in high-income countries during the past centuries. However, little is known about the effectiveness of a sewerage diffusion initiative in a low capacity, middle-income country government, who tend to overlook the quality of social infrastructure projects and delay their completion or never actually complete them. Strikingly, policy and academic debates have largely ignored potential risks linked to infrastructure development.

This paper estimates the impact of sewerage diffusion on infant and under-five mortality rates in Peruvian districts between 2005 and 2015. The National Sanitation Plan 2006-2015 introduced the goal of expanding sewerage connectivity, which resulted in substantial variation in sewerage diffusion across years and districts within provinces. Using several sources of administrative data, this paper relies on an instrumental variable approach exploiting the fact, well documented in the sewerage engineering literature, that gradient favors a district's technical suitability for sewerage. This approach is expected to solve the endogeneity problem that arises with sewerage diffusion taking place in districts with greater wealth and/or interest in improving living standards, which affects mortality trends beyond sewerage diffusion.

Results show that IMR and U5MR increase by 2.1 and 0.08, respectively, with each extra started sewerage project. These unintended mortality consequences seem to be linked to the construction works required to install sewerage lines, which exposed the population to hazards. IMR and U5MR increase by 4.29 and 0.11, respectively, for each additional sewerage project in construction, translated into a 10 percent and 2 percent increase from baseline mortality rates. These results are robust to a series of tests regarding the power and validity of the instruments, suggesting that there is room to interpret the results as a causal effect of sewerage diffusion on early-life mortality. While the results suggest short-term impact on IMR, the increase in U5MR is sustained over time until the benefits of sewerage systems kick-in 6 years after project completion.

There are several possible explanations for the observed rise in IMR and U5MR and I perform additional tests to shed lights on possible mechanisms. The first hypothesis is that a lack of technical rigor during the construction works exposed the population to hazards. Open ditches resulting from excavation works required to install sewerage pipes, release of sludge from old pipes into local areas and cuts on piped water provision can expose the local population to hazards. Consistent with this hypothesis, I find that the increase in IMR and U5MR is driven by deaths from infectious and respiratory diseases, as well as accidents. I also find evidence that sewerage diffusion increased child diarrhea incidence and decreased child height. The second hypothesis is that these adverse mortality consequences could be exacerbated due to delays and high mid-construction abandonment. Consistent with this, I find that infant and under-five deaths increased with each extra year that the district is exposed to sewerage projects in construction. The third hypothesis is that, even after sewerage projects are completed, universal adoption is not ensured, and even if so, the quality of these systems is overlooked. In line with this hypothesis, I find that sewerage diffusion does not increase sewerage connectivity nor the probability of the district to treat its sludge and water. I also investigates whether IMR and U5MR impacts could be driven by fertility or migration changes in response to sewerage diffusion. Census data reveals that these alternative channels do not appear to explain the mortality increase observed.

The findings of this paper have truly important policy implications. Taken together, my results suggest that failures on the government's urban infrastructure planning are threatening infant and child survival. Vast amounts of resources are spent every year to expand access to sanitation infrastructure in low and middle-income countries with the aim of improving living standards. However, there is no acknowledgement of the adverse mortality effects that may arise from inadequate planning and management of the works and quality of the infrastructure. Stricter health and safety standards and accurate environmental assessments of sewerage development projects are needed to mitigate these lethal effects from the construction period that net out any potential benefits from improvements in access to adequate sanitation facilities. Furthermore,

Finally, reforms to overcome the underlying political imperfections that impair government services to citizens are also needed. For instance, survey instruments, such as citizen report cards that provide feedback on the state of public goods, is a potentially powerful tool to overcome the effects of incomplete information and for mobilizing voters around the issue of quality of social infrastructure.

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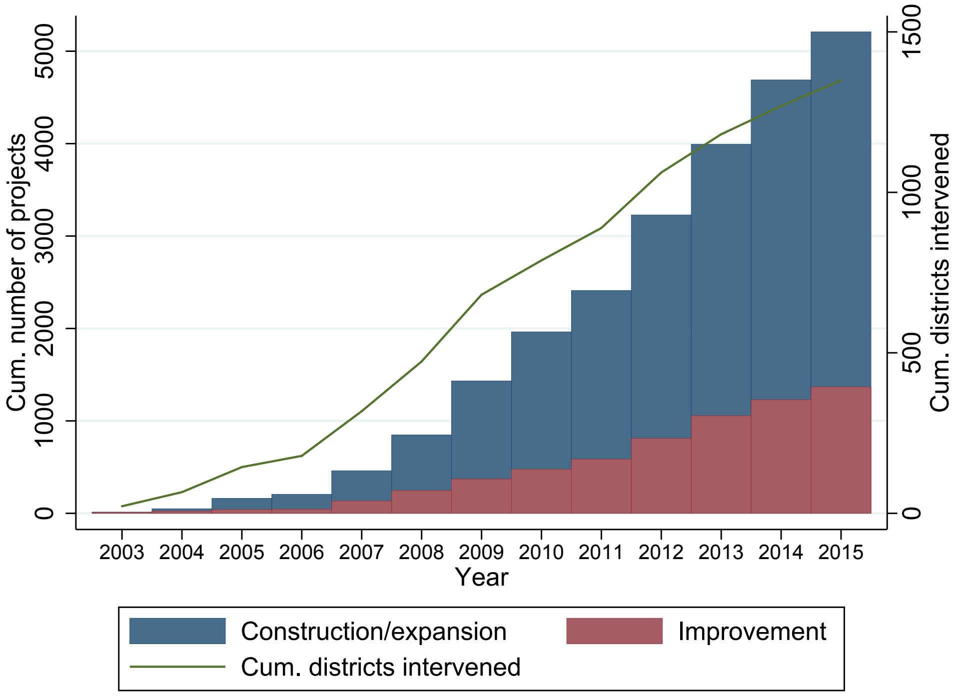
Figure 1: Number of started sewerage projects and districts intervened, 2005-2015



Notes: Data on the number of sewerage projects started between 2005 and 2015 from the National System of Public Investment (SNIP for its Spanish acronyms) and the Integrated System of Financial Administration (SIAF for its Spanish acronyms). Construction/expansion projects are those that constructed new sewerage systems or expanded pipe networks from the existing infrastructure. Improvement corresponds to projects that improved sewerage lines already in place. Each project represents a fraction of a district. District intervened are those in which at least one sewerage project was started.

Figure 2: Started sewerage projects, 2005-2015

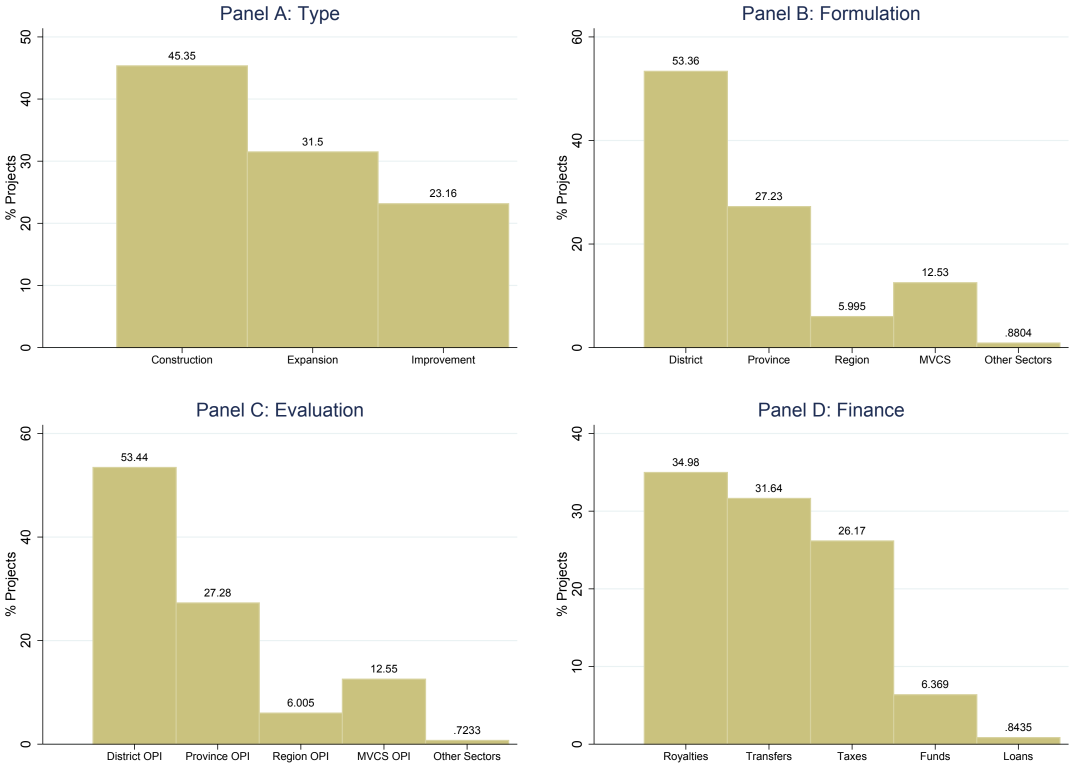


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Figure 3: Early-life mortality rates trends

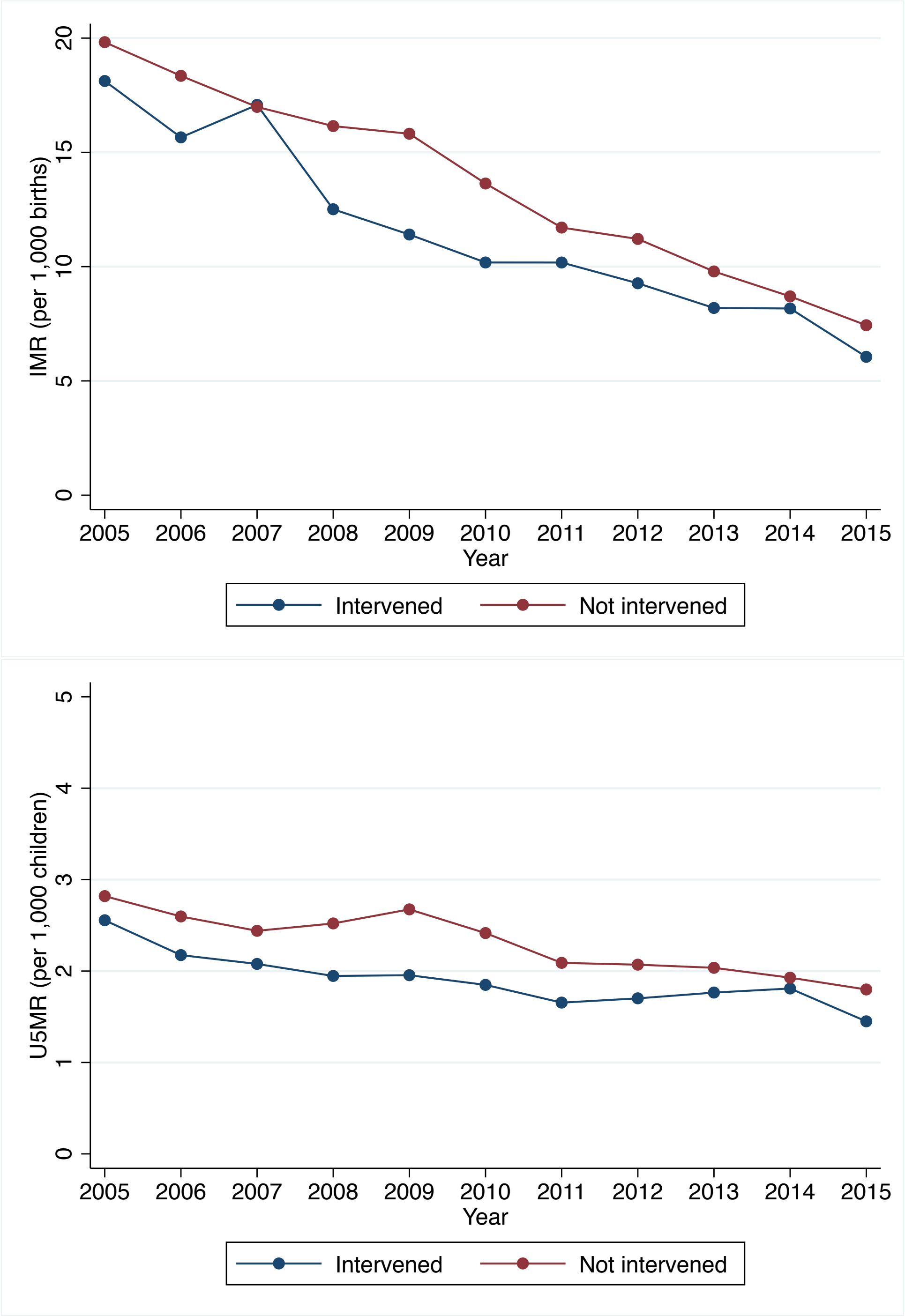

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Figure 4: Sewerage diffusion across districts in Peru, 2005-2015

Notes: Data on the number of sewerage projects started between 2005 and 2015 from the National System of Public Investment (SNIP for its Spanish acronyms) and the Integrated System of Financial Administration (SIAF for its Spanish acronyms). Each project represents a community. I assign sewerage projects to districts in the year that the first disbursement is made.

Figure 5: Fraction of area in gradient category, by district

Note: From top to bottom and left to right blue shaded area indicates (i) gradient [0-0.8]; (ii) gradient {0.8-4.19]; (iii) gradient {4.19-13]; and (iv) gradient > 13%. Gradient computed using a digital elevation map provided by the Peruvian Ministry of Environment, which provides information on surface elevation for multiple cells (1x1 km). Gradient is a measure of the steepness of the ground surface calculated with ArcMap using elevation in each cell and neighboring cells.

Table 2: First stage: Gradient and district sewerage diffusion (cum. started projects)

		First stage		Reduced form	
	Cross-section		Interacted with S^p_{pt}		
		IMR sample	U5MR sample	IMR	U5MR
	(1)	(2)	(3)	(4)	(5)
Gradient {0.8-4.19]	4.274**	0.137***	0.134***	0.0763	0.00680
	[1.587]	[0.0303]	[0.0274]	[0.120]	[0.00673]
Gradient {4.19-13]	3.185*	0.146***	0.133***	0.0965	0.0193**
	[1.405]	[0.0366]	[0.0322]	[0.126]	[0.00720]
Gradient > 13	2.820*	0.170*	0.171**	0.110	0.00179
	[1.303]	[0.0664]	[0.0606]	[0.202]	[0.00806]
Fstat	2.991	10.38	12.75		
Year*Gradient	No	Yes	Yes	Yes	Yes
District FE	No	Yes	Yes	Yes	Yes
District-year	1630	10032	10632	10032	10632

Note: All regressions include district fixed effects and a full set of province*year interactions and gradient*year interactions. Columns (2) and (4) include municipal controls. Municipal controls include dummy variables indicating when the district municipality manages at least one health center, when it needs technical assistance to formulate investment projects, when it has access to Internet and when the mayor is affiliated to the government party, municipal income (ln) and total district population. Sample restricted to district-years with IMR data (Columns 1 and 2) and U5MR data (Columns 3 and 4). Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 1: Descriptive statistics of district characteristics, 2005

	(1) All Mean	(2) Not Intervened Mean	(3) Intervened Diff.	(4) Later Mean	(5) Early Diff.	(6) Low Mean	(7) High Diff.
Population	23366.87	17660.98	7086.56	18234.31	16606.82***	14056.84	19792.54***
Population density (pop/sq km)	641.82	1564.63	-1146.11***	311.33	273.29**	356.10	115.57
District area (sq. km)	636.09	441.04	242.24*	595.83	222.99*	567.18	214.96*
Total income (ln)	14.39	14.03	0.45***	14.29	0.47***	14.05	0.79***
Internet access	0.37	0.23	0.18***	0.33	0.19***	0.24	0.31***
Manages health centers	0.22	0.23	-0.01	0.22	-0.02	0.21	0.02
TA in formulation of investment projects	0.66	0.61	0.06	0.67	0.01	0.67	-0.01
Mayor affiliated to the government party	0.11	0.17	-0.07***	0.10	-0.02	0.10	-0.01
Share of HHs connected to sewerage	0.25	0.22	0.04*	0.21	0.12***	0.17	0.16***
Share of HHs with piped-water	0.54	0.54	-0.00	0.53	0.01	0.51	0.06***
Mean age of HH heads	47.87	49.31	-1.79***	47.64	-0.29	48.29	-1.41***
Share of HHs living in overcrowded housing	0.14	0.13	0.01	0.15	-0.02***	0.15	-0.01
Share of HHs where head has above secondary	0.05	0.04	0.00	0.04	0.01***	0.04	0.01***
Share of HHs w/ children 6-12 not attending school	0.01	0.01	0.00**	0.01	-0.00***	0.01	0.00
Observations	1083	211	1083	530	872	401	872

Note: Early intervened are districts in which the first sewerage project started before 2014 and high where more than 2 projects were started. Both cut-offs were set following the median of the sample of districts intervened. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 3: Impact of sewerage diffusion on early-life mortality

	OLS				2SLS			
	IMR		U5MR		IMR		U5MR	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Cum. number of started sewerage	-0.296*	0.124	0.000341	0.00190	0.794	2.079*	0.0716**	0.0753**
	[0.175]	[0.241]	[0.00577]	[0.00593]	[0.610]	[1.116]	[0.0365]	[0.0376]
Fstat					10.28	11.61	12.86	12.69
Num. sewerage in construction	-0.451*	-0.0348	-0.000289	-0.00329	1.552	4.286**	0.0986*	0.102*
	[0.253]	[0.359]	[0.00690]	[0.00731]	[0.982]	[1.893]	[0.0558]	[0.0538]
Fstat					10.02	11.62	11.01	12.53
Cum. number of completed sewerage	-0.330	0.745	-0.00470	0.0117	0.827	2.575	0.131**	0.145*
	[0.333]	[0.507]	[0.0151]	[0.0146]	[1.117]	[1.946]	[0.0644]	[0.0758]
Fstat					13.93	11.18	17.34	12.02
Muni	No	Yes	No	Yes	No	Yes	No	Yes
BL								
District-year	10032	6543	10519	6835	10032	6483	10519	6780
Districts	1408	1210	1419	1223	1408	1150	1419	1168

Note: All regressions include a set of interactions of province sewerage diffusion with district elevation categories and land area district fixed effects and a full set of province*year interactions and gradient*year interactions. Muni controls include dummy variables indicating when the district municipality manages at least one health center, when it needs technical assistance to formulate investment projects, when it has access to Internet and when the mayor is affiliated to the government party and municipal income (ln) and population. Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Lead and lagged effect of the number of completed sewerage projects on IMR

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
t-2	-2.041								
	[5.632]								
t-1		9.048*							
		[5.089]							
t	19.96***	18.76***	9.313	6.585	5.826	4.100	3.024	2.357	-2.505
	[6.105]	[6.513]	[6.071]	[7.057]	[6.487]	[5.644]	[5.586]	[6.235]	[4.385]
t+1				2.539					
				[5.232]					
t+2					4.296				
					[8.820]				
t+3						-6.226			
						[5.697]			
t+4							-11.64		
							[10.51]		
t+5								-1.937	
								[3.844]	
t+6									-0.772
									[5.309]
F-stat	15.24	7.382	11.03	12.21	6.382	5.869	8.784	8.848	22.29
District-year	5627	5627	6219	5476	5476	4721	3933	3127	2331
Districts	1078	1078	1096	1049	1049	1008	946	865	750

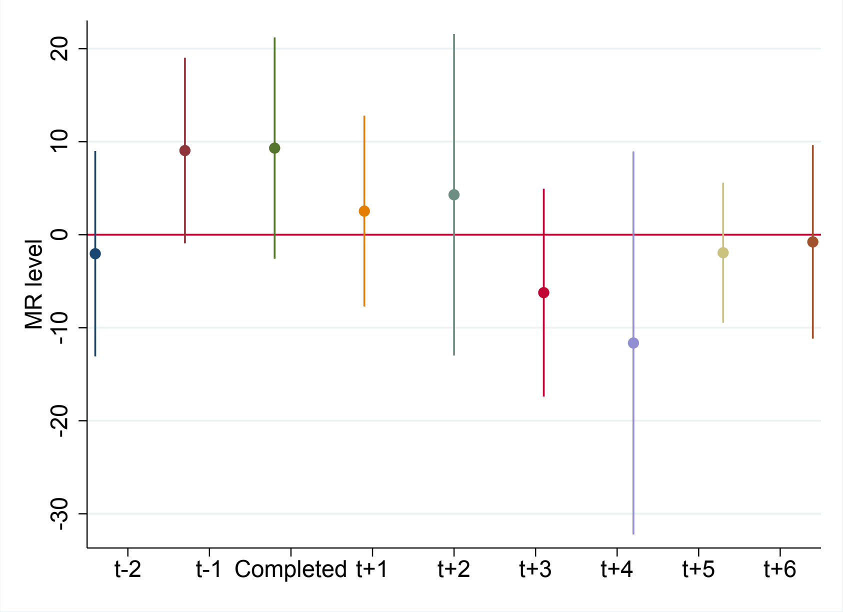
Note: All regressions include district fixed effects and a full set of province*year interactions and gradient*year interactions and municipal controls. Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5: Lead and lagged effect of the number of completed sewerage projects on U5MR

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
t-2	0.143								
	[0.141]								
t-1		0.263*							
		[0.141]							
t	0.195	0.123	0.192	0.0541	0.0548	0.141	0.0146	0.00987	-0.0270
	[0.145]	[0.185]	[0.173]	[0.127]	[0.133]	[0.139]	[0.0814]	[0.0752]	[0.0720]
t+1				0.173					
				[0.111]					
t+2					0.310**				
					[0.142]				
t+3						0.405*			
						[0.213]			
t+4							0.455*		
							[0.263]		
t+5								0.0301	
								[0.121]	
t+6									-0.191**
									[0.0963]
F-stat	14.64	7.047	11.56	14.11	6.819	7.354	9.018	8.317	11.00
District-year	5928	5928	6572	5785	5785	5016	4180	3336	2506
Districts	1128	1128	1143	1105	1105	1070	1004	921	803

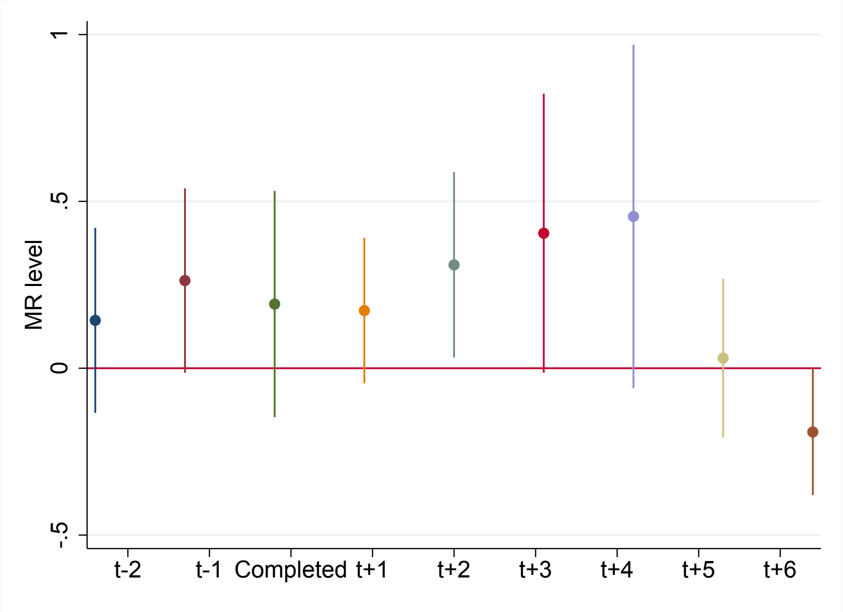
Note: All regressions include district fixed effects and a full set of province*year interactions and gradient*year interactions and municipal controls. Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Figure 6: Lead and lagged effect of completed sewerage projects on IMR



Notes: All regressions include district fixed effects and a full set of province*year interactions and gradient*year interactions and municipal controls. Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Figure 7: Lead and lagged effect of completed sewerage projects on U5MR



Notes: All regressions include district fixed effects and a full set of province*year interactions and gradient*year interactions and municipal controls. Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 6: Lead and lagged effect of sewerage projects in construction on IMR

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
t-2	-6.897***								
	[2.312]								
t-1		-8.422**							
		[4.085]							
t	8.045***	11.72**	4.290**	8.160*	2.753	0.934	4.015	3.046	7.720
	[2.441]	[4.692]	[1.897]	[4.645]	[2.213]	[2.126]	[2.479]	[2.988]	[4.987]
t+1				-4.612					
				[4.027]					
t+2					0.536				
					[1.944]				
t+3						2.667			
						[2.530]			
t+4							-0.570		
							[3.133]		
t+5								0.934	
								[2.314]	
t+6									-4.158*
									[2.447]
F-stat	8.578	9.644	11.73	7.889	5.307	5.151	7.504	8.636	10.44
District-year	5870	5870	6483	5693	5693	4897	4082	3247	2418
Districts	1132	1132	1150	1094	1094	1046	981	899	778

Note: All regressions include district fixed effects and a full set of province*year interactions and gradient*year interactions and municipal controls. Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 7: Lead and lagged effect of sewerage projects in construction on U5MR

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
t-2	0.00807								
	[0.0415]								
t-1		-0.0609							
		[0.0641]							
t	0.0772	0.133*	0.108**	0.0260	0.0335	-0.0152	-0.00121	0.0235	-0.0317
	[0.0598]	[0.0764]	[0.0537]	[0.0684]	[0.0583]	[0.0458]	[0.0456]	[0.0529]	[0.0528]
t+1				0.0448					
				[0.0550]					
t+2					0.0581				
					[0.0396]				
t+3						0.100***			
						[0.0325]			
t+4							0.0750*		
							[0.0400]		
t+5								0.0415	
								[0.0432]	
t+6									0.0218
									[0.0696]
F-stat	9.666	10.35	13.19	9.288	5.946	5.256	7.572	7.517	7.655
District-year	6186	6186	6861	6020	6020	5211	4345	3469	2608
Districts	1186	1186	1203	1153	1153	1113	1043	958	837

Note: All regressions include district fixed effects and a full set of province*year interactions and gradient*year interactions and municipal controls. Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 8: Robustness check: Impact of sewerage diffusion on IMR

	Intervened (1)	Exc. Lima (2)	Pop density (3)	Top-coded (4)	Cons/exp (5)
Cum. number of started sewerage	2.073*	2.898*	2.003*	3.150***	1.151
	[1.208]	[1.533]	[1.089]	[1.181]	[1.307]
F-stat	11.53	6.290	11.62	17.76	17.27
Num. sewerage in construction	4.239**	5.973**	4.165**	2.699***	2.324
	[2.119]	[2.772]	[1.867]	[1.046]	[2.563]
F-stat	8.668	7.454	11.47	19.96	28.89
Cum. number of completed sewerage	2.478	3.156	2.384	3.931*	1.732
	[1.903]	[2.180]	[1.858]	[2.187]	[1.628]
F-stat	17.34	9.393	11.37	8.768	13.27
Baseline mean	54.14	54.09	54.14	54.14	54.14
District-year	5180	5957	6483	6483	6483
Districts	889	1074	1150	1150	1150

Note: All regressions include interactions of province sewerage diffusion with district elevation categories and land area, district fixed effects, a full set of province*year interactions and gradient*year interactions. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 9: Robustness check: Impact of sewerage diffusion on U5MR

	Intervened (1)	Exc. Lima (2)	Pop density (3)	Top-coded (4)	Cons/exp (5)
Cum. number of started sewerage	0.0437	0.0787*	0.0812**	0.0659*	0.113**
	[0.0300]	[0.0466]	[0.0386]	[0.0369]	[0.0556]
Fstat	11.51	7.076	12.56	19.58	17.52
Num. sewerage in construction	0.0502	0.0812	0.113**	0.0381	0.138*
	[0.0480]	[0.0810]	[0.0541]	[0.0290]	[0.0736]
F-stat	9.662	8.585	12.65	21.44	28.76
Cum. number of completed sewerage	0.0883*	0.128*	0.153*	0.119*	0.135
	[0.0523]	[0.0660]	[0.0800]	[0.0618]	[0.0876]
F-stat	15.32	10.75	12.16	9.491	13.80
Baseline mean	3.862	3.971	3.862	3.862	3.862
District-year	5447	6303	6861	6861	6861
Districts	923	1123	1203	1203	1203

Note: All regressions include interactions of province sewerage diffusion with district elevation categories and land area, district fixed effects, a full set of province*year interactions and gradient*year interactions. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 10: Alternative channels? Impact on IMR when adding province controls

	(1)	(2)	(3)	(4)	(5)
Num. sewerage in construction	4.546**	4.126*	4.440*	0.828	3.022
	[1.883]	[2.447]	[2.423]	[3.275]	[2.878]
Population density (sq. km)	-16.56	-14.52	-15.52	-450.9**	-32.80
	[44.92]	[49.99]	[54.77]	[223.1]	[53.36]
Transport expenditure (ln)		0.219	0.113	15.19**	
		[3.264]	[3.534]	[7.055]	
Energy expenditure (ln)			-0.659	0.259	
			[1.033]	[2.271]	
Health centres (ln)				-52.45	
				[33.80]	
Electricity connectivity (F2)					26.33
					[33.28]
F-stat	11.69	9.684	9.402	10.55	6.026
District-year	6483	5693	5443	1592	824
Districts	1150	1094	1072	652	412

Note: All regressions include interactions of province sewerage diffusion with district elevation categories and land area, district fixed effects, a full set of province*year interactions and gradient*year interactions. Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 11: Alternative channels? Impact on U5MR when adding province controls

	(1)	(2)	(3)	(4)	(5)
Num. sewerage in construction	0.121**	0.0936*	0.0759	0.0617	0.271***
	[0.0490]	[0.0516]	[0.0515]	[0.0753]	[0.0933]
Population density (sq. km)	4.806***	4.685***	4.835***	1.520	6.253***
	[0.939]	[0.908]	[1.148]	[4.839]	[1.721]
Transport expenditure (ln)		-0.116	-0.132	0.132	
		[0.0878]	[0.0905]	[0.113]	
Energy expenditure (ln)			0.0481	-0.0283	
			[0.0319]	[0.0557]	
Health centres (ln)				-0.242	
				[0.734]	
Electricity connectivity (F2)					2.326
					[1.858]
F-stat	12.84	10.85	10.54	11.77	6.645
District-year	6861	6020	5757	1693	948
Districts	1203	1153	1127	688	474

Note: All regressions include interactions of province sewerage diffusion with district elevation categories and land area, district fixed effects, a full set of province*year interactions and gradient*year interactions. Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 12: IV operating through alternative channels?

		IMR			U5MR	
	(1)	(2)	(3)	(4)	(5)	(6)
Pop density (sq. km)	-67.02			-4.988**		
	[87.85]			[2.522]		
Electricity connectivity (F2)		-305.2			-34.10	
		[320.5]			[21.25]	
Health centres (ln)			61.01			-1.974
			[54.94]			[1.685]
F-stat	3.288	1.986	1.955	3.409	1.319	1.860
District-year	6483	824	1780	6861	948	1883
Districts	1150	412	706	1203	474	743

Note: All regressions include interactions of province sewerage diffusion with district elevation categories and land area, district fixed effects, a full set of province*year interactions and gradient*year interactions. Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 13: Reverse causality? Alternative IV

	IMR		U5MR	
	(1)	(2)	(3)	(4)
Cum. number of started sewerage	1.029*	3.058**	0.0452	0.0537
	[0.600]	[1.333]	[0.0370]	[0.0385]
F-stat	14.44	12.80	16.08	13.86
Num. sewerage in construction	1.921*	6.236**	0.0786	0.0831
	[1.120]	[2.504]	[0.0657]	[0.0713]
F-stat	20.93	17.85	23.83	21.87
Cum. number of completed sewerage	1.620	4.038	0.0795	0.0918
	[1.253]	[2.524]	[0.0664]	[0.0638]
F-stat	16.73	17.53	16.82	12.97
Muni controls	No	Yes	No	Yes
Baseline mean	57.74	57.74	4.954	4.954
District-year	10021	6474	10621	6852
Districts	1407	1149	1466	1202

Note: All regressions include interactions of province sewerage diffusion with district elevation categories and land area, district fixed effects and a full set of province*year interactions and gradient*year interactions. Muni controls include dummy variables indicating when the district municipality manages at least one health center, when it needs technical assistance to formulate investment projects, when it has access to Internet and when the mayor is affiliated to the government party, municipal income (ln) and total district population. Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 14: Impact of sewerage diffusion on IMR, by cause of deaths

	Infec	Peri	Resp	Accid	Malf
	(1)	(2)	(3)	(4)	(5)
Cum. number of started sewerage	0.0708	0.0738	0.178**	0.146*	0.0887
	[0.0503]	[0.262]	[0.0798]	[0.0838]	[0.0546]
F-stat	10.26	10.26	10.26	10.26	10.26
Num. sewerage in construction	0.128	0.217	0.278**	0.219	0.146*
	[0.0869]	[0.504]	[0.125]	[0.138]	[0.0861]
F-stat	10.06	10.06	10.06	10.06	10.06
Cum. number of completed sewerage	0.0883	-0.0387	0.276*	0.309**	0.142
	[0.0677]	[0.319]	[0.157]	[0.140]	[0.100]
Fstat	13.76	13.76	13.76	13.76	13.76
Baseline mean	2.174	17.53	4.330	5.838	2.453
District-year	10032	10032	10032	10032	10032
Districts	1408	1408	1408	1408	1408

Note: All regressions include interactions of province sewerage diffusion with district elevation categories and land area, district fixed effects, a full set of province*year interactions and gradient*year interactions. Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 15: Impact of sewerage diffusion on U5MR, by cause of deaths

	Infec (1)	Peri (2)	Resp (3)	Accid (4)	Malf (5)	Nerv (6)	Circ (7)
Cum. number of started sewerage	0.017**	0.005	0.017*	0.020**	0.002	-0.001	0.002
	[0.009]	[0.016]	[0.010]	[0.010]	[0.006]	[0.002]	[0.002]
F-stat	12.747	12.747	12.747	12.747	12.747	12.747	12.747
Num. sewerage in construction	0.025**	0.009	0.020	0.026*	0.000	0.001	0.003
	[0.012]	[0.026]	[0.017]	[0.016]	[0.010]	[0.002]	[0.003]
F-stat	10.641	10.641	10.641	10.641	10.641	10.641	10.641
Cum. number of completed sewerage	0.034*	0.001	0.039*	0.038**	0.010	-0.004	0.003
	[0.018]	[0.030]	[0.023]	[0.018]	[0.014]	[0.004]	[0.003]
F-stat	16.703	16.703	16.703	16.703	16.703	16.703	16.703
Baseline mean	0.632	1.526	0.764	1.244	0.394	0.041	0.058
District-year	10632	10632	10632	10632	10632	10632	10632
Districts	1467	1467	1467	1467	1467	1467	1467

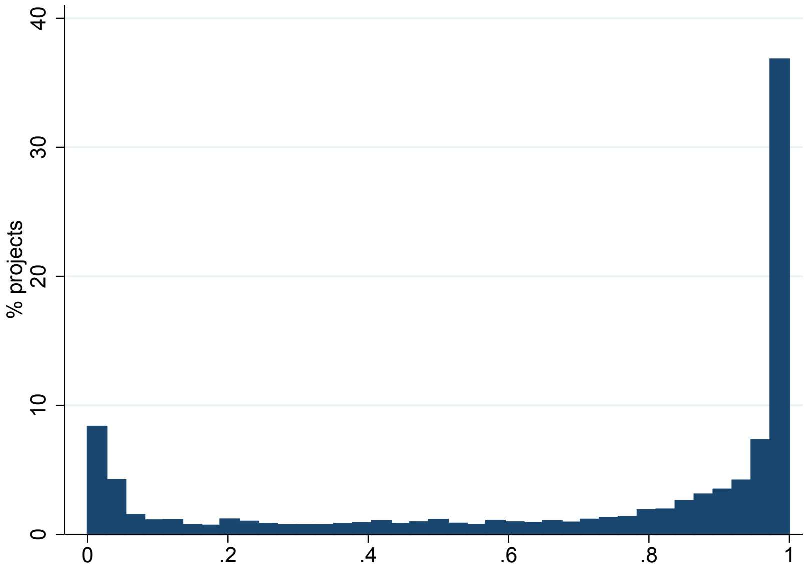
Note: All regressions include interactions of province sewerage diffusion with district elevation categories and land area, district fixed effects, a full set of province*year interactions and gradient*year interactions. Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 16: Child morbidity: Anthropometrics and diarrhoea incidence

	hfaz (1)	wfaz (2)	wfhz (3)	Diarrhoea 2w (4)
Cum. number of started sewerage	-0.005	0.220	0.744	0.002**
	[0.003]	[0.417]	[0.479]	[0.001]
F-stat	21.972	21.637	21.889	26.808
Num. sewerage in construction	-0.006	0.577	1.292	0.002
	[0.007]	[0.712]	[0.931]	[0.001]
F-stat	21.012	20.371	20.807	19.383
Cum. number of completed sewerage	-0.010*	-0.005	0.964	0.003
	[0.006]	[0.752]	[0.849]	[0.002]
F-stat	11.282	11.287	11.295	12.503
Baseline mean	-1.442	-39.183	61.897	0.164
Children	51831	51501	51141	61516
Districts	1140	1140	1140	1174

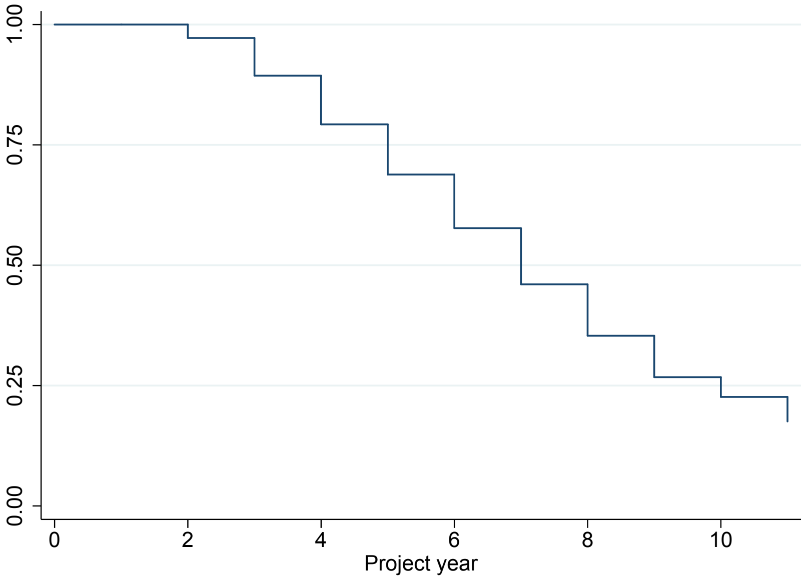
Note: The dependent variables of columns 1-3 are anthropometric indicators expressed in z-scores for children under-five computed from the WHO 2006 standardized age- and sex- specific growth reference. All regressions include district fixed effects, a full set of province*year interactions and gradient*year interactions and municipal controls. Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Figure 8: Completion rate, projects between 2005-2015



Notes: Completion rate computed as total accrued investment until 2015 divided by budgeted investment. Data on annual investment from SIAF. Sample restricted to projects started before 2015 because of the right-censoring of the data (finished in 2015) and the fact that sewerage projects optimally take one year to be completed.

Figure 9: Project completion hazard rate



Notes: Completion time computed as the time it takes for projects that ever accrued more than 90 percent of the budgeted investment. Data on annual investment from SIAF.

Table 17: Impact of time exposed to construction works on early-life mortality

	IM		U5M	
	(1)	(2)	(3)	(4)
Panel A: Mortality rates				
Works time	35.09***	33.39**	5.406*	4.782
	[12.27]	[16.92]	[2.873]	[3.567]
Fstat	7.642	4.368	6.866	4.317
Panel B: Deaths				
Works time	9.650**	7.529*	5.601*	4.799
	[3.295]	[3.777]	[2.827]	[3.519]
Fstat	7.284	4.381	6.866	4.317
Muni/project controls	No	Yes	No	Yes
District-year	1237	1017	1281	1051

Note: All regressions control for district elevation categories, land area and changes in population and include province fixed effects. Municipal controls include dummy variables indicating when the district municipality initially managed at least one health center, needed technical assistance to formulate investment projects, had access to Internet and their initial municipal income (ln). In addition I include the budgeted investment to control for project complexity. Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 18: Discrete-time hazard model: Likelihood of project completion

	(1)	(2)	(3)	(4)	(5)	(6)
Executed: District	0.0416*	0.0416*				
	[0.0216]	[0.0228]				
Mayor gov party	-0.0322	-0.0194	-0.00720	0.00815	-0.00299	0.00977
	[0.0243]	[0.0256]	[0.0161]	[0.0179]	[0.0165]	[0.0197]
Executed: District × Mayor gov party	0.0512*	0.0576*				
	[0.0291]	[0.0302]				
District and gov funds			0.000122	0.00577		
			[0.0264]	[0.0270]		
District and gov funds × Mayor gov party			0.0268	0.0377		
			[0.0428]	[0.0442]		
District and own funds			-0.0515***	-0.0477**	-0.0759***	-0.0731***
			[0.0187]	[0.0186]	[0.0187]	[0.0185]
District and own funds × Mayor gov party			0.0459	0.0546*	0.0459	0.0547*
			[0.0299]	[0.0295]	[0.0311]	[0.0314]
Elect: cent	-0.0202**	-0.0212**	-0.0228***	-0.0217**	-0.0141	-0.0123
	[0.00834]	[0.00972]	[0.00854]	[0.00969]	[0.0117]	[0.0130]
Elect: local	0.00334	-0.0277**	0.00266	-0.0285**	0.00108	-0.0228
	[0.00402]	[0.0128]	[0.00407]	[0.0129]	[0.00517]	[0.0171]
Budgeted investment (ln)	-0.0226***	-0.0224***	-0.0197***	-0.0205***	-0.00991*	-0.00999*
	[0.00454]	[0.00436]	[0.00493]	[0.00470]	[0.00568]	[0.00546]
Num. sewerage in construction	-0.00660***	-0.00789***	-0.00621***	-0.00762***	-0.00663***	-0.00729***
	[0.00164]	[0.00139]	[0.00154]	[0.00132]	[0.00159]	[0.00131]
Population density (sq kms)		-0.000175***		-0.000163***		-0.000152***
		[0.0000559]		[0.0000566]		[0.0000569]
Population		0.00000578***		0.00000583***		0.00000490***
		[0.00000114]		[0.00000111]		[0.00000105]
Total income (ln)		0.00861		0.0127		0.00373
		[0.0138]		[0.0139]		[0.0167]
Manages health centers		0.00334		0.00480		-0.00246
		[0.00907]		[0.00910]		[0.0115]
TA in formulation of investment projects		-0.0133*		-0.0138*		-0.0125
		[0.00748]		[0.00747]		[0.00928]
Internet access		-0.0167		-0.0130		-0.0344**
		[0.0137]		[0.0137]		[0.0170]
Project-year	20967	16671	20967	16671	14691	11568

Note: Project-level data spanning from the first disbursement until either completion (investment budget accrued at least by 90 percent) or right censoring (end of dataset in 2015). * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 19: Impact of sewerage diffusion on sludge and water treatment and sewerage connectivity

	Connectivity (1)	Chg. connectivity (2)	Treat water (3)	Treat sludge (4)
Cum. number of started sewerage	-0.0000178	0.0208	-0.00376	0.00165
	[0.00319]	[0.0171]	[0.00368]	[0.00893]
Fstat	10.16	1.003	11.39	11.63
Cum. number of completed sewerage	-0.00116	0.0434	-0.00937	0.00646
	[0.00570]	[0.0353]	[0.00643]	[0.0238]
Fstat	12.24	0.931	16.31	16.55
BL mean	0.250	0.250	0.852	0.239
District-year	2632	815	6362	8327
Districts	1015	156	1280	1370

Note: All regressions include interactions of province sewerage diffusion with district elevation categories and land area, district fixed effects and a full set of province*year interactions and gradient*year interactions. Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

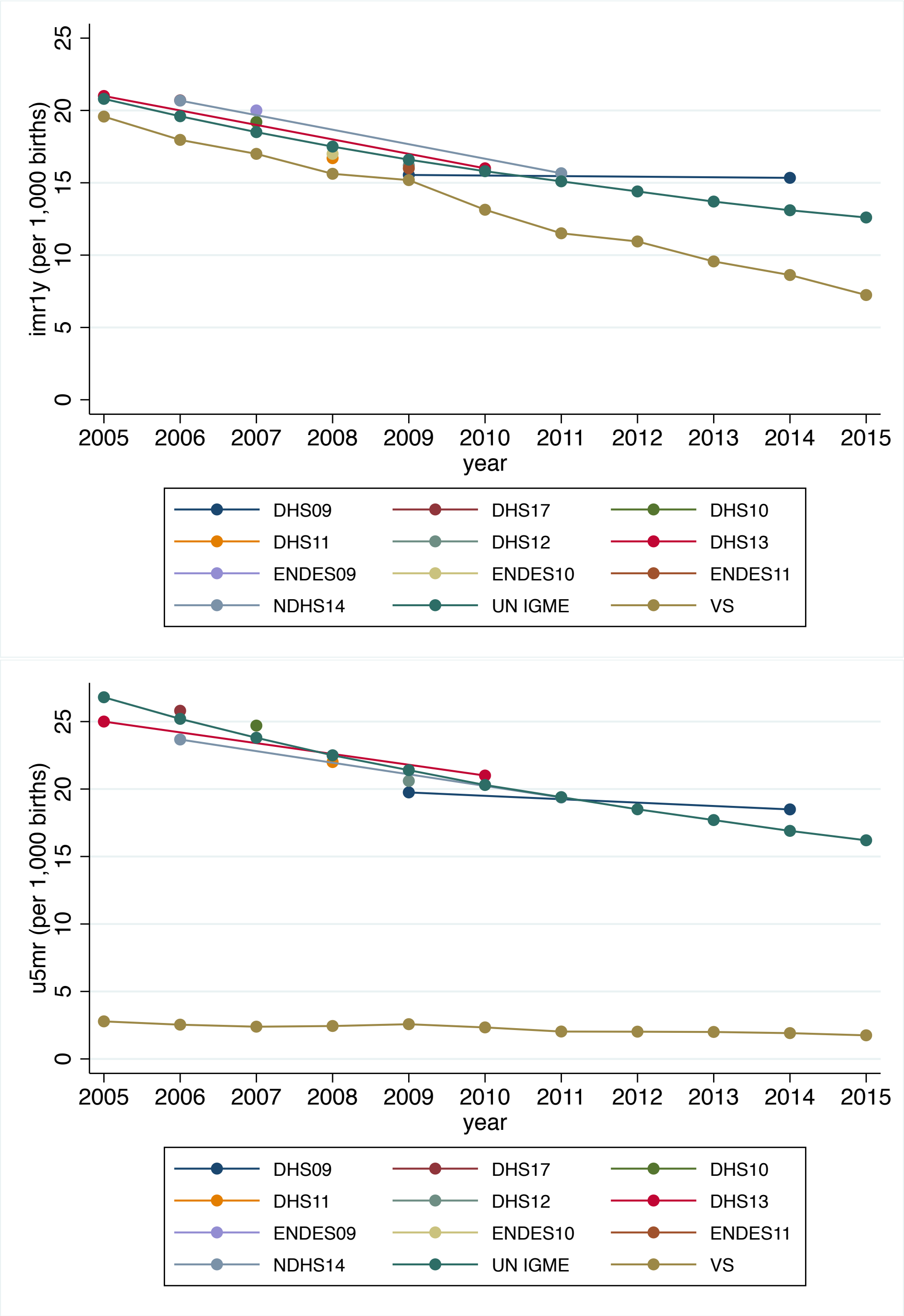
Appendix

Table 20: Fertility and selective migration do not explain the results

	IMR sample	U5MR sample		IMR and U5MR sample			
	Births(log) (1)	U5 pop(log) (2)	Pop(log) (3)	Pop dens(log) (4)	Urban pop (5)	Sec educ (6)	Electricity (7)
Cum. number of started sewerage	-2.709	-15.59	0.00127	0.00127	0.00294	-0.002***	-0.00134
	[10.17]	[10.39]	[0.00143]	[0.00143]	[0.00193]	[0.000750]	[0.00262]
F-stat	11.58	12.70	12.70	12.70	12.35	12.35	9.455
Num. sewerage in construction	-7.085	-21.66	0.00128	0.00128	0.00624*	-0.003***	-0.00293
	[17.76]	[14.24]	[0.00263]	[0.00263]	[0.00365]	[0.00119]	[0.00451]
F-stat	11.73	13.19	13.19	13.19	11.39	11.39	7.719
Cum. number of completed sewerage	-1.343	-35.45	0.00233	0.00233	0.00428	-0.005**	-0.000802
	[14.51]	[27.09]	[0.00196]	[0.00196]	[0.00344]	[0.00200]	[0.00574]
F-stat	11.18	11.96	11.96	11.96	10.61	10.61	8.287
Baseline mean	297.7	2413.3	2.173	-3.233	0.474	0.218	0.558
District-year	6483	6861	6861	6861	1933	1933	948
Districts	1150	1203	1203	1203	777	777	474

Note: All regressions include interactions of province sewerage diffusion with district elevation categories and land area, district fixed effects, a full set of province*year interactions and gradient*year interactions. Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Figure 10: Vital statistics compared to other data sources



Note: Alternative data obtained from the Health and Demographic Surveys (DHS), National Survey of Health and Demography (ENDES) and Inter-agency Group for Child Mortality Estimation (UN IGME).

Table 21: First stage: Gradient and district sewerage diffusion (Num. projects in construction)

		First stage		Reduced form	
	Cross-section	Interacted with S^p_{pt}			
		IMR sample	U5MR sample	IMR	U5MR
	(1)	(2)	(3)	(4)	(5)
Gradient {0.8-4.19]	1.521	0.125***	0.124***	0.156	0.0105
	[1.047]	[0.0296]	[0.0268]	[0.172]	[0.00907]
Gradient {4.19-13]	1.319	0.119***	0.111***	0.123	0.0254*
	[0.927]	[0.0313]	[0.0285]	[0.196]	[0.0101]
Gradient $>$ 13	0.841	0.168*	0.168**	0.269	0.00164
	[0.860]	[0.0705]	[0.0645]	[0.256]	[0.0112]
Fstat	1.153	9.529	10.64		
Year*Gradient	No	Yes	Yes	Yes	Yes
District FE	No	Yes	Yes	Yes	Yes
District-year	1630	10032	10632	10032	10632

Note: All regressions include district fixed effects and a full set of province*year interactions and gradient*year interactions. Columns (2) and (4) include municipal controls. Municipal controls include dummy variables indicating when the district municipality manages at least one health center, when it needs technical assistance to formulate investment projects, when it has access to Internet and when the mayor is affiliated to the government party, municipal income (ln) and total district population. Sample restricted to district-years with IMR data (Columns 1 and 2) and U5MR data (Columns 3 and 4). Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 22: First stage: Gradient and district sewerage diffusion (Cum. started projects)

		First stage		Reduced form	
	Cross-section	Interacted with S^p_{pt}			
		IMR sample	U5MR sample	IMR	U5MR
	(1)	(2)	(3)	(4)	(5)
Gradient {0.8-4.19]	2.753***	0.164***	0.157***	0.0119	0.00695
	[0.682]	[0.0324]	[0.0317]	[0.307]	[0.0152]
Gradient {4.19-13]	1.866**	0.242**	0.219**	0.261	0.0512**
	[0.604]	[0.0758]	[0.0672]	[0.353]	[0.0175]
Gradient $>$ 13	1.979***	0.183**	0.184**	-0.179	-0.00275
	[0.560]	[0.0704]	[0.0632]	[0.668]	[0.0207]
Fstat	6.205	13.52	16.70		
Year*Gradient	No	Yes	Yes	Yes	Yes
District FE	No	Yes	Yes	Yes	Yes
District-year	1630	10032	10632	10032	10632

Note: All regressions include district fixed effects and a full set of province*year interactions and gradient*year interactions. Columns (2) and (4) include municipal controls. Municipal controls include dummy variables indicating when the district municipality manages at least one health center, when it needs technical assistance to formulate investment projects, when it has access to Internet and when the mayor is affiliated to the government party, municipal income (ln) and total district population. Sample restricted to district-years with IMR data (Columns 1 and 2) and U5MR data (Columns 3 and 4). Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 23: Effects of sewerage and piped-water diffusion on early-life mortality

	OLS				2SLS			
	IMR		U5MR		IMR		U5MR	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Cum. number of started piped	-0.367***	-0.104	0.00305	0.00137	-0.167	0.680	0.0809***	0.0814***
	[0.118]	[0.170]	[0.00478]	[0.00433]	[0.633]	[0.957]	[0.0299]	[0.0299]
Fstat					13.84	16.68	15.68	17.80
Num. piped in construction	-0.500***	-0.208	0.00233	-0.000984	-0.285	1.028	0.120***	0.126***
	[0.159]	[0.225]	[0.00611]	[0.00583]	[1.066]	[1.756]	[0.0452]	[0.0452]
Fstat					10.72	12.37	11.64	14.06
Cum. number of completed piped	-0.628**	0.0353	0.00896	0.00918	-0.232	1.284	0.152**	0.159**
	[0.247]	[0.385]	[0.0111]	[0.0103]	[1.115]	[1.673]	[0.0637]	[0.0718]
Fstat					15.29	15.13	20.43	15.22
Muni	No	Yes	No	Yes	No	Yes	No	Yes
BL	19.57	19.57	2.780	2.780	19.57	19.57	2.780	2.780
District-year	10032	6543	10519	6835	10032	6483	10519	6780
Districts	1408	1210	1419	1223	1408	1150	1419	1168

Note: All regressions include interactions of province sewerage diffusion with district elevation categories and land area, district fixed effects, a full set of province*year interactions and gradient*year interactions. Columns (2) and (4) include municipal controls. Municipal controls include dummy variables indicating when the district municipality manages at least one health center, when it needs technical assistance to formulate investment projects, when it has access to Internet and when the mayor is affiliated to the government party, municipal income (ln) and total district population. Sample restricted to district-years with IMR data (Columns 1 and 2) and U5MR data (Columns 3 and 4). Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 24: Alternative channels? Impact on IMR when adding province controls

	(1)	(2)	(3)	(4)	(5)
Cum. number of completed sewerage	2.863	1.814	2.153	0.454	0.816
	[2.071]	[2.108]	[2.135]	[2.953]	[3.200]
Population density (sq. km)	-41.43	-43.73	-48.79	-438.9*	-57.03
	[38.16]	[42.88]	[43.94]	[226.3]	[53.57]
Transport expenditure (ln)		-0.357	-0.360	14.90**	
		[3.376]	[3.660]	[7.127]	
Energy expenditure (ln)			-0.573	0.439	
			[1.056]	[2.352]	
Health centres (ln)				-47.20	
				[34.35]	
Electricity connectivity (F2)					22.65
					[36.52]
F-stat	12.23	12.53	16.55	17.90	9.446
District-year	6483	5693	5443	1592	824
Districts	1150	1094	1072	652	412

Note: All regressions include interactions of province sewerage diffusion with district elevation categories and land area, district fixed effects, a full set of province*year interactions and gradient*year interactions and municipal controls. Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 25: Alternative channels? Impact on U5MR when adding province controls

	(1)	(2)	(3)	(4)	(5)
Cum. number of completed sewerage	0.136**	0.0973**	0.0794*	-0.0168	0.297**
	[0.0632]	[0.0490]	[0.0412]	[0.0478]	[0.129]
Population density (sq. km)	4.263***	4.310***	4.548***	1.784	5.051***
	[0.830]	[0.777]	[0.976]	[4.921]	[1.372]
Transport expenditure (ln)		-0.0854	-0.101	0.149	
		[0.0875]	[0.0907]	[0.113]	
Energy expenditure (ln)			0.0425	-0.0248	
			[0.0320]	[0.0567]	
Health centres (ln)				-0.0261	
				[0.724]	
Electricity connectivity (F2)					1.351
					[1.871]
F-stat	13.54	13.42	16.77	16.99	7.419
District-year	6861	6020	5757	1693	948
Districts	1203	1153	1127	688	474

Note: All regressions include interactions of province sewerage diffusion with district elevation categories and land area, district fixed effects, a full set of province*year interactions and gradient*year interactions and municipal controls. Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 26: IV operating through alternative channels?

		IMR			U5MR	
	(1)	(2)	(3)	(4)	(5)	(6)
Pop density (sq. km)	-226.5			-13.42*		
	[198.2]			[7.783]		
Electricity connectivity (F2)		-200.1			-18.70**	
		[136.2]			[8.802]	
Health centres (ln)			-12.82			-1.604
			[61.20]			[1.326]
F-stat	1.836	3.166	3.034	2.367	2.812	2.604
District-year	6483	824	1780	6861	948	1883
Districts	1150	412	706	1203	474	743

Note: All regressions include interactions of province sewerage diffusion with district elevation categories and land area, district fixed effects, a full set of province*year interactions and gradient*year interactions and municipal controls. Standard errors clustered by province in parenthesis. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$