London School of Economics and Political Science

Public Infrastructure and Health in Low- and Middle-Income Countries

Antonella Bancalari Valderrama

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Declaration of Authorship

I certify that the thesis I have presented for examination for the PhD degree of the London School of Economics and Political Science is solely my own work other than where I have clearly indicated that it is the work of others (in which case the extent of any work carried out jointly by me and any other person is clearly identified in it). The copyright of this thesis rests with the author. Quotation from it is permitted, provided that full acknowledgement is made. This thesis may not be reproduced without my prior written consent. I warrant that this authorization does not, to the best of my belief, infringe the rights of any third party.

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I confirm that Chapter 3, "Challenges to Promoting Demand for Shared Infrastructure: Experimental Evidence from Slums in India", was jointly coauthored with Dr Alex Armand (NOVA SBE) and Dr Britta Augsburg (IFS). This statement is to confirm that I contributed 70 percent of this work.

Declaration of Editorial Help

I can confirm that my thesis was copy edited for conventions of language, spelling and grammar by Clare Sandford and Rachel Lumpkin.

Antonella Bancalari Valderrama

London, September 2020

Abstract

Public infrastructure provides the services that allow societies to function and economies to thrive. Economic research has been very useful at identifying the social returns to investing in public infrastructure, once projects are completed and in use. Yet, we know little about what made these infrastructure projects successful in improving living standards in the first place. A key policy question moving forward is not "how much" but "how well" we invest in public infrastructure. In thinking about the "how well", we need to look at both supply and demand side factors during infrastructure development. This thesis explores these separate, but interlinked, research agendas in the form of three papers. The specific focus is on the sanitation market and its link to public health in low- and middle-income countries.

In the first paper, "Can White Elephants Kill? Unintended Consequences of Infrastructure Development in Peru", I analyse the consequences of a common inefficiency in the supply of public infrastructure: unfinished projects. I specifically evaluate the effect of unfinished sewerage projects on early-life mortality —the outcome this intervention aimed at improving— in Peru. I use an instrumental variable strategy, exploiting geographic characteristics and partisan alignment. The large variation in the number of unfinished projects is generated by the high prevalence of mid-construction abandonment and delays. I find that unfinished infrastructure —the so called "white elephants"— can cause high social costs: it can kill children. The mechanisms behind these non-trivial effects are: i) water cuts force the population to rely on unsafe sources of water and jeopardise their sanitation practices, (ii) open ditches filled with stagnant water become pools of infection, and together these cause (i) increased deaths due to water-borne diseases; and (iii) construction works increases deaths due to accidents. Finally, the results suggest that the social benefits of completed sewerage projects may not fully manifest due to less than universal connectivity rates.

A natural question arising from the first paper is how to promote the use of public sanitation infrastructure once it is completed. In the second paper, "Challenges to Promoting Demand for Shared Infrastructure: Experimental Evidence from Slums in India", I explore the demand-side of the sanitation market. In this co-authored chapter (with B. Augsburg and A. Armand), I specifically study the market of community toilets, which suffer from rampant free-riding and a remarkably low valuation and usage. We use a randomised field experiment to test the effectiveness of two interventions aimed at breaking the vicious cycle of low quality public health infrastructure and low willingness to pay: (i) a "supply push" that rehabilitates the infrastructure and promotes cleanliness; and (ii) a complementary campaign aimed at generating awareness of the importance of payment and the negative externalities resulting from unsafe sanitation behaviour. We find that externally funding public infrastructure rehabilitation backfires. The "supply push" reduces willingness to pay at a time when households appreciate improvements in infrastructure; and attitudes towards paying a user fee deteriorate further with time. In addition, the "supply push" shifts the demand for public

intervention away from other pressing issues in the community towards the maintenance of community toilets. Altogether, these findings provide evidence that external funds crowd-out private contributions in our study context.

The third paper titled "Running the Last Mile: Sewerage Connectivity Density and Child Height" provides a comprehensive picture of the sanitation market at the point at which supply meets demand for infrastructure. Even in “equilibrium”, achieving safe sanitation environments depends on three key factors: the local adoption level, the population density and the quality of the sanitation solution. In this paper, I aim to bring together these three factors by exploring the relationship between child health and the local connectivity density of sewerage —i.e. the interaction between the share of neighbouring households connected to sewerage and the population density. I specifically focus on height because it has been widely recognized as an important measure of human capital with long-lasting consequences. I present three complementary analyses: (i) a cross-country analysis among LMICs; (ii) a within-country analysis focusing specifically on Latin American countries; (iii) a within-country analysis in Peru aimed at improving the internal validity of the association of interest using an instrumental variable strategy. I find that sewerage connectivity density increases child height. Interestingly, the increase goes beyond the sewerage connectivity of the child’s household, which serves as evidence of a positive externality. I document two mechanisms behind the results: improvements in the disease environment and malnutrition. The results also reveal that sewerage connectivity density decreases the mortality of children under the age of five.

Altogether, the thesis suggests that while barriers to adequate supply and demand for sanitation infrastructure can pose threats to public health, once these are released, this infrastructure protects early life survival and promotes human capital accumulation.

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List of Abbreviations

ATP	Ability to Pay
BL	Baseline survey
CTs	Community Toilets
EL	Endline survey
HFA	Height for Age
JMP	Joint Monitoring Programme
LMICS	Low- and Middle-Income Countries
MDBs	Multilateral Development Banks
ML	Midline survey
HH	Household
IMR	Infant Mortality Rate
IV	Instrumental Variable
OD	Open defecation
PPP	Purchasing Power Parity
ppts	percentage points
PSU	Primary Sampling Unit
RCT	Randomized Controlled Trial
Rs	Indian Rupees
SDGs	Sustainable Development Goals
U5MR	Under-five Mortality Rate
USD	United States Dollars
WTP	Willingness to Pay
WHO	World Health Organisation

Dedicated to the millions of children that suffer every day due to poor public health.

Chapter 1

Introduction

1.1 Public Infrastructure and Development

Public infrastructure provides the services that allow societies to function and economies to thrive, from water and sanitation networks, to transport and electricity systems. Public infrastructure has long been acknowledged to be a driver of economic development. Among other development drivers, public infrastructure is said to enable growth, poverty alleviation and social inclusion (Bhattacharya et al., 2015).

Beginning in the early 2000s, a strong focus on infrastructure took place to achieve the United Nations' Millennium Development Goals (MDGs). Child and maternal mortality, the burden of malnutrition and infectious diseases and extreme poverty fell dramatically (United Nations, 2015). Accompanying this, the percentage of the population using safely managed sanitation services has almost doubled since the beginning of the new millennium —going from only 28 per cent in 2000 to 45 per cent in 2017 (World Bank, 2020). In 2015, the global commitment was renewed through the Sustainable Development Goals, which set out a new roadmap to achieve improvements in living standards by 2030, with public infrastructure at the heart of these achievements.

For almost a century, different actors have worked together to invest large amounts of resources to close investment gaps in public infrastructure in low- and middle-income countries (LMICs). Multilateral Development Banks (MDBs) have long provided financial support to LMIC governments' provision of infrastructure. Currently, MDB lending for public infrastructure projects ranges between USD 30 and 40 billion per year, in the water, sanitation, transportation, energy and telecommunication sectors (Bhattacharya et al., 2015). East Asia and the Pacific countries spend as much as 7.7 per cent of their GDP on public and private infrastructure, while South Asia spends 5 per cent and Latin America and the Caribbean 2.8 per cent (Fay et al., 2017).

Yet, there is still a long way to go. Even with all of the money currently spent on infrastructure across LMICs, billions of people worldwide do not have access to or have not adopted essential goods, like safe water, sanitation and handwashing facilities, schools and health technologies. The World Bank has estimated an investment gap in public infrastructure equivalent to USD 1.3 trillion per year if we are to achieve the SDGs by 2030 (World Bank, 2020). A key issue moving forward is not "how much" but "how well" we invest in public infrastructure. Reflecting on our approaches allows us to assess what has worked and where the opportunities for improvement lie.

Economic research has been very useful at identifying the social returns on investing in public infrastructure, but once it is completed and in use. We have learnt that water and sanitation systems can improve public health (Alsan and Goldin, 2019), irrigation dams can enable agricultural productivity and decrease poverty (Duflo and Pande, 2007), electricity can advance manufacturing productivity and employment (Dinkelman, 2011; Lipscomb et al., 2013; Rud, 2012), communication technologies can make markets more efficient (Jensen and Miller, 2018) and roads and railroads can promote trade, increase income and welfare and promote growth (Banerjee et al., 2020; Donaldson, 2018). Yet, there is limited evidence about what made these infrastructure projects successful, in the first place, in improving living standards.

In thinking about the "how well", we need to look at both supply and demand side factors during infrastructure development. On the supply-side, governments face the challenge of ensuring that resources are well targeted and used efficiently during the implementation of projects, especially in LMICs, where public resources are scarce. Evidence suggests that the economic return of public infrastructure projects depends on the initial level of regional income and the policy environment, which is defined as "good governance" (Isham and Kaufmann, 1999; Costa-I-Font and Rodriguez, 2005). Alas, in most LMICs, inequality is high and the policy environment and overall institutional quality are particularly weak; corruption and clientelism are rampant (Costa-I-Font et al., 2003). For instance, in Latin America, inefficient public expenditure is estimated to account for 4.4 per cent of the GDP in the entire region —enough to provide social protection to the extreme poor (Izquierdo et al., 2018). A common type of public expenditure inefficiency in LMICs is the mid-construction abandonment of public infrastructure projects. New evidence suggests that over one third of the public infrastructure projects started are not completed (Rasul and Rogger, 2018; Williams, 2017). This inefficiency is typically ascribed to principal-agent and commitment problems, steaming from unstable political dynamics, which delay and prevent physical completion. Yet, we know very little about the consequences of this wasteful use of public resources. To date, the literature has ignored the effects of unfinished projects, despite their implications for conducting a sound cost-effectiveness analysis of public infrastructure.

On the demand-side, we see additional problems. Governments often assume that the supply of public infrastructure will meet an existing demand. Yet, the adoption of public infrastructure by citizens and firms depends on a number of factors, including valuation, market failures, peer effects, distance and even corruption (Besley and Case, 1993; Kremer et al., 2011; Sequeira and Djankov, 2014). Given the high burden of infectious diseases in LMICs, it is particularly puzzling that the marginal willingness to pay for public infrastructure that affects environmental quality is very low (Dupas, 2011). Greenstone and Jack (2015) proposes four potential explanations for this: (1) due to low income levels, individuals value increases in income more than marginal improvements in environmental quality; (2) the marginal costs of environmental quality improvements are high; (3) political economy factors undermine efficient policymaking; and (4) classic market failures (e.g. externalities), as well as those typical of LMICs (e.g. weak enforcement of property rights) distort willingness to pay. The so-called "envirodevonomics" agenda raises the need for further empirical research estimating the willingness to pay for public goods affecting environmental quality and exploring its determinants in LMICs. It also states the importance of investigating the costs and benefits of different policies, such as analysing whether providing information can change attitudes and behaviour, as well as the extent to which external funds can crowd-out investments.

Assuming that one can overcome bottlenecks in the supply of infrastructure and release the constraints to demand, the next step is to analyse the effectiveness of public infrastructure in improving living standards. Particularly relevant for this dissertation is the potential of public infrastructure to improve early-life human capital accumulation. Beginning with the work of Grossman (2014), economists have long envisioned health as a form of human capital that is a function of an inherited initial health stock that can be increased with investment (e.g. parental time and market goods), as well as certain "environmental" variables. It is through this latter input that public infrastructure enters the production function of human capital. While there is ample empirical evidence of the role of genetics (Thompson, 2014; Costa-i-Font, 2015) and parental investment (Currie, 2000; Cunha et al., 2010; Maluccio et al., 2009; Gertler et al., 2014; Campbell et al., 2014), little is known about the role of public health infrastructure.

This dissertation explores these three separate, but interlinked, research agendas in the form of three papers. The first paper evaluates supply-side failures —i.e. unfinished infrastructure projects — and their effects on early-life mortality in Peru through a nationwide study. The second paper analyses the constraints to demand for public infrastructure and the challenges to release them in urban slums of India. The third paper investigates the effectiveness of the local adoption of public infrastructure to improve child height, a key factor of the human capital production function in LMICs. By moving along the external and internal validity scale, in this last paper I start the analysis with all LMICs, narrowing it down to the Latin American region and lastly to Peru.

1.2 Sanitation Infrastructure and Early Life Health

Each year nearly 1.1 million early-life deaths could be prevented by improvements in the sanitation environment, representing 1.5 per cent of the global disease burden (Prüss-Ustün et al., 2014). Epidemiological research has long established a clear link between chronic environmental exposure to faecal germs and the prevalence of infectious diseases (Esrey and Habicht, 1986; Esrey et al., 1991; Burger and Esrey, 1995). A primary barrier consisting of the safe disposal of faeces through adequate sanitation facilities prevents the transmission of pathogens to the host via fluids, fields, flies and fingers (Wagner and Lanoix, 1958). Faecal pathogens are the main cause of water-borne diseases, which may be life-threatening to young children with impaired immunity. These diseases may also have negative consequences for surviving children because they limit the absorption of nutrients needed by the essential organs for growth and development (Ngure et al., 2014). Child stunting —i.e. when children do not achieve their height potential — has long-lasting consequences because it impairs cognitive ability and reduces educational attainment and adult productivity, as well as increasing the risk of adult chronical health impediments (Case et al., 2002; Case and Paxson, 2010; Grantham-McGregor et al., 2007; Currie and Vogl, 2013). Therefore, sanitation is a key factor in the human capital production function in LMICs.

Poor sanitation also costs LMICs billions, amounting to the equivalent of 6.3 per cent of GDP in Bangladesh (2007), 6.4 per cent of GDP in India (2006), 7.2 per cent of GDP in Cambodia (2005), 2.4 per cent of GDP in Niger (2012), and 3.9 per cent of GDP in Pakistan (2006). These economic losses are mainly driven by premature deaths, the cost of health care treatment, and lost time and productivity due to seeking treatment and seeking access to sanitation facilities (World Bank, 2018).

A poor sanitation environment is a characteristic of LMICs, where six in every ten individuals do not use safely managed sanitation services. South Asia, although a richer region than Sub-Saharan Africa, ranks almost as badly as the latter in terms of access to improved sanitation, with around 40 per cent of the population lacking access (Fay et al., 2017). The situation is particularly bad in India, where open defecation is still practised by 25 per cent of the population, both in rural and overcrowded urban areas (World Bank, 2017). The Latin American region also performs badly compared to countries of the same income level. While 83 per cent of the Latin American population has access to some form of improved sanitation, only 30 per cent of the region's wastewater is treated —with significant implications for public health and environmental sustainability. This average masks significant variations within and across countries. Peru stands out, with access in the bottom rural quintile at 40 per cent, while everybody in the top urban quintile has access to, and uses safe sanitation facilities. Likewise, while Chile treats 100 per cent of its wastewater, Costa Rica treats only 4 per cent and Peru and Colombia only 30 per cent (Fay et al., 2017).

The global challenge of expanding the coverage and promoting the adoption of sanitation facilities due to their relevance for well-being has not gone unnoticed. The SDGs have introduced a specific goal of "Ensuring Availability and Sustainable Management of Water and Sanitation for All by 2030" (SDG6) (United Nations, 2016). This goal has been recognised as the most interconnected one of the SDGs because improving sanitation aids education (SDG4), economic growth (SDG8), poverty reduction (SDG1), health (SDG3) and equality (SDG10) amongst many others (Water Aid, 2015). Bill Gates talks of "reinventing the toilet" and the great attention that the Bill and Melinda Gates Foundation has paid to this effort is evidence of the global trend (Bill & Melinda Gates Foundation, 2011).

The protective role of sanitation is not a given because the technological quality of sanitation solutions varies greatly in the LMICs and not all of them ensure a safe environment. Most of the evidence available focuses on the effect of exposure to open defecation and improvements in access to, and the adoption of rudimentary latrines (see for example Duflo et al. (2015); Geruso and Spears (2018)). Rural areas have commonly relied on these on-site sanitation solutions, which have to be emptied to remain functional and pose health risks otherwise (Bancalari and Martinez, 2018). This thesis will focus on the higher end of the sanitation rung. During recent decades, access to sewerage has increased substantially in urban and peri-urban areas of the LMICs. In this sanitation system, wastewater from flush toilets is piped out of residential areas for disposal elsewhere. Sewerage has been classified by the WHO and UNICEF Joint Monitoring Program as the safest sanitation solution when the sludge is properly disposed of (Joint Monitoring Program WHO-UNICEF, 2017). Despite the global increase in access to sewerage during recent decades, rapid population growth in urban areas is straining the sanitation infrastructure beyond capacity. This challenge is leaving an important proportion of the urban population without access to in-house toilets and at risk of open defecation. To alleviate this problem, community toilets, connected to either septic tanks or sewers have been introduced in slums of Africa and South Asia.

Expanding access to and promoting widespread adoption of sanitation facilities is not a trivial task. The sanitation market has several characteristics that pose challenges. On the supply-side, the high fixed costs and economies of scale associated with the sanitation infrastructure make its provision a natural monopoly. Moreover, due to the long average asset life of treatment plants, dynamic competition is deterred. It is for these reasons that, historically, governments have supplied sanitation services with monopolistic power. The problem lies in the fact that, in the absence of competition, public firms have weak efficiency incentives, which can result in undesirable quality deterioration during the implementation phase (Galiani et al., 2005). Furthermore, public provision of sanitation infrastructure is vulnerable to political pressure to keep costs and prices low, preventing the use of advanced technologies and the promotion of innovation(Kessides, 2004). Given how disruptive the construction of sanitation systems can be, overlooking quality in the implementation phase can pose hazards to the population.

On the demand-side, there are several constraints to the adoption of sanitation infrastructure. It has been estimated that willingness to pay for water (Kremer et al., 2011; Devoto et al., 2012; Ashraf et al., 2010; Berry et al., 2020) and private (or in-house) sanitation services (Ben Yishay et al., 2017) is low in LMICs, reflecting the low valuation of these services. Market failures are key determinants of such low willingness to pay. The market failure that characterises the sanitation market is externalities. With open defecation as a natural alternative, sanitation entails large externalities (Geruso and Spears, 2018). The problem lies in the fact that, for the social benefits to fully manifest, there must be universal adoption of safe sanitation solutions. Because the social benefits of using the sanitation infrastructure exceed the private marginal willingness to pay for adopting the infrastructure, households underinvest (i.e. lower private contribution) (Ashraf et al., 2016). Negative externalities may be more pervasive in LMICs than in advanced economies because the former are characterised by weak institutions that make enforcement difficult to implement and susceptible to distortions (Greenstone and Jack, 2015). Therefore, coordination problems are more salient and free-riding is rampant. Non-payment for using public infrastructure can lower effective prices below the marginal cost of operation and maintenance, ultimately leading to low-quality services, reinforcing the already low WTP (Burgess et al., 2020; Coville et al., 2020).

Another of these market failures is information asymmetry—i.e. unknown benefits of the adoption of sanitation infrastructure (Dupas, 2011; Dupas and Miguel, 2016). A big challenge to updating priors is the fact that the benefits of safe sanitation, as with many other preventive health technologies, are uncertain and unknown in the future. In LMICs, in particular, misinformation is more persistent given the lower levels of literacy and lack of liability rules around the provision of health information.

Once the supply- and demand-side constraints to the adoption of sanitation infrastructure have been overcome, different factors moderate the effectiveness of sanitation solutions to improve public health and human capital. Given the externalities associated with sanitation, the social benefits fully manifest only if individuals internalise the externalities. Key factors are thus the level of adoption of neighbours and how close people live to each other. Although the literature has mainly focused on individual adoption of sanitation infrastructure, the role of local adoption has recently attracted attention (Augsburg and Rodríguez-Lesmes, 2018; Cameron et al., 2019), as well as its interaction with population density (Hathi et al., 2017; Spears, 2020). However, there is still a need to bridge different studies in order to achieve greater external validity and understand the mechanisms well.

1.3 Thesis Outline and Contributions

This thesis is composed of three independent papers presented in chapters 2, 3 and 4. In each chapter, I explore the relationship between public infrastructure and living standards in the context of the sanitation market: (i) from the supply-side; (ii) from the demand-side; and (iii) in "equilibrium". Overall, the thesis informs the debate on how to provide public infrastructure in an efficient and effective manner.

In all three chapters, I employ applied micro-econometric tools, which are used to address causal questions. In Chapters 2 and 4, I rely on an instrumental variable strategy (Angrist and Pischke, 2009; Greene, 2019). In Chapter 3, I use field experiments, in particular, a clustered-randomised control trial (cRCT) and incentive-compatible elicitation methods (Duflo et al., 2007).

In Chapter 2, I study the supply-side of public infrastructure. Specifically, I analyse the consequences of a common inefficiency in government expenditure in public infrastructure: unfinished projects. I evaluate the effect of unfinished sewerage projects on the mortality of children under the age of five —the outcome this intervention aimed at improving— in Peru. The diffusion of sewerage in Peru is an excellent case to study because the scale of this public intervention was national, allowing for considerable spatial variation in its implementation. The Government of Peru invested USD 3 billion to start more than 6,000 sewerage projects between 2005 and 2015.

I construct district-level panel data by combining several sources of novel administrative data and grid-cell level spatial data. I rely on the variation in the number of unfinished projects generated by the high prevalence of mid-construction abandonment and delays. In other to deal with the endogenous implementation of projects, I use an instrumental variable methodology exploiting geographic characteristics and partisan alignment.

I find that unfinished infrastructure can cause high social costs: it can kill children. With every additional unfinished sewerage project, infant and under-five mortality increases, as opposed to not starting a project. The mechanisms behind these non-trivial effects are: i) water cuts force the population to rely on unsafe sources of water and jeopardise their sanitation practices, (ii) open ditches filled with stagnant water become pools of infection, and together these cause (i) increased deaths due to water-borne diseases; and (iii) construction works increases deaths due to accidents.

The contributions of this paper are threefold. First, the paper broadens the literature on public goods provision by moving beyond assessing inefficiencies to encompass social costs (Besley and Burgess, 2002; Bandiera et al., 2009; Rasul and Rogger, 2018; Williams, 2017). Second, this paper is the first in the literature on public infrastructure effectiveness to focus on the potential risks generated by projects that are still in progress or have been abandoned (Dinkelman, 2011; Rud, 2012; Dinkelman, 2011; Lipscomb et al., 2013; Duflo and Pande, 2007; Mettetal, 2019; Cesur et al., 2017; Gupta and Spears, 2017). Finally, this study informs the literature on public health, which has focused mainly on water technologies (Cutler and Miller, 2005; Bhalotra et al., 2018), by exploring the effects of sanitation infrastructure at scale in a contemporary setting (Watson, 2006; Alsan and Goldin, 2019; Kesztenbaum and Rosenthal, 2017) and on a high rung of the sanitation ladder (Duflo et al., 2015; Geruso and Spears, 2018).

A natural question arising from Chapter 2 is how to promote demand for public sanitation infrastructure once it is completed. In Chapter 3, I explore the demand-side of the sanitation market in urban slums of India. Shared infrastructure can help improve living standards in urban slums, where insufficient public goods provision has led to extremely poor health and low levels of human capital. However, poor quality infrastructure, generated partially by low valuation and payment, can hamper environmental quality even further. In this co-authored chapter (with B. Augsburg and A. Armand), I study how to break this vicious cycle in the context of community toilets in Uttar Pradesh, India. While considered an important public health solution for the foreseeable future in slums, our data reveals rampant free-riding and a remarkably low valuation for CTs. In line with this, the CTs are of very poor quality, which is reflected in the measures taken by the state in regard to the infrastructure, the observed dirtiness, and the presence of harmful bacteria. Interestingly, we find a hypothetical WTP for the CTs of the highest standard that is more than double the actual WTP. The worse the observed dirtiness, the higher the rate of open defecation.

We use a randomised field experiment to test the effectiveness of two interventions aimed at breaking the vicious cycle of low quality public health infrastructure and low WTP: (i) a "supply push" that rehabilitates the infrastructure and promotes cleanliness; and (ii) a complementary campaign aimed at generating awareness of the importance of payment and the negative externalities resulting from unsafe sanitation behaviour. Building on five rounds of data on the 110 study CTs and three waves of a household panel of more than 1,500 households living in the CT catchment areas, we find that externally funding public infrastructure rehabilitation backfires. The "supply push" reduces WTP at a time when households appreciate CT improvements; and attitudes towards paying a user fee deteriorate further with time. In addition, the "supply push" shifts the demand for public intervention away from other pressing issues in the community towards the maintenance of CTs. Altogether, these findings provide evidence that external funds crowd-out private contributions in our study context.

Importantly, we find that the campaign is ineffective in counteracting any of these effects, despite having a lasting impression on households. The only exception is an attenuation in the reduction in the number of users, which accompanies the lower WTP. Over time, the interventions increases the percentage of users that paid. Although diminishing free-riding might be desirable, it is questionable if it comes at the expense of safe sanitation behaviour.

This study contributes to three literature streams. First, it contributes to the growing subfield of "envirodevonomics", which explores why environmental quality is so poor in LMICs. In particular, this chapter adds to studies exploring the determinants of low willingness-to-pay for environmental improvements (Kremer et al., 2011; Dupas, 2011; Devoto et al., 2012; Ashraf et al., 2010; Greenstone and Jack, 2015; Ben Yishay et al., 2017; Berry et al., 2020) by focusing on an infrastructure where coordination problems are very salient and in an understudied setting: urban slums. Second, this study is connected to the literature stream exploring the costs and benefits of policies to adopt health goods (e.g. toilets, vaccines, bednets), in particular the provision of subsidies and information (Jalan and Somanathan, 2008; Luoto et al., 2011; Kremer and Miguel, 2007; Ashraf et al., 2010; Dupas, 2014; Ashraf et al., 2013; Guiteras et al., 2015). It adds to this by exploring the effectiveness of a direct intervention in infrastructure supply to promote demand. Finally, this study joins Mcrae (2015); Burgess et al. (2020); Coville et al. (2020) in showing that non-payment affects infrastructure quality. We add to this stream by providing evidence that the distortions also affect the demand for public infrastructure.

Chapter 4 completes the study by providing a comprehensive picture of the sanitation market at the point at which supply meets demand for infrastructure. Even in "equilibrium", achieving safe sanitation environments in LMICs depends on three key factors: the local adoption level, the population density and the quality of the sanitation solution. In this paper, I aim to bring together these three factors by exploring the relationship between child health and the local connectivity density of sewerage: the interaction between the share of neighbouring households connected to sewerage and the population density.

From Chapter 1 we learn that the construction of sewerage systems can increase under-five mortality. The aim of this chapter lies in understanding the effect of sanitation infrastructure on the health of survivor children and those born after projects are completed, conditional on connectivity rates. I focus specifically on height because it has been widely recognised as an important measure of human capital with long-lasting consequences.

I present three complementary analyses. The first is a cross-country analysis that establishes the broad importance of sewerage connectivity density for predicting child height in LMICs. The second provides further evidence of this relationship by focusing specifically on Latin American countries because: (i) they have lower levels of connectivity relative to other countries with a similar income level, so this region is a special case in which economic development is not accompanied by an improvement in diseases environment; and (ii) there is significant variation within countries in both child height and connectivity. Finally, the third analysis supports the internal validity of the association of interest. For this I focus on Peru, one of the special cases in Latin America where the recent economic development has not been followed by greater adoption of sewerage and has left a large per cent of children under the age of five stunted. In this analysis, I attempt to improve identification by using an instrumental variable strategy. I use as an instrument for connectivity density the average two-year lag connectivity density of adjacent districts.

Using Demographic and Health Surveys (DHS), complemented by census and spatial data, the three separate analyses represent different points in a trade-off between external and internal validity. I find that sewerage connectivity density increases child height. Interestingly, the increase goes beyond the sewerage connectivity of the child's household, which serves as evidence of a positive externality. I also find that the effect is driven by the oldest group of children aged 25 to 59 months —those more likely to be exposed to outdoor hazards. I document two mechanisms behind the results: improvements in the disease environment and malnutrition. The results also reveal that sewerage connectivity density decreases the mortality of children under the age of five.

This paper makes several contributions to the literature on economics, human capital, and health. First, it contributes to the literature exploring the drivers of international height disparities in human capital, specifically height (Deaton, 2007; Bozzoli et al., 2009; Deaton and Drèze, 2009; Spears, 2020). Second, it contributes to the literature focused on early-life human capital accumulation (Cunha et al., 2010; Gertler et al., 2014; Campbell et al., 2014; Maluccio et al., 2009) by providing evidence of the determinants of child height. Third, by advancing evidence on the importance of sanitation *adoption* on a higher-rung of the sanitation ladder and population density in LMICs, this paper contributes to the active and growing literature on sanitation and child health (Dickinson et al., 2015; Augsburg and Rodríguez-Lesmes, 2018; Cameron et al., 2019; Spears, 2020; Hathi et al., 2017).

The final thesis chapter summarises the findings of the three empirical chapters and discusses the broad contribution of this thesis to the literature. Additionally, it discusses the main policy implications of this thesis.

Overall, the thesis makes three broad contributions. First, it amplifies our empirical knowledge of where public infrastructure projects may go wrong, by analysing the implementation phase and placing emphasis on the efficient use of resources. Next, it provides useful guidance for overcoming behavioural obstacles to the adoption of public infrastructure. Finally, through its detailed analysis of infrastructure and public health, the thesis also provides a more nuanced understanding of the human capital production function in LMICs.

Chapter 2

Can White Elephants Kill? Unintended Consequences of Infrastructure Development in Peru

Abstract

It is widely accepted that investing in public infrastructure promotes economic development. However, there is little awareness of the prevalence of unfinished infrastructure projects and their consequences. In this paper, I study the effect of unfinished sewerage infrastructure on early-life mortality in Peru. I compile several sources of administrative panel data for 1,400 districts spanning 2005–2015, and I rely on the budgetary plans and timing of expenditure for 6,000 projects to measure unfinished projects and those completed in a given district. I document that mid-construction abandonment and delays are highly prevalent. I exploit geographical features and partisan alignment to instrument for project implementation. Surprisingly, I find that unfinished sewerage projects increased early-life mortality, driven by lack of water availability, water-borne diseases and accidents. I also show that while unfinished projects pose hazards to the population, completed sewerage projects decrease early-life mortality, in line with public health studies in advanced economies during the previous centuries.

2.1 Introduction

It is widely accepted that investing in large infrastructure promotes economic growth and development (Aschauer, 1989; Isham and Kaufmann, 1999). In fact, the World Bank directs 40 per cent of its lending portfolio to the development of large infrastructure in the water and sanitation, transportation and energy sectors as a means to alleviate poverty (World Bank, 2017).

However, to date, much more emphasis has been placed on the volume of infrastructure expenditure, rather than the quality of that expenditure (Besley and Ghatak, 2006). Recent evidence suggests that over one-third of the infrastructure projects started in low- and middle-income countries (LMICs) are not completed (Williams, 2017; Rasul and Rogger, 2018). Unfinished infrastructure projects are, however, not an exclusive problem of LMICs, as roads without tarmac and bridges to nowhere, for example, are commonly seen in advanced economies. Economic research has been very useful at identifying the effectiveness of infrastructure projects (e.g. sewerage, dams, roads and electricity networks) once they are completed and in use (Duflo and Pande, 2007; Dinkelman, 2011; Rud, 2012; Lipscomb et al., 2013; Alsan and Goldin, 2019; Donaldson, 2018; Banerjee et al., 2020). It is less clear what the consequences of such projects are while they are still unfinished (i.e. underway, delayed or abandoned half-way). It is regrettable that the literature has ignored the effects of unfinished infrastructure projects, given the important implications for a sound cost-effectiveness analysis.

In this paper, I seek to fill this gap in the literature. In particular, I study the effect of unfinished sewerage projects on the mortality rate of infants and children under the age of five (hereafter under-five) in Peru. This is the outcome that sewerage infrastructure has improved in advanced economies during the previous centuries (Watson, 2006; Alsan and Goldin, 2019). The diffusion of sewerage in Peru is an excellent case to study because the scale of this public intervention was national, allowing for considerable spatial variation in implementation. The Government of Peru invested three billion US dollars (USD) to start more than 6,000 sewerage projects.

I construct a district-level panel of 1,400 districts for every year between 2005 and 2015 by combining several sources of novel administrative data, and spatial data at a grid-cell level. Specifically, I rely on detailed data on budgetary plans and the timing of expenditures to identify the number of unfinished projects and those completed in a given district. I exploit variation in unfinished projects generated by the high prevalence of mid-construction abandonment and delays in project completion. 60 per cent of the projects started between 2005 and 2015 were abandoned for at least one year and up to the whole decade of study. Moreover, I find large variation in project duration, with projects lasting for up to eight years, mostly because of cost overruns. Thus, districts have a combination of unfinished projects that have been abandoned (temporarily or indefinitely) and that are still underway (in time or delayed).

In order to deal with project placement bias, as richer districts with different mortality trends started and completed more projects, I rely on an instrumental variable strategy that exploits Peru's natural geographic variation. I use as an instrument a prediction of how the diffusion of sewerage would have evolved over time had project placement been based solely on cost considerations. I rely on the fact that a combination of geographic characteristics (i.e. land slope, elevation and river density) affects a district's technical suitability for low-cost sewerage projects. A time-variant project allocation is predicted with an algorithmic approach, subject to a nationwide budget constraint and maximum threshold allocation. The instrument predicts that a central planner would have allocated more projects to "cheaper" districts in terms of developing sewerage, and would have done so earlier in the period of study.

The identification assumption is that no other factors affecting mortality rates (e.g. a citizen's preference for preventive health care and other infrastructure and policies) changed over time along the same spatial lines as the predicted allocation of projects. The panel dimension of the data allows the inclusion of district and year fixed effects that control for time-invariant effects of geography on health and common shocks, respectively. A number of tests support the validity of my identification. I find that my instrument is not correlated with mortality before the start of projects. Furthermore, the results are not driven by other types of infrastructure development, geography-specific mortality trends or sorting.

I find that unfinished infrastructure projects — the so-called "white elephants" — can cause high social costs: they can kill children. With every additional unfinished sewerage project, infant mortality increased by 5 per cent and under-five mortality by 6 per cent, over the initial average mortality rate.

The mechanisms behind these non-trivial effects are threefold. First, water cuts are needed during the installation of sewerage lines. I find evidence that water and sanitation practices deteriorated as a result. While there is no effect on the connectivity to piped water, I find that an additional unfinished project increased the percentage of households relying on unsafe sources of water by 4 per cent over the initial averages. The limited access to safe water resulted in a decrease of the share of households relying on latrines and an increase in those practising open defecation, both by 10 per cent over the initial averages. Second, in order to install public sewers, extensive excavations are required, which leave open ditches that become filled with stagnant water and become pools of infections. Third, sewerage works pose hazards to the population. This entails large building sites that, for instance, divert traffic chaotically into previously quiet residential areas where children roam freely. In line with these mechanisms, I find that every additional unfinished project increased the infant and under-five mortality caused by water-borne diseases by 11 and 9.8 per cent from the initial rate, respectively. An additional unfinished project also increased the under-five mortality caused by accidents by 7.2 per cent from the initial rate. The results are consistent with the fact that older and more mobile children are more exposed to outdoor risks. Notably, I find no effects of unfinished projects on the mortality caused by other diseases and complications unrelated to infections or external hazards.

In order to get a full picture of project implementation and to understand better the counterfactual scenario, I also estimate the effect of completed projects. For a just-identified specification, I use as an additional instrument the interaction between a district's geographical suitability for low-cost sewerage projects and the partisan alignment between the district mayor and central government. Mayors politically connected to the Parliament are better able to secure funds to complete projects, conditional on starting them because of the district's geographic characteristics.

I find that early-life mortality increased with unfinished projects and decreased with completed projects, compared with no projects started. The estimated effect of unfinished infrastructure on mortality remains robust even after including project completion. Furthermore, infant and under-five mortality decreased with every additional completed project by 33 and 25 per cent over the initial averages, respectively.

Finally, I document that providing access to public sewers does not ensure a universal connectivity rate or sludge treatment, at least in the short run. This finding serves as evidence of the "last-mile" problem — the inability of governments to connect costly infrastructure to the final user (Ashraf et al., 2016) — and suggests that the social benefits from sewerage systems take time to be fully manifested.

The contributions of this paper are threefold. First, the paper broadens the literature on public goods by moving beyond assessing inefficiencies to encompass social costs. Influential papers have identified the determinants of waste in government spending and misallocation, highlighting the role of democratic institutions, political dynamics, governance structures and local managerial practices (Bandiera et al., 2009; Burgess et al., 2015; Williams, 2017; Rasul and Rogger, 2018). However, there is a need to gain a better understanding of how inefficiencies in the provision of public goods jeopardise economic development and well-being. For example, Burgess et al. (2015) acknowledge this need in the context of a misallocation of public resources in Kenyan road building, where they quantify the extent of ethnic favouritism and document how it disappears during periods of democracy, stating that: "linking [our] findings to aggregate economic outcomes represents a key priority for future research".

Second, this paper contributes to the literature on large public infrastructure effectiveness by extending the scope of analysis to the potential risks generated by projects that are still in progress or abandoned. There is growing evidence in this literature on the effectiveness of electrification and large dams in improving labour and productivity (Dinkelman, 2011;

Rud, 2012), and decreasing poverty (Duflo and Pande, 2007; Dinkelman, 2011; Lipscomb et al., 2013). The literature also provides evidence that transport infrastructure increases productivity, inter-regional trade and welfare (Donaldson, 2018; Banerjee et al., 2020). More closely related papers find that environmental hazards from large infrastructure affect early-life mortality (Cesur et al., 2017; Gupta and Spears, 2017; Mettetal, 2019).

Finally, this study informs the literature on public health, which has mainly focused on water technologies (Cutler and Miller, 2005; Bhalotra et al., 2018), by exploring the effects of sewerage at scale in a contemporary setting (Watson, 2006; Kesztenbaum and Rosenthal, 2017; Alsan and Goldin, 2019). Recent studies in LMICs have mainly focused on the effectiveness of private sanitation infrastructure (Geruso and Spears, 2018) or have provided evidence from experimental studies with a limited time-horizon and geographical setting (Duflo et al., 2015). My study, by contrast, focuses on a nationwide setting and a longer temporal focus.

The rest of the paper proceeds as follows. In Section 2.2, I provide the context. I explain the data and present descriptive statistics in Section 2.3. In Section 2.4, I provide details of the instrumental variable strategy. In Sections 2.5 and 2.6, I present the results of the effect of unfinished and completed projects, respectively. In each of these sections I describe the mechanisms driving the results. I conclude in Section 2.7 by discussing the significance of the study for a wider body of literature as well as potential extensions to other institutional contexts and other types of infrastructure.

2.2 Sewerage diffusion in Peru

Half of Peru's households lacked sewerage connectivity in 2005 (World Bank, 2020). To remedy this, the National Sanitation Plan 2006–2015 set the goal of increasing access to sewerage in urban areas, representing the first nationwide effort towards sewerage diffusion in Peru. In this period, the Government of Peru invested more than USD 3 billion to start 6,090 sewerage projects[1] in 80 per cent of the districts.[2]

The roll-out of sewerage projects across districts was not random. The starting of sewerage projects depended on two crucial factors: (i) the willingness and capabilities of the implementing agent; and (ii) the allocation of funds.

Between 2005 and 2015, most projects were implemented by local municipalities: more than 56 were implemented by district municipalities and almost 30 per cent by province municipalities (see Figure 2.7). District municipalities can implement sewerage projects if they are incorporated into the National System of Public Investment (SNIP, Spanish acronym),

[1] Out of these, 4,783 were construction and expansion of new systems and 1,307 were improvement of existing lines (see Figure 2.16 in the Appendix).

[2] According to the 2005 Peruvian Census, Peru had 1,830 districts belonging to 196 provinces and 25 regions. An average district had a population density of 642 people per km^2.

which requires the following: (i) access to the Internet; (ii) approval from the municipal council to receive technical assistance in formulation and implementation of investment projects from the Central government; and (iii) an annual budget above one million soles (approximately 200,000 sterling pounds). In line with these criteria, richer municipalities with a revenue above the median and with access to the Internet by 2005 started a greater number of sewerage projects (see Figures 2.8 and 2.9).

For the portfolio of projects implemented by the Ministry of Sanitation, the National Sanitation Plan 2006–2015 states that previously unattended and poor areas should be prioritised when expanding access to sewerage. This was not the case as more sewerage projects were started in districts with a lower percentage of the population with unmet basic needs and with a higher sewerage connectivity by 2005 (see Figures 2.10 and 2.11).

In addition, sewerage diffusion depends on the cost of implementing a given project. The National Sanitation Plan 2006–2015 states that projects must achieve economic and technical viability to be implemented, which depends crucially on project costs. Projects using cheaper technologies are more likely to be declared viable. This criterium is crucial for the instrumental variable strategy, explained in the next section.

Sewerage diffusion, and more specifically the completion of projects, depends on funds allocation. The largest sources of funding were transfers from the central government: 40 per cent of sewerage projects were funded by royalties and 30 per cent by direct transfers (see Figure 2.12). District municipalities do not have full discretion over the use of these funds. In the case of royalties, for instance, funds can only be used in social infrastructure. Only 22 per cent of started projects were funded by local tax revenue, and municipalities have more discretion over the use of this revenue.

The allocation of funds to projects is conducted by an annual budgeting process in which agents with different incentives interact. Understanding these interactions is important for the instrumental variable strategy used in Section 2.6. For projects financed by the central government (executed directly by the Ministry of Housing, Construction and Sanitation or through transfers to local municipalities), funds are allocated through an annual budgeting process approved by the Parliament. For projects financed by local revenues, funds are allocated from the budgeting process done by Municipal Councils, which are chaired by the mayor and council members. Given that most sewerage projects are implemented by the local municipality, but financed by the central government, partisan alignment between local majors and members of the Parliament makes it easier to attract funds to complete projects.

Once projects are selected for funds, the government agency that formulates the project starts the procurement process to hire private contractors to develop the works. During the construction phase, the Enterprises of Provision of Sanitation Services (EPS) are in charge of supervising and evaluating the technical quality of sanitation works in urban areas. Once public sewers are installed, it is compulsory for landlords to connect the dwelling's wastewater pipes to the public sewerage lines. The EPS are in charge of regulating and supervising the connectivity of dwellings to the public sewerage lines. Understanding the limitations of the work conducted by the EPS will be crucial to understand the mechanisms behind the results of this paper. These limitations are discussed in Section 2.6.1.

2.3 Data and descriptives

2.3.1 Data

I construct a district-level panel data set of more than 1,400 districts in Peru from 2005 to 2015 by combining data from several novel sources. I compute infant and under-five mortality using vital statistics registries and population forecasts. For the core data set measuring sewerage diffusion, I compile and combine project-level data from viability studies and annual budget reports, which allows me to identify unfinished projects and those completed. To construct the instrumental variable, I use spatial data at grid-cell level, including elevation (from which I compute gradient), river flow and district boundaries. In addition, I draw on population forecasts to control for time-variant population density and district population size. The final data set is an unbalanced panel of 1,408 districts spanning 2005–2015, with a total of 10,494 district–year observations.

The outcome variables are constructed using vital records provided by the Ministry of Health and population forecasts built by the National Institute of Statistics and Informatics (INEI, Spanish acronym) for every calendar year between 2005 and 2015 at the district level. The vital records provide the number of infants born alive and the number of deaths of infants (under one year old) and children under five years old. The mortality data are disaggregated by cause of death following the International Classification of Diseases – ICD10. The population forecast provides data on the number of children under five years old. I construct the infant mortality rate (IMR) and the under-five mortality rate (U5MR) for each district d and year t, using as the denominator the population at risk, as described by Preston et al. (2001):

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

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

The IMR is generally computed as the ratio of infant deaths over live births. However, because of the incompleteness of birth registries in Peru, where the coverage was 93 per cent by 2005 (UNICEF, 2005), I use an alternative approach. I use as a denominator the total population of children aged between 0 and 5, divided by 5 (assuming that the distribution across ages is similar).

To alleviate concerns linked to the quality of the vital registers in Peru, I compare nationwide mortality trends using the vital statistics data versus data from several nationally representative surveys. I find that vital statistics generate mortality rates that are slightly lower in level, but the trends do not differ greatly (see Figures 2.14 and 2.15).

To measure sewerage diffusion, I use raw data from viability studies registered in the SNIP and budget reports from the Integrated System of Financial Administration (SIAF, Spanish acronym) of the Ministry of Economy and Finance. These sources provide information on the number of sewerage projects declared viable between 2005 and 2015 in a given district and detailed project-level data on the budgeted investment and accrued investment by years. Using this information, I set as the starting year the year in which a given project receives the first disbursement. Because the Ministry of Sanitation does not keep a record of project completion, I follow their advice to set the year of completion as the one in which the budgeted investment — including cost updates — is accrued by at least 90 per cent. The Ministry claims that, at this level, construction works are completed (i.e. excavation works finished and open ditches closed) and the last leg consists of paperwork. I set the years in which projects are unfinished as the years between start and completion. Projects without a completion year but with a start year are defined as unfinished until the end of the study period.

I construct three alternative indicators of sewerage diffusion at the district level to identify effects not only once the infrastructure is completed, but also during its construction phase: (i) the cumulative number of sewerage projects started; (ii) the number of unfinished sewerage projects; (iii) the 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. An important limitation is that sanitation projects are formulated in a sub-area of districts (the smallest jurisdictional level in Peru), but this is not easily identifiable (i.e. no address or geo-codes) and there are no early-life mortality data at the same level. For projects formulated at a higher governmental level that lacks data on the number of projects per district, I assign one project to each district within the corresponding province or region. This approach does not capture the intensity of sewerage diffusion within each of the districts, but it is done in only 3.7 per cent of the districts that ever implemented projects.

I use spatial data provided by the Ministry of Environment to compute geographic characteristics influencing the cost of sewerage development. I rely on these data to construct an instrumental variable. The spatial data include information on surface elevation for multiple cells (1×1 km^2), which I match to district boundaries in 2015. I construct indicators for four main geographical characteristics: elevation, gradient, area and river density. First, I compute the total area within the boundaries of each district. Second, I use the information on surface elevation at each cell to compute the fraction of district area in four different elevation categories considering quintiles of the elevation distribution: [0–250] metres above mean sea level (mamsl), {250–500] mamsl, {500–1,000] mamsl and above 1,000 mamsl. Third, I compute gradient using surface elevation at each cell and neighbouring cells. I construct indicators capturing the fraction of district area falling into four gradient categories: [0–0.8] per cent, {0.8, 4.19] per cent, {4.19–13] per cent and above 13 per cent. The first category captures flat areas below or equal to 0.8 per cent in which sewerage construction is costliest as determined by technical guidelines (Panamerican Center of Sanitation Engineering and Environmental Sciences, 2005). The remaining categories are created considering quintiles of the gradient distribution. I use quintiles because this ensures enough variation across categories, while allowing the capture of differences in elevation and gradient within districts (compared with, say, using the mean per district). Finally, I compute river density as the fraction of the district area that falls in inland waters. The maps shown in Figure 2.17 show that districts in Peru vary greatly in their ruggedness, altitude and river density. I draw on data from the National Register of Municipalities (RENAMU, Spanish acronym) to measure municipal characteristics. As explained in Section 2.2, only districts that had access to the Internet, numerous resources and approval to receive technical assistance were able to formulate and implement sewerage projects. I control for these characteristics as a robustness check. From RENAMU, I also obtain reports concerning whether water and faecal sludge is treated in the district. I use these variables to explore whether sewerage diffusion had any effect on the removal of bacteria and contaminants from the sources of drinking water and waste water. Data on the treatment of water are available only between 2008 and 2014, and data on the treatment of sludge are available between 2006 and 2014.

Furthermore, to compute measures of sewerage connectivity, I compile household-level data from three Census rounds: 2005, 2010 and 2017. I use these data to evaluate whether sewerage diffusion increased the percentage of households connected to the public sewers. I also use these data to compute the percentage of households that have a head of household who attained education above the secondary school level and the percentage of households that are connected to the electricity network in each district. These variables are alternative outcomes used to evaluate whether sewerage diffusion affected early-life mortality rates through changes in the population composition (i.e. selective migration).

Finally, I compute measures of other infrastructure development that could have affected early-life mortality rates beyond sewerage diffusion. I use the SIAF budget reports from the Ministry of Economy and Finance to identify the level of expenditure on transportation, energy and health. These data are available at the district level between 2007 and 2014 (2015 only available for transport expenditure).

2.3.2 Descriptive statistics

Table 2.1 provides descriptive statistics for the beginning and end periods of analysis. The first and third columns provide the sum for the variables of interest and the mean for the geographical and control variables for 2005 and 2015, respectively. The second and fourth columns provide the standard deviation for the geographical factors and additional variables used in the analysis for 2005 and 2015. The last column shows the data source used to compute the variables.

Between 2005 and 2015, both infant and under-five mortality fell by 35 per cent. Both early-life deaths and the population of children under the age of five decreased, but the decrease in the number of deaths was greater. Meanwhile, the number of started and completed sewerage projects grew dramatically.

Municipalities became richer during the period of study. The average revenue of a district municipality quadrupled — from 4 million to 15 million soles ($\sim$ USD 4.5 million) — and many municipalities gained access to the Internet. The share of municipalities registered as requiring technical assistance for the formulation of investment projects decreased, while those managing a health centre increased.

Districts improved their access to public services greatly in the decade of analysis. Water connectivity and treatment increased, while the share of households relying on unsafe sources of water decreased. As expected, sewerage connectivity and treatment increased, as well as the share of households relying on on-site sanitation increased, while those practising open defecation decreased. Districts also improved regarding the share of households that had heads who had completed secondary education and households that had electricity connectivity. Furthermore, public expenditure increased over the period of analysis in the transportation, energy and health sectors.

Peru has a great geographical diversity, which I am able to exploit in my instrumental variable strategy. On average, the largest share of area of districts falls in the highest elevation category (74 per cent), followed by the lowest category (15 per cent) and all categories have a relatively high standard deviation (20 per cent). Districts in the sample tend to have rugged terrains. The lowest share of area, on average, falls in the flattest gradient category (only 10 per cent) and the largest share in the steepest category (37 per cent). River density is, on average, 53 km per km^2 and there is great variation across districts (124 standard deviations).

2.3.3 Project characteristics

Two factors are linked to the variation over time in the number of unfinished projects: mid-construction abandonment and project duration. First, there is a high prevalence of projects that stopped receiving funds while they were still underway. Figure 2.1 shows the distribution of the number of years that a started project was abandoned. Strikingly, more than 60 per cent of the started projects in the period of study are "white elephants", as they were abandoned at least one year. Almost half of the projects were abandoned for at least two years and for up to ten years (or indefinitely). Smaller projects, proxied by the number of potential beneficiaries, tend to suffer slightly more mid-construction abandonment than larger projects. Bureaucratic procedures to restart abandoned projects can put at risk whether the project is ever completed.

Second, there is great variation in the time to complete projects. I find that half of projects took more than one year to be completed (see Figure 2.2). As expected, larger projects take longer to be completed. However, even amongst larger projects, half took three years or more (up to eight years) to be completed. This variation in project duration, even after taking into account project complexity, suggests that delays are common. The prevalence of cost overruns serves as additional evidence in support of delays. Figure 2.13 shows that larger projects have greater cost overruns, as high as five times the planned cost. Only 5 per cent of large projects had no cost overrun. Bureaucratic procedures to update costs can delay project completion.

The measure of unfinished projects is thus a combination of projects still underway (on time or delays) and abandoned (temporarily or indefinitely) in a given district.[3] Figure 2.3 shows that the average number of unfinished projects per district increased over time. Between 2005 and 2015, on average, districts started four sewerage projects. Strikingly, by 2015, districts completed fewer than one project, on average. The low rate of completion results in districts having, on average, more than one unfinished project between 2009 and 2012 and more than two unfinished projects in later years.

2.4 Empirical strategy

In order to understand the consequences of unfinished sewerage projects on early-life mortality, I rely on an instrumental variable approach.

2.4.1 Instrument: project allocation by technical suitability

The instrument I use is a prediction of how sewerage diffusion would have evolved over the decade of study had investments been based only on exogenous cost considerations. I exploit the fact that a combination of geographic characteristics (i.e. elevation, land gradient and river density) affects the suitability of districts to low-cost sewerage projects. I use an

[3]Although the majority of projects are "white elephants", I would ideally disentangle the effects of a project underway versus one that was abandoned. Because of the aggregate nature of the mortality data, I would have to focus on districts with only one project being developed. Unfortunately, I do not have the capacity in this paper to conduct such an analysis. By 2015, only 20 per cent of districts have started only one project, equivalent to 2,069 district–year observations. The statistical power is reduced even further if I focus on districts developing only one project in previous years.

algorithmic approach to generate variation over time in predicted sewerage diffusion, subject to a nationwide budget constraint and a threshold of maximum project allocation.

The key identification assumption is that no other factors affecting mortality rates independently moved over time along the same spatial lines as the predicted allocation of projects. In other words, I assume that behavioural changes and the implementation of other health policies or social infrastructure that affect early-life mortality did not move from the most suitable districts for low-cost sewerage in early years to slightly less suitable districts in later years. The panel dimension of the data allows the inclusion of district and year fixed effects that control for time-invariant effects of geography on health and common shocks, respectively. Lipscomb et al. (2013) demonstrate that isolating the variation in infrastructure linked to exogenous geographic cost and budget considerations is useful for studying the effects of large infrastructure projects.

Relying on the technical suitability of a district makes the instrument comply with the monotonicity assumption. While the instrument may have no effect on the launch of sewerage projects in some districts — that is, very suitable district with low political will (never-takers) or unsuitable districts with high political will (always-takers) — all districts affected by the instrument (compliers) are affected in the same way. In other words, all suitable districts predicted to receive more and earlier sewerage projects are more likely to implement more sewerage projects earlier on. It is sensible to assume that no district decreased its likelihood of experiencing sewerage diffusion by being more technically suitable (defiers).

The predicted sewerage diffusion is constructed following three steps.

(1) **District's technical suitability for low-cost sewerage projects**

For each district, an index is constructed capturing the technical suitability for implementing low-cost sewerage systems. Although sewerage diffusion is likely to respond mainly to demand-side factors, such as socio-economic characteristics and political will, it also responds to exogenous geographical factors.

The cost of developing sewerage infrastructure is affected by a unique combination of geographic factors. The gradient of the terrain plays a major role in determining a district's suitability for low-cost projects. The cheapest sewerage system is the conventional gravity system, in which steepness allows waste water to flow rapidly through pipes from houses to disposal areas (Romero Rojas, 2000). Fewer pipes and lower depths are required to install pipe networks in steeper districts, reducing the costs even further (Hammer, 1986). In very flat areas, it is necessary to install costly electric bombs to pump water and effluent (Panamerican Center of Sanitation Engineering and Environmental Sciences, 2005). Elevation above the level of the sea is another topographic factor that affects districts' suitability for low-cost sewerage projects. The cheapest waste-water treatment plant works in low-altitude areas because it requires oxygen to work through aerobic digestion (i.e. the biological decomposition of organic sludge; Romero Rojas, 2000). Sludge requires additional costly treatment (i.e. the injection of oxygen and chemicals) in high-altitude areas. The cost of sewerage projects also depends on the availability of water to discharge effluent. Factors linked to geographical dispersion also affect the district's technical suitability for sewerage and related costs. Considering that the span of settlements is greater in larger districts, developing sewerage systems in districts that cover large areas of land requires the installation of longer networks of pipes. This increases both the complexity and cost of projects.

A regression of the total number of projects developed in a given district between 2005 and 2015 on the above-described geographic factors confirms the hypotheses raised by the engineering literature. I estimate the following ordinary least-squares (OLS) regression:

$$S_d = \sum_{k=2}^{4} \beta_{1k} Gr_{dk} + \sum_{k=2}^{4} \beta_{2k} E_{dk} + \beta_4 R_d + \beta_3 A_d + \epsilon_d. \tag{2.1}$$

Here, S_d is the total number of started projects in district d between 2005 and 2015, Gr_d is the fraction of area of district d falling in each of the three steep categories k (flat gradient is the reference category), E_d is the fraction of area of district d falling in each of the three elevated categories k (low altitude is the reference category), R_d is the district's river density (river length in km per area in km^2) and A_d is the total area of land within district boundaries.

Table 2.13 in the Appendix shows that, as predicted by the engineering literature, steep gradient categories and river density favour sewerage diffusion, while elevation and district area are negatively associated with project placement. Steep gradient and elevation predicts the allocation of sewerage projects non-monotonically: the largest coefficient is the lower-middle ({0.8, 4.19] per cent) gradient category and the highest elevation category (above 1,000 mamsl).

I compute a technical suitability index for all districts in Peru using principal component analysis, including all the above-described geographic factors. The computed index is the first component with an eigenvalue larger than 1.

(2) **Nationwide budget as a constraint**

The nationwide budget for projects to construct new sewerage systems and to expand and improve existing sewerage systems is identified based on the total disbursement made to all sewerage projects in a given year. The average cost of a sewerage project is calculated from the cost of all sewerage projects. The nationwide budget for sewerage projects increased year to year and this generates variation over time on the expenditure on sewerage projects. To get an idea of the over-time variation in budget spent, see Figure 2.18.

(3) **Time-variant allocation of projects**
The final phase consists of an algorithmic approach to construct a time-variant instrument. Ranking all districts in Peru based on the technical suitability index, the algorithm predicts how a central planner would allocate one project to each district until the nationwide budget is exhausted (considering the average cost of a sewerage project). The highest-ranking districts are forecast to receive sewerage projects earlier and with more projects across the years. For instance, for 2005, the prediction allocates one project for each of the 20 highest-ranking districts because the budget spent that year amounts to the average cost of 20 projects. The prediction follows the same procedure for the following years until a district receives a maximum of five projects, which is the median of the distribution of projects allocated to districts that developed sewerage between 2005 and 2015. This threshold of maximum project allocation leaves extra generation capacity that is subsequently relocated to other districts further down the ranking. Projects that would have been allocated to higher-ranked districts that already hit the maximum are placed in lower-ranked districts. Therefore, by 2015, the highest-ranked districts would have received up to five sewerage projects, while the lowest-ranked districts would have received none. This creates an allocation roll-out that provides variation across districts and years.

Description of the instrumental variable

Figure 2.4 shows a map of Peru, plotting the diffusion of sewerage from 2005 to 2015. The early development of sewerage projects was focused on the affluent and populous north coast as well as on the relatively less affluent centre region of the Andes. The intensity of sewerage diffusion increases in these regions and expands eastward every year, until the Amazon region is covered. By 2015, there is great variation in the number of sewerage projects across districts. The regions that experienced relatively lower diffusion of sewerage are the north-east region of the Amazon and the south of Peru.

Figure 2.5 plots the districts predicted to receive sewerage projects by year. Between 2005 and 2015, districts were predicted to receive up to five projects. Water-rich areas with steeper gradients and lower altitudes are predicted to receive sewerage infrastructure earlier, but the dynamics are mediated by the budget constraints and the restriction that districts that received five projects in previous years do not receive more projects. Ignoring the demand-side drivers of sewerage diffusion forces the prediction to over-allocate projects to unattended places, such as the north-east Amazon area and the south coast. This weakens the relevance of the instrument, but allows the extraction of exogenous variation linked to geographical characteristics. The strength of the spatial correlation between Figures 2.4 and 2.5 in a model with district fixed effects determines the predictive power of the instrumental variable estimator. I test formally the relevance of the instrument in the first-stage estimation explained in the next section.

2.4.2 Empirical model

I estimate the effect of unfinished sewerage projects on the IMR and U5MR rates between 2005 and 2015 relying on variation in the intensity of sewerage projects across districts and years and using predicted sewerage projects as an instrument. The instrumental variable strategy corrects for the bias introduced by the endogenous placement of projects. To formally evaluate the relationship between actual and predicted projects, I estimate the following first-stage regression:

$$S_{dt} = \alpha Z_{dt} + \gamma_d + \delta_t + \nu_{dt}. \tag{2.2}$$

Here, S_{dt} denotes the number of unfinished sewerage projects and Z_{dt} is the number of projects predicted in district d and year t. This first-stage estimation attempts to isolate the portion of the variation in sewerage diffusion that is attributable to exogenous cost considerations.

I estimate the effect of sewerage diffusion on the IMR and U5MR using the following two-stage least-squares (2SLS) model:

$$MR_{dt} = \alpha_2 \hat{S}_{dt} + \gamma_2 d + \delta_2 t + \xi_{dt}. \tag{2.3}$$

Here, MR_{dt} denotes infant ($1q_o$) or under-five ($5q_o$) mortality rates and $\hat{S_{dt}}$ is the instrumented number of unfinished sewerage projects in district d and year t. Because my endogenous variable captures treatment intensity, there is more than one causal effect for a given district: the effect of going from zero to one project, from one to two projects, and so on. The following underlying functional relation generates the counterfactuals:

$$MR_{dt} = f_{dt}(S). \tag{2.4}$$

Equation (2.4) indicates what the mortality rate of district d in year t would be for any number of sewerage projects S, and not just for the realised value S_{dt}. Because S_{dt} takes on values in the set $0, 1, 2, 3, S_{\max}$, there are $S_{\max}$ causal effects. In this case, the 2SLS estimates are a weighted average of the unit causal response along the length of the potential causal relation described by $f_{dt}(S)$. The unit causal response is the average difference in potential mortality rates for compliers at point S; that is, districts driven by the instrument to implement a number of sewerage projects less than S to at least S.

The estimation strategy includes both district γ_d and year δ_t fixed effects. The former controls for time-invariant characteristics in districts and the latter for annual shocks common to all districts. Standard errors are clustered at the district level to deal with serial correlation due to the panel characteristics of the data and the fact that the intra-cluster correlation is lower within higher spatial levels.

Table 2.2 shows that the predicted sewerage diffusion is a relevant instrument for the number of unfinished sewerage projects. This table presents the first-stage results, where the dependent variable in column (1) is the number of unfinished sewerage projects. I find that, on average, an additional project predicted to be allocated in a district is associated with 0.4 unfinished projects. The Sanderson–Windmeijer F-statistic of excluded instruments is high and above the rule of thumb of Stock and Yogo (2002) (an F-statistic equal to or higher than 10), which confirms the relevance of the instrument.

In support of the identification assumption, columns (2) and (3) show that the instrument is not associated with infant and under-five mortality before the start of sewerage projects. The dependent variable in columns (2) and (3) is the infant and under-five mortality rate, respectively. I find that, on average, an additional project predicted to be allocated in a district has no effect on infant or under-five mortality in the years prior to the start of the first sewerage project.

2.5 Effect of unfinished projects on early-life mortality

The main result of this paper is that unfinished projects increased early-life mortality. Table 2.3 presents the estimated effect of the number of unfinished sewerage projects on a district's IMR and U5MR. Columns (1) and (2) show OLS estimates and columns (3) and (4) show 2SLS estimates. All specifications include district and year fixed effects. Both the OLS and 2SLS estimates show that sewerage diffusion increased the IMR and U5MR, though the 2SLS estimates are larger in magnitude.

On average, an additional unfinished sewerage project increased the IMR by 0.001 deaths per 1,000 infants and the U5MR by 0.299 deaths per 1,000 children. These results translate into a 5 and 6.2 per cent increase, respectively, from initial average mortality rates.

Figure 2.6 plots the mortality trends of districts predicted and not predicted to receive projects by the instrument. In support of the identification strategy, infant (upper plot) and under-five (lower plot) mortality trends are parallel before the start of the very first sewerage project. After the start of the first project, infant mortality decreases at a slower rate in districts that started a sewerage project because they were predicted to (i.e. compliers),[4] compared with districts that started a project although they were not predicted to (i.e. always-takers). Under-five mortality even increases during the first years after the start of the first project.

The fact that the mortality of "always-takers" decreases at a steeper rate after the start of the very first project is evidence that these districts were better able to mitigate hazards during the construction works and to take advantage of the social benefits of sewerage infrastructure. This explains partially why the OLS estimates are smaller than the 2SLS estimates. The compliers in the instrumental variable strategy (based on a district's technical suitability for low-cost sewerage projects) are different from the average district whose placement of projects was affected by socio-economic and political considerations or other demand-side factors. "Always-takers" are likely richer districts, better politically connected and with greater willingness to improve living standards.

The OLS downward biased estimates also reveal the expected project placement bias, as richer municipalities with lower mortality experienced greater diffusion. Finally, the 2SLS estimates are larger than the OLS estimates likely because the 2SLS model corrects measurement error. While the actual number of unfinished projects constructed using a combination of administrative records likely suffers from classical measurement error, the geographical variables used to predict the placement of projects are measured quite precisely (based on 1×1 km^2 satellite maps). The 2SLS model may be addressing the associated attenuation bias.

2.5.1 Robustness checks

A variety of checks bolster the robustness of the main results. I estimate the 2SLS model with district and year fixed effects with a series of modifications.

First, I control for time-varying lagged population density. This addresses the concern that the instrument may be capturing variation in population density.

Second, I control for municipal characteristics that were correlated with actual sewerage diffusion (as discussed in Section 2.2). These include indicators for whether the district municipality has access to the Internet and needs technical assistance to formulate investment projects and municipal revenue, in order to control for public investment capabilities. I also add as a covariate an indicator for whether the municipality manages at least one health centre, in order to control for political will on health policy. If the instrumental variable strategy is as good as random when predicting unfinished projects, then I expect that controlling for these factors will affect the point estimates only slightly.

[4]Compliers are also those that did not start a project because they were not predicted to, captured by the blue dot in the red line.

Third, I add an indicator for whether the district is located in the Amazon region, given that peculiar factors of this area could be driving the results.

Fourth, I restrict the sample of analysis to districts that started at least one sewerage project, in order to make the sample of study more comparable. Also, this test clarifies the counterfactual scenario better: the effect of more versus fewer unfinished projects, as opposed to also considering as counterfactual starting no projects.

Fifth, I exclude the capital and main province of Peru, Lima, to check that this different region is not driving the results.

Moreover, I replace the independent variable with a version top-coded at the 90th percentile of the distribution of sewerage projects to ensure that the results are not driven by outliers. Finally, I replace the independent variable with one capturing unfinished project density, measured as projects per 10,000 people per km^2. This transformation helps us to understand the extent to which population density is a mediator of the effect.

Table 2.4 shows the different robustness checks (or specifications) in each row. The magnitude and precision of the estimated effect of unfinished projects on IMR (column 1) and U5MR (column 2) remain robust and highly significant. The Sanderson–Windmeijer F-statistic of excluded instruments (column 3) remains similar in most cases (it drops to 8 for the project density transformation).

2.5.2 Validity of the instrument

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

The main threat to my identification strategy is the delivery of other infrastructure that could affect early-life mortality. Infrastructure is frequently developed as a bundle. The estimated results could be driven by other types of infrastructure that are developed following the same spatial and temporal pattern as my instrument if these also pose health hazards, such as pollution from roads and energy plants (Marcus, 2017; Gupta and Spears, 2017). Furthermore, my results could be explained by other types of infrastructure that are beneficial for early-life health, but developed following the opposite pattern to my instrument. Another concern could be if investing in sewerage systems crowds out investment in other type of infrastructure beneficial for early-life health.

To alleviate these concerns, I first control for district expenditure on transportation, energy and health. Next, I explore if the alternative infrastructure investments can explain the direct effect of the instrument on early-life mortality. In other words, I test whether my instrument is a strong predictor of variation in other infrastructure expenditure and, if so, whether the predicted variation can explain the increase in mortality rates.

Table 2.5 presents the estimates of the effect of unfinished projects on IMR (column 1) and U5MR (column 2) when controlling for expenditure in transport, energy and health projects (specifications 1–3). This exercise confirms the main results: the magnitude of the estimates remain similar. The Sanderson–Windmeijer F-statistic of excluded instruments (column 3) also remains similar

Table 2.5 also presents 2SLS estimates of transport, energy and health expenditure on early-life mortality rates using the predicted sewerage diffusion as an instrument (specifications 4–6). None of the three alternative infrastructure developments explains the estimated effects in mortality. The transportation and energy expenditure channels are not statistically significant. If anything, the health expenditure channel has a negative effect on early-life mortality. Because this effect is opposite to the one estimated, if anything my results would be downward biased. Yet, in all cases, the first-stage is weak, as shown by the low Sanderson–Windmeijer F-statistic of excluded instruments (column 3).

Another concern would be if the instrument is capturing variation driven by specific geographic characteristics or regions with greater suitability for low-cost sewerage projects. In Table 2.6, I test the robustness of the estimated effect of unfinished projects on early-life mortality when controlling for geography-specific trends and interactions with the annual budget. I include as controls the following components interacted with year and annual budget: the flat gradient category (specifications 1 and 5); the low elevation category (specifications 2 and 6); the district area in km^2 (specifications 3 and 7); an indicator for the Amazon region (specifications 4 and 8); and population density per km^2 (specifications 9 and 10). The estimated effects of unfinished sewerage projects on IMR (column 1) and U5MR (column 2) remain robust. The different specifications also have little effect on the first-stage power (column 3), in some cases even increasing it (as with population density controls). When controlling for elevation-specific trends and its interaction with nationwide budget, the magnitude remains similar, but the precision and F-statistic of the excluded instrument are lower. This finding reveals that elevation is an important driver of the variation used in the instrument.

Another threat to my identification strategy is the possibility of my instrument being correlated with the distribution of rural population across districts. Because the instrument is computed using geographic factors, such as gradient and elevation, which are likely to affect residential sorting, the results could be driven by channels other than sewerage diffusion. Flat and steep districts with greater river density may be beneficial for agriculture and might attract households with farming as their main occupation. This sorting could explain the main results as rural life has long been associated with higher mortality rates (Hathi et al., 2017). Figure 2.19 shows that, while the actual sewerage diffusion is correlated with the percentage of rural population (upper plot), this is not the case for predicted sewerage diffusion (lower plot). Districts with a percentage of rural population above the median by 2005 have an identical distribution of predicted sewerage projects as those with a percentage of rural population below the median.

2.5.3 Mechanisms

There are several explanations for the observed rise in infant and under-five mortality, and I perform tests to shed light on possible mechanisms.

I first investigate whether sewerage diffusion affected early-life mortality rates through systematic demographic changes. The observed increase in mortality rates could be a result of a decrease in the denominator, namely the number of infants (IMR denominator) and the number of children aged under 5 (U5MR denominator). For instance, a decrease in births and population could be a result of families moving away from disruptive infrastructure works. Columns (1) and (2) in Table 2.7 show that this is not the case: the estimated effects on live births and the under-five population go in the opposite direction. The coefficients of the effect of unfinished projects on early-life mortality are, if anything, underestimated. The increase in the under-five population could be explained by the increase in mortality, as the death of a young child may motivate families to have more children in order to achieve their desired fertility.

Another channel explaining the estimated positive effect on early-life mortality is selective emigration of the most well-off households and immigration of poorer households. Disruptive sewerage works may create incentives for well-off households to move away, reducing housing prices and rent and hence attracting poorer households. Columns (3) and (4) show that there is no evidence of sorting across districts. The effect of sewerage diffusion on the number of household heads with completed secondary education is not statistically significant. There is a negative and statistically significant effect on households that have electricity connectivity, but this could be because the results are restricted to a small subsample (data are only available for 50 per cent of the districts of analysis and for two years). Table 2.14 alleviates concerns that the results may be driven by education and electricity trends picked up by the instrument: the estimates remain robust when controlling for education and electricity-specific trends.

Next, I argue that the main mechanisms behind the estimated increase in mortality are linked to the disruptions posed by the construction works to install sewerage lines. Interviews with local engineers reveal that water cuts are needed in order to install sewerage pipes. Cases of unfinished sewerage projects leaving the population without access to piped water have attracted media attention (RPP Noticias, 2018). I find evidence that piped-water cuts affected the water and sanitation behaviour in affected districts.

Table 2.8 shows the coefficients of a 2SLS model of the effect of unfinished projects on water and sanitation practices. The dependent variables in columns (1)–(5) are, respectively, an indicator capturing whether the district has high connectivity to piped water (between 75 and 100 per cent), an indicator capturing whether the municipality treats water, the share of households that rely on unsafe sources of water, the share of households that use a latrine and the share of households that practise open defecation. Although, as expected, there is no effect on the connectivity to piped water, I find a negative effect of the likelihood of the municipality treating the piped water to make it safe (though not statistically significant). Notably, I find that an additional unfinished project increased the percentage of households relying on unsafe sources of water by 3 percentage points (ppts), which translates into a 4 per cent increase over the initial average. The limited access to safe water resulted in a decrease in the share of households relying on latrines by 0.04 ppts and an increase in those practising open defecation by 0.05 ppts. These results are exactly opposite and equivalent to a 10 per cent change over the initial average.

Further disruptions are linked to the excavation works. Open ditches required to install sewerage pipes pose a number of hazards to children. [5] Environmental dangers documented in Peru are linked to dust particles, stagnated ground water that creates sources of vector-borne diseases and the use of ditches as landfill sites (Malpartida Tabuchi, 2018). Shockingly, there is evidence of children falling and drowning in ditches from sewerage works that were as deep as 2 m, became filled with water from nearby sources and had no security fence (Serquen, 2018). Another important risk linked to open ditches is traffic diversion into previously quiet residential areas. An interview with an engineering expert on the implementation of sewerage projects disclosed that contractors frequently divert traffic in an unorganised matter (i.e. failing to put in place effective signaling systems), which leads to traffic accidents.

Table 2.9 investigates the effect of unfinished sewerage projects on different measures of mortality depending on the diseases and health-related problems that caused the death. Mortality data are disaggregated for general pathological groups following the World Health Organization's International Classification of Diseases (ICD 10). The outcome in the first row is all deaths caused by water-borne diseases, including infectious diseases (ICD-10 category I), peri-natal complications (ICD-10 category XVI), diseases of the digestive system (ICD-10 category XI) and malnutrition and other nutritional deficiencies (ICD-10 category IV). The outcome in the second row is the mortality rate linked to external causes (ICD-10 category XX), which mostly includes deaths caused by falls, drowning and traffic-related accidents. The following rows estimate the effect of sewerage works on deaths unrelated to sanitation and external hazards. The outcome in the third row is the mortality rate resulting

[5] Figures 2.21 and 2.22 show how sewerage works look while underway and abandoned, respectively. Both show how a sewerage project underway leaves equally dangerous open ditches as one abandoned.

from diseases of the respiratory system (category X) and the fourth row shows the mortality rate due to congenital malformations (ICD-10 category XVII). The outcome in the last row is the mortality rate linked to other unrelated factors, including diseases of the nervous system (ICD-10 category VI), circulatory system (ICD-10 category IX) and neoplasms (ICD-10 category II).

I find estimates in line with unfinished projects affecting mortality due to hazards from the excavation works, in addition to potential infectious diseases from deteriorations in water and sanitation behaviour. An additional unfinished sewerage project increased the mortality caused by water-borne diseases by 0.001 deaths per 1,000 infants and by 0.2 deaths per 1,000 children (11 and 9.8 per cent increases from the initial rate, respectively). Furthermore, an additional unfinished project increased the U5MR caused by accidents by 0.09 deaths per 1,000 children (7.2 per cent increase from the initial rate). Both infants and children are exposed to infectious diseases, directly as a result of the pools of infection that open ditches become, or indirectly because of the greater use of unsafe sources of water and the increase in faecal exposure. As expected, there is no effect on the infant mortality caused by accidents, as only older children are exposed to outdoor hazards.

If my estimates are well identified, then only an increase in mortality caused by pathogenic infections and accidents would be observed. In line with this prediction, I find no statistically significant effect of unfinished sewerage projects on mortality caused by other diseases or unrelated to external hazards from the construction works. Encouragingly, this means that the instrumental variable methodology is not picking up a general difference in mortality trends by all causes.

2.6 Effect of completed projects on early-life mortality

In order to get a full picture of the project implementation and to understand better the counterfactual scenario, I additionally estimate the effect of completed sewerage projects. It is necessary to consider project completion, given its potential confounding effect. On the one hand, one may expect the social benefits of sewerage systems to manifest upon project completion. On the other hand, mortality might not decrease if users do not connect to the infrastructure, and it might even increase if systems become a collection of sludge that contaminates the environment due to unsafe disposal.

To estimate both the effect on early-life mortality from unfinished sewerage projects and those completed, I use two instruments. The first instrument is the low-cost prediction of sewerage diffusion used in the main analysis. The second instrument is the interaction between the geographical suitability for low-cost sewerage projects with an indicator capturing partisan alignment between the municipal mayor and the central government.

I define partisan alignment as the case when the district mayor is from the same political party as the party forming the Parliament. In Peru, there is a great percentage of municipal mayors whose affiliation is to a new political party or an independent movement that has no representation at the central level. Given that there were three municipal elections and two central elections for the Parliament and President, there is variation over time in the percentage of districts aligned (see Figure 2.20).

Table 2.10 presents the first-stage results. The dependent variables in columns (1) and (2) are, respectively, the number of unfinished projects and the number of projects completed. An additional predicted sewerage project increases the number of unfinished projects by 0.26 and those completed by 0.11. This result corroborates the fact that completed projects confound the effect of unfinished projects, as my original instrument predicts both unfinished and completed projects.

Notably, the geographic suitability for low-cost projects increases by 0.88 the number of projects completed in districts with partisan alignment. Mayors politically connected to the Parliament are better able to secure funds to complete projects, conditional on starting them due to the district's geographic characteristics. This interaction has no statistically significant effect on the number of unfinished projects.

The first-stage is weak, but there is no concern with this generating a bias. Following the recommendation of Sanderson and Windmeijer (2016) for applied work with multiple endogenous variables, I report the Kleibergen–Paap rk Wald F-statistic (a robust version of the Cragg–Donald statistic) and the Stock and Yogo (2002) weak ID test critical values. The latter essentially tests if the bias of the instrumental variable estimator (IV), relative to the bias of OLS, could exceed a certain threshold. For example, if one were willing to tolerate a maximal size of 15 per cent, the size of the IV–OLS distortion would be 10 per cent for the 5 per cent level test. The 10 per cent maximal IV size for my instrumental variable estimation just identified is 7.03. Given that the Kleibergen–Paap rk Wald F-statistic is less than all critical values, the instruments are weakly identifying the number of unfinished and completed projects. Yet, the estimated first-stage coefficient above 0.1 and the exactly identified model alleviate concerns linked to the low F-statistic generating a bias in the 2SLS coefficients (Bound et al., 1995).

The omission of completed projects generates a downward bias of the estimated effect of unfinished projects. Table 2.11 presents the effect of unfinished projects and those completed on IMR (columns 1 and 3) and U5MR (columns 2 and 4). Columns (1) and (2) show OLS estimates and columns (3) and (4) show 2SLS estimates. The naïve OLS estimates suggest that both unfinished and completed projects increased mortality. The 2SLS estimates, however, reveal the expected results. While an additional unfinished project increased mortality, an additional completed project decreased it, compared with not starting a project. Although

I am unable to estimate statistically significant effects here, this exercise serves as a "sanity check". Once completed projects are included in the estimation strategy, the effect of unfinished projects is slightly larger than the original estimation.

Panel A shows that the magnitude of the negative effect of a completed project is greater than the positive effects of an unfinished project; that is, an increase of 0.004 infant deaths versus a decrease of 0.006 infant deaths and an increase of 0.862 child deaths versus a decrease of 1.214 child deaths. In line with my main hypothesis, early-life mortality increased during the construction phase but these unintended consequences dissipate once projects are completed (e.g. when water supply is resumed and open ditches are closed).

Given that the interaction between the geographical suitability for low-cost sewerage projects and partisan alignment only predicts completed projects (as seen in Table 2.10), we could use this as an instrument in a specification where we exclude unfinished projects. The results of this alternative specification are shown in Panel B of Table 2.11. The estimated effect of completed projects on mortality remains robust, though slightly lower in magnitude. The Sanderson–Windmeijer F-statistic is now higher (3.62) and in the margin of the 25 per cent maximal IV size. Hence, I assume a size distortion (bias of the IV estimator related to the OLS) of 20 per cent for the 5 per cent level test.[6]

2.6.1 Mechanisms

Even when projects are completed, the health benefits associated with sewerage systems may not fully materialise in the short run for two main reasons. First, if less than universal connectivity is achieved, then this means that neighbours are still contaminating the environment. There are negative externalities from using rudimentary sanitation prone to leakages (Augsburg and Rodríguez-Lesmes, 2018). Expanding access to sewerage systems may not ensure universal connectivity. Governments often do not guarantee the connection of expensive infrastructure to its final user, which is known as the "last mile problem" (Ashraf et al., 2016).

Second, even if universal connectivity is achieved, untreated faecal sludge can contaminate bodies of water used for drinking or irrigation purposes. A study has revealed that in Latin American, particularly in Peru, only about 30 per cent of waste water is treated, with the remaining sludge being discharged in open waters (Fay et al., 2017).

The sustainability of sewerage systems depends on the effectiveness of government agencies to operate and maintain the systems. A diagnosis of the institutional quality of the public firms in charge of the operation and maintenance of sewerage systems in Peru revealed that

[6]The results are not statistically significant likely because this study does not have the statistical power to estimate the effects of completed projects. Recall from Figure 2.3 that, on average, a district completed only one project over ten years. The lack of variation in the intensive margin restricts the analysis of the effects of completed projects. However, the purpose of this paper is to fill the gap in the literature on the effects of unfinished projects, rather than completed.

more than 80 per cent perform poorly, measured by transparency, customer support, institutional management, financial and operational sustainability and work environment (Von Hesse, 2016).

Although the Peruvian norm establishes that it is compulsory for landlords to connect households to public sewers when available, the enforcement of this norm is weak (Von Hesse, 2016). Furthermore, there is evidence that the bad performance of public firms leads to inoperative treatment plants, which contaminate local sources of water and agricultural fields, and to a deterioration in the environment, which causes disease (Vega Ysela, 2015).

To quantify the extent to which sewerage diffusion was accompanied by an improvement in the operation of sewerage systems, I use census data on the percentage of households connected to sewerage (connectivity) and municipal reports indicating if water and sludge is treated (treatment).

I estimate the effects of completed projects (using the same 2SLS specification as in Panel B of Table 2.11, due to the higher first-stage F-statistic) on sewerage connectivity and the likelihood of treating water and sludge. Table 2.12 shows that an additional completed project increases connectivity by 23 ppts and sludge treatment by 15 ppts. Although public sewers are introduced, the district's average connectivity rate and prevalence of sludge treatment are still less than universal (i.e. 46 and 39 per cent, respectively). Although a higher number of completed projects may lead to universal connectivity and treatment, recall that during the period of study, on average, a district completed one project. Moreover, water treatment decreases by 6 ppts (a decrease of 7 per cent), perhaps because better sludge management is a substitute for supplying safer water. [7]

2.7 Conclusions

Large public infrastructure can be a driver of development, setting LMICs on track to achieve sustainable development goals (SGDs) by 2030. However, the implementation of large public infrastructure can be highly disruptive, resulting in negative unintended consequences. In this paper, I examine the logic of this trade-off by asking the following question. What are the consequences of unfinished infrastructure projects? To answer this question, I focus on the diffusion of sewerage infrastructure across district municipalities between 2005 and 2015 in Peru. The aim of this public intervention was to improve early-life mortality, as was the case in advanced economies during the previous centuries.

There is a large prevalence of unfinished projects across years due to mid-construction abandonment and delays. The majority of projects are "white elephants" (i.e. expensive infrastructure projects that are useless or troublesome) at some point, and the rest are projects

[7] Again, this study does not have the statistical power to estimate significant effects from the completion of projects.

at the verge of becoming one (i.e. experiencing delays). By the end of this study, 40 per cent of the projects were still abandoned, with an average 40 per cent of the contractual sum disbursed. If these projects are never completed, then a back-of-the-envelope calculation suggests that this would generate a waste equal to 5 per cent of the public expenditure on education or 4 per cent of the expenditure on health in 2015 in Peru (World Bank, 2020). These figures reflect the high social opportunity cost of the non-completion of public infrastructure.

In this paper, I document that unfinished infrastructure projects could not only be a wasteful use of public resources, but could also generate high social costs (i.e. kill children). Infant and under-five mortality increased with every additional unfinished sewerage project, as opposed to not launching a project. The estimated effect is equivalent to ∼6–7 per cent over the initial averages. Considering that, on average, districts in Peru started four projects, the estimated increase in under-five mortality is equivalent to almost half the mortality rate in 2005 (3.08 deaths per 1,000 children). Because mortality decreased over the period of study, these results can be interpreted as mortality decreasing at a lower rate because of the unfinished infrastructure than it would have otherwise.

I find that water cuts forced the population to rely on unsafe sources of water and jeopardised sanitation practices. Furthermore, the construction works exposed the population to hazards, generating pools of infection from open ditches and increasing accidents among older children. The estimated effect on infant mortality is mostly driven by water-borne diseases, while the effect on under-five mortality can be separated into water-borne diseases (0.20 deaths per 1,000 children) and accidents (0.1 deaths per 1,000 children).

I also show that an additional completed project decreases early-life mortality, as opposed to not starting a project. The estimated negative effects of completed projects are comparable to those of Alsan and Goldin (2019) in the United States during the late 19th century (∼30–40 per cent from the initial averages). Completing one project did not ensure universal connectivity or sludge treatment, and it crowded out water treatment, preventing the social benefits of sewerage systems from fully manifesting.

By no means is the policy implication of the results that governments should not provide public infrastructure, but its delivery should be complemented with other policies that can mitigate the negative effects. Stricter health and safety measures, improvements in the quality of primary health care and the provision of alternative safe sources of water and sanitation can prevent child deaths during the construction phase.

There is a need to understand better if the social costs of infrastructure development are a result of the monopolistic nature of the institutional arrangement. Galiani et al. (2005), for example, find large gains in connectivity and performance linked to the privatisation of sewerage services in Argentina, which decreased child mortality. The estimated negative effect is of a similar magnitude to the estimated positive effect of an unfinished sewerage project in this paper. Post-construction privatisation could be as good as offsetting the negative effects of the implementation phase of sewerage systems. Nonetheless, Granados and Sánchez (2014) find that municipalities that privatised sewerage services exhibited a slower reduction of child mortality rates and lower increases in coverage.

Regardless of ownership, however, any institutional arrangement will have to deal with the lumpy nature of finance and construction of infrastructure. A reform of the contractual system can help finish projects that are started, such as leaving a high lump sum of the contractual payment for when projects are finalised and including a penalty for not completing infrastructure. The literature has pointed to other policy alternatives to attain project completion and universal connectivity, but there is room to explore further. Rasul and Rogger (2018) suggest that managerial practices of local bureaucrats, such as incentive schemes, increase the probability of completing infrastructure projects. Williams (2017) suggests the inclusion of inter-governmental rules for completing a project before starting a new one, as a way to deal with unstable local political dynamics that deter project completion. Ashraf et al. (2016) suggests finding a "sweet spot" between fines and subsidies to promote connectivity to public sewers.

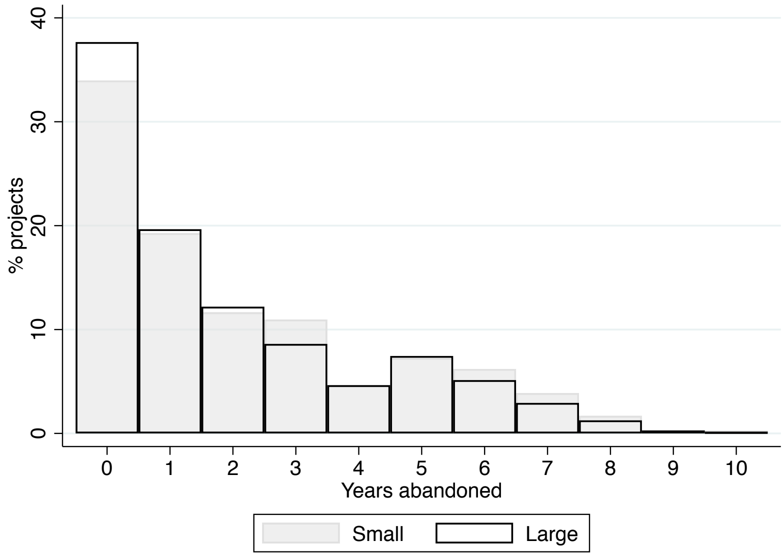
Another avenue of future research is to identify whether sewerage is unique in triggering early-life mortality or if such an adverse effect can also be seen with other forms of infrastructure. Equally, it is vital to quantify other negative consequences of unfinished public infrastructure projects on well-being and economic outcomes. In short, we must gain a better understanding of how dangerous "white elephants" can be.

TABLE 2.1: Summary statistics and data sources

	(1)	(2)	(3)	(4)	(5)
	Beginning period		End period		Source
	Sum		Sum		
1. Outcomes					
Deaths under 1y	6,404		3,820		Vital records
Deaths under 5y	8,256		4,987		
Population under 5y	2,672,357		2,481,908		INEI Pop forecast
Infant mortality (per 1,000 infants)	11.98		7.70		
Under-five mortality (per 1,000 children)	3.08		2.01		
2. Sewerage diffusion					
Started projects	161		4,873		SNIP and SIAF reports
Completed projects	11		1,754		
	Mean	SD	Mean	SD	
2. District characteristics					
Population density (pop/sq km)	642.91	2837.77	847.34	3188.96	Census and Spatial data
Population	23,403.32	57,020.49	32,947.11	75,973.03	Census
Municipal revenue (millions)	4.84	21.82	15.50	55.47	Municipal Registry
Internet access	0.38	0.48	0.93	0.26	
TA in formulation of investment projects	0.66	0.46	0.58	0.49	
Manages health centers	0.22	0.41	0.32	0.47	
Water connectivity	0.61	0.49	0.86	0.34	
Water treated	0.85	0.36	0.99	0.10	
Sewerage treated	0.23	0.42	0.57	0.50	
Share HH unsafe water	0.46	0.27	0.28	0.23	Census
Share HH sewer	0.25	0.27	0.46	0.29	
Share HH on-site	0.34	0.23	0.40	0.25	
Share HH open defecation	0.41	0.26	0.13	0.13	
Share HH head secondary	0.22	0.15	0.34	0.16	
Share HH electrified	0.56	0.26	0.79	0.16	
Transport expenditure (millions)	1.50	7.62	1.92	7.94	SIAF reports
Energy expenditure (millions)	0.04	0.22	0.19	1.13	
Health expenditure (millions)	0.71	2.53	0.36	1.49	
Major affiliated to the government party	0.11	0.31	0.13	0.33	Electoral data
3. Geography					
Fraction district gradient $\leq$ 0.8%	0.10	0.23			Spatial data
Fraction district gradient {0.8-4.19]%	0.19	0.22			
Fraction district gradient {4.19-13]%	0.34	0.20			
Fraction district gradient above 13%	0.37	0.29			
Fraction district elevation $\leq$ 250 mamls.	0.15	0.33			
Fraction district elevation {250-500] mamls.	0.05	0.14			
Fraction district elevation {500-1000] mamls.	0.06	0.15			
Fraction district elevation above 1000 mamls.	0.74	0.41			
River density (km/sq km)	53.32	124.30			
District area (sq. km)	635.93	1,655.50			

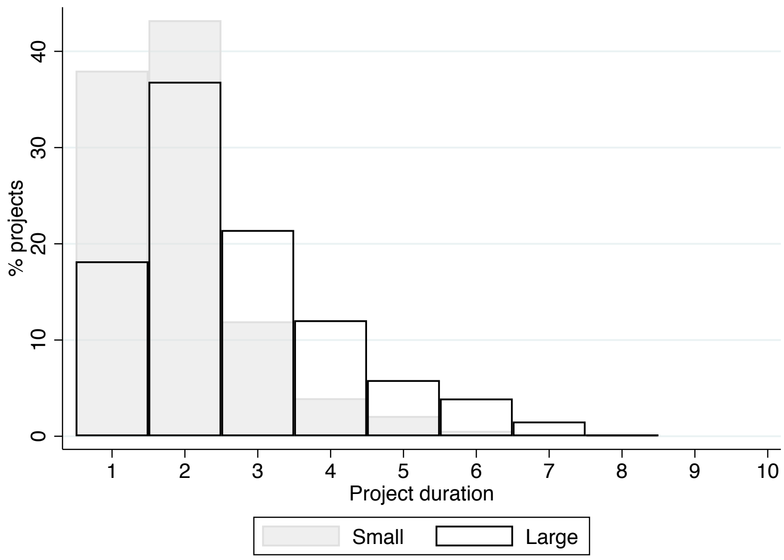
Notes: The beginning period is 2005 and the end period is 2015. Columns (1) and (3) provide the sum for the variables of interest and the mean for the geographical and control variables for 2005 and 2015, respectively. Columns (2) and (4) provide the standard deviation for control variables for 2005 and 2015, respectively, and column (2) also provides the standard deviation for the cross-sectional geographical variables. Column (5) shows the data source used to compute each of the variables.

FIGURE 2.1: Mid-construction abandonment, between 2005 and 2015



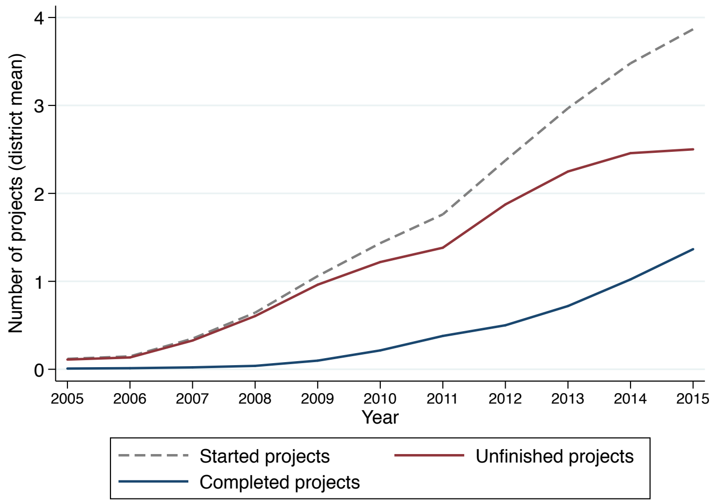
Notes: Abandonment is computed as the number of years that no additional funds are disbursed even when a project is still underway. Projects are considered small if they are planned to affect below the median of the distribution of beneficiaries, and large projects otherwise. Sample is restricted to projects that were ever started between 2005 and 2015.

FIGURE 2.2: Project duration, between 2005 and 2015



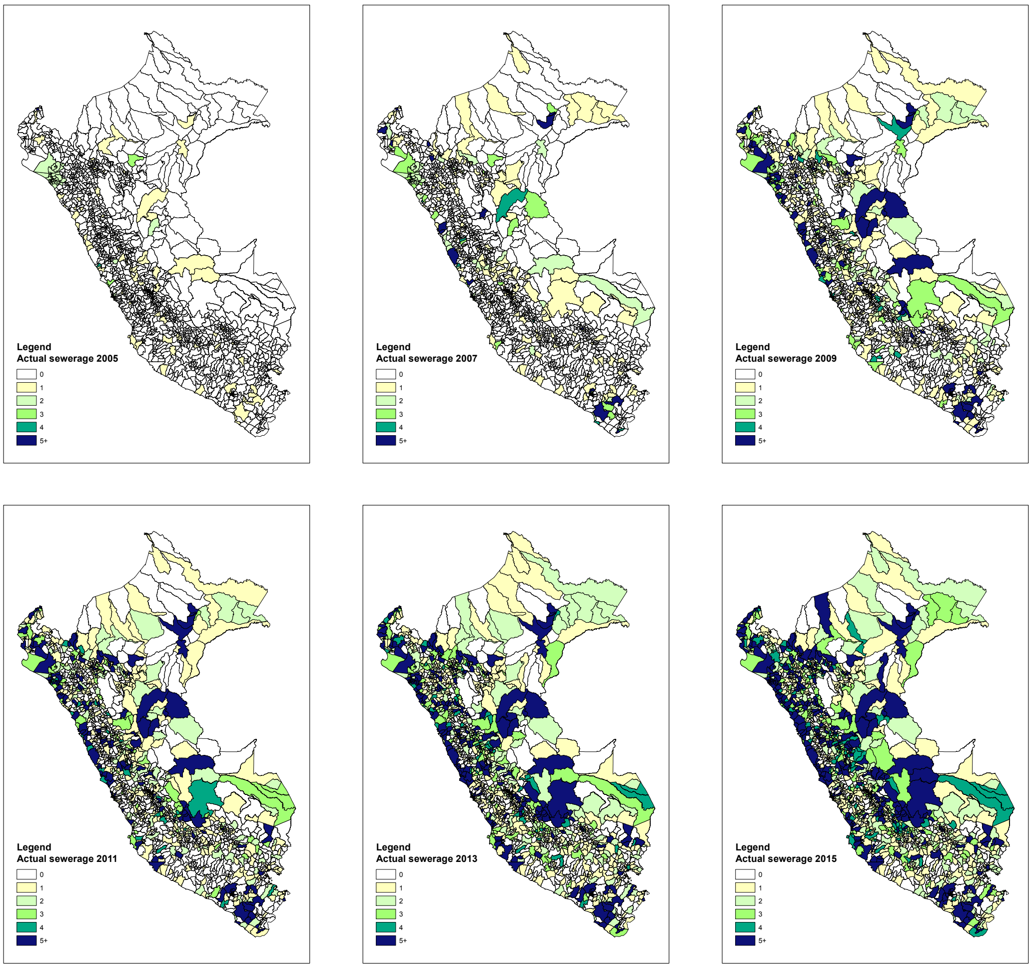
Notes: Project duration is computed as the number of years it takes for a project to be completed (if it ever accrued more than 90 per cent of the budgeted investment). Projects are considered small projects if they are planned to affect below the median of the distribution of beneficiaries, and large projects otherwise. Sample is restricted to projects that were ever started and completed between 2005 and 2015.

FIGURE 2.3: Number of projects between 2005 and 2015 (district average)



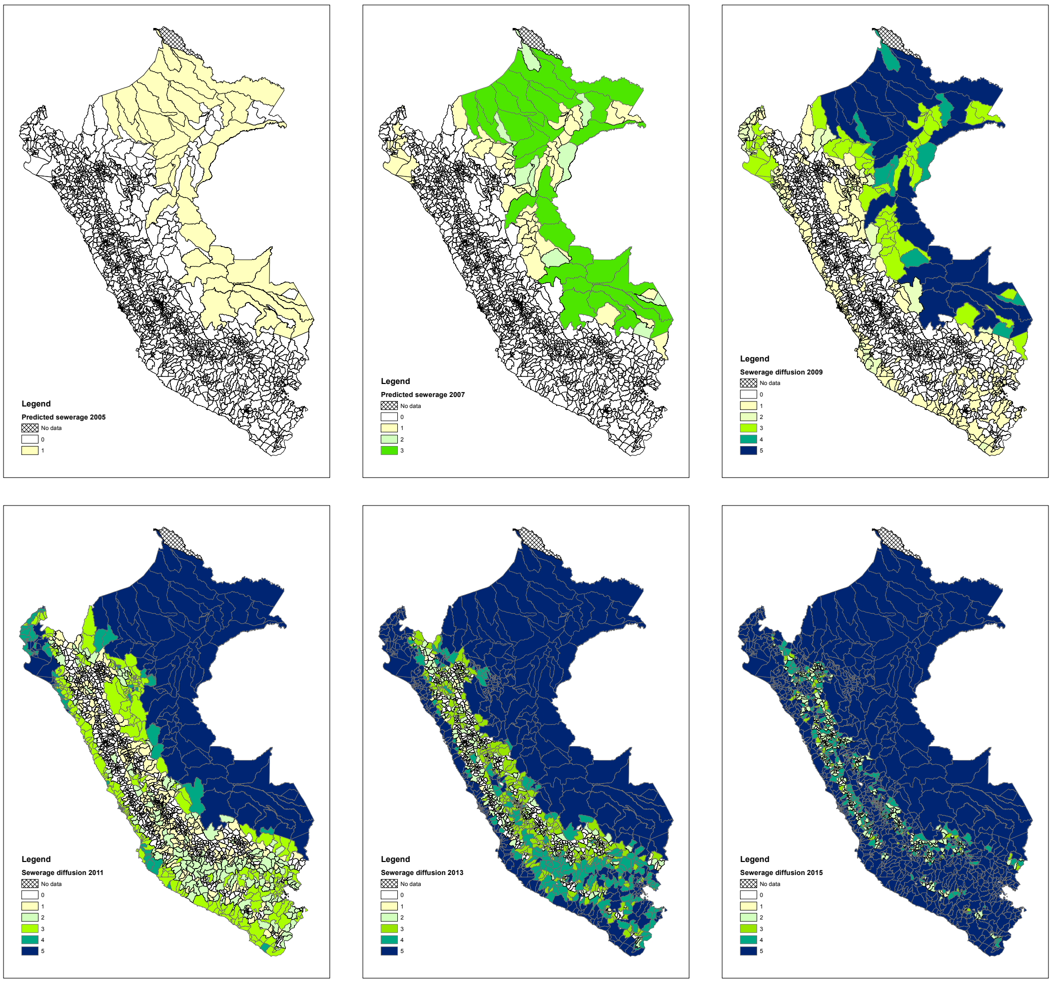
Notes: The grey dashed line shows the average cumulative number of projects started, the red line shows the average number of projects unfinished and the blue line shows the average cumulative number of projects completed.

FIGURE 2.4: Actual projects across districts in Peru, 2005–2015



Notes: These maps show the district boundaries of Peru and the distribution across districts of the actual number of sewerage projects started between 2005 and 2015. From top left to top right, the maps show the years 2005, 2007 and 2009, respectively. From bottom left to bottom right, the maps show the years 2011, 2013 and 2015, respectively. Light-shaded districts are those in which no or few sewerage projects were allocated and dark-shaded districts are those in which several sewerage projects were allocated.
Source: Author's calculations using data on the number of sewerage projects started between 2005 and 2015 from the SNIP and the SIAF.

FIGURE 2.5: Predicted projects across districts in Peru, 2005–2015



Notes: These maps show the district boundaries of Peru and the distribution across districts of the predicted number of sewerage projects to be started and completed between 2005 and 2015. From top left to top right, the maps show the years 2005, 2007 and 2009, respectively. From bottom left to bottom right, the maps show the years 2011, 2013 and 2015, respectively. Light-shaded districts are those in which no or few sewerage projects were allocated and dark-shaded districts are those in which several sewerage projects were allocated.
Source: Author's calculations using data on the number of sewerage projects started between 2005 and 2015 from the SNIP and the SIAF.

TABLE 2.2: First-stage and reduced-form before the start of projects

	(1)	(2)	(3)
	Unfinished projects	IMR	U5MR
Predicted projects	0.356***	0.000	0.069
	(0.069)	(0.000)	(0.065)
F-statistic (SW)	27.00		
Sample	All years	Before start	Before start
District–year	10,494	5,443	5,443
Districts	1,408	1,234	1,234

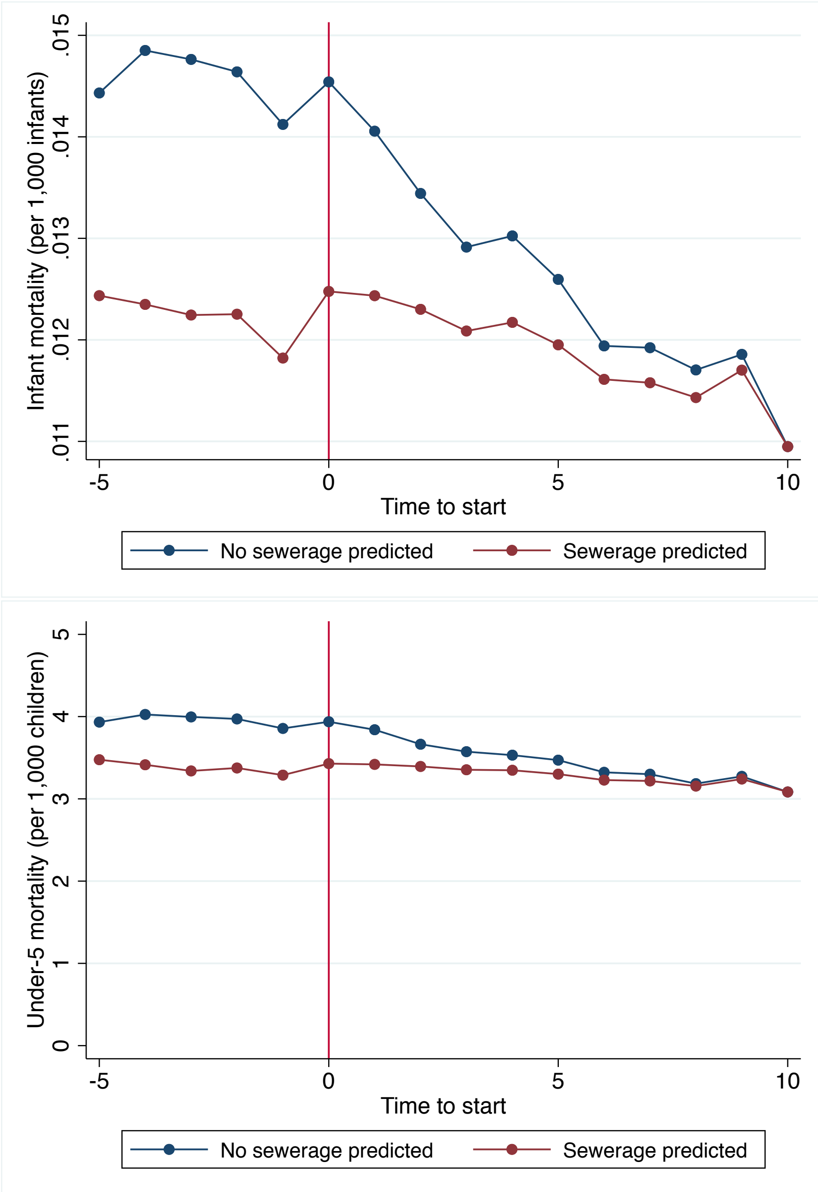
Notes: The dependant variable in columns (1)–(3), respectively, is the number of unfinished projects, the IMR and the U5MR. Column (1) includes all years, prior to and after the start of sewerage projects. Columns (2) and (3) restrict the sample to years before the start of sewerage projects. The table also shows the Sanderson–Windmeijer F-statistic. All regressions include district and year fixed effects. Standard errors clustered by district are given in parentheses. Statistical significance denoted by *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

TABLE 2.3: Effect of unfinished projects on early-life mortality

	(1)	(2)	(3)	(4)
	OLS		2SLS	
Dependent variable	IMR	U5MR	IMR	U5MR
Unfinished projects	0.000***	0.030***	0.001***	0.299***
	(0.000)	(0.007)	(0.000)	(0.105)
F-statistic (Sanderson–Windmeijer)			27.00	27.00
IMR	0.018	4.816	0.018	4.816

Notes: This table presents the main results of the effect of the number of unfinished sewerage projects on early-life mortality rates. Columns (1) and (2) show OLS estimates and columns (3) and (4) show 2SLS estimates. The dependent variable in columns (1) and (3) is the infant mortality rate (IMR) and in columns (2) and (4) it is the under-five mortality rate (U5MR). The table also shows the Sanderson–Windmeijer F-statistic and the average initial (2005) mortality rates. All regressions include district and year fixed effects. Standard errors clustered by district are given in parentheses. Statistical significance denoted by *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

FIGURE 2.6: Before and after starting projects: compliers and always-takers



Notes: The plots show trends for infant mortality (upper plot) and under-five mortality (lower plot) before and after the first project started in districts. The red vertical line denotes the time in which the first sewerage project in a given district was started. The average mortality rate of districts that never started a sewerage project is also placed in time to start equal to zero. The analysis is split into districts predicted to receive sewerage projects and those not predicted to.

TABLE 2.4: Sensitivity analysis

Specification	(1) IMR	(2) U5MR	(3) F-statistic (SW)
Additional controls			
1. Population density ($t-1$)	0.001	0.212*	21.43
	(0.001)	(0.116)	
2. Municipal characteristics	0.001***	0.322***	24.44
	(0.001)	(0.115)	
3. Amazon location dummy	0.001***	0.299***	27.00
	(0.000)	(0.105)	
Changing sample			
4. Districts with interventions	0.001***	0.267***	27.47
	(0.000)	(0.094)	
5. Lima excluded	0.001**	0.250**	24.24
	(0.000)	(0.106)	
Transformation			
6. Projects top-coded	0.001**	0.198**	18.14
	(0.000)	(0.087)	
7. Project density (10,000 people per km^2)	0.002*	0.427**	8.81
	(0.001)	(0.207)	

Notes: Each row represents a different sensitivity test on the specifications reported in columns (3) and (4) in Table 2.3. Columns (1) and (2) in this table report the coefficient and standard error on unfinished projects where the dependent variable is the infant mortality rate (1) and under-five mortality rate (2). Column (3) reports the associated first-stage F-statistic (Sanderson–Windmeijer). The different specifications in each row are reported in the left-hand column. Coefficients correspond to 2SLS estimations. All regressions include district and year fixed effects. Standard errors clustered by district are given in parentheses. Statistical significance denoted by *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. Specifications are as follows: 1, controls for lagged population density; 2, controls for municipal characteristics, including indicators capturing whether district municipality has access to the Internet, needs technical assistance to formulate investment projects, and manages at least one health centre, and municipal income (ln), where missing values are replaced by the district's average value; 3, controls for a dummy capturing whether the district is located in the Amazon region; 4, restricts the sample of analysis to those districts that ever had an intervention (at least one sewerage project ever started); 5, excludes the region of the capital of Peru, Lima, from the sample of analysis; 6, transforms endogenous variable (unfinished projects) to a version top-coded at the top 10 percentile; 7, transforms endogenous variable (unfinished projects) and instrumental variable (predicted projects) to a version interacted with population density (10,000 people per km^2).

TABLE 2.5: Validity of IV: projects in other sectors

Specification	(1) IMR	(2) U5MR	(3) F-statistic (SW)
Expenditure controls			
1. Transportation	0.001***	0.306***	25.47
	(0.000)	(0.110)	
2. Energy	0.001***	0.309***	25.27
	(0.000)	(0.110)	
3. Health	0.001***	0.307***	24.93
	(0.000)	(0.111)	
Alternative endogenous variable			
4. IV for transportation	−0.012	−3.040	0.28
	(0.023)	(5.770)	
5. IV for energy	0.007	1.595	1.03
	(0.007)	(1.668)	
6. IV for health	−0.002**	−0.609**	7.96
	(0.001)	(0.288)	

Notes: Each row represents a different sensitivity test on the specifications reported in columns (3) and (4) in Table 2.3. Columns (1) and (2) in this table report the coefficient and standard error on unfinished projects where the dependent variable is the infant mortality rate (1) and under-five mortality rate (2). Column (3) reports the associated first-stage F-statistic (Sanderson–Windmeijer). The different specifications in each row are reported in the left-hand column. Coefficients correspond to 2SLS estimations. All regressions include district and year fixed effects. Standard errors clustered by district are given in parentheses. Statistical significance denoted by *$p < 0.1$, **$p < 0.05$, *** $p < 0.01$. Specifications are as follows: 1, controls for district's expenditure in transportation projects (log); 2, controls for district's expenditure in energy projects (log); 3, controls for district's expenditure in health projects (log); 4, alternative endogenous variable – district's expenditure in transportation projects (log); 5, alternative endogenous variable – district's expenditure in energy projects (log); 6, alternative endogenous variable – district's expenditure in health projects (log).

TABLE 2.6: Validity of IV: geographic controls

	(1)	(2)	(3)
Specification	IMR	U5MR	F-statistic (SW)
1. Gradient × year dummies	0.001**	0.297**	21.15
	(0.001)	(0.125)	
2. Elevation × year dummies	0.001	0.230	13.41
	(0.001)	(0.164)	
3. Area × year dummies	0.001***	0.293***	26.94
	(0.000)	(0.104)	
4. Amazon × year dummies	0.001***	0.295***	26.89
	(0.000)	(0.106)	
5. Gradient × annual budget	0.001*	0.279**	15.70
	(0.001)	(0.141)	
6. Elevation × annual budget	0.001	0.130	7.10
	(0.001)	(0.219)	
7. Area × annual budget	0.001**	0.284***	26.70
	(0.000)	(0.104)	
8. Amazon × annual budget	0.001**	0.288***	26.51
	(0.000)	(0.107)	
9. Population density × year dummies	0.001**	0.231**	29.85
	(0.000)	(0.092)	
10. Population density × annual budget	0.001**	0.212**	30.47
	(0.000)	(0.089)	

Notes: Each row represents a different sensitivity test on the specifications reported in columns (3) and (4) in Table 2.3. Columns (1) and (2) in this table report the coefficient and standard error on unfinished projects where the dependent variable is the infant mortality rate (1) and under-five mortality rate (2). Column (3) reports the associated first-stage F-statistic (Sanderson–Windmeijer). The different specifications in each row are reported in the left-hand column. Coefficients correspond to 2SLS estimations. All regressions include district and year fixed effects. Standard errors clustered by district are given in parentheses. Statistical significance denoted by *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. Specifications are as follows: 1 and 5, gradient is the percentage of area falling in the lowest gradient category (0–0.8 per cent); 2 and 6, elevation is the percentage of area falling in the lowest elevation category (below 250 mamsl); 3 and 7, area is km^2; 4 and 8, Amazon location dummy is one if the region is in the Amazon; 9 and 10, population density corresponding to the initial year (2005).

TABLE 2.7: Effects on fertility and migration

	(1)	(2)	(3)	(4)
Dependent variable	Births	Pop U5	Educ sec	Electricity
Unfinished projects	0.369	0.018***	-0.002	-0.036***
	(0.256)	(0.005)	(0.002)	(0.011)
F-stat (SW)	27.03	27.00	19.46	21.30
Initial mean	2.92	6.99	0.22	0.56
District-year	10494	10494	2630	1406
Districts	1408	1408	1014	703

The dependent variable in columns (1)–(4), respectively, is the number of live births (ln), the under-five population (ln), the percentage of household heads with secondary education completed and the percentage of households connected to the electricity network. Coefficients correspond to a 2SLS estimation. All regressions include district and year fixed effects. Standard errors clustered by district are given in parentheses. Statistical significance denoted by *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

TABLE 2.8: Effects on water and sanitation behaviour

	(1)	(2)	(3)	(4)	(5)
	Water			Sanitation	
	Connectivity	Treated	% Unsafe	% Latrine	% OD
Unfinished projects	0.031	−0.067*	0.030**	−0.039***	0.049***
	(0.024)	(0.037)	(0.012)	(0.012)	(0.013)
F-statistic (SW)	26.14	7.98	19.46	19.46	19.46
Initial mean	0.97	0.85	0.46	0.34	0.41
District–year	3,326	6,355	2,630	2,630	2,630
Districts	1,054	1,277	1,014	1,014	1,014

The dependent variables are the following: the district has high connectivity to piped water (column 1); the municipality treats water (column 2); the percentage of households that rely on unsafe sources of water (column 3); the percentage of households that use a latrine (column 4); the percentage of households that practise open defecation (OD; column 5). Coefficients correspond to a 2SLS estimation. All regressions include district and year fixed effects. Standard errors clustered by district are given in parentheses. Statistical significance denoted by *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

TABLE 2.9: Effect of unfinished projects on mortality by cause of death

	(1)	(2)	(3)	(4)
	Coeff.		Initial mean	
Specification	IMR	U5MR	IMR	U5MR
Water borne	0.001**	0.221***	0.009	2.265
	(0.000)	(0.078)		
Accidents	0.000	0.091*	0.004	1.248
	(0.000)	(0.051)		
Respiratory	−0.000	−0.003	0.003	0.736
	(0.000)	(0.044)		
Malformation	0.000	0.030	0.002	0.388
	(0.000)	(0.034)		
Other	0.000	−0.012	0.005	1.303
	(0.000)	(0.056)		

Notes: Each row represents a different cause of death. Columns (1) and (2) report the coefficient and standard error on unfinished projects where the dependent variable is the IMR and U5MR. Columns (3) and (4) report the mean mortality of the initial year (2005). Coefficients correspond to 2SLS estimations. All regressions include district and year fixed effects. Standard errors clustered by district are given in parentheses. Statistical significance denoted by *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

TABLE 2.10: First stage for unfinished and completed projects

	(1) Unfinished	(2) Completed
Predicted projects	0.259***	0.113***
	(0.067)	(0.038)
Geography * partisan alignment	1.027	0.887**
	(0.705)	(0.452)
Partisan alignment	0.002	−0.049
	(0.100)	(0.061)
F-statistic (Kleibergen–Paap)		0.60
10% maximal IV size		7.03
15% maximal IV size		4.58
20% maximal IV size		3.95
25% maximal IV size		3.63
District–year	8,517	8,517
Districts	1,212	1,212

Notes: The dependant variable in columns (1) and (2) is the number of unfinished projects and the number of completed projects, respectively. The lower number of observations is due to omissions in the partisan alignment variable. The table also shows the Kleibergen–Paap rk Wald F-statistic and the Stock–Yogo weak ID test critical values. All regressions include district and year fixed effects. Standard errors clustered by district are given in parentheses. Statistical significance denoted by * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

TABLE 2.11: Effect of unfinished and completed projects on early-life mortality

	(1)	(2)	(3)	(4)
	OLS		2SLS	
Dependent variable	IMR	U5MR	IMR	U5MR
Panel A: Multiple endogenous				
Unfinished projects	0.000***	0.023***	0.004	0.862
	(0.000)	(0.008)	(0.004)	(0.830)
Completed projects	0.000***	0.033***	−0.006	−1.214
	(0.000)	(0.012)	(0.008)	(1.700)
F-statistic (Kleibergen–Paap)			0.60	0.60
Panel B: Single endogenous				
Completed projects	0.000***	0.050***	−0.001	−0.244
	(0.000)	(0.012)	(0.003)	(0.558)
F-statistic (SW)			3.62	3.62
IMR	0.018	4.816	0.018	4.816
District–year	8,517	8,517	8,517	8,517
Districts	1,212	1,212	1,212	1,212

Notes: This table presents the results of the effect of the number of unfinished sewerage projects and cumulative completed projects on early-life mortality rates. Columns (1) and (2) show OLS estimates and columns (3) and (4) show 2SLS estimates. The dependent variable in columns (1) and (3) is the infant mortality rate (IMR) and in columns (2) and (4) it is the under-five mortality rate (U5MR). The lower number of observations is due to omissions in the partisan alignment variable. The table also shows the Kleibergen–Paap rk Wald F-statistic for the regression with multiple endogenous variables and the Sanderson–Windmeijer F-statistic for the regression with a single endogenous variable. All regressions include district and year fixed effects. Standard errors clustered by district are given in parentheses. Statistical significance denoted by *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

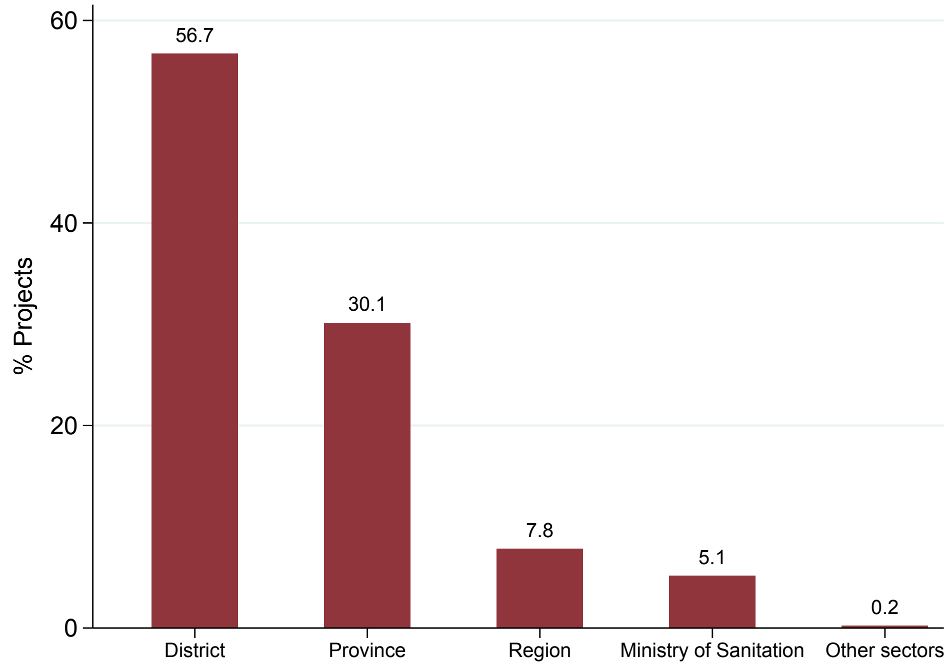
TABLE 2.12: Effects on connectivity and treatment

	(1)	(2)	(3)
	Sewerage		Water
	Connectivity	Treatment	Treatment
Completed projects	0.231	0.158	−0.066
	(0.372)	(0.155)	(0.080)
F-statistic (SW)	0.41	3.28	4.17
Initial mean	0.227	0.234	0.838
District–year	3,583	10,395	8,209
Districts	1,211	1,212	1,212

The dependent variables in columns (1)–(3), respectively are the percentage of households connected to sewerage, an indicator for whether the municipality reports that sludge is treated in the district and an indicator for whether water is treated in the district. All regressions include district and year fixed effects. Standard errors clustered by district are given in parentheses.

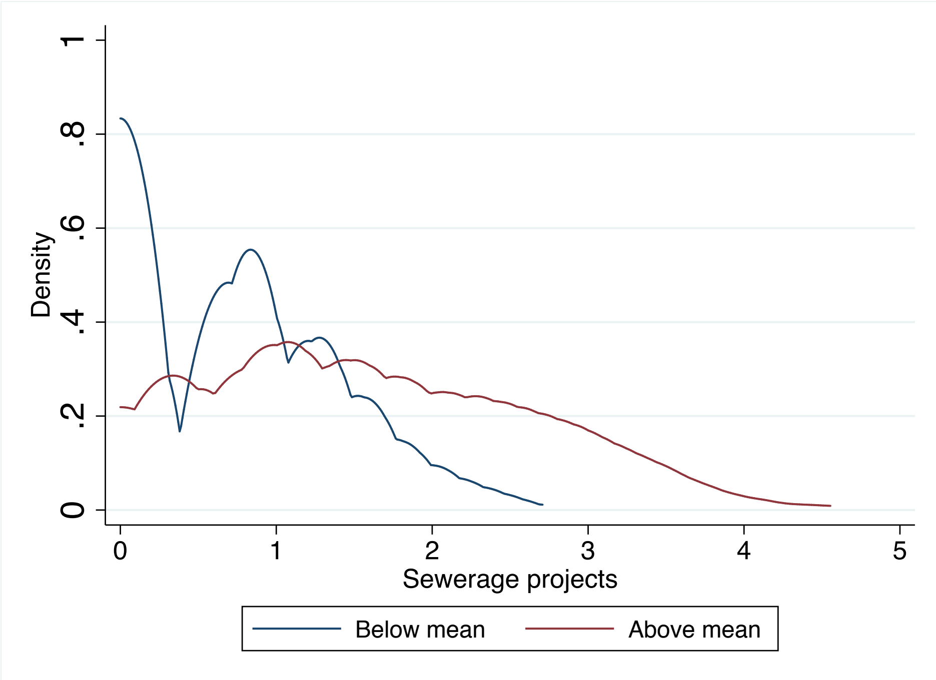
2.8 Appendix

FIGURE 2.7: Agency formulating sewerage projects, 2005–2015



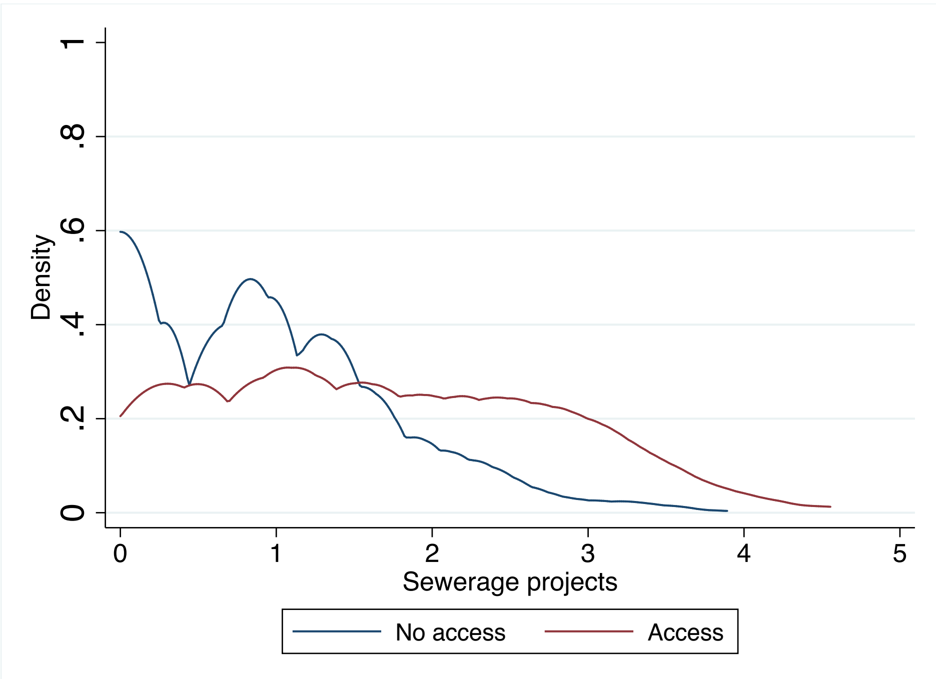
Notes: This figure shows the percentage of sewerage projects formulated by each government agency. The percentage is calculated from the pool of projects declared viable and started between 2005 and 2015.
Source: Author's calculations using data from the SNIP and SIAF.

FIGURE 2.8: More sewerage projects allocated to richer municipalities



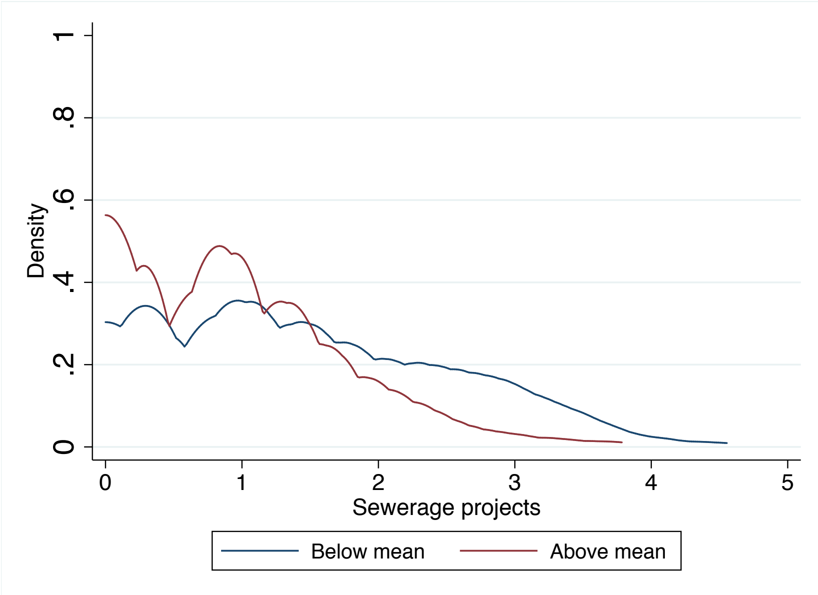
Notes: This figure shows the distribution of started sewerage projects by initial municipal revenue. The blue distribution corresponds to municipalities with budgets below the median and the red distribution corresponds to municipalities with budgets above the median of the distribution of municipal budget by 2005.

FIGURE 2.9: More sewerage projects allocated to municipalities with Internet access



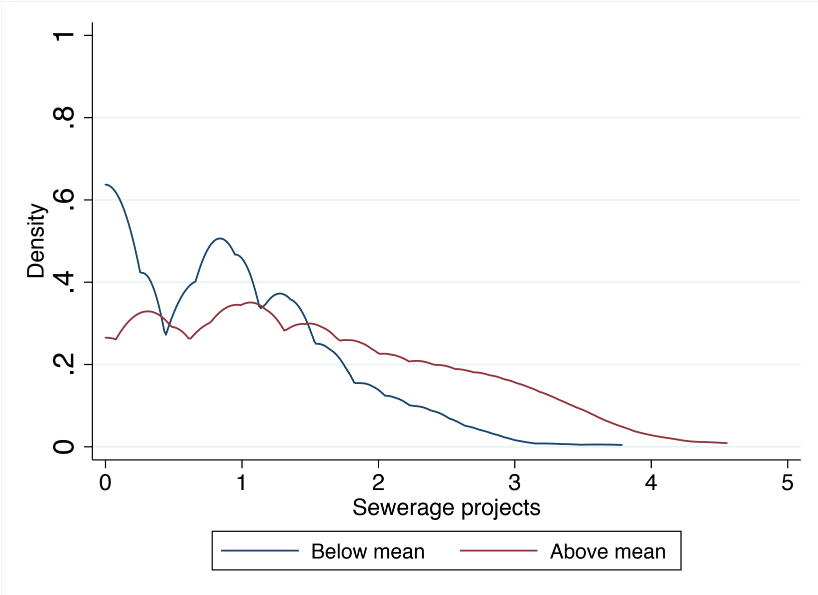
Notes: This figure shows the distribution of started sewerage projects by initial Internet access. The blue distribution corresponds to municipalities without access and the red distribution corresponds to municipalities with Internet access by 2005.

FIGURE 2.10: Distribution of projects by percentage of population with unmet basic needs



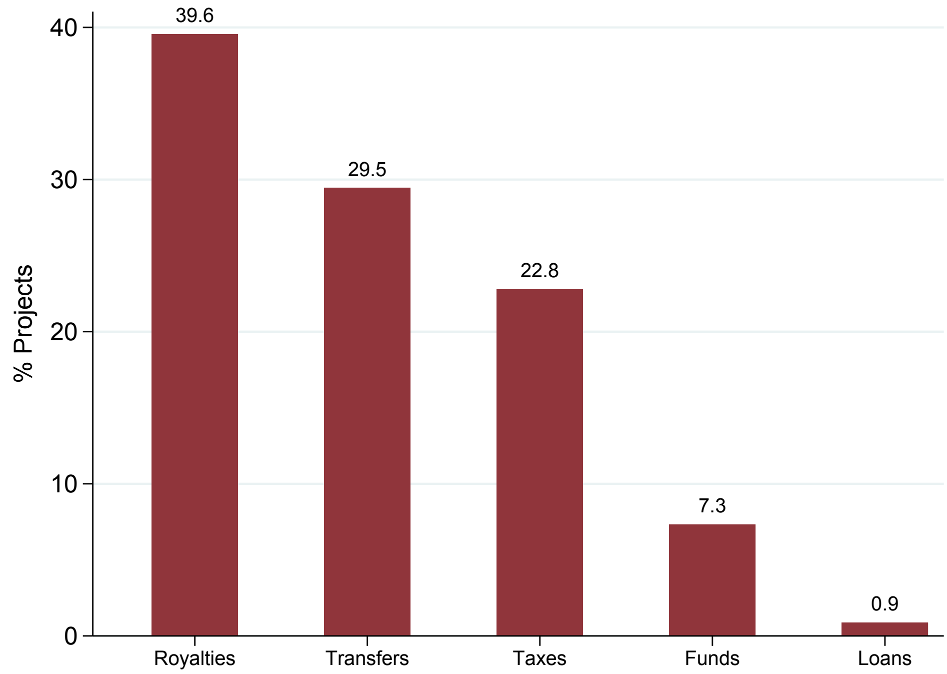
Notes: This figure shows the distribution of started sewerage projects by the district's percentage of households with unmet basic needs. The blue distribution corresponds to districts with a percentage of households with unmet basic needs below the median and the red distribution corresponds to districts above the median of the distribution by 2005.

FIGURE 2.11: Distribution of projects by percentage of sewerage connectivity



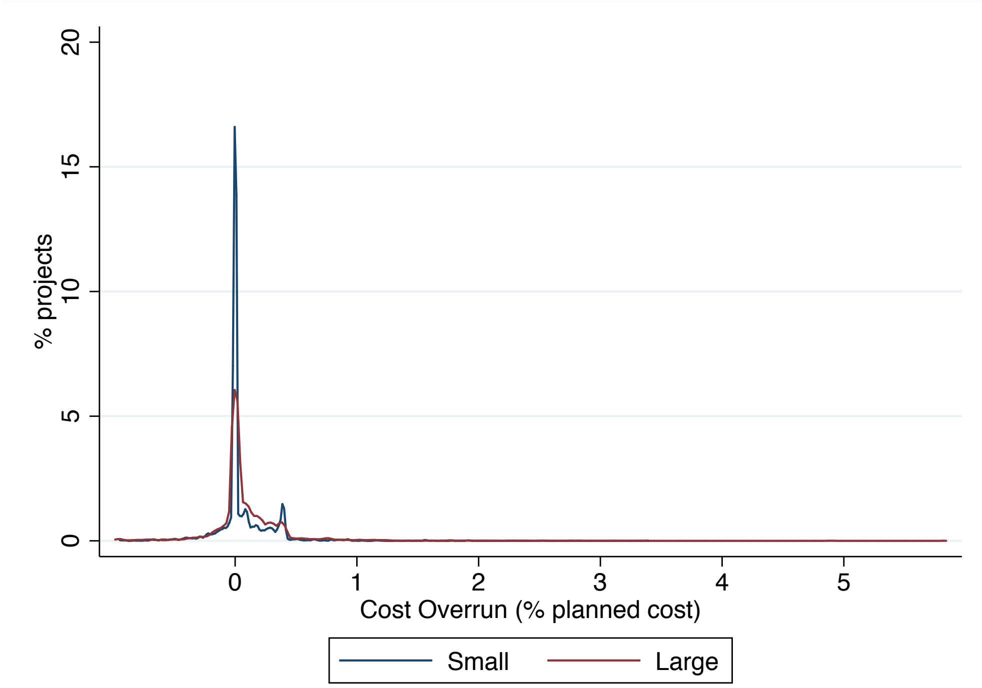
Notes: This figure shows the distribution of started sewerage projects by the district's percentage of households already connected to sewerage. The blue distribution corresponds to districts with a percentage of households connected to sewerage below the median and the red distribution corresponds to districts above the median of the distribution of sewerage connectivity by 2005.

FIGURE 2.12: Financing sources for sewerage projects, 2005–2015



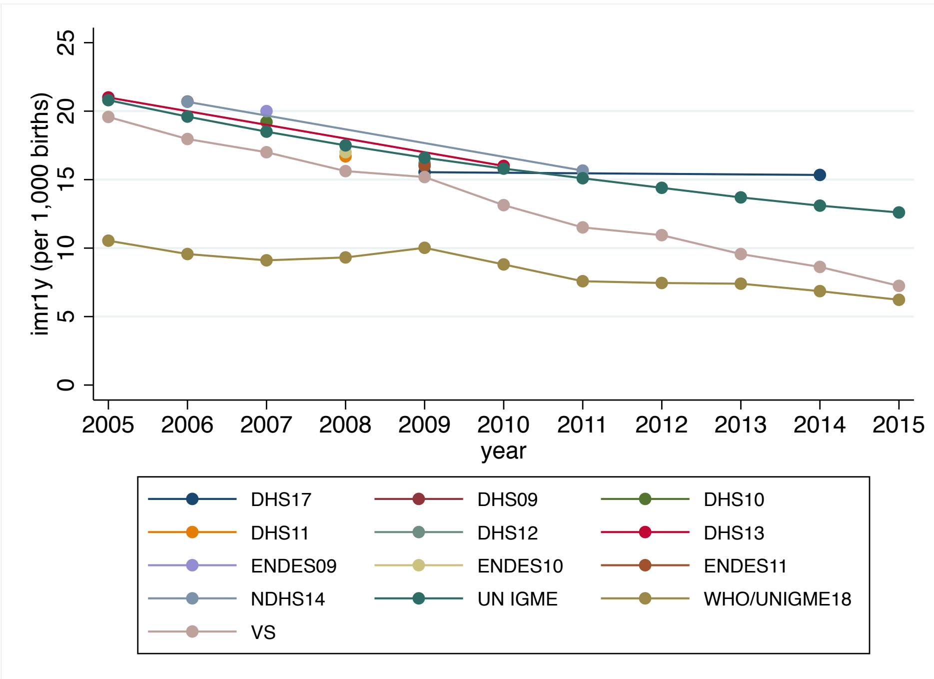
Notes: This figure shows the percentage of sewerage projects financed by each of the different public resources. The percentage is calculated from the pool of projects declared viable and started between 2005 and 2015.
Source: Author's calculations using data from the SNIP and the SIAF.

FIGURE 2.13: Distribution of cost overrun for sewerage projects, 2005–2015



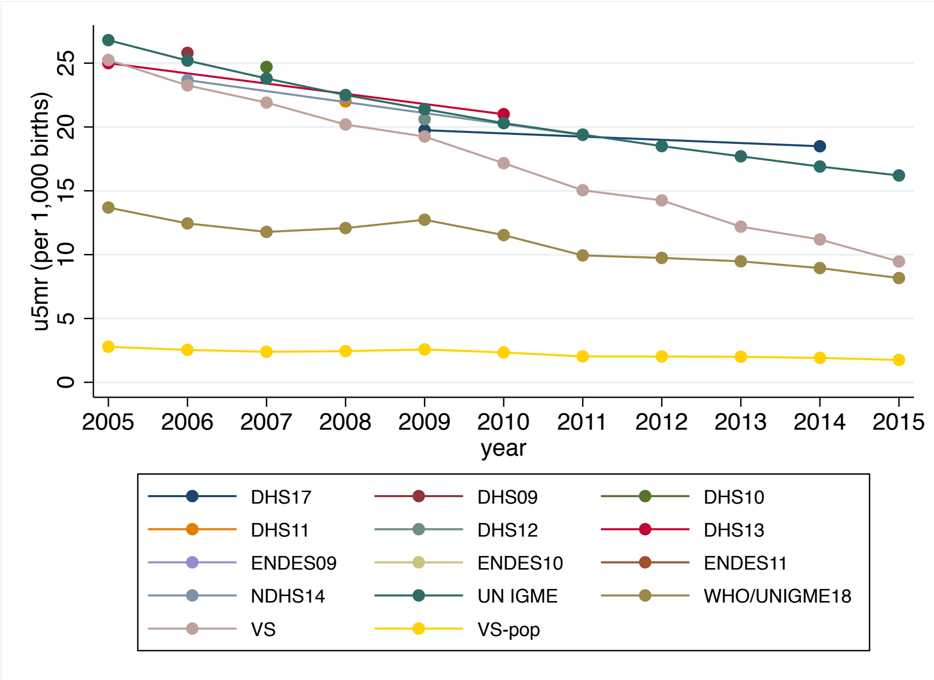
Notes: This figure shows the distribution of cost overrun as a percentage of the planned cost. It is calculated as the difference between actual and planned costs, divided by the planned cost.

FIGURE 2.14: IMR from vital statistics compared with other data sources



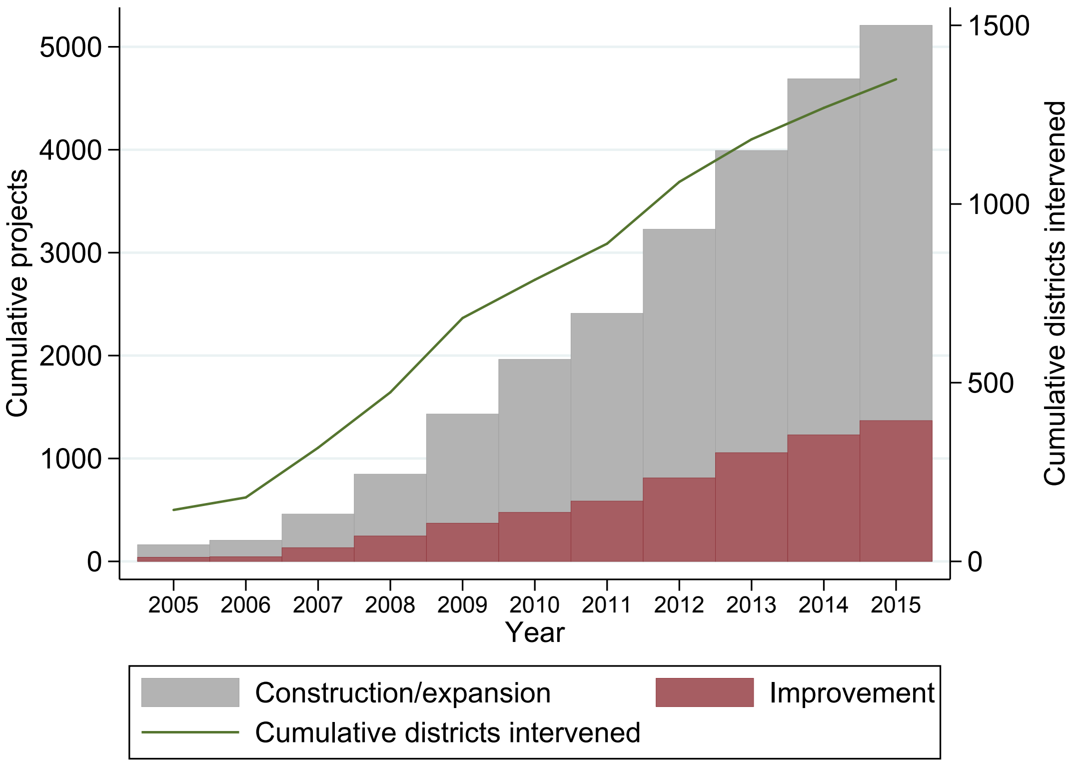
Notes: Alternative data obtained from the Health and Demographic Surveys (DHS), the National Survey of Health and Demography (ENDES) and Inter-Agency Group for Child Mortality Estimation (UN IGME).

FIGURE 2.15: U5MR from vital statistics compared with other data sources



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

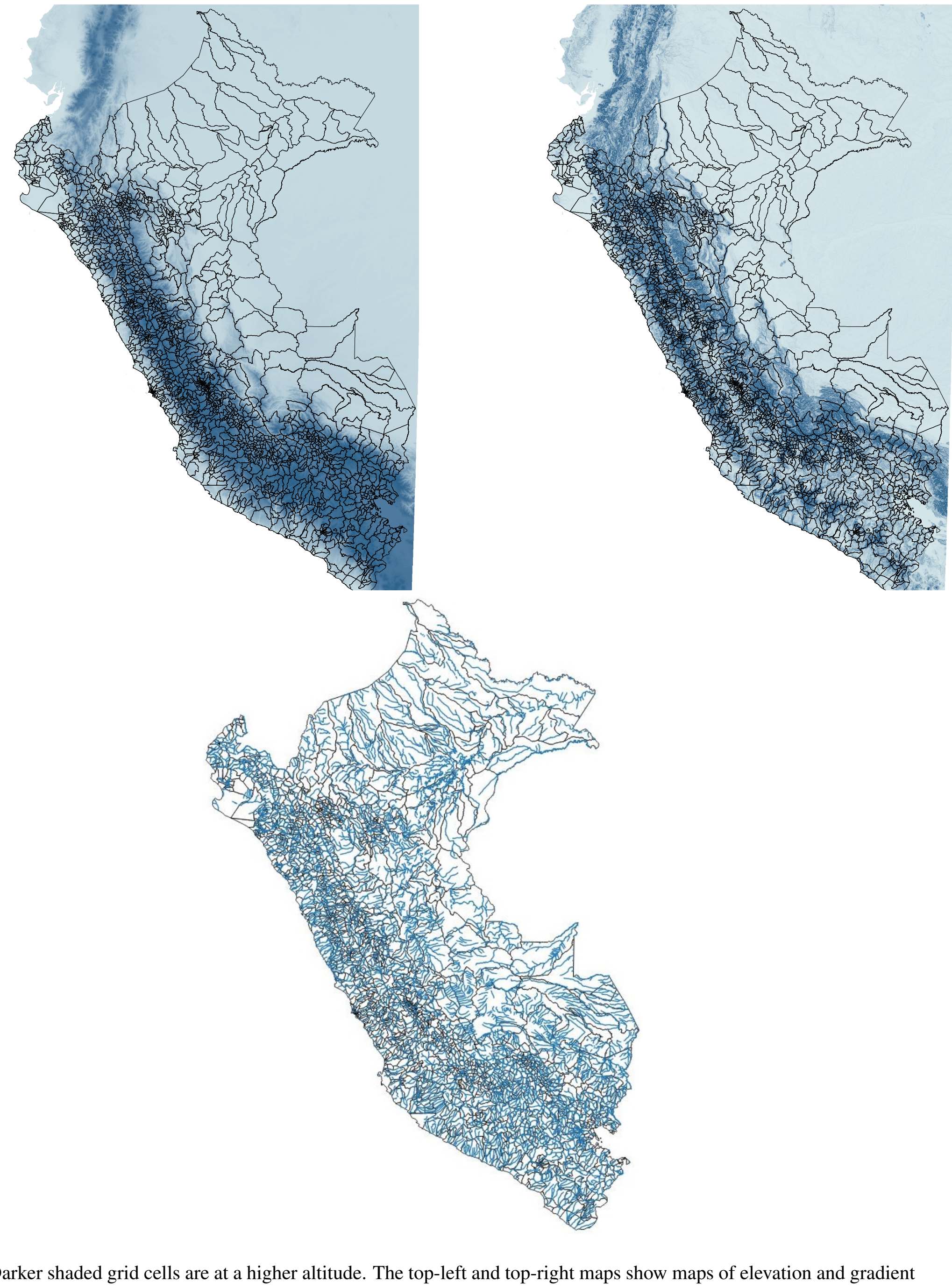
FIGURE 2.16: Number of sewerage projects and districts with interventions, 2005–2015



Notes: This figure shows the cumulative number of started sewerage projects and districts with interventions between 2005 and 2015. The y-axis on the left-hand side indicates the cumulative number of started projects. The grey bars indicate the cumulative number of started projects for the construction of new sewerage systems and the expansion of existing sewerage systems. The lower red bars indicate the cumulative number of started projects for the improvement of existing sewerage systems. The y-axis on the right-hand side indicates the cumulative number of districts with interventions. A district is classified as having an intervention when at least one sewerage project was started. The green line indicates the cumulative number of districts with interventions.

Source: Author's calculations using data from the SNIP and the SIAF.

FIGURE 2.17: Geography in Peru



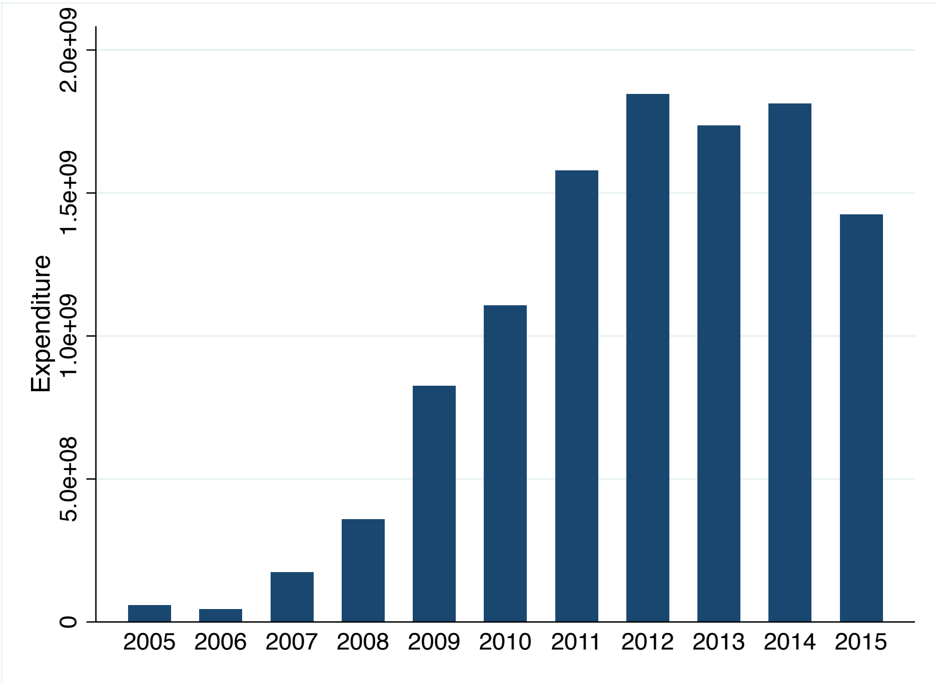
Notes: Darker shaded grid cells are at a higher altitude. The top-left and top-right maps show maps of elevation and gradient in Peru, respectively. The lower map shows river density in Peru.
Source: Digital elevation maps provided by the Peruvian Ministry of Environment with information on multiple cells (1×1 km^2).

TABLE 2.13: Geographic cost parameters for sewerage projects

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

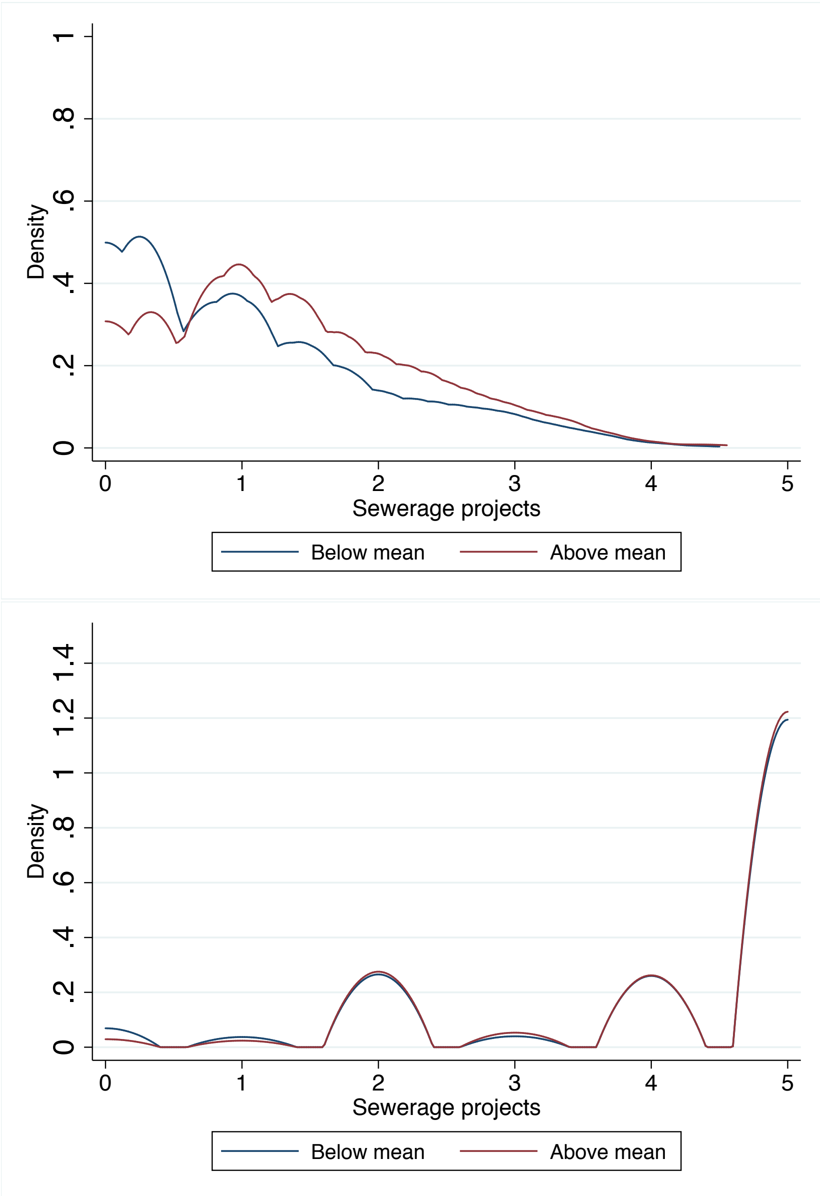
Notes: The dependent variable is the number of sewerage projects started between 2005 and 2015. Column (1) shows the coefficients of an OLS regression and column (2) shows the standardised beta coefficients. The omitted gradient category is the fraction of district area in the flat category (below 0.8 per cent) and the omitted elevation category is the fraction of district area in the low-altitude category (below 250 mamsl). Robust standard errors are given in parentheses. Statistical significance denoted by *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.

FIGURE 2.18: Annual Budget Spent in Sewerage Projects



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

FIGURE 2.19: Distribution of actual and predicted projects by percentage of rural population



Notes: This figure shows the distribution of actual (upper plot) and predicted (lower plot) sewerage projects by the district's percentage of rural population. The blue distribution corresponds to districts with a rural population below the median and the red distribution corresponds to districts above the median of the distribution of the percentage of rural population by 2005.

TABLE 2.14: Robustness check: socio-economic trends

	(1)	(2)	(3)
Specification	IMR	U5MR	F-stat (SW)
1. Education × year dummies	0.001**	0.300**	21.51
	(0.001)	(0.126)	
2. Electrification × year dummies	0.001**	0.328**	16.46
	(0.001)	(0.153)	

Notes: Each row represents a different sensitivity test on the specifications reported in columns (3) and (4) in Table 2.3. Columns (2) and (3) in this table report the coefficient and standard error on unfinished projects where the dependent variable is the infant mortality rate (1) and under-five mortality rate (2). Column (3) reports the associated first-stage F-statistic (Sanderson–Windmeijer). The different specifications in each row are reported in column (1). Coefficients correspond to 2SLS estimations. All regressions include district and year fixed effects. Standard errors clustered by district are given in parentheses. Statistical significance denoted by * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. 1. Share of households with the head having completed secondary education. 2. Share of households connected to the electricity grid.

FIGURE 2.20: Partisan alignment between district major and central government

Notes: Blue lines for municipal elections and green lines for central elections.

FIGURE 2.21: Sewerage project abandoned in Piura with a completion rate below 60 per cent

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

FIGURE 2.22: Sewerage project abandoned in Huanuco

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

Chapter 3

Challenges to Promoting Demand for Shared Infrastructure: Experimental Evidence from Slums in India

Abstract

Shared infrastructure can help improve living standards in urban slums, where insufficient public goods provision has led to extremely poor health and low levels of human capital. However, poor quality infrastructure, generated partially by low valuation and payment, can hamper environmental quality even further. We study how to break this vicious cycle in the context of community toilets in Uttar Pradesh, India. Our data reveals rampant free-riding and a remarkably low willingness to pay for community toilets which are usually of very bad quality and underutilised. We used a randomised field experiment to test the effectiveness of two interventions: (i) a "supply push" that rehabilitates the infrastructure and promotes cleanliness; and (ii) a complementary information campaign. We document that externally funded improvements crowd-out willingness to pay and to use the shared infrastructure, worsen attitudes towards paying the users' fees, increase the demand for public intervention and generate no sustained improvement in usage. [1]

[1]joint work with Alex Armand (Nova School of Business and Economics) and Britta Augsburg (Institute for Fiscal Studies). I certify that the writing and data analysis presented in this chapter is solely my own work. While I led the fieldwork, the research idea, funding application, project management, survey design, research design, sampling and randomization, analysis plan, interpretation of results and framing of the paper was joint work. My co-authors also edited the Introduction section of the paper. We gratefully acknowledge financial support from the 3ie - International Initiative for Impact Evaluation (grant number DPW1-1105). Ethics approval was secured from University College London (application n. 2168/012). The experiment was pre-registered as Armand, A., Augsburg, B. and Bancalari, A. 2018. "Community toilet use in slums - willingness to pay and the role of informational and supply side constraints." AEA RCT Registry. June 20. https://doi.org/10.1257/rct.3087-1.0.

3.1 Introduction

While urbanisation can bring benefits for economic development, cities in low and middle-income countries (LMICs) are struggling to keep up with the necessary investment to build, operate and maintain public infrastructure. In particular in densely populated urban settlements, commonly known as "slums", the public infrastructure is stressed beyond capacity. Slums lack adequate living space and have insufficient public goods provision, which lead to extremely poor health and low levels of human capital (Marx et al., 2013). To tackle this problem, governments are backing infrastructure-sharing projects in slums, such as community toilets (CTs), public taps and solar powered community hubs.

After providing access to shared infrastructure in slums, an additional problem emerges: the infrastructure quality is extremely poor in LMICs. Poor infrastructure quality can hamper environmental quality even further in slums, generating health and productivity costs (Greenstone and Jack, 2015). An important determinant of infrastructure quality is the financial sustainability of its operation and maintenance and user charge financing is commonly used for this purpose (Bird, 2010). Yet, studies reveal a very low willingness to pay (WTP) among affected households, particularly for public health infrastructure and goods (Kremer et al., 2011; Devoto et al., 2012; Ashraf et al., 2010; Berry et al., 2020). Non-payment for public infrastructure can lower effective prices below the marginal cost of operation and maintenance, jeopardising supply and ultimately diminishing the already low WTP even further (Burgess et al., 2020; Coville et al., 2020; Mcrae, 2015). How to break this vicious cycle is a question that is yet to be answered.

We study this question in the context of CTs in the slums of two Indian cities, Lucknow and Kanpur, Uttar Pradesh. While considered an important public health solution for the foreseeable future in slums, our data reveal rampant free-riding and remarkably low valuation for CTs. Using incentive-compatible measures of WTP, we find that the average respondent is willing to pay just below 27 per cent of the official rate to use the community toilet. In line with this, the CTs are of very poor quality, which is reflected in the measures taken by the state in terms of the infrastructure, the observed dirtiness, and the presence of harmful bacteria. Interestingly, we find a hypothetical WTP for the highest standard CTs that is more than double the actual WTP. The worse the observed dirtiness, the higher the rate of open defecation, which 30 per cent of households regularly using CTs reported that members occasionally revert to. It is estimated that such a practice of openly defecating is responsible for 9 per cent of India's total infant mortality and that the country's economy is significantly hampered in terms of its sanitation status, having lost 6.4 per cent of its annual GDP in 2006 alone (Geruso and Spears, 2018; World Bank, 2018).

We used a randomised field experiment to test the effectiveness of two interventions aimed at breaking the vicious cycle of low quality public health infrastructure and low WTP and use. 70 catchment areas with a total of 110 CTs in the two study cities were allocated to receive a "supply push", which promoted cleanliness and maintenance. The first of the two components of this intervention was a grant scheme, whereby CT managers could choose whether the grant was used for deep cleaning, repairs, or cleaning tools, agents and training. The second component was a financial rewards scheme, aimed at incentivising caretakers to maintain the facility. The financial reward they could receive at four points in time was high —equivalent to one third of their average monthly salary. The second intervention, allocated to 35 CTs subject to the "supply push", targeted households with a campaign aimed at generating awareness of the importance of payment and the negative externalities resulting from unsafe sanitation behaviour. We refer to this intervention as the "supply push plus campaign". In the control group of 40 CT catchment areas, participants did not receive any intervention.

This field experiment, combined with several rounds of data collection over a period of 18 months, both at the household and the community toilet level, allowed us to address our research objective. We first conducted a census of 33,000 households living in slums and close to CTs. We then collected five rounds of observations and survey data on the 110 study CTs and three waves of a household panel survey involving more than 1,500 households living in the CT catchment areas. In addition, we conducted behavioural games to obtain incentive-compatible measures of WTP and demand for public intervention, as well as to measure sensitive behaviour. Furthermore, we collected swabs during each of the five visits to the CT, which were tested in a laboratory for the presence of bacteria.

We found that the "supply push" generated marginal improvements in CT quality shortly after the grant implementation, evidenced by a reduced bacteria count and by users reporting improved infrastructure perception and washing their hands with soap. These improvements, however, were not sustained over the 18-month study period, implying that the substantial financial reward scheme was ineffective in sustaining, let alone further increasing, the marginal improvement achieved by the one-off supply push —a typical public intervention when rehabilitating infrastructure.

Surprisingly, by analysing households' WTP over the course of the experiment, we found that externally funding public infrastructure rehabilitation backfires. The "supply push" reduced WTP by 24 per cent over the control mean at a time when households appreciated the improvements from the grant scheme; and furthermore, with time, attitudes towards paying a user fee deteriorated by ten per cent over the control mean. Those residing in catchment areas of treated CTs were more likely to state that CT operation and maintenance should be funded by external agents (government and NGOs), rather than by the users themselves. In addition, the intervention shifted the demand for public intervention away from other pressing issues in the community towards the maintenance of the CTs. We estimate an increase equivalent to 50 per cent over the control mean in the reports to public officials that CT dirtiness is the most pressing issue in the community. Altogether, these findings provide evidence that external funds crowd-out private contribution in our study context.

Importantly, we found that the information campaign was ineffective in counteracting any of these effects, despite having left a lasting impression on households. The only exception was an attenuation in the reduction in the number of users (estimated to be 23 per cent lower than the control), driven mainly by men, which we found accompanied the reduced WTP. Over time, the interventions increased the percentage of users that paid by 20 per cent over the control. Although diminishing free-riding might be desirable, it is questionable if it comes at the expense of safe sanitation behaviour. Indeed, we found that open defecation increased by 23 per cent over the control, again driven by men.

This study contributes to three literature streams. First, it contributes to the growing sub-field of "envirodevonomics", focused on understanding why environmental quality is so poor in LMICs. A key question arising from this literature is: given the poor environmental quality and high health burdens in LMICs, why is the WTP seemingly so low? (Kremer et al., 2011; Dupas, 2011; Devoto et al., 2012; Ashraf et al., 2010; Berry et al., 2020; Ben Yishay et al., 2017). This study provides a unique opportunity to identify the determinants of the low WTP in a setting with significant health externalities. Besides, CTs are a type of sanitation infrastructure with salient coordination problems. Our results provide direct answers to questions raised by Greenstone and Jack (2015): Do transfers of funds crowd out investments? Can providing information to the public change their behaviour and exposure to environmental risks?

Another related literature stream is the one exploring the costs and benefits of policies related to the adoption of health goods (e.g. toilets, vaccines, bednets), in particular the provision of subsidies and information. Numerous studies have estimated the impact of information programmes (Jalan and Somanathan, 2008; Luoto et al., 2011) and subsidies (Kremer and Miguel, 2007; Ashraf et al., 2010; Dupas, 2014) in isolation. This study is closely related to the growing literature on the interactions between the two policies. While Ashraf et al. (2013) and Guiteras et al. (2015) find that subsidies and information campaigns are complementary when promoting the take-up of a newly introduced health good (water purification and latrines), we find that the complementarity is weak when respondents are familiarised with the good and the aim is to increase adoption.

Finally, our paper is connected to the literature stream exploring the determinants of low quality infrastructure in LMICs. We join Mcrae (2015); Burgess et al. (2020); Coville et al. (2020) in showing that non-payment affects infrastructure quality. We add to this stream by providing evidence that the distortions also affect the demand for public infrastructure. Our results provide evidence supporting their narrative: a non-payment equilibrium persists in the longer-run and the demand for public intervention in the provision of public infrastructure increases. We also show evidence of the effectiveness of two policy options recommended by Burgess et al. (2020). We show that an intensive information campaign has limited power to incentivise payment and that financial incentives involving large amounts for the employees who collect the payments have little effect on the collection effort.

The paper proceeds as following. Section 3.2 explains the data collection efforts and presents the context of the study, describing key features of the market of CTs. Section 3.3 presents the research design, including details of the field experiment and the estimation strategy. Section 3.4 presents the results of the study and Section 3.5 discusses and concludes.

3.2 Background and data

More than four million households living in slums in India (13 per cent of the total) do not have access to a toilet at home, and thus their only option is to use a community toilet or practice open defecation (IndianMinistryofHomeAffairs, 2011). CTs are a compound of several defecation cubicles and urinals, arranged in gender-specific areas. The sanitation facilities are either connected to the sewerage system or septic tanks (classified as improved facilities), contrary to the rudimentary private sanitation facilities (e.g. pit latrines without a slab or platform) widely available in peri-urban areas. Hand-washing and bathing facilities are also available and soap is frequently supplied. CTs are constructed by local municipalities and their management is conducted by private contractors and NGOs. In general, a public-private partnership (PPP) is formed for the operation and maintenance of CTs with a long-term duration.

The operation and maintenance of the CTs consist of hiring and supervising a caretaker, centrally providing the cleaning agents and tools, hiring cleaners, and arranging services such as repairs (e.g. to water taps, doors, locks, lights) and the cleaning of sanitation systems. The caretakers are charged with collecting the fees and either cleaning or supervising the cleaning of the compound and cubicles. A community toilet is typically located in or near a specific slum area and used by a defined group of residents in that area. The standard price to use the community toilet is Rs. 5, which allows for using all of the facilities and services. Some CTs charge Rs. 2 for using the urinals only, which are mostly located outside the compound.

In Section 3.2.1 we first provide details about the different data collection efforts we carried out. Based on the analysis of these data, we then proceed to examine the CTs market at the baseline in Section 3.2.2. The evaluation, literature review and on-ground observations will motivate the form of our empirical analysis, exploring how to promote demand for shared infrastructure in slums, which is covered in Section 3.3.

3.2.1 Data

This section describes the range of data sources we collected to conduct our analysis. Our aim was to obtain a comprehensive picture of the community toilet market in the slums, gathering rich information on both the supply and demand sides. We orchestrated a substantial amount of original data gathering in the form of geo-coded censuses of CTs and households, a four-round household panel survey and a six-round panel survey of CTs including observations and the collection of bacteria swabs. Furthermore, we conducted several innovative behavioural games that allowed us to obtain high-quality incentive compatible measurements.

Figure 3.5 in the Appendix illustrates how our different data collection efforts were structured. During the first half of 2017, we undertook a census of all CTs and households living within the slum borders and 400 metres from a pay-to-use community toilet. These censuses were subsequently used to identify eligible CTs and households and assign slums to the treatment and control groups, and as the basis from which we drew the sample of households for our panel survey. We collected household-level data in a sequence of four waves: A baseline survey in April-June 2018, a Rapid Assessment between July and September 2018, a Midline survey between January and March 2019 and an Endline survey in July-September 2019. In addition, we collected community toilet-level data in a sequence of six waves: a Baseline survey in April-June 2018, Follow-up 1 between July and September 2018, Follow-up 2 in October-November 2018, a Midline (or Follow-up 3) survey between January and March 2019, Follow-up 4 between April-May 2019 and an Endline (or Follow-up 5) survey in July-September 2019.

CT and household censuses

To construct our sample for analysis, first a CT census was performed to map all of the CTs in Lucknow and Kanpur, together with the distribution of slums close to these CTs, to understand how many CTs there are and how they are distributed, who uses them (from the community, passers-by, workers), and their characteristics, management structure and payment, among others. Through this census, 409 CTs were identified in Lucknow (201) and Kanpur (208). The instrument was administered to CT caretakers and/or supervisors. In addition, the census included the collection of GPS coordinates for all of the CTs. This community toilet census allowed for identifying eligible CTs for the study: pay-to-use, mostly used by slums residents and not close to another community toilet [2].

Afterwards, a household census was performed with the purpose of identifying our sample of eligible households. The household census covered more than 30,000 households located within the slum borders and 400 metres from each of the 144 pre-selected CTs based

[2] We set 200 metres as a minimum distance between CTs because after this point sanitation behaviour and open defecation are not associated anymore

on the above-mentioned eligibility criteria. This census collected demographics, dwelling characteristics and sanitation practices and beliefs. We identified eligible households based on this household census: those in which at least one household member used a sanitation facility other than the private latrine and where the household had no intention of migrating within the following 18 months. The collection of GPS coordinates was extremely valuable to link eligible households to a given community toilet based on distance estimates.

Finally, we selected 110 slums and their corresponding CTs given the availability of eligible households. See Appendix 3.6.1 for more details of the selection procedure.

Household panel survey

In each selected slum, a random sample of households from those eligible was selected to be part of the study (see Appendix 3.6.1 for a description of the sampling procedure). These households participated in up to four waves of household surveys.

We first collected a standard Baseline survey, including information on socio-demographics as well as dwelling characteristics, assets, income and expenditure. In addition, we collected baseline information on health status and sanitation and hygienic behaviour and priors, attitudes and health expectations linked to open defecation and CTs. Sanitation behaviour was measured by asking where each demographic group went to defecate the last two times [3]. The main respondent to the household survey was the most senior household member in terms of decision-making —in most cases the household head, but sometimes the spouse or other knowledgeable household member, always falling in the age range of 18-64 years. The scope of the baseline survey was 110 slums and 1,575 households, with an average cluster size of 12 households.

We then collected three follow-up data rounds: a Rapid-Assessment survey, a Mid-line survey and an End-line survey. The purpose of these follow-up surveys was to update the information on household demographics and re-collect data on exposure to campaigns, hygienic and sanitation behaviour, priors, attitudes and health expectations linked to open defecation and CTs. During the End-line survey we also collected data on attitudes towards paying the fee for the community toilet. To keep the sample size in line with our power calculations, we interviewed replacement households, who were randomly sampled, in a random order. In total, we interviewed 1,532 households during the Rapid-Assessment, 1,586 households during the Mid-line and 1,772 households during the End-line. Appendix Table 3.11 shows that the attrition rate of the Rapid Assessment with respect to the baseline survey

[3] To prevent under-reporting of open defecation due to social stigma, we included the following prelude: "I've been to many similar communities and I've seen that even people owning latrines and having nearby CTs defecate in the open" (Coffey et al., 2014)

was 9 per cent; for the Mid-line survey it was 19 per cent [4]; and for the End-line survey it was 14 per cent.

Community toilet panel survey

The second source of data used in the analysis was a panel survey of CTs. All 110 CTs participated in up to six rounds of surveys and recorded data during regular unannounced visits: Baseline and five follow-ups. The recorded data consisted of three different types of indicators: 1) observed number of users and those that pay within one hour, at dawn when there is higher user traffic; 2) observed cleanliness and maintenance, including the presence of faeces, flies and a bad smell; and 3) number of bacteria species identified in the swabs we collected from the floor of randomly selected areas in the community toilet and analysed by a local laboratory. We also administered a survey to the caretaker to collect data on cleaning practices and daily tasks.

We were able to obtain data for all of the 110 selected CTs at the Baseline, but only for 108 in Follow-up 1, 109 in Follow-up 2, 107 in Follow-up 3, 105 in Follow-up 4 and 106 in Follow-up 5, given that some CTs closed temporarily/permanently for refurbishment or due to problems with the caretaker. In addition, two new CTs opened very close to the study toilets. Because households also used these new CTs, we collected data from these additional toilets during Follow-ups 2 to 5. These new CTs did not increase the number of clusters, since we consider them part of the same cluster as the old CTs given their close proximity.

Behavioural measurements

We also employed lab-in-the-field experiments, using incentive-compatible methods and structured community activities, to measure behaviour; each of these was administered after either the household survey or the community toilet survey. First, we elicited the willingness to pay of potential users of the closest community toilet to their household using a Multiple Price List methodology and random draw. This methodology bounds the WTP for using the community toilet by prompting the participant to choose between different amounts of money or a bundle of ten tickets to use the CTs with a market value of Rs. 50, before randomly drawing one allocation to be paid. We offered different choices of price, starting from Rs. 0, up to above the current market price (Rs.55 and Rs.60) to deal with truncation. Because the choice of the price to be paid at the end was randomly selected, each choice was independent. We identified the WTP for community toilet use as the point at which the participant was willing to take the cash as opposed to the bundle of tickets. We piloted the

[4] there was slightly higher attrition in this round because the timing of the survey coincided with school vacations when families go back to their villages

design of the experiment in great detail in order to apply the most effective methodology in our setting, both in terms of question framing and the actual and expected price points. We measured the WTP for community toilet use for both the most senior male and female member in terms of decision-making. To prevent the presence of the other senior member affecting elicitation, we revisited households and played the behavioural games with each member alone. We elicited WTP four times during the study, after each of the household survey rounds: Baseline, Rapid Assessment, Midline and Endline.

Second, we measured the demand for public intervention using "voice-to-the-people" style cards. A similar instrument was used by Collier et al. (2014); Batista et al. (2011); Armand et al. (2017) to measure the demand for political accountability. We provided respondents with the opportunity to fill in these cards, in which they could report the most pressing issue in their community from a set of different topics (including community toilet cleanliness) to local public officers. Respondents were informed that the content of these cards would be summarised and provided to the municipal corporation of their city. We conducted this structured community activity after the household panel survey at the Midline.

Third, we used List Randomisation to measure sanitation behaviour more accurately. This technique created privacy for respondents, as it allowed them to report on potentially sensitive behaviour without allowing the researcher or surveyors to identify individual responses. In practice, some proportion of the survey respondents was randomly selected to receive a short-list of statements (e.g. general behaviour) and asked to report how many, but not which, statements were true. Other survey respondents were presented with the same list of statements and one key additional statement designed to capture sensitive behaviour (i.e. open defecation, CT use or handwashing). The difference between the mean number of true statements in the first group from the mean number of true statements in the second group allowed for estimating the proportion of the sample that engaged in the sensitive behaviour. This approach has been widely used to study sensitive behavioural choices (Karlan et al., 2011).

External validity

This study is set in the slums of Lucknow and Kanpur, Uttar Pradesh, India. Uttar Pradesh is home to 200 million people and it is the fourth most densely populated state in India (out of 32 states). More than six million people live in slums in Uttar Pradesh, making it the sixth state in terms of the percentage of the population living in such slums (IndianMinistryofHomeAffairs, 2011). Appendix Table 3.9 shows that the slum population in Uttar Pradesh is comparable to that of the whole of India in terms of the share of adult males, females and children, as well as the sex ratio and share of the population belonging to Schedule Castes.

Furthermore, Appendix Table 3.9 shows that our study sample is representative of households located in the slums of Uttar Pradesh, in terms of their socio-demographic characteristics. The difference lies in the fact that our study sample is restricted to potential users of CTs. Due to this eligibility criteria, our study sample is composed of the poorest households in the slums —i.e. we study a larger share of households from the scheduled caste (0.45 vs. 0.20 in slums of India) and with a lower literacy rate (0.46 vs. 0.78 in India).

3.2.2 The Market of CTs at Baseline

This section uses the baseline data to analyse the market of CTs. The facts that we will document in this section are: (i) free-riding is rampant; (ii) WTP is low; (iii) the infrastructure quality is poor; and (iv) open defecation is prevalent.

CTs are a particular type of sanitation that resembles a traditional public good. While the maintenance of private latrines relies on the households, CTs rely on users' fees, and hence there is a risk of coordination problems. In line with this, we find that free-riding is rampant. On average, only 64 per cent of users pay the community toilet fee. This is mainly driven by women: on average, half of women users do not pay the fee, compared to 75 per cent of men. Figure 3.1 documents the distribution of the share of men (grey bars) and women (white bars) that use the community toilet without paying, across the CTs. Strikingly, in 30 per cent of CTs no women pay and only in 20 per cent of CTs do all women pay. One may wonder whether caretakers offer women the use of the community toilet for free because it is socially desirable, but there is great variation in the percentage of women that pay. In half of the CTs, the percentage of women paying ranges from 15 per cent to 90 per cent. Although there is a smaller percentage of CTs in which no men pay (5 per cent) the fee and a larger percentage in which all men pay (35 per cent) it, there is also great variation in the percentage of men that pay the fee across CTs.

Free-riding is possible because it is difficult to exclude users. Caretakers have low enforcement power, as evidenced by only 5 per cent of respondents claiming that the caretaker had told them off for not paying the fee and 7 per cent claiming that they had been prevented from using the facility during the last month. Free-riding could be a result of inability to pay, rather than low WTP. An average household of 5 members would spend Rs. 750 per month to use daily the community toilet, which translates into 8 per cent of the average household income. Yet, households spend more than this required amount on intoxicants per month (Rs. 817). One could argue that women's low bargaining power in regard to household expenditure drives this result, but we still find that households spend twice as much on hygienic products as they do on CT fees. To disentangle ability to pay from WTP, we elicited WTP by offering a choice between cash and a bundle of ten tickets to use the community toilet, as explained in Section 3.2.1. WTP was hence computed as the minimum price per ticket at which the respondent started to prefer cash.

WTP for using the community toilet is very low. Figure 3.2 shows that a large percentage of households are not willing to pay to use the community toilet (35 per cent). The distribution of WTP for men (grey bars) is slightly shifted towards the right compared to that of women (white bars). On average, women are willing to pay Rs. 1.34 and men Rs. 1.46. We note that this average WTP is significantly below the market price for a community toilet use —it is equivalent to just 27 per cent of the official rate of Rs.5 per ticket. The low average WTP is the same even among women who report that they must pay a price greater than zero to use the community toilet. The average WTP for men is the same between households that always use the community toilet and between those that do not. Yet, for women the WTP is marginally higher for households that always use it (only by Rs. 0.35). Such low WTP may therefore reflect a truly low valuation of CTs. Meanwhile just 11 per cent of respondents reported a WTP more for CT use than the official price of Rs. 5. However, care must again be taken in interpreting this WTP as a maximum, since even respondents who value community toilet use at a rate higher than Rs.5 may, rationally, not have been willing to give up more than the market price in our incentivised task if they could obtain usage tickets for less.

Due to non-payment and low WTP, the operation and maintenance of CTs can be compromised. Evidence suggests that this is common in the water and sanitation market. Sridhar (2007) found that the revenues of water and sewerage services cover approximately 50 per cent of the total expenditure in the urban area of Punjab, India, affecting the quality of supply. In the urban slums of Uttar Pradesh, we also found that the CTs are of very poor quality. We found an average score of 0.33 standard deviation units in the index capturing dirtiness in the compound, 0.51 in the index capturing dirtiness in the cubicle and 0.83 in the index capturing bad infrastructure quality (standardised scores ranging between 0 and 1) [5]. Additionally, we found an average of 3.5 dangerous bacteria species in the swabs taken from the CTs. Notably, this low quality was perceived by households. Less than half of the households reported liking the sanitation and water services offered in their community toilet. 36 per cent reported that they considered it clean, only 15 per cent reported liking the infrastructure (e.g. well-functioning facilities) and 28 per cent reported that they considered it safe (e.g. locks and lights). Non-payment may force providers to ration supply across slums, resulting in supply not being governed by market powers. Appendix Figure 3.8 shows that CT dirtiness is negatively correlated with the percentage of people paying when CTs are cleaner, but the correlation is lost once CTs become very dirty.

To better understand the relationship between low quality and WTP, we elicited respondents' WTP for a hypothetical high-quality toilet. Figure 3.3 shows that men and women would be willing to pay more than double for CTs that have been improved to the highest standard — very clean, with good handwashing facilities, and well-lit and locked cubicles.

[5]See Appendix 3.6.2 for more information on how these indices were constructed

Both women and men reported that they would, on average, be willing to pay above the market price of Rs. 5 if the quality of CTs were to be improved.

Given that CTs are poorly maintained, it is not surprising that households continue practising open defecation, as opposed to using the infrastructure. At the baseline, in 30 per cent of households that reported using the community toilet, at least one member above the age of five practised open defecation. Figure 3.4 confirms this conjecture: the practice of open defecation is a function of the dirtiness of the community toilet. While less than 15 per cent of households openly defecate when the community toilet has a relatively low dirtiness index (0.2 standard deviations units), almost 50 per cent openly defecate when the dirtiness index is at its maximum (1 standard deviation unit). Notably, few CTs are relatively clean (dirtiness index below 0.2 standard deviations units), as denoted by the confidence intervals.

The preference for defecating in the open over using a dirty community toilet may be driven by information asymmetries about the health risks that open defecation poses to families and communities. Yet, at the baseline we find that 70 per cent of households are well aware of the risks that open defecation can pose to their families and 65 per cent are aware of the risks that this practice can pose to their communities. Although the information is imperfect, the awareness of health risks is not low. It could be then that individuals underestimate the health risk of open defecation compared to that of dirty toilets. When measuring expectations at the baseline, we find this postulation to be true. On average, respondents expected 64 per cent more adults and 62 per cent more children to become ill due to widespread open defecation practice as opposed to the eradication of this practice. In contrast, respondents expected 72 per cent more adults and 69 per cent more children to become ill due to the use of a dirty community toilet as opposed to a clean one.

Taken together, the evidence suggests a vicious cycle of non-payment that jeopardises quality and, ultimately, diminishes the already low WTP even further. How to break this vicious cycle is an empirical question that is yet to be answered. In the light of the market failures identified in our context —i.e. coordination problems, negative externalities and asymmetric information— we explore how an external push towards the maintenance of CTs, alone and coupled with a campaign to generate awareness of the importance of payment and release informational constraints about public health, affects WTP and usage.

3.3 Intervention and Research Design

3.3.1 Intervention

We tested the effectiveness of two interventions aimed at breaking the vicious cycle of low quality public health infrastructure and low WTP and use. The first intervention we called the "supply push", which was designed to maintain the infrastructure and promote cleanliness.

The first component of this intervention was a one-off push to rehabilitate the infrastructure, which represents "low-hanging fruit" in the spectrum of policy interventions. We provided a grant scheme offering a choice of packages of the same monetary value: (i) deep cleaning (i.e. septic tank sewage removal, unclogging latrines and sewerage pipes and cleaning walls, floors and inside toilets); (ii) repairs (i.e. sanitation/water connection repairs and/or infrastructure refurbishment); or (iii) cleaning tools and agents (i.e. disinfectants, soap) and cleaning training. The caretakers of each community toilet could choose one of these packages according to the toilet's needs and their expectations in terms of increasing usage. 41 per cent of CTs selected deep cleaning and the same percentage repairs, while only 17.7 per cent selected cleaning tools, agents and training.

After this initial push, we introduced a financial reward scheme as a means to sustain the initial improvement in quality resulting from the grants provided. Two months after the grant scheme (and every two months from then on), caretakers received a financial reward conditional on achieving the following: (i) availability of soap in the hand-washing facilities; (ii) latrines free of visible faeces; and (iii) bacteria count in defecation cubicles kept to a minimum standard (i.e. above the mean of the baseline distribution) [6].

In each round, caretakers could receive Rs. 500 for achieving goal (i), an additional Rs. 500 for achieving goal (ii) and an additional Rs. 1,000 for achieving goal (iii). The maximum amount that caretakers could receive at the four points in time was equivalent to one third of their average monthly salary. In CTs with more than one caretaker, the reward was split between them. On average, treated caretakers won Rs. 778.6 in the first round (39 per cent of the potential reward), Rs. 1,036 in the second round (52 per cent of the potential reward), Rs. 1,058 in the third round (53 per cent of the potential reward) and Rs. 972 in the last round (49 per cent of the potential reward).[7]

The second intervention complemented the "supply push" intervention with an information campaign. We designed this campaign to increase awareness of the negative externalities resulting from unsafe sanitation behaviour (e.g. open defecation, polluting CTs) and the importance of paying to use CTs for their operation and daily maintenance. This component

[6]When announcing the financial reward scheme and making the subsequent payments, caretakers were informed of their performance during the previous round, though their payment for the next round was not a function of their performance during previous rounds to prevent strategic behaviour. The aim of providing feedback on past performance was to increase the perceived return on effort (substitution effect), though we were aware that the caretakers may not increase their effort if they knew they could achieve the same outcome with less effort (income effect) (Bandiera et al., 2015)

[7]We implemented the "supply push" intervention at the caretaker level for three main reasons. First, caretakers are able to improve the cleanliness of CTs by exerting more effort when cleaning or supervising the cleaner. Second, caretakers can (to some extent) stop users if they refuse to pay the fee to use the facilities. Third, caretakers work only in one community toilet, contrary to mid-level managers, who supervise more than one toilet in the study. In terms of sample size and contamination concerns, we did not treat mid-line managers. To prevent control caretakers from learning about the intervention, we provided a list to the city managers of all of the CTs in the study without revealing which toilet had been allocated to which treatment arm. City managers were informed about the intervention, but were encouraged not to discuss with contractors, mid-line managers and caretakers the different interventions in order to prevent complaints.

targeted all household members, especially household heads and spouses, and was designed such that participants with low literacy could process the information. We provided the information in four forms. The first was a door-to-door information campaign using a flipchart with cartoons and messages targeted at all household members. This campaign was conducted three times: after the baseline, rapid assessment and midline rounds of the household panel survey. Secondly, a leaflet was left with households after the door-to-door campaign that included a summary of the flipchart. Thirdly, posters were placed in the community toilet, highlighting messages provided during the door-to-door campaign. Fourthly, monthly reminders were sent [8] in the form of voice messages to all mobile phones collected in the household.

To disentangle the effects of receiving voice messages, all of the treatment arms received messages including no new information (specifically stating that the community toilet was open from early morning until late evening). Households allocated to the "supply push" additionally received voice messages informing them that the community toilet has been granted aid to improve its service.

Figure 3.5 in the Appendix shows the timeline of the different interventions. At the community toilet level (upper panel), we started by providing the Grant Scheme immediately after the baseline data collection; we announced the Financial Reward Scheme two months later and we paid the reward every two months after that. At the household level (middle panel), we started the information campaign immediately after the baseline and we repeated the door-to-door visits immediately after the rapid assessment and midline survey rounds. We also sent messages during every month of the study (denoted by M). The timeline shows the evolution of the intervention and its different components relative to the data collection (lower panel).

3.3.2 Research Design

Allocation to the treatment arms was randomised in the catchment area of a community toilet, namely within a radius of maximum 250 metres away from the facility and within the slum borders. One group was allocated to receive the "supply push" intervention, another to receive the "supply push plus campaign" intervention and another to not be treated (control). Randomising at the catchment area level has the advantage of limiting contamination of the control group, especially considering the possible spread of information. To allocate clusters to treatment arms, we stratified the sampled clusters by the main organisation managing the CTs in our study area (versus other organisations) and by city of study (Lucknow and Kanpur). We then built blocks of three CTs using m-distance (Mahalanobis) relative proximity. To construct the m-distances, we used the rich census information we had collected,

[8] Cortes (2018) suggest that this is an adequate frequency for behavioural change.

including community toilet and slum-dweller characteristics. After forming blocks of similar clusters, we randomly allocated each community toilet and catchment area in a block to each treatment group. Each one of the three possibilities had the same probability. 35 catchment areas were allocated to "supply push" (557 households with an average cluster size of 16 households); another 35 catchment areas were allocated to "supply push plus campaign" (559 households with an average cluster size of 17 households) and 40 catchment areas were allocated to the control (673 households with an average cluster size of 16.7 households).

Table 3.16 in the Appendix presents the balance test for our main outcomes, both at the household and community toilet level. For each outcome we present the mean and standard deviation when the sample is restricted to the control group only (column 1), and the balance test on the joint treatment groups versus the control group (column 2) and for each treatment group (columns 3 and 4). We also present the p-values of the test of joint-significance of differences across both treatment arms (column 5). Overall, the results show that the randomisation was successful in creating observationally equivalent groups. None of the 20 tests yielded a p-value lower than 0.05 and we cannot reject the null hypothesis of equal means in difference across the treatment arms for any of the outcomes.

Over the whole study from the Baseline to the Endline, 29 per cent of households dropped out in at least one survey round. Table 3.17 in the Appendix estimates the probability of attrition as a function of treatment status and baseline WTP and sanitation practice. This shows that the attrition rates did not differ between the treatment and control groups, that the likelihood of attrition was not associated with WTP for using the community toilet or the practice of open defecation and, most importantly, that there was no differential attrition by baseline outcomes: the coefficients of the interaction terms between the treatment status and each outcome at the baseline are not statistically significant.

3.3.3 Estimation strategy

We evaluated the effect of the "supply push" and "supply push plus campaign" treatments on the individual, household and community toilet level outcomes exploiting the experimental variation caused by the random assignment of slums to treatment groups. We estimated the following specification for each survey round:

$$Y_{ijt} = \beta_1 T1_j + \beta_2 T2_j + \alpha_x Xij + \delta_t + \epsilon_{ijt} \tag{3.1}$$

where Y_{ijt} is the outcome of interest for the individual/household/community toilet i in slum j at time t, where the time periods refer to the different survey rounds. $T1_j = 1$ if the slum was assigned to the "supply push" treatment and $T2_j = 1$ if slum was assigned to the "supply push plus campaign" treatment and 0 otherwise. Xij are city and manager indicators that were included to improve efficiency because the randomisation was stratified by those variables, as well as gender indicators included in the specifications at the individual level. δ_t are survey round indicators. The error term ϵ_{ijt} is clustered by slum, the unit of randomisation.

β_1 and β_2 identify the intent-to-treat (ITT) impact of the "supply push" and "supply push plus campaign" on the individual/household/toilet i under the identification assumption of random assignment; there are no spillovers between the treatment and control slums. These estimates compare the levels in outcomes among the units in the treated slums to the levels among counterfactual units in the control slums in the same city and among CTs managed by the same provider. The identification assumption is supported by the fact that households and CTs were identified in identical ways in the treatment and control locations before the start of the interventions (as shown in Table 3.16).

As robustness checks, following work by Mckenzie (2012), we ran an analysis of covariance (ANCOVA) specification, accounting for the baseline value of the outcomes considered, namely $Y_{ij,t=0}$. Appendix 3.6.6 probes the robustness to using this alternative specification. [9] All of the results are quantitatively and qualitatively robust. To deal with the fact that testing multiple null hypotheses simultaneously increases the probability of false rejections, we ran two sets of tests. First, we reduced the number of hypotheses tested by merging the two treatment arms. The results are presented in Appendix 3.6.7. Second, we adjusted the p-values following List et al. ([2019)'s bootstrap-based procedure, which has been proven to asymptotically control the familywise error rate (the probability of one or more false rejections) and be asymptotically balanced (in that the marginal probability of rejecting any true null hypothesis is approximately equal in large samples). The procedure was modified to be used in a multivariate regression setting. The adjusted p-values are presented in Appendix 3.6.5.

3.4 Results

This section tests the impact of the interventions at each step of the causal chain that links releasing constraints to improving community toilet quality and available information, to WTP and sanitation behaviour. The comparison between shorter-run (few months after Baseline) and longer-run effects (6 to 1 years after Baseline) reveals how the effects change over time, which is important for understanding whether a one-off push can set CTs on a sustainable trajectory.

[9] We also estimated a different specification controlling for baseline variables selected using Double LASSO. The results are very similar to those of the ANCOVA specification and thus are not included in the Appendix.

3.4.1 CT quality

We start by exploring whether the treatments were effective at improving the quality of the CTs. Table 3.1 presents the treatment impacts on the quality of the CTs. Panel A shows the shorter-run effect of the Grant Scheme (up to four months after the Baseline) and Panel B the longer-run effect of the Grant Scheme combined with the effect of the Financial Reward Scheme (after 6 to 12 months). Column (1) of Panel A shows that CTs allocated to the "supply push" treatment had 0.14 fewer types of bacteria than the control: between two and four months after the Grant Scheme, the number of bacteria species was 4 per cent lower relative to the control CTs in the same time frame.

We cannot rule out that the impacts of the "supply push" and "supply push plus campaign" treatments were statistically different (the p-value of the t-test of differences in impact is 0.92), meaning that the effects were driven by the "supply push". This is the case for most of the estimated effects; hence, we will focus first on the effect of the "supply push" and in Section 3.4.5 we will describe the cases in which the campaign generated a different effect.

Although we find a negative effect on the observed dirtiness of the toilet compounds and cubicle indices, as well as the index of bad infrastructure quality, we are underpowered to estimate the statistically significant effects in the shorter-run.

Comparing the shorter-run and longer-run effects, we note that the marginal improvement in bacteria species happened immediately after the Grant Scheme and that the Financial Reward Scheme was not effective at sustaining the initial marginal improvement. Yet, we found in the longer-run that CTs allocated to the "supply push" treatment had 13 per cent less observed dirtiness in the cubicles than the control toilets. Again, we cannot rule out that the impacts of the treatments were statistically different (the p-value of the t-test of differences in impact is 0.22).

The results highlight two policy-relevant facts: first, that a one-off supply push — a typical public intervention when rehabilitating infrastructure— is not enough to improve the quality of public sanitation infrastructure in a sustainable manner; and second, that a financial reward scheme, even when it involves a large amount, is not effective in terms of ensuring adequate maintenance of CTs.

Although the estimated shorter-run improvements in the quality of CTs were marginal, we did find improvements in the attitude of potential users towards their community toilet. In column (3) of Table 3.2 we can see that households allocated to the "supply push" treatment were more likely to report that they liked the infrastructure of their community toilet (i.e. well-functioning facilities, somebody else maintaining it, walls well-painted, functional doors, looks nice, etc.) by 8 percentage points (ppts) —40 per cent more than the respondents in the control slums.

The perceived improvement in the CT infrastructure was as expected. Recall from section 3.3 that more than 40 per cent of the treated toilets selected the "repairs" intervention during the Grant Scheme, which consisted of improving the infrastructure quality of the community toilet. The impact was purely driven by the "supply push", as we cannot rule out that the impacts of the treatments were statistically different (the p-value of the t-test of differences in impact is 0.13).

The effect on attitudes towards CTs was, however, immediate: we found no statistically significant effect on the likelihood of participants reporting that they liked something about their community toilet in the longer-run (Panel B).

3.4.2 WTP, attitudes and demand for public intervention

We now explore the impacts of the interventions on WTP for using CTs. On the one hand, users may now value the facility and its services more highly, due to the marginal improvements in the CT quality, and hence we could observe an increase in their WTP for its use. On the other hand, externally funding (without increasing the users' fees) the maintenance of CTs may crowd-out users' private contributions, as evidenced by Peltzman (1973); Cutler (1996) in advanced economies and discussed in Bennett (2012); Das et al. (2013); Armand et al. (2017) for low- and middle-income countries.

Recall from Section 3.2.1 that we elicited WTP for a bundle of 10 tickets to use the community toilet using an incentive-compatible Multiple Price List and random draw method. We measured WTP as the point at which the respondent chose cash as opposed to the tickets.

Table 3.3 column (1) analyses the effect of the treatments on the WTP for using the community toilet during the rapid assessment (Panel A)—two months after the Baseline and immediately after the Grant Scheme— and during the Midline and Endline survey rounds (Panel B) — six and twelve months after the Baseline respectively.

Column (1) shows that respondents allocated to the "supply push" treatment were willing to pay, on average, Rs. 0.24 less per usage than those allocated to the control (24 per cent lower than the control's average WTP). This negative effect on WTP was observed immediately after the Grant Scheme was provided in the community toilet and disappeared in the longer-run. The results are in line with the second conjecture stated above: an externally funded supply push crowds-out private contribution. Therefore, external funds and private contributions are substitutes.

As evidence that the "supply push" treatment was perceived by users as externally funded, we found that most respondents believed that the improvement in their community toilet had been funded by the Government (65 per cent) or an external organisation (15 per cent), rather than users' fees.

We further explored whether there had been an impact on users' attitudes towards paying the fee. We measured this outcome by building a "negative attitudes to pay" index, which standardised and aggregated the answers to the following questions: (i) "Why do you think the community toilet charges a fee to use it?"; (ii) "Who do you think should be paying for the operation and maintenance of the community toilet?"; (iii) "Do you think the community toilet should charge a fee for usage?"; (iv) "Do you think people are justified to pay less/not pay for the CT if the government would increase funds for maintaining the CT in good shape?"; and (v) "Do you prefer paying the community toilet fee and having a clean toilet or not?". We constructed the index using principal component analysis, with the highest load coming from (iii) and (iv). The index captured the answers to the questions in the same direction, such that higher values corresponded to worse attitudes towards paying to use CTs. Table 3.13 in the Appendix provides more details on how this index was constructed.

Table 3.3 examines the treatments' impact on the index capturing negative attitudes towards paying to use CTs in column (2). Respondents allocated to the "supply push" treatment had worse attitudes towards paying the community toilet fee by almost 10 per cent compared to the average of the control group. Notably, these effects were only measured at the Endline, one year after the Grant Scheme had been implemented, meaning that even a one-off push in infrastructure maintenance can crowd-out private contributions.

Because most users believed that the government funded the "supply push", next we explored whether a one-off intervention generated greater demand for public intervention. To measure this outcome, we used the reports of the "voice-to-the-people" style cards. Recall that we gave participants the chance to report the most pressing issue in their community to the local municipality. The idea was to capture whether treated respondents demanded more public intervention in the operation and maintenance of CTs, relative to other issues in their community.

Columns (3) to (5) in Table 3.3 present the treatments' impact on this incentivised measure of demand for public intervention. The dependent variables capture the likelihood of at least one participant in the household reporting each of the following community issues: community toilet dirty (column 3); open defecation (column 4); and other issues (column 5), including children being ill, limited water availability, no jobs, bad quality roads, no solid waste collection, poor lighting at night and limited access to healthcare.

Column (3) shows that the likelihood of reporting to public officials that the community toilet was dirty as the most pressing issue in their community was 6 ppts higher for respondents allocated to the "supply push" —i.e. 50 per cent more likely than the control households. Interestingly, in column (4) we can see that the likelihood of reporting open defecation as the main issue in the community was 8 ppts lower for those treated (16 per cent less likely than the control households). The effects were estimated more precisely when the two treatment arms were merged (Panel C). Notably, our treatments had no effect on the demand for public intervention in issues unrelated to sanitation in the community. We cannot rule out that the estimated effects were the same across the treatment arms for any of the outcomes, meaning that the impact was mainly driven by the "supply push" treatment.

3.4.3 Sanitation behaviour

We now explore what happens with sanitation behaviour, relying on two types of measures: (i) observed usage and payment of the fees; and (ii) self-reported behaviour by respondents.

Table 3.4 first presents in columns (1) and (2) the effects of the treatments on the observed number of users during one hour at dawn (i.e. the time of most traffic in the CTs) and the percentage of those that pay. In CTs allocated to the "supply push" treatment, usage was lower by 7 users than in the control CTs (which translated into 23 per cent lower usage). This effect was not statistically significant in the longer-run, but the effect on the percentage of users paying was. In column 2, Panel B, we can see that the percentage of users that paid the fee was 11 ppts higher in CTs allocated to the "supply push" treatment than those in the control group (20 per cent higher payment). Apparently, externally funding the operation and maintenance of CTs not only crowds-out private contributions, but also disincentivises usage. If anything, the treatment seems to screen-out users who are not willing to pay, which decreases free-riding in the longer-run. Although reducing free-riding is desirable, it is not if the reduction is at the expense of lowering the total usage of CTs.

Table 3.4 next examines the treatments' effect on self-reported sanitation and hygiene behaviour. Column (3) analyses the effect on the likelihood of at least one member of the household practising open defecation; column (4) on the likelihood of household members always using the community toilet; column (5) on the ownership of a private latrine and column (6) on the likelihood of the household head and spouse washing their hands with soap.

We found no statistically significant effects on sanitation behaviour nor the ownership of a latrine using these self-reported measures. We did find, however, that the likelihood of reporting washing hands with soap was 4 ppts higher for households allocated to the "supply push" treatment than for those in the control group (i.e. 4 per cent more likely). We cannot rule out that the effect was purely driven by the "supply push" treatment (the p-value of the t-test of differences in impact is 0.01). Furthermore, we found that the impact of the supply push intervention on hand-washing with soap was immediate, as there was no statistically significant effect in the longer-run. We therefore attribute this effect to the Grant Scheme, which distributed soap and dispensers to CTs. Recall from Section 3.3 that almost 18 per cent of CTs selected the grant providing cleaning agents and tools.

3.4.4 Heterogeneity by gender

Treatment effects are likely to be heterogeneous depending on gender. Women have greater biological needs (e.g. attending to menstrual hygiene) and face more psychosocial stress in regard to addressing their sanitation needs. Concerns about privacy and dignity are greater for women since they suffer disproportionately from male harassment when they serve their needs in public places (Stopnitzky, 2017; Augsburg and Rodríguez-Lesmes, 2018). Due to these issues, there has been a growing push to consider sanitation as a right for women (Jansz et al., 2018). Section 3.2.2 reveals that free-riding is more prevalent among women, who also reveal a lower WTP.

We tested for heterogeneous effects of the treatments by estimating the following specification:

$$Y_{ijt} = \beta_{0k} T_j + \sum_k \beta_k d_{ik} * T_j + \sum_k \nu_k d_{ik} + \alpha_x Xij + \delta_t + \epsilon_{ijt} \tag{3.2}$$

where k is a sub-group such that $d_{ik} = 1$ or $d_{ik} = 0$. The impact on outcome Y_{ijt} of the treatments combined in sub-group $k = 1$ is given by $\beta_{0k} + \beta_k$ and in sub-group $k = 0$ is given by β_{0k}. The heterogenous effects are captured by β_k.

Table 3.5 reveals that the positive effect on negative attitudes to paying and on the demand for public intervention was driven mostly by women. The negative attitudes to paying the CT fee were 11 per cent higher (column 3) and the demand for public intervention 80 per cent higher (column 4) for women allocated to the "supply push" treatment than those in the control group.

The effects were also positive for men, but slightly lower in magnitude and not statistically significant. Given that women use the toilet for free more than men (as shown in Section 3.2.2), it is not surprising that externally funding the operation and maintenance of CTs is mainly reinforcing the non-payment among women.

We also estimated heterogeneous effects on observed usage. Table 3.6 shows that the "supply push" decreased the number of men users, though it had no statistically significant effect on women users. We found no differential effect in the observed percentage of users that paid in the longer-run across genders.

Because self-reported behaviour suffers from social desirability bias, we also measured sanitation behaviour using list randomisation. As explained in Section 3.2.1, list randomisation is a survey technique that creates privacy for respondents by reporting only the number of behaviours that respondents perform. Because we randomly assigned the number of items from which respondents could report, the difference in the number of items reported reveals whether the behaviour was performed. We formally estimated the impact on the number of behaviours performed by interacting the treatments with the randomly assigned number of items for each behaviour (open defecation, CT use and hand-washing behaviour). Consistent with a decrease in the WTP of a slightly higher magnitude for men and a decrease in the use of CTs by men, we found that our interventions increased the practice of open defecation by men by 23 ppts. This increase is not trivial: it is almost double the prevalence of open defecation by men in the control group.

3.4.5 Information campaign

In this section we explore in detail what happened when the information campaign is added to the "supply push" intervention.

We start by identifying whether the information campaign was effective at changing expectations and awareness of the health risks of unsafe sanitation behaviour and facilities.

Table 3.8 shows that respondents allocated to the "supply push" expected a greater difference in child illness between a clean and dirty community toilet (column 4) by 12 ppts (15 per cent higher than the expected difference for the control group). We cannot rule out that this effect was purely driven by the "supply push" and not the additional campaign. However, in the longer-run (Panel B), we found that those allocated to the "supply push plus campaign" expected a greater difference in adult illness between a clean and dirty community toilet (column 3) by 3 ppts (3.5 per cent higher than the expected difference for the control group). The coefficients remain robust and the statistical significance is higher when estimating an ANCOVA specification, as shown in Appendix Table 3.28.

In the longer-run (Panel B), we found that respondents allocated to the complementary campaign had greater awareness of private health risks (i.e. family illness) from open defecation by 8 ppts (13 per cent relative to the control group). Contrary to the aim of the campaign, this intervention had no effect on the awareness of public health risks.

These small effects on expectations were, however, not explained by the low-intensity information campaign. All households received a door-to-door information campaign and leaflet at least once, all CTs had posters that were replaced when damaged and participants listened on average to seven of the ten monthly rounds of voice messages. In fact, Table 3.18 Panel A in the Appendix shows that households allocated to the "supply push plus campaign" were 7 ppts more likely to recall being exposed to information about sanitation through any communication means two months after the beginning of the information campaign. During this period, households exposed to the information campaign were 9 ppts more likely to recall hearing messages (evidence of monthly reminders in the form of voice messages), 19 ppts more likely to recall door-to-door visits and 10 per cent more likely to recall community activities (though this was not part of our campaign, we allowed neighbours to join the flipchart demonstrations when conducting the door-to-door visits). The effects were statistically different from those allocated to the "supply push" only (all p-values of the t-test of differential effects were lower than 0.1).

Table 3.18 Panel B in the Appendix shows that even when measuring recall four months (at Midline) and six months (at Endline) after exposure to the last door-to-door visit, households allocated to the "supply push and campaign" were 12 ppts (20 per cent) more likely to recall the campaign than the control group. During this period, households exposed to the information campaign were 9 ppts more likely to recall hearing messages and 16 ppts more likely to remember posters in the community toilet, the two activities that happened throughout the year of study. We did not find statistically different effects on the recall of the door-to-door visit and community activities between the treatment arms in this period, which is not surprising given that many months had passed since their last exposure to such an event.

After identifying that the information campaign had a limited effect on expectations and awareness of health risks, we explored whether the campaign had a differential effect on willingness and attitudes towards CTs and sanitation behaviour. Table 3.2 shows that, in the shorter-run (Panel A), respondents allocated to the information campaign were 9 ppts less likely to like the CT's water, sanitation and hygienic facilities. Perhaps the messages related to the benefits of using CTs in the information campaign increased expectations of the water and sanitation services to be found in these compounds.

When looking at heterogenous effects by gender in Table 3.5, we can see in column (2) that the negative effect on WTP was mainly driven by the information campaign for women (though when merging both shorter- and longer-run effects, the estimated effect was not statistically significant anymore). Perhaps the information campaign made women more aware of the externalities of unsafe sanitation behaviour (i.e. open defecation), which reinforces the notion of "sanitation is a right" and non-payment among this group.

Even though we found no differential effect of the information campaign on WTP and attitudes towards paying, as well as the demand for public intervention on CTs, we did find an effect on observed usage. Tables 3.4 and 3.6 column (1) show that the information campaign counteracted the reduction in observed users (in the latter table for men), resulting in no change on average. Interestingly, respondents allocated to the information campaign were also more likely to report using a private latrine (column 5, Panel A), though the estimated effect was not statistically significant.

3.5 Conclusions

Non-payment for public infrastructure can lower effective prices below the marginal cost of operation and maintenance, jeopardising supply and ultimately diminishing WTP and usage even further. We explored how to break this vicious cycle in the context of CTs —a shared public health infrastructure with salient coordination problems. We showed that externally funding the rehabilitation of infrastructure backfires: it reduces the already low WTP, deteriorates users' attitudes towards paying a fee and increases the demand for public intervention. Altogether, these findings provide evidence that external funds crowd-out private contributions in our study context. Despite showing that improving infrastructure quality significantly reduces free-riding, it is done at the expense of reducing usage and worsening environmental quality. Hence, the vicious cycle is not broken, but rather reinforced.

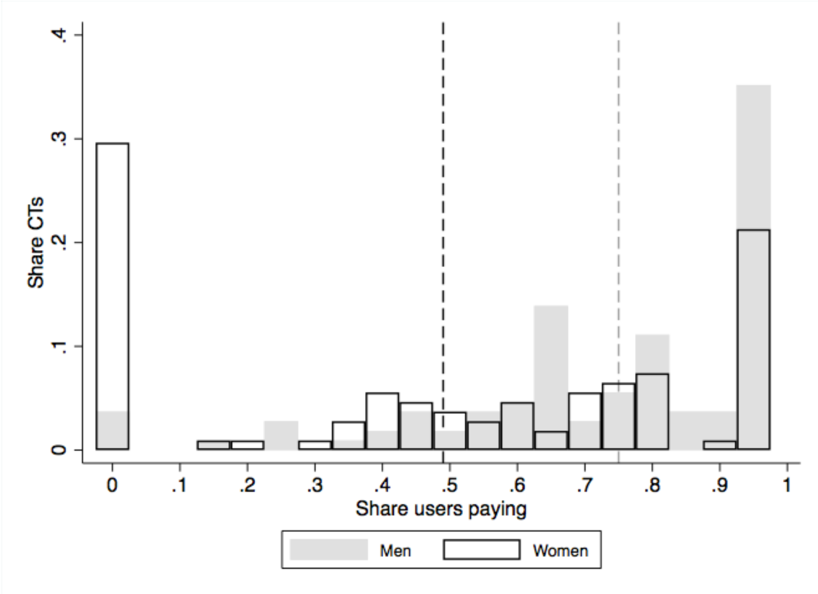
The implications of our study go beyond shared sanitation infrastructure. Our results are consistent with Burgess et al. (2020)'s and Mcrae (2015) thesis, which explains the low-quality equilibrium in the electricity market. A vicious cycle is generated by treating public infrastructure as a right: theft and non-payment are widely tolerated, which results in utilities losing money and facing no other option but to ration supply, and ultimately supply is no longer governed by market forces. Over the past decades in India, large government programmes have provided universal rights to electricity, sanitation and education, among others. Particularly relevant for this study is Modi's insignia Swachh Bharat Mission to declare India open defecation free by fully subsidising the construction of private latrines and CTs. At the core of the vicious cycle is supplying infrastructure on criteria other than economic and social return, leading consumers to learn that the way to get more is to appeal to their local elected representatives. This results in allocative inefficiency of large subsidies, which deters private investment to improve infrastructure, trapping households and firms in a non-payment, low-quality equilibrium. This vicious cycle is exacerbated in settings with weak institutions, such as the case of slums, where increasing enforcement may be challenging to implement and susceptible to extortion (Ashraf et al., 2016).

How can we effectively break the vicious cycle then? Further research is needed to answer this question and we provide three key areas to focus on. First, it is important to understand which policy option is cost-effective to achieve sustainable improvements in environmental quality. Despite directing resources towards improving CT quality, as opposed to providing subsidies that are allocated inefficiently, we document that a one-off push is not enough to sustain improvements over time, valuation and usage. Exploring other solutions in a similar setting to ours, Coville et al. (2020) shows that hard threats of disconnection decrease non-payment. Yet, disconnecting/preventing usage may not be socially desirable in a high disease burden and low environmental quality setting such as slums, so there is a need to explore policy alternatives. Policies range from fully subsidising usage to removing explicit subsidies while continuing to support the poor. Guiteras et al. (2015) shows that fully subsidising the purchase of private latrines, coupled with an information campaign, increases usage and decreases open defecation. However, additionally subsidising the operation and maintenance of infrastructure may be too costly to sustain for local governments with limited resources and may create distortions due to weak institutional capacity. Few CTs that have been made free in the slums of Uttar Pradesh are still of bad quality and thus underutilised. Another approach is to remove any explicit subsidies, which are often enjoyed by users across the income distribution. Instead, funds could be used to provide cash transfers to poorer users, ear-marked for example to pay for public services. Though this strategy is subject to effective targeting, conditional cash transfers have been proven to incentivise the adoption of public goods (Attanasio et al., 2011).

Second, there is a need to investigate how to change the social norm making free-riding acceptable, while not deterring safe behaviour. Externally funding improvements in CTs, although decreasing free-riding, screens-out users that revert to open defecation. An intense information campaign and large financial incentives to the employees who collect the payments, as suggested by Burgess et al. (2020), proved to have limited power to deter free-riding and improve behaviour. Perhaps a more effective campaign could be one that exposes free-riders, for example, by comparing the expenditure on intoxicants to that on public health. Collective action, such as community group surveillance, could be another effective avenue. Community Total Sanitation Campaigns (CLTS), which uses psychosocial levers of shame and disgust and appoints a local monitoring committee, has proven to be effective to improve sanitation behaviour in poorer settings (Abramovsky et al, 2018). Though evidence of CLTS mainly comes from rural areas, there is scope to understand whether an approach adapted to urban areas could be effective at reducing free-riding in slums. Incentive schemes at the community level based on the percentage of people that pay to use CTs could also be effective at creating and reinforcing a new local norm of payment (Neal et al., 2015).

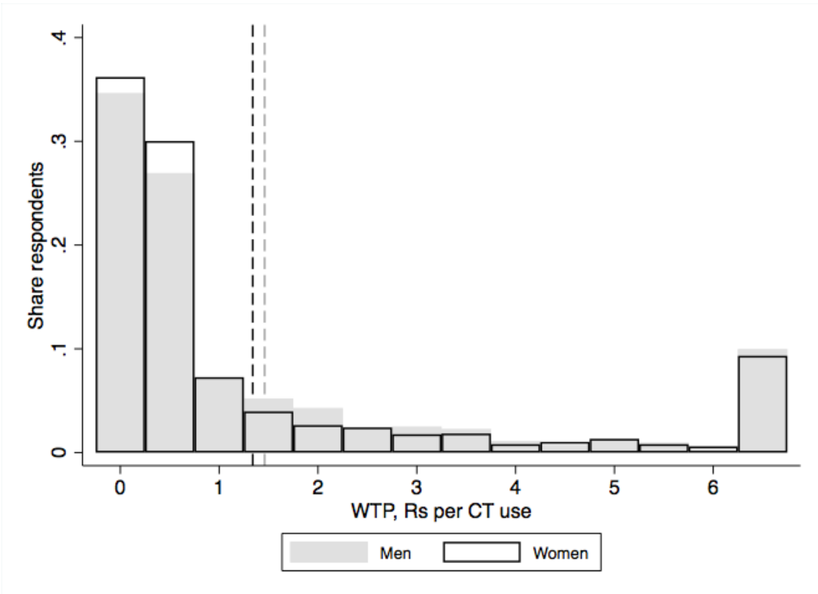
Finally, we must explore technologies that make public infrastructure excludable, making it possible to link payments with supply. Like many other public goods, CTs are not easily excludable and anyone can access the facilities regardless of whether they have paid to use them. Coin operated doors, for example, could help caretakers who are not empowered to enforce payment. The downside of making public infrastructure excludable is that greater control can actually decrease usage (Greenstone and Jack, 2015). Better monitoring can also be undermined by bureaucratic collusion, as highlighted in the healthcare literature (Banerjee et al., 2008). Further research is needed in order to understand the effectiveness of better control and monitoring technologies in high free-riding environments.

FIGURE 3.1: Distribution of share of users that pay, by gender



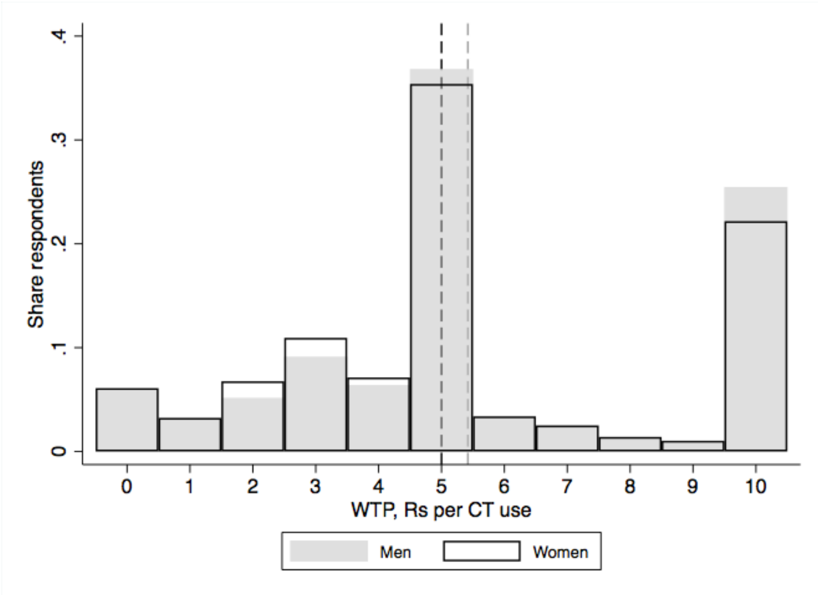
Note: Data collected in the baseline community toilet survey. Data corresponds to counts of the number of users and those that pay in the lapse of 1 hour at dawn, when users traffic is the highest. The distribution of the percentage of men that pay is denoted by the gray bars and the distribution of women by the white bars.

FIGURE 3.2: Distribution of willingness to pay for using community toilets, by gender



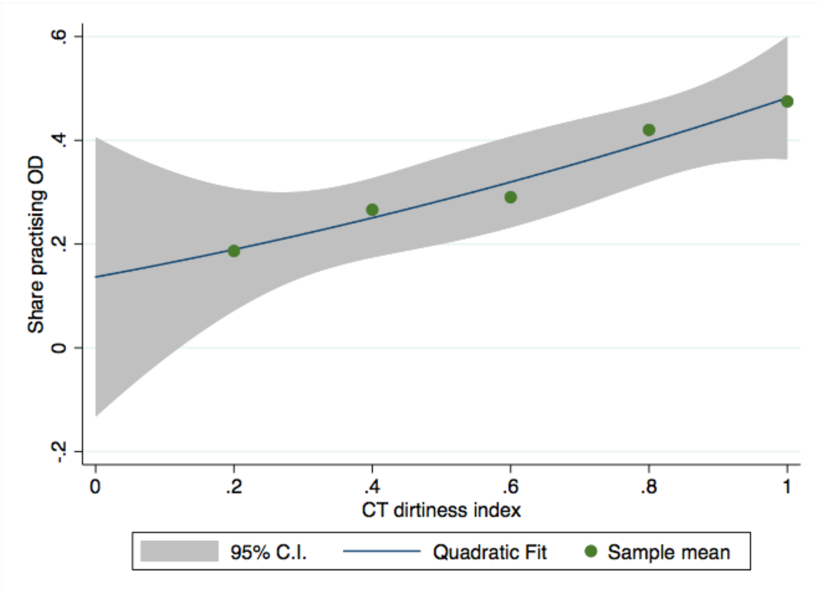
Note: Data collected in the Baseline community toilet survey. Data corresponds to the minimum price per ticket at which the respondent started to prefer cash in the willingness to pay behavioural experiment. The distribution of the percentage of men that pay is denoted by the gray bars and the distribution of women by the white bars.

FIGURE 3.3: Distribution of WTP for using hypothetical high-quality CTs, by gender



Note: Data collected in the Baseline community toilet survey. Data corresponds to the minimum price per ticket at which the respondent started to prefer cash in the willingness to pay behavioural experiment. The distribution of the percentage of men that pay is denoted by the gray bars and the distribution of women by the white bars.

FIGURE 3.4: Share practising open defecation, by CT dirtiness



Note: Data collected in the Baseline household and community toilet surveys. The x-axis shows the dirtiness index ranging from 0 to 1 and the y-axis the share of households reporting that at least one member defecates in the open. The blue line shows the quadratic fit, the gray area the confidence intervals and the green dots the open defecation share for every dirtiness index bin.

TABLE 3.1: Treatment effects on the quality of CTs

	(1) Bacteria	(2) Dirty compound	(3) Dirty cubicle	(4) Bad infrastructure
Panel A: Shorter-run				
Supply push	-0.14*	-0.04	-0.02	-0.02
	(0.09)	(0.03)	(0.03)	(0.05)
Supply push + Campaign	-0.14	-0.04	-0.04	-0.05
	(0.09)	(0.02)	(0.03)	(0.04)
SS = SS + C [p-value]	0.92	0.98	0.45	0.46
Mean (Control)	3.07	0.23	0.46	0.27
Obs-round	219	217	217	217
Community	111	111	111	111
Panel B: Longer-run				
Supply push	0.02	-0.02	-0.06*	-0.03
	(0.07)	(0.02)	(0.03)	(0.04)
Supply push + Campaign	0.12	-0.01	-0.01	-0.04
	(0.07)	(0.03)	(0.04)	(0.04)
SS = SS + C [p-value]	0.22	0.68	0.22	0.94
Mean (Control)	3.07	0.23	0.46	0.27
Obs-round	324	325	325	325
Community	111	111	111	111

*Notes. Analysis at the community toilet level. Sample in Panel A includes follow up 1 (2 months after Baseline) and follow-up 2 (4 months after Baseline), right after the Grant Scheme was provided and before the first payment of the Financial Reward Scheme. Sample in Panel B includes the remaining follow-up rounds of the community toilet panel survey: Follow-up 3 (6 months after Baseline), Follow-up 4 (8 months after Baseline) and Endline (more than 1 year after Baseline). All specifications include round dummies and strata variables as control: (i) city and (ii) managed by main provider. Standard errors clustered by slum in parenthesis to deal with serial correlation. Statistical significance denoted by * $p<0.1$, ** $p<0.05$, and *** $p<0.01$.*

TABLE 3.2: Treatment effects on attitudes towards CTs

	(1) WASH	(2) Clean	(3) Infrastructure	(4) Safe
Panel A: Shorter-run				
Supply push	0.02	0.01	0.08**	0.03
	(0.05)	(0.05)	(0.04)	(0.05)
Supply push + Campaign	-0.09*	-0.00	0.01	-0.02
	(0.05)	(0.05)	(0.04)	(0.04)
SS = SS + C [p-value]	0.03	0.76	0.13	0.31
Mean (control)	0.52	0.42	0.20	0.31
Obs-round	1,532	1,532	1,532	1,532
Slums	110	110	110	110
Panel B: Longer-run				
Supply push	0.00	-0.01	0.01	0.02
	(0.04)	(0.04)	(0.02)	(0.02)
Supply push + Campaign	-0.01	-0.02	0.03	-0.00
	(0.04)	(0.04)	(0.02)	(0.02)
SS = SS + C [p-value]	0.84	0.84	0.32	0.41
Mean (control)	0.53	0.35	0.13	0.17
Obs-round	3,358	3,358	3,358	3,358
Slums	110	110	110	110

*Notes. Analysis at the household level. Sample in Panel A includes the Rapid Assessment round of the household panel survey, after the Grant Scheme was provided and before the first payment of the Financial Reward Scheme. Sample in Panel B includes the Midline and Endline rounds. All specifications include round dummies and strata variables as control: (i) city and (ii) managed by main provider. Standard errors clustered by slum in parenthesis. Statistical significance denoted by: *** p<0.01, ** p<0.05, * p<0.1.*

TABLE 3.3: Treatment effects on willingness and attitudes to pay and demand for public intervention

	(1)	(2)	(3)	(4)	(5)
	WTP	Negative ATP	Public intervention		
			CT dirty	OD	Other
Panel A: Shorter-run					
Supply push	-0.07				
	(0.12)				
Supply push + Campaign	-0.24*				
	(0.13)				
SS = SS + C [p-value]	0.15				
Mean (Control)	1.20				
Obs-round	2,695				
Community	110				
Panel B: Longer-run					
Supply push	0.09	0.04***	0.06*	-0.08*	-0.03
	(0.11)	(0.01)	(0.03)	(0.04)	(0.03)
Supply push + Campaign	-0.06	0.02	0.05	-0.07*	-0.02
	(0.10)	(0.02)	(0.03)	(0.04)	(0.03)
SS = SS + C [p-value]	0.18	0.22	0.91	0.81	0.66
Panel C: Merged treatment					
Treatments	0.01	0.03**	0.05**	-0.07**	-0.03
	(0.09)	(0.01)	(0.03)	(0.04)	(0.02)
Mean (Control)	1.20	0.41	0.10	0.43	0.85
Obs-round	6,113	3,301	1,580	1,582	1,580
Community	110	110	110	110	110

*Notes. Analysis at the individual level for columns (1) and (2) and household level for columns (3) to (5). Sample in Panel A includes only the Rapid Assessment follow-up round of the panel household survey. For the willingness to pay outcome, the sample in Panel B includes both Midline and Endline follow-up rounds. The attitudes towards paying the fees were measured only during the Endline follow-up survey. The demand for public interventionw as measured only during the Midline survey. All specifications include round dummies and strata variables as control: (i) city and (ii) managed by main provider. Columns (1) and (2) additionally control for gender. Standard errors clustered by slum in parenthesis. Statistical significance denoted by: *** p<0.01, ** p<0.05, * p<0.1.*

TABLE 3.4: Treatment effects on sanitation behaviour

	(1)	(2)	(3)	(4)	(5)	(6)
	CT use	% Pay	OD	CT use	Latrine	Use soap
Panel A: Shorter-run						
Supply push	-7.13**	0.03	-0.03	0.01	-0.01	0.04***
	(3.44)	(0.06)	(0.06)	(0.06)	(0.01)	(0.01)
Supply push + Campaign	0.37	0.06	-0.08	0.01	0.03	0.02
	(4.01)	(0.06)	(0.05)	(0.06)	(0.02)	(0.02)
SS = SS + C [p-value]	0.04	0.60	0.45	0.96	0.05	0.01
Mean (Control)	30.08	0.55	0.28	0.66	0.05	0.95
Obs-round	218	218	1,532	1,532	1,532	1,532
Community	111	111	110	110	110	110
Panel B: Longer-run						
Supply push	-0.39	0.08	0.03	-0.02	-0.02	0.01
	(1.77)	(0.05)	(0.06)	(0.04)	(0.02)	(0.01)
Supply push + Campaign	-0.61	0.11**	0.02	-0.04	0.00	0.01
	(1.62)	(0.05)	(0.05)	(0.03)	(0.02)	(0.01)
SS = SS + C [p-value]	0.89	0.52	0.89	0.67	0.19	0.65
Mean (Control)	30.08	0.55	0.28	0.33	0.10	0.95
Obs-round	324	324	3,358	3,358	3,358	3,358
Community	111	111	110	110	110	110

*Notes. Analysis at the community toilet level for columns (1) and (2), where the outcomes correspond to a tally of the number of users and those that pay in a random day at dawn (when the CT has the highest traffic). For the CT-level analysis, Sample in Panel A includes follow up 1 (2 months after) and follow-up 2 (4 months after), right after the Grant Scheme was provided and before the first payment of the Financial Reward Scheme. Sample in Panel B includes the remaining follow-up rounds of the community toilet panel survey. Analysis at the household level for columns (3) to (6), where the outcomes correspond to self-reports. The first outcome is an indicator of whether at least one household members practices open defecation the last time he/she defecated (column 3); the second outcome indicates whether all household members always use the community toilet to defecate (column 4); the third outcome indicates whether the household owns a private latrine (column 5) and the last outcome is an indicator of whether the respondent and its partner, usually the household head and spouse, washed their hands with soap the last time they washed their hands (column 6). For the household level analysis, sample in Panel A includes only the Rapid Assessment follow-up round of the panel household survey and in Panel B, the Midline and Endline survey rounds. All specifications include round dummies and strata variables as control: (i) city and (ii) managed by main provider. Standard errors clustered by slum in parenthesis to deal with serial correlation. Statistical significance denoted by * $p<0.1$, ** $p<0.05$, and *** $p<0.01$.*

TABLE 3.5: Heterogeneous treatment effects on WTP, ATP and demand for public intervention, by gender

	(1)	(2)	(3)	(4)	(5)	(6)
	WTP		Negative ATP		Public int - CT	
	Men	Women	Men	Women	Men	Women
Supply push	-0.01	0.09	0.03	0.05***	0.02	0.04*
	(0.10)	(0.09)	(0.02)	(0.02)	(0.02)	(0.02)
Supply push + Campaign	-0.13	-0.10	0.01	0.02	0.01	0.04
	(0.10)	(0.08)	(0.02)	(0.02)	(0.02)	(0.02)
SS = SS + C [p-value]	0.23	0.05	0.47	0.14	0.81	0.91
Mean (control)	1.28	1.02	0.38	0.43	0.06	0.05
Obs-round	111	111	110	110	110	110
Slums	4,234	4,574	1,635	1,666	1,580	1,580

*Notes. Analysis at the individual level for columns (1) and (2) and household level for columns (3) to (5). Sample in column (1)-(2) include all rounds, columns (3)-(4) only Endline and columns (5)(6) Endline follow-up rounds. The attitudes towards paying the fees were measured only during the Endline follow-up survey and the demand for public interventionw as measured only during the Midline survey. All specifications include round dummies and strata variables as control: (i) city and (ii) managed by main provider. Standard errors clustered by slum in parenthesis. Statistical significance denoted by: *** p<0.01, ** p<0.05, * p<0.1.*

TABLE 3.6: Heterogeneous treatment effects on sanitation behaviour, by gender

	(1)	(2)	(3)	(4)
	CT use		% Pay	
	Men	Women	Men	Women
Panel A: Shorter-run				
Supply push	-4.40**	-2.73	0.04	0.02
	(1.95)	(1.87)	(0.06)	(0.08)
Supply push + Campaign	0.99	-0.62	0.07	0.02
	(2.36)	(2.51)	(0.05)	(0.08)
SS = SS + C [p-value]	0.02	0.34	0.51	0.98
Mean (Control)	19.17	10.90	0.66	0.36
Obs-round	218	218	218	218
Community	111	111	111	111
Panel B: Longer-run				
Supply push	-1.00	0.61	0.09*	0.08
	(1.22)	(0.80)	(0.05)	(0.07)
Supply push + Campaign	-0.94	0.32	0.12***	0.12*
	(1.14)	(0.76)	(0.04)	(0.07)
SS = SS + C [p-value]	0.96	0.73	0.60	0.59
Mean (Control)	19.17	10.90	0.66	0.36
Obs-round	324	324	324	324
Community	111	111	111	111

*Notes. Analysis at the community toilet level for columns (1) and (2), where the outcomes correspond to a tally of the number of users and those that pay in a random day at dawn (when the CT has the highest traffic). For the CT-level analysis, Sample in Panel A includes follow up 1 (2 months after) and follow-up 2 (4 months after), right after the Grant Scheme was provided and before the first payment of the Financial Reward Scheme. Sample in Panel B includes the remaining follow-up rounds of the community toilet panel survey. All specifications include round dummies and strata variables as control: (i) city and (ii) managed by main provider. Standard errors clustered by slum in parenthesis to deal with serial correlation. Statistical significance denoted by * $p<0.1$, ** $p<0.05$, and *** $p<0.01$.*

TABLE 3.7: Treatment effects on sanitation behaviour (list randomization), by gender

	(1) Men	(2) Women
Treatments * OD	0.23*	0.12
	(0.12)	(0.12)
Treatments * CT use	0.03	0.17
	(0.13)	(0.14)
Treatments * Hand-washing with soap	0.07	0.03
	(0.11)	(0.12)
Mean OD (Control)	0.20	0.24
Mean CT (Control)	0.66	0.52
Mean HW (Control)	0.73	0.90
Obs-round	1,643	1,682
Community	110	110

Notes. Sample includes Endline round of the panel household survey. All specifications include strata variables as control: (i) city and (ii) managed by main provider. Standard errors in parenthesis. Statistical significance denoted by * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

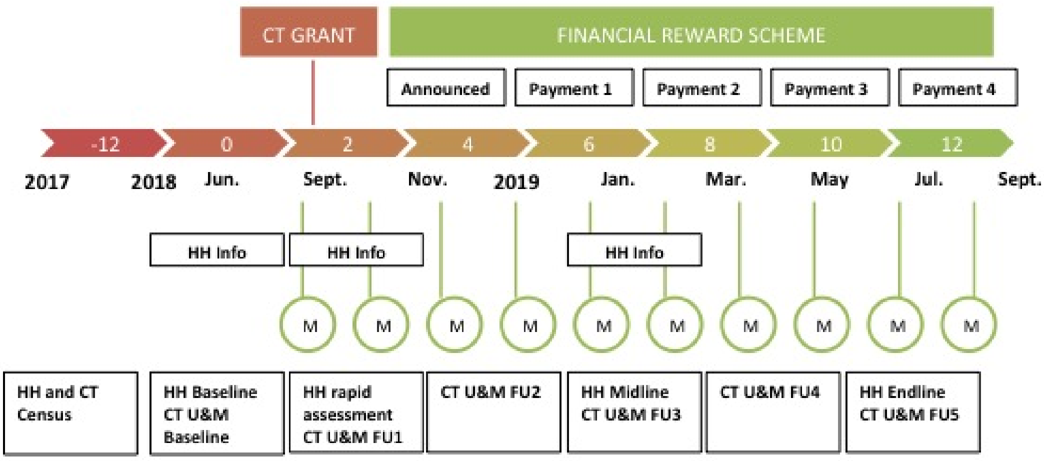
TABLE 3.8: Treatment effects on expectations and awareness of health risks

	(1)	(2)	(3)	(4)	(5)	(6)
	Illness OD vs. CT		Illness dirty vs. clean CT		Health risks	
	Adults	Children	Adults	Children	Private	Public
Panel A: Shorter-run						
Supply push	-0.01	0.21	-0.12	0.09	-0.02	-0.00
	(0.03)	(0.14)	(0.08)	(0.07)	(0.03)	(0.04)
Supply push + Campaign	0.00	0.08	-0.09	0.12**	-0.02	-0.03
	(0.02)	(0.10)	(0.06)	(0.06)	(0.03)	(0.04)
SS = SS + C [p-value]	0.64	0.43	0.73	0.73	0.85	0.51
Mean (control)	0.77	0.77	0.80	0.82	0.77	0.54
Obs-round	1,532	1,532	1,532	1,532	1,532	1,532
Slums	110	110	110	110	110	110
Panel B: Longer-run						
Supply push	0.01	-0.00	0.00	0.01	0.02	0.02
	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)	(0.03)
Supply push + Campaign	0.02	0.01	0.03*	0.01	0.08***	-0.03
	(0.01)	(0.02)	(0.02)	(0.02)	(0.03)	(0.03)
SS = SS + C [p-value]	0.38	0.62	0.10	0.81	0.04	0.09
Mean (control)	0.76	0.77	0.85	0.85	0.61	0.60
Obs-round	3,358	3,358	3,358	3,358	3,358	3,358
Slums	110	110	110	110	110	110

*Notes. Analysis at the household level. Sample in Panel A includes the Rapid Assessment round of the household panel survey, right after the Grant Scheme was provided and before the first payment of the Financial Reward Scheme. Sample in Panel B includes the Midline and Endline rounds. All specifications include round dummies and strata variables as control: (i) city and (ii) managed by main provider. Standard errors clustered by slum in parenthesis. Statistical significance denoted by: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.*

3.6 Appendix

FIGURE 3.5: Time of data collection and intervention



Note: This figure illustrates how our different data collection efforts were structured. During the first half of 2017, we undertook a census of more than 400 community toilets in the two cities of study and during the second half of 2017, we conducted a census of more than 30,000 households living within slum borders and 400 meters from a pay-to-use community toilet. These censuses were subsequentially used to identify eligible community toilets and households, assign slums to treatment and control groups and as the basis from which we drew the sample of households for our panel survey. We collected household-level data in a sequence of four waves: a baseline survey in April-June 2018, a rapid assessment between July and September 2018, a midline survey between January and March 2019 and an endline survey one year after the baseline in July-September 2019. In addition, we collected community toilet-level data in a sequence of six waves: a baseline survey in April-June 2018, a first follow-up between July and September 2018, a second follow-up in October-November 2018, a midline survey between January and March 2019, a fourth follow-up between April-May 2019 and an endline survey one year after the baseline in July-September 2019. This figure also shows the timeline of the different interventions. At the community toilet level (upper panel), we start by providing the Grant Scheme right after the baseline data collection; we announce the Financial Reward Scheme two months after and we pay the reward every two months onwards. At the household level (middle panel), we start the information campaign right after the baseline and we repeat the door-to-door visits right after the rapid assessment and midline survey rounds. We also send messages every month of the study (denoted by M). The timeline shows the evolution of the intervention and its different components relative to the data collection (lower panel).

3.6.1 Sampling strategy

This study performs a two-level randomization design and therefore, we are interested in two different level of the sampling frame. 3.6 summarizes the sampling strategy. The first level of the sampling frame is defined by all community toilets (CTs) in the cities of Lucknow and Kanpur. In order to obtain this sampling frame, we performed a CT Census in both study cities. This census collected GPS coordinates and information on CT characteristics. We identified at total of 409 CT. Figure 3.6 presents the distribution of CTs in Lucknow (left map) and Kanpur (right map).

FIGURE 3.6: Sampling frame

The second-level sampling frame is characterized by all households in the catchment areas of selected community toilets (which represents a cluster). Out of the 409 CTs identified in the first stage, we chose a subset of CTs to become part of the study, based on the following criteria: the CT has to be pay-to-use; the CT has to be located close to a residential area (slum) and used by residents. We drop CTs for which the distance to another CT is below a certain threshold. In particular, there should be sufficient distance between two CTs to avoid users switching between CTs (possibly driven by their treatment status). We drop CTs that are closer than 300 meters to each other, and CTs that have two other CTs closer than 350 meters.

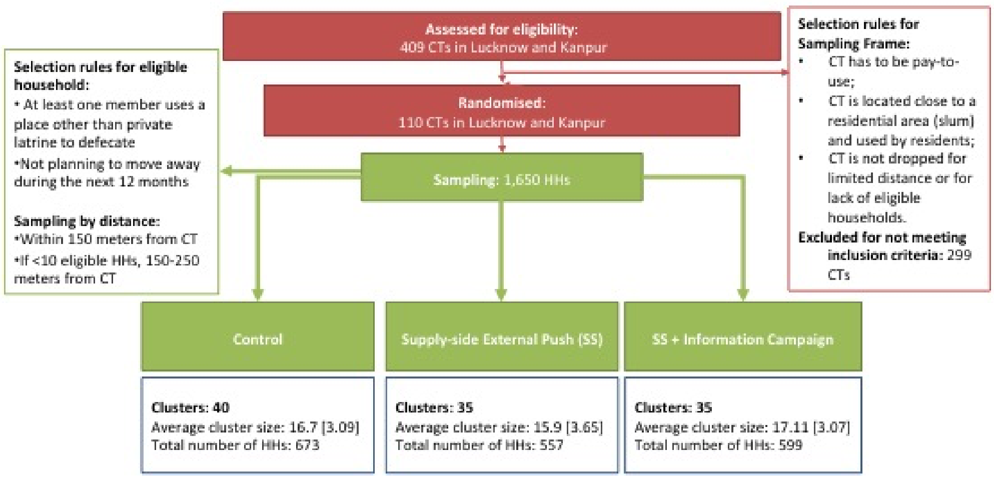
In addition, we drop CTs in whose catchment areas fewer than eight eligible households are living. A household is considered eligible if the following conditions are respected: the household lives in the catchment area of a selected CT, which is broadly defined as slum area within 250 meters from the CT building. Households are linked to CTs based on GPS coordinates collected during the census;[10] at least one household member uses a CT or shared toilets (i.e. neighbours, makeshift, work, school), or practices open defecation; the

[10]A small percentage of households with inaccurate geo-coordinates (missing geocodes or distance to closest community toilet greater than the 400 meters buffer area set for household census) were linked to the community toilet located in the slum (0.7 percent in Lucknow and 1.6 percent in Kanpur). In these cases, we imputed the distance to the community toilet using the median of eligible households in the slum.

household must have reported during the census interview not to intend to migrate during the following 18 months (i.e. until the planned study endline survey).

Figure 3.7 shows the flowchart for the CT and household sampling procedure. Within each of the 110 CTs and their catchment areas, we sampled up to 17 eligible households. Given that distance is a major determinant of CT usage, we focused on eligible households living closer to the CT (within 150 meters). Since some CTs have more dispersed populations, we conducted a two-step sampling procedure. First, in large-population catchment areas (where 10 or more eligible households are available within 150 meters), we sampled only from eligible households that are located within this bound. Second, in small-population CTs (where less than 10 eligible households are available within 150 meters), we first sampled all eligible households within 150 meters and then randomly selected the remaining households from those that are located between 150 and 250 meters from the CT. In total, we sampled for interview 1,650 households in 110 randomization units (catchment areas of CTs) and one CT caretaker per randomization unit.

FIGURE 3.7: Sampling procedure



Notes. The flowchart presents the procedure followed for the sampling of community toilets and its catchment area for the surveys.

TABLE 3.9: Descriptive statistics of slum population

	(1) India	(2) Uttar Pradesh	(3) Study sample
Male	0.52	0.53	0.53
Female	0.48	0.47	0.47
Sex ratio	1.08	1.12	1.12
Children 0-6	0.12	0.14	0.09
Scheduled Castes	0.20	0.22	0.45
Literacy rate	0.78	0.69	0.46

Note: The table describes the slum population in India (column 1), Uttar Pradesh (column 2) and the study sample (column 3). All rows denote the share of the population with each characteristic, except for the sex ratio and the literacy rate. The source of data for the first and second column is the Indian Slum Population Census of 2011.

TABLE 3.10: Distribution of selected CTs and households, by treatment arm and city

	Control (1)	**External push** (2)	**Push + Campaing** (3)	**Total** (4)
A. CTs				
Total (%)	40(36.36)	35 (31.82)	35 (31.82)	110 (100)
- Lucknow (%)	19 (36.54)	17 (32.69)	16 (30.77)	52 (100)
-Kanpur (%)	21 (36.21)	18 (31.03)	19 (32.76)	58 (100)
B. Households				
Total (%)	576 (36.57)	487 (30.92)	512 (32.51)	1,575 (100)
-Lucknow (%)	255 (35.47)	225 (31.29)	239 (33.24)	719 (100)
-Kanpur (%)	321 (37.5)	262 (30.61)	273 (31.89)	856 (100)

Notes. This table presents the distribution of selected CTs (panel A) and households (panel B) by treatment arm and city.

TABLE 3.11: Attrition across rounds of household panel survey

	(1) Rapid assessment	(2) Midline	(3) Endline	(4) Total
Baseline	9%	19%	14%	1,575
Rapid assessment		17%	12%	1,532
Midline			9%	1,586
Endline				1,772

Note: The table shows the attrition rate across different household survey rounds. Row (1) shows the attrition rate with respect to the baseline survey. Rows (2)-(4) shows the attrition rate with respect to the rapid assessment and midline surveys, respectively. Column presents the total number of households surveyed in each survey round, including replacements.

3.6.2 Measurements

TABLE 3.12: Variable definition

Variable name	Definition
Household:	
Attitudes towards CTs: WASH	Dummy =1 if likes water, sanitation and hygiene facilities in CT
Attitudes towards CTs: Clean	Dummy =1 if likes cleanliness of CT
Attitudes towards CTs: Infrastructure	Dummy =1 if likes infrastructure of the CT
Attitudes towards CTs: Safe	Dummy =1 if likes safety of the CT
Expectations: Illness OD vs. CT	Difference in % adults or children expected to get ill if everybody practices OD vs. using CT
Expectations: Illness dirty vs. clean CT	Difference in % adults or children expected to get ill if everybody practices uses a dirty CT vs. a clean CT
Awareness of OD health risks: private	Dummy=1 if mentions OD can affect health of their own family
Awareness of OD health risks: public	Dummy=1 if mentions OD can affect health of their community
Willingness to pay	Amount of cash that respondent prefers instead of ticket to use CT
Demand for public intervention: CT dirty	Dummy = 1 if reports CT dirty as most pressing policy issue
Demand for public intervention: OD	Dummy = 1 if reports open defecation as most pressing policy issue
Demand for public intervention: Child ill	Dummy = 1 if reports child illness as most pressing policy issue
Demand for public intervention: No water	Dummy = 1 if reports lack of water as most pressing policy issue
Demand for public intervention: Other issues	Dummy = 1 if reports other issues as most pressing policy issue
OD	Dummy =1 if at least 1 member (above 5y) practiced open defecation during last episode
CT use	Dummy =1 if all HH members (above 5y) used CT during last episode
Latrine	Dummy =1 if reports having functional latrine
Handwash	Dummy =1 if respondent reports (and spouse) washing hands with soap during last episode
Community Toilet:	
Bacteria	Number of bacteria species
% Collect fees	% time caretaker allocates to collect fees
% Clean	% time caretaker allocates to clean and supervise cleaner
% Repairs	% time caretaker allocates to conduct repairs
% Manager	% time caretaker allocates to deal with the manager
% Leisure	% time caretaker allocates to socialize and rest
CT use	Total number of users counted in the tally at dawn
% Pay	% users that pay in the tally at dawn
Indexes	
Dirty compound	Index of dirtiness in CT compound
Dirty cubicles	Index of dirtiness in CT female and male cubicles
Bad infrastructure	Index of bad CT infrastructure quality
Negative attitudes to pay	Index of negative attitudes towards paying the fee to use the CT

We construct our outcome indexes using principal components analysis. We use all principal components for each family of outcomes. The index is standardized to range between 0 and 1. Below we report a list of variables contained in each index, denoting whether the variable enters the index with a positive or negative sign. The individual variables and their loading factors are shown below.

TABLE 3.13: HH index construction

Index family	**Sign**	**1st component's loading**
Negative attitudes to pay		0.262
Why do you think the community toilet charges a fee to use it?	+	
To pay for services (lighting, honey sucker, etc.) in CT	-	
To pay for caretaker and/or cleaner salaries	-	
To fill CT managers' pockets	+	
To fill the government's pockets	+	
Who do you think should be paying for the operation and maintenance of the community toilet?	+	0.427
Fees from users	-	
Government	+	
CT managers	+	
Caretakers	+	
Do you think the community toilet should charge a fee for usage?	+	0.599
Yes, for everybody	-	
Yes, but free for some people	+	
No, it should be free for everybody	+	
Do you think people are justified to pay less or not pay for the CT if the government increases funds for maintaining the CT in good shape?	+	0.582
No, fees are still needed to keep CT clean and running	-	
If government gives funds, people should pay less	+	
If government gives funds, CT should be free	+	
What would you prefer:		0.225
Paying community toilet fees and having a clean toilet	-	
Paying half price, but having a not so clean toilet	+	
Not paying fee and having a dirty toilet	+	

TABLE 3.14: CT index construction

Index family	**Sign**	**1st component's loading**
Bad infrastructure		
At least one latrine not functioning	+	0.297
At least one door not functioning	+	0.344
At least one lock not functioning	+	0.325
Rudimentary walls	+	0.246
Poor painting	+	0.207
Female cubicle lighting	+	0.395
Working	-	
Intermittent	+	
No	+	
Male cubicle lighting	+	0.390
Working	-	
Intermittent	+	
No	+	
Compound lighting	+	0.310
Working	-	
Intermittent	+	
No	+	
Hand-washing facilities available for both genders	-	0.307
Soap available and visible for both genders	-	0.295
Dirty compound		
CT dirty	+	0.524
Strong	+	
Mild	+	
No	-	
CT stinky	+	0.552
Strong	+	
Mild	+	
No	-	
Flies	+	0.526
Heavy	+	
Some	+	
None	-	
Sewage leaks inside	+	0.288
Heavy	+	
Some	+	
None	-	
Sewage leaks outside	+	0.248
Heavy	+	
Some	+	
None	-	

TABLE 3.15: CT index construction (continuation)

Index family	**Sign**	**1st component's loading**
Dirty cubicle		
Female cubicle dirty		0.258
Strong	+	
Mild	+	
No	-	
Female cubicle stinky		0.291
Strong	+	
Mild	+	
No	-	
Female cubicle with faeces inside latrine	+	0.352
Majority	+	
Some	+	
None	-	
Female cubicle with faeces outside latrine	+	0.353
Majority	+	
Some	+	
None	-	
Female cubicle with flies	+	0.356
Majority	+	
Some	+	
None	-	
Male cubicle dirty		0.286
Strong	+	
Mild	+	
No	-	
Male cubicle stinky		0.271
Strong	+	
Mild	+	
No	-	
Male cubicle with faeces inside latrine	+	0.313
Majority	+	
Some	+	
None	-	
Male cubicle with faeces outside latrine	+	0.344
Majority	+	
Some	+	
None	-	
Male cubicle with flies	+	0.320
Majority	+	
Some	+	
None	-	

3.6.3 Balance and attrition

TABLE 3.16: Baseline households' and CTs' characteristics balanced across treatments

	(1) Control Mean	(2) Treatments Diff.	(3) Supply-side Diff.	(4) Supply-side+Info Diff.	(5) Joint test (4)-(5) p-value
Household:					
Like CT (items)	1.710	-0.094	-0.156	-0.036	0.495
	[1.392]	(0.122)	(0.140)	(0.135)	
Knowledge: OD private health risk	0.712	0.037	0.036	0.038	0.445
	[0.453]	(0.029)	(0.034)	(0.035)	
Knowledge: OD public health risk	0.651	-0.008	-0.010	-0.007	0.964
	[0.477]	(0.033)	(0.039)	(0.039)	
Illness OD vs. CT (adult)	0.604	0.028	0.015	0.040	0.392
	[0.389]	(0.026)	(0.030)	(0.029)	
Illness OD vs. CT (child)	0.626	0.015	0.011	0.019	0.768
	[0.366]	(0.024)	(0.031)	(0.027)	
Illness dirty vs. clean CT (adult)	0.723	-0.016	-0.014	-0.018	0.763
	[0.334]	(0.022)	(0.025)	(0.027)	
Illness dirty vs. clean CT (child)	0.687	0.005	0.004	0.006	0.969
	[0.378]	(0.023)	(0.026)	(0.026)	
WTP for CT use (men)	1.476	-0.025	0.142	-0.187	0.420
	[2.043]	(0.173)	(0.203)	(0.220)	
WTP for CT use (women)	1.367	-0.037	-0.135	0.054	0.622
	[2.020]	(0.153)	(0.166)	(0.208)	
Price to use CT (men)	4.398	0.059	0.032	0.084	0.811
	[1.298]	(0.145)	(0.171)	(0.145)	
Price ot use CT (women)	3.160	0.212	0.263	0.164	0.625
	[1.846]	(0.254)	(0.271)	(0.308)	
Open defecation	0.321	-0.028	0.022	-0.075	0.199
	[0.467]	(0.051)	(0.060)	(0.056)	
Always uses CT	0.224	-0.007	-0.006	-0.007	0.970
	[0.417]	(0.028)	(0.034)	(0.031)	
Private latrine	0.071	0.014	0.011	0.017	0.706
	[0.257]	(0.017)	(0.019)	(0.021)	
Hand-wash w/ soap	0.929	0.001	0.018	-0.015	0.222
	[0.257]	(0.016)	(0.017)	(0.020)	
Community Toilet:					
Users (observed)	37.410	-2.251	-1.501	-2.938	0.587
	[13.331]	(2.600)	(3.195)	(2.844)	
% users paying (observed)	0.672	-0.046	-0.078	-0.016	0.472
	[0.304]	(0.058)	(0.068)	(0.064)	
Bacteria	3.551	0.072	0.085	0.060	0.784
	[0.503]	(0.105)	(0.130)	(0.122)	
Dirty compound	0.342	-0.014	-0.034	0.003	0.711
	[0.219]	(0.043)	(0.050)	(0.048)	
Dirty cubicles	0.512	-0.002	0.021	-0.024	0.528
	[0.171]	(0.034)	(0.037)	(0.042)	
Bad infrastructure	0.826	0.019	0.046	-0.005	0.189
	[0.210]	(0.038)	(0.035)	(0.048)	

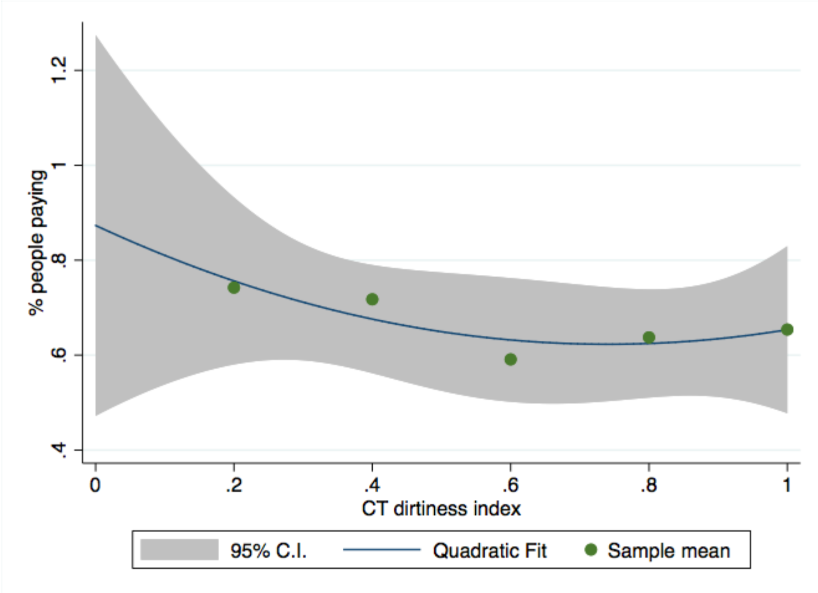
*Notes. Column (1) reports sample mean and standard deviation in brackets for the control group. Column (2) reports the difference with the control group with all treatment groups pooled together using an OLS regression of the correspondent outcome on the treatment indicator. Columns (3)-(4) report the difference with the control group for each treatment group. Standard errors clustered at slum level are reported in parentheses. Column (5) present a joint test of significance of the coefficients for each treatment dummy. Statistical significance denoted by: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.*

TABLE 3.17: Attrition balanced across treatments

	(1)	(2)	(3)
Treatments	-0.01	-0.01	0.03
	(0.04)	(0.04)	(0.05)
Willigness-to-pay (HH mean)		-0.00	0.00
		(0.01)	(0.01)
Open defecation		0.00	0.08
		(0.03)	(0.06)
Willigness-to-pay (HH mean) x Treatments			-0.00
			(0.02)
Open defecation x Treatments			-0.12
			(0.07)
Attrition rate	0.29		
Community	110	110	110
CT-round	1,575	1,575	1,575

Note: The dependent variable is a dummy variable equal to one if the household dropped from at least one of the three follow-up survey rounds (rapid assessment, midline, endline) and zero otherwise. All specifications control for strata variables (managed by main provider and city) and cluster the standard errors at the slum level. Standard errors in parenthesis. Statistical significance denoted by * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

FIGURE 3.8: Share paying to use the CT, by CT dirtiness



Note: Data collected in the Baseline household and community toilet surveys. The x-axis shows the dirtiness index ranging from 0 to 1 and the y-axis the share of users paying to use the CT. The blue line shows the quadratic fit, the gray area the confidence intervals and the green dots the open defecation share for every dirtiness index bin.

3.6.4 Implementation Fidelity

TABLE 3.18: Households exposed to the information campaign recall it

	(1) Any means	(2) Message	(3) Visit	(4) Community	(5) Posters
Panel A: Shorter-run					
Supply push	0.02	0.04	0.03	0.02	0.00
	(0.03)	(0.03)	(0.05)	(0.04)	(.)
Supply push + Campaign	0.07***	0.09***	0.19***	0.10**	0.00
	(0.02)	(0.03)	(0.05)	(0.04)	(.)
SS = SS + C [p-value]	0.03	0.06	0.00	0.06	.
Mean (control)	0.85	0.79	0.40	0.65	0.00
Obs-round	1,532	1,532	1,532	1,532	1,532
Slums	110	110	110	110	110
Panel B: Longer-run					
Supply push	0.05	0.01	0.01	0.02	0.02
	(0.03)	(0.03)	(0.02)	(0.02)	(0.03)
Supply push + Campaign	0.12***	0.09***	0.02	0.05**	0.16***
	(0.03)	(0.03)	(0.02)	(0.02)	(0.03)
SS = SS + C [p-value]	0.03	0.01	0.69	0.31	0.00
Mean (control)	0.59	0.47	0.17	0.17	0.33
Obs-round	3,358	3,358	3,358	3,358	3,358
Slums	110	110	110	110	110

Notes. Sample includes all follow-up rounds of the panel household survey. All specifications include round dummies and strata variables as control: (i) city and (ii) managed by main provider. Standard errors in parenthesis. Statistical significance denoted by * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

3.6.5 Multiple Hypothesis Testing

TABLE 3.19: Treatment effects on the quality of CTs

Hypo	Coef	Pvalue	Adjpvalue
Panel A: Shorter-run			
1	-0.14	0.10	0.50
2	-0.14	0.14	0.54
3	-0.04	0.25	0.55
4	-0.04	0.16	0.52
5	-0.02	0.59	0.83
6	-0.04	0.13	0.58
7	-0.02	0.71	0.71
8	-0.05	0.24	0.62
Panel B: Longer-run			
1	0.02	0.79	0.79
2	0.12	0.13	0.55
3	-0.02	0.29	0.82
4	-0.01	0.67	0.95
5	-0.06	0.09	0.47
6	-0.01	0.79	0.96
7	-0.03	0.44	0.89
8	-0.04	0.38	0.87

Note: Odd rows show the hypothesis of the "Supply push" treatment arm and even of the "Supply push + Campaign" treatment arm. Rows (1) and (2) have "Bacteria" as the outcome, rows (3) and (4) "Dirty compound", rows (5) and (6) "Dirty cubicle" and rows (7) and (8) "Bad infrastructure".

TABLE 3.20: Treatment effects on attitudes towards CTs

Hypo	Coef	Pvalue	Adj-pvalue
Panel A: Shorter-run			
1	0.02	0.65	0.98
2	-0.09	0.09	0.42
3	0.01	0.77	0.94
4	-0.00	0.97	0.97
5	0.08	0.06	0.32
6	0.01	0.74	0.98
7	0.03	0.57	0.99
8	-0.02	0.58	0.98
Panel B: Longer-run			
1	0.00	0.92	0.92
2	-0.01	0.91	1.00
3	-0.01	0.70	0.98
4	-0.02	0.59	0.98
5	0.01	0.68	0.99
6	0.03	0.18	0.67
7	0.02	0.47	0.96
8	-0.00	0.92	0.99

Note: Odd rows show the hypothesis of the "Supply push" treatment arm and even of the "Supply push + Campaign" treatment arm. Rows (1) and (2) have the CT characteristics "WASH" as the outcome, rows (3) and (4) "Clean", rows (5) and (6) "Infrastucture" and rows (7) and (8) "Safe".

TABLE 3.21: Treatment effects on WTP and ATP

Hypo	Coef	Pvalue	Adj-pvalue
1	0.09	0.43	0.64
2	-0.06	0.55	0.55
3	0.04	0.01	0.07
4	0.02	0.23	0.54
5	0.06	0.10	0.44
6	0.05	0.13	0.41
7	-0.08	0.06	0.34
8	-0.07	0.11	0.42

Note: Odd rows show the hypothesis of the "Supply push" treatment arm and even of the "Supply push + Campaign" treatment arm. Rows (1) and (2) have "Willigness to pay" as the outcome, rows (3) and (4) "Attitude to pay", rows (5) and (6) "Demand for public intervention in CTs" and rows (7) and (8) "Demand for public intervention in OD".

TABLE 3.22: Treatment effects on sanitation behaviour (reported)

Hypo	Coef	Pvalue	Adj-pvalue
Panel A: Shorter-run			
1	-0.03	0.64	0.93
2	-0.08	0.17	0.64
3	0.01	0.86	0.98
4	0.01	0.88	0.88
5	-0.01	0.37	0.77
6	0.03	0.22	0.62
7	0.04	0.02	0.15
8	0.02	0.19	0.65
Panel B: Longer-run			
1	0.03	0.68	0.96
2	0.02	0.74	0.93
3	-0.02	0.67	0.98
4	-0.04	0.26	0.81
5	-0.02	0.24	0.82
6	0.00	0.94	0.94
7	0.01	0.60	0.98
8	0.01	0.38	0.91

Note: Odd rows show the hypothesis of the "Supply push" treatment arm and even of the "Supply push + Campaign" treatment arm. Rows (1) and (2) have "CT use" as the outcome, rows (3) and (4) "Open defecation", rows (5) and (6) "Has a toilet" and rows (7) and (8) "Hand-washing with soap".

TABLE 3.23: Treatment effects on expectations and awareness of health risks

Hypo	Coef	Pvalue	Adj-pvalue
Panel A: Shorter-run			
1	-0.01	0.74	0.98
2	0.00	0.88	0.99
3	0.21	0.23	0.87
4	0.08	0.45	0.98
5	-0.12	0.20	0.83
6	-0.09	0.15	0.76
7	0.09	0.27	0.90
8	0.12	0.06	0.45
9	-0.02	0.47	0.97
10	-0.02	0.61	0.97
11	-0.00	0.99	0.99
12	-0.03	0.47	0.95
Panel B: Longer-run			
1	0.01	0.77	0.96
2	0.02	0.14	0.62
3	-0.00	0.83	0.96
4	0.01	0.71	0.98
5	0.00	0.89	0.89
6	0.03	0.08	0.44
7	0.01	0.67	0.98
8	0.01	0.55	0.95
9	0.02	0.40	0.94
10	0.08	0.01	0.05
11	0.02	0.53	0.97
12	-0.03	0.31	0.89

Note: Odd rows show the hypothesis of the "Supply push" treatment arm and even of the "Supply push + Campaign" treatment arm. Rows (1) and (2) have "Illness OD vs. CT - Adults" as the outcome, rows (3) and (4) "Illness OD vs. CT - children", rows (5) and (6) "Illness dirty vs. clean CT - adults" and rows (7) and (8) "Illness dirty vs. clean CT - children", rows (9) and (10) "Public health risks" and rows (11) and (12) "Private health risks".

3.6.6 ANCOVA

TABLE 3.24: Treatment effects on the quality of CTs (ANCOVA)

	(1)	(2)	(3)	(4)
	Bacteria	Dirty compound	Dirty cubicle	Bad infrastructure
Panel A: Shorter-run				
Supply push	-0.15*	-0.02	0.01	-0.01
	(0.08)	(0.03)	(0.03)	(0.05)
Supply push + Campaign	-0.14	-0.04	-0.04	-0.05
	(0.09)	(0.02)	(0.03)	(0.04)
SS = SS + C [p-value]	0.89	0.51	0.12	0.31
Mean (Control)	3.07	0.23	0.46	0.27
Obs-round	217	213	213	213
Community	109	108	108	108
Panel B: Longer-run				
Supply push	0.01	-0.01	-0.03	-0.02
	(0.08)	(0.02)	(0.03)	(0.05)
Supply push + Campaign	0.11	-0.01	0.01	-0.04
	(0.08)	(0.03)	(0.03)	(0.04)
SS = SS + C [p-value]	0.21	0.94	0.26	0.67
Mean (Control)	3.07	0.23	0.45	0.28
Obs-round	318	315	315	315
Community	109	107	107	107

*Notes. Analysis at the community toilet level. Sample in Panel A includes follow up 1 (2 months after Baseline) and follow-up 2 (4 months after Baseline), right after the Grant Scheme was provided and before the first payment of the Financial Reward Scheme. Sample in Panel B includes the remaining follow-up rounds of the community toilet panel survey: Follow-up 3 (6 months after Baseline), Follow-up 4 (8 months after Baseline) and Endline (more than 1 year after Baseline). All specifications include round dummies and strata variables as control: (i) city and (ii) managed by main provider. Standard errors clustered by slum in parenthesis to deal with serial correlation. Statistical significance denoted by * $p<0.1$, ** $p<0.05$, and *** $p<0.01$.*

TABLE 3.25: Treatment effects on attitudes towards CTs (ANCOVA)

	(1) WASH	(2) Clean	(3) Infrastructure	(4) Safe
Panel A: Shorter-run				
Supply push	0.02	0.01	0.07*	0.02
	(0.05)	(0.05)	(0.04)	(0.05)
Supply push + Campaign	-0.07	0.01	0.02	-0.01
	(0.05)	(0.05)	(0.04)	(0.05)
SS = SS + C [p-value]	0.07	0.93	0.26	0.47
Mean (control)	0.52	0.42	0.20	0.30
Obs-round	1,434	1,434	1,434	1,434
Slums	110	110	110	110
Panel B: Longer-run				
Supply push	-0.01	-0.03	0.01	0.02
	(0.04)	(0.04)	(0.02)	(0.03)
Supply push + Campaign	-0.02	-0.02	0.02	0.00
	(0.04)	(0.04)	(0.02)	(0.02)
SS = SS + C [p-value]	0.86	0.83	0.50	0.49
Mean (control)	0.54	0.36	0.13	0.16
Obs-round	2,622	2,622	2,622	2,622
Slums	109	109	109	109

*Notes. Analysis at the household level. Sample in Panel A includes the Rapid Assessment round of the household panel survey, after the Grant Scheme was provided and before the first payment of the Financial Reward Scheme. Sample in Panel B includes the Midline and Endline rounds. All specifications include round dummies and strata variables as control: (i) city and (ii) managed by main provider. Standard errors clustered by slum in parenthesis. Statistical significance denoted by: *** p<0.01, ** p<0.05, * p<0.1.*

TABLE 3.26: Treatment effects on WTP (ANCOVA)

	(1)
	WTP
Panel A: Shorter-run	
Supply push	-0.09
	(0.13)
Supply push + Campaign	-0.25**
	(0.13)
SS = SS + C [p-value]	0.16
Mean (control)	1.04
Obs-round	2,272
Slums	110
Panel B: Longer-run	
Supply push	0.06
	(0.12)
Supply push + Campaign	-0.04
	(0.11)
SS = SS + C [p-value]	0.43
Mean (control)	1.16
Obs-round	4,192
Slums	109

*Notes. Sample in Panel A includes only the Rapid Assessment follow-up round of the panel household survey and Panel B the Midline and Endline. All specifications include round dummies and strata variables as control: (i) city and (ii) managed by main provider. Columns (1) and (2) additionally control for gender. Standard errors clustered by slum in parenthesis. Statistical significance denoted by: *** p<0.01, ** p<0.05, * p<0.1.*

TABLE 3.27: Treatment effects on sanitation behaviour (ANCOVA)

	(1) CT use	(2) % Pay	(3) OD	(4) CT use	(5) Latrine	(6) Use soap
Panel A: Shorter-run						
Supply push	-6.72*	0.05	-0.04	0.00	-0.01	0.04***
	(3.57)	(0.05)	(0.05)	(0.06)	(0.01)	(0.01)
Supply push + Campaign	0.16	0.06	-0.06	0.01	0.03	0.02
	(3.81)	(0.05)	(0.04)	(0.05)	(0.02)	(0.02)
SS = SS + C [p-value]	0.06	0.83	0.77	0.89	0.02	0.01
Mean (Control)	3.07	0.23	0.28	0.66	0.05	0.05
Obs-round	214	214	1,434	1,434	1,434	1,434
Community	108	108	110	110	110	110
Panel B: Longer-run						
Supply push	-0.56	0.08*	0.02	-0.01	-0.02	0.00
	(1.82)	(0.05)	(0.05)	(0.05)	(0.02)	(0.01)
Supply push + Campaign	-0.80	0.10**	0.03	-0.05	0.00	0.02
	(1.60)	(0.04)	(0.04)	(0.03)	(0.02)	(0.01)
SS = SS + C [p-value]	0.89	0.59	0.88	0.44	0.26	0.33
Mean (Control)	3.07	0.23	0.28	0.33	0.10	0.10
Obs-round	314	314	2,622	2,622	2,622	2,622
Community	107	107	109	109	109	109

*Notes. Analysis at the community toilet level for columns (1) and (2), where the outcomes correspond to a tally of the number of users and those that pay in a random day at dawn (when the CT has the highest traffic). For the CT-level analysis, Sample in Panel A includes follow up 1 (2 months after) and follow-up 2 (4 months after), right after the Grant Scheme was provided and before the first payment of the Financial Reward Scheme. Sample in Panel B includes the remaining follow-up rounds of the community toilet panel survey. Analysis at the household level for columns (3) to (6), where the outcomes correspond to self-reports. The first outcome is an indicator of whether at least one household members practices open defecation the last time he/she defecated (column 3); the second outcome indicates whether all household members always use the community toilet to defecate (column 4); the third outcome indicates whether the household owns a private latrine (column 5) and the last outcome is an indicator of whether the respondent and its partner, usually the household head and spouse, washed their hands with soap the last time they washed their hands (column 6). For the household level analysis, sample in Panel A includes only the Rapid Assessment follow-up round of the panel household survey and in Panel B, the Midline and Endline survey rounds. All specifications include round dummies and strata variables as control: (i) city and (ii) managed by main provider. Standard errors clustered by slum in parenthesis to deal with serial correlation. Statistical significance denoted by * p<0.1 , ** p<0.05, and *** p<0.01.*

TABLE 3.28: Treatment effects on expectations and awareness of health risks (ANCOVA)

	(1)	(2)	(3)	(4)	(5)	(6)
	Illness OD vs. CT		Illness dirty vs. clean CT		Health risks	
	Adults	Children	Adults	Children	Private	Public
Panel A: Shorter-run						
Supply push	-0.01	0.23	-0.14*	0.10	-0.02	0.00
	(0.03)	(0.15)	(0.08)	(0.08)	(0.03)	(0.04)
Supply push + Campaign	-0.00	0.10	-0.11*	0.13**	-0.03	-0.03
	(0.03)	(0.11)	(0.06)	(0.06)	(0.03)	(0.04)
SS = SS + C [p-value]	0.87	0.43	0.75	0.68	0.95	0.41
Mean (control)	0.76	0.76	0.80	0.81	0.77	0.54
Obs-round	1,434	1,434	1,434	1,434	1,434	1,434
Slums	110	110	110	110	110	110
Panel B: Longer-run						
Supply push	0.00	-0.01	0.01	0.01	0.02	-0.00
	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)	(0.03)
Supply push + Campaign	0.03	0.00	0.04**	0.02	0.07**	-0.03
	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)	(0.03)
SS = SS + C [p-value]	0.27	0.65	0.12	0.67	0.06	0.43
Mean (control)	0.75	0.77	0.84	0.84	0.61	0.62
Obs-round	2,622	2,622	2,622	2,622	2,622	2,622
Slums	109	109	109	109	109	109

*Notes. Analysis at the household level. Sample in Panel A includes the Rapid Assessment round of the household panel survey, right after the Grant Scheme was provided and before the first payment of the Financial Reward Scheme. Sample in Panel B includes the Midline and Endline rounds. All specifications include round dummies and strata variables as control: (i) city and (ii) managed by main provider. Standard errors clustered by slum in parenthesis. Statistical significance denoted by: *** p<0.01, ** p<0.05, * p<0.1.*

3.6.7 Merged Treatments

TABLE 3.29: Treatment effects on the quality of CTs

	(1) Bacteria	(2) Dirty compound	(3) Dirty cubicle	(4) Bad infrastructure
Panel A: Shorter-run				
Merged treatments	-0.14*	-0.04	-0.03	-0.04
	(0.07)	(0.02)	(0.03)	(0.04)
Mean (control)	3.81	0.35	0.64	0.27
Obs-round	219	217	217	217
Slums	111	111	111	111
Panel B: Longer-run				
Merged treatments	0.07	-0.02	-0.03	-0.04
	(0.06)	(0.02)	(0.03)	(0.04)
Mean (control)	3.07	0.23	0.46	0.27
Obs-round	325	325	325	325
Slums	111	111	111	111

*Notes. Analysis at the community toilet level. Sample in Panel A includes follow up 1 (2 months after Baseline) and follow-up 2 (4 months after Baseline), right after the Grant Scheme was provided and before the first payment of the Financial Reward Scheme. Sample in Panel B includes the remaining follow-up rounds of the community toilet panel survey: Follow-up 3 (6 months after Baseline), Follow-up 4 (8 months after Baseline) and Endline (more than 1 year after Baseline). All specifications include round dummies and strata variables as control: (i) city and (ii) managed by main provider. Standard errors clustered by slum in parenthesis to deal with serial correlation. Statistical significance denoted by * $p<0.1$, ** $p<0.05$, and *** $p<0.01$.*

TABLE 3.30: Treatment effects on attitudes towards CTs

	(1) WASH	(2) Clean	(3) Infrastructure	(4) Safe
Panel A: Shorter-run				
Merged treatments	-0.03	0.01	0.05	0.00
	(0.04)	(0.04)	(0.03)	(0.04)
Mean (control)	0.52	0.42	0.20	0.31
Obs-round	1,532	1,532	1,532	1,532
Slums	110	110	110	110
Panel B: Longer-run				
Merged treatments	-0.00	-0.02	0.02	0.01
	(0.04)	(0.03)	(0.02)	(0.02)
Mean (control)	0.53	0.35	0.13	0.17
Obs-round	3,358	3,358	3,358	3,358
Slums	110	110	110	110

*Notes. Analysis at the household level. Sample in Panel A includes the Rapid Assessment round of the household panel survey, after the Grant Scheme was provided and before the first payment of the Financial Reward Scheme. Sample in Panel B includes the Midline and Endline rounds. All specifications include round dummies and strata variables as control: (i) city and (ii) managed by main provider. Standard errors clustered by slum in parenthesis. Statistical significance denoted by: *** p<0.01, ** p<0.05, * p<0.1.*

TABLE 3.31: Treatment effects on WTP

	(1) WTP
Panel A: Shorter-run	
Merged treatments	-0.16
	(0.11)
Mean (control)	1.02
Obs-round	2,695
Slums	110
Panel B: Longer-run	
Merged treatments	0.01
	(0.09)
Mean (control)	1.20
Obs-round	6,113
Slums	110

*Notes. Sample in Panel A includes only the Rapid Assessment follow-up round of the panel household survey and Panel B the Midline and Endline. All specifications include round dummies and strata variables as control: (i) city and (ii) managed by main provider. Columns (1) and (2) additionally control for gender. Standard errors clustered by slum in parenthesis. Statistical significance denoted by: *** p<0.01, ** p<0.05, * p<0.1.*

TABLE 3.32: Treatment effects on sanitation behaviour

	(1) CT use	(2) % Pay	(3) OD	(4) CT use	(5) Latrine	(6) Use soap
Panel A: Shorter-run						
Merged treatments	-3.43	0.05	-0.05	0.01	0.01	0.03**
	(3.28)	(0.05)	(0.05)	(0.05)	(0.02)	(0.01)
Mean (Control)	30.08	0.55	0.28	0.66	0.05	0.95
Obs-round	218	218	1,532	1,532	1,532	1,532
Community	111	111	110	110	110	110
Panel B: Longer-run						
Merged treatments	-0.50	0.09**	0.02	-0.03	-0.01	0.01
	(1.48)	(0.04)	(0.05)	(0.03)	(0.02)	(0.01)
Mean (Control)	30.08	0.55	0.28	0.33	0.10	0.95
Obs-round	324	324	3,358	3,358	3,358	3,358
Community	111	111	110	110	110	110

*Notes. Analysis at the community toilet level for columns (1) and (2), where the outcomes correspond to a tally of the number of users and those that pay in a random day at dawn (when the CT has the highest traffic). For the CT-level analysis, Sample in Panel A includes follow up 1 (2 months after) and follow-up 2 (4 months after), right after the Grant Scheme was provided and before the first payment of the Financial Reward Scheme. Sample in Panel B includes the remaining follow-up rounds of the community toilet panel survey. Analysis at the household level for columns (3) to (6), where the outcomes correspond to self-reports. The first outcome is an indicator of whether at least one household members practices open defecation the last time he/she defecated (column 3); the second outcome indicates whether all household members always use the community toilet to defecate (column 4); the third outcome indicates whether the household owns a private latrine (column 5) and the last outcome is an indicator of whether the respondent and its partner, usually the household head and spouse, washed their hands with soap the last time they washed their hands (column 6). For the household level analysis, sample in Panel A includes only the Rapid Assessment follow-up round of the panel household survey and in Panel B, the Midline and Endline survey rounds. All specifications include round dummies and strata variables as control: (i) city and (ii) managed by main provider. Standard errors clustered by slum in parenthesis to deal with serial correlation. Statistical significance denoted by * p<0.1 , ** p<0.05, and *** p<0.01.*

TABLE 3.33: Heterogeneous treatment effects on WTP, ATP and demand for public intervention, by gender

	(1)	(2)	(3)	(4)	(5)	(6)
	WTP		Negative ATP		Public int - CT	
	Men	Women	Men	Women	Men	Women
Merged treatments	-0.07	-0.01	0.02	0.04**	0.02	0.04**
	(0.09)	(0.08)	(0.01)	(0.01)	(0.01)	(0.02)
Mean (control)	1.28	1.02	0.38	0.43	0.06	0.05
Obs-round	111.00	111.00	110.00	110.00	110.00	110.00
Slums	4,234	4,574	1,635	1,666	1,580	1,580

*Notes. Analysis at the individual level for columns (1) and (2) and household level for columns (3) to (5). Sample in column (1)-(2) include all rounds, columns (3)-(4) only Endline and columns (5)(6) Endline follow-up rounds. The attitudes towards paying the fees were measured only during the Endline follow-up survey and the demand for public interventionw as measured only during the Midline survey. All specifications include round dummies and strata variables as control: (i) city and (ii) managed by main provider. Standard errors clustered by slum in parenthesis. Statistical significance denoted by: *** p<0.01, ** p<0.05, * p<0.1.*

TABLE 3.34: Heterogeneous treatment effects on sanitation behaviour, by gender

	(1)	(2)	(3)	(4)
	CT use		% Pay	
	Men	Women	Men	Women
Panel A: Shorter-run				
Merged treatments	-1.74	-1.69	0.05	0.02
	(1.85)	(1.92)	(0.05)	(0.07)
Mean (control)	25.18	18.65	0.78	0.43
Obs-round	218	218	218	218
Slums	111	111	111	111
Panel B: Longer-run				
Merged treatments	-0.97	0.46	0.11**	0.10*
	(1.03)	(0.66)	(0.04)	(0.06)
Mean (control)	19.17	10.90	0.66	0.36
Obs-round	324	324	324	324
Slums	111	111	111	111

*Notes. Analysis at the community toilet level for columns (1) and (2), where the outcomes correspond to a tally of the number of users and those that pay in a random day at dawn (when the CT has the highest traffic). For the CT-level analysis, Sample in Panel A includes follow up 1 (2 months after) and follow-up 2 (4 months after), right after the Grant Scheme was provided and before the first payment of the Financial Reward Scheme. Sample in Panel B includes the remaining follow-up rounds of the community toilet panel survey. All specifications include round dummies and strata variables as control: (i) city and (ii) managed by main provider. Standard errors clustered by slum in parenthesis to deal with serial correlation. Statistical significance denoted by * p<0.1 , ** p<0.05, and *** p<0.01.*

TABLE 3.35: Treatment effects on expectations and awareness of health risks

	(1)	(2)	(3)	(4)	(5)	(6)
	Illness OD vs. CT		Illness dirty vs. clean CT		Health risks	
	Adults	Children	Adults	Children	Private	Public
Panel A: Shorter-run						
Merged treatments	-0.00	0.15	-0.11**	0.11**	-0.02	-0.01
	(0.02)	(0.09)	(0.05)	(0.05)	(0.03)	(0.03)
Mean (control)	0.77	0.77	0.80	0.82	0.77	0.54
Obs-round	1,532	1,532	1,532	1,532	1,532	1,532
Slums	110	110	110	110	110	110
Panel B: Longer-run						
Merged treatments	0.01	0.00	0.02	0.01	0.05**	-0.01
	(0.01)	(0.02)	(0.01)	(0.02)	(0.02)	(0.02)
Mean (control)	0.76	0.77	0.85	0.85	0.61	0.60
Obs-round	3,358	3,358	3,358	3,358	3,358	3,358
Slums	110	110	110	110	110	110

*Notes. Analysis at the household level. Sample in Panel A includes the Rapid Assessment round of the household panel survey, right after the Grant Scheme was provided and before the first payment of the Financial Reward Scheme. Sample in Panel B includes the Midline and Endline rounds. All specifications include round dummies and strata variables as control: (i) city and (ii) managed by main provider. Standard errors clustered by slum in parenthesis. Statistical significance denoted by: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.*

Chapter 4

Running the Last Mile: Sewerage Connectivity Density and Child Height

Abstract

Stunting is widely recognised as major impediment to human capital development. In this study, I contribute to the understanding of key drivers of international child height disparities. Specifically, I examine the role of the sanitation environment, defined as the density of the local adoption of sewerage systems. I present three complementary analyses: (i) a cross-country analysis among low- and middle-income countries; (ii) a within-country analysis in Latin America; and (ii) an over-time analysis in Peru. In the latter analysis, I rely on an instrumental variable strategy, making use of the average two-year lag connectivity density of adjacent districts. Using Demographic and Health Surveys (DHS), complemented by census and spatial data, the three separate analyses represent different points in a trade-off between external and internal validity. I find that sewerage connectivity density is robustly associated with higher child height across the three different strategies. The mechanisms behind this result are a safer disease environment and greater parental investment in nutrition.

4.1 Introduction

Physical height has been widely recognised as an important measure of human capital. There is evidence that impaired growth during the early years is associated with lower cognitive ability, educational attainment and adult productivity, as well as a greater risk of adult chronical health impediments (Case et al., 2002; Case and Paxson, 2010; Grantham-McGregor et al., 2007; Currie and Vogl, 2013). Child height has been increasing over recent decades in low- and middle-income countries (LMICs), but two out of ten children in these countries are still estimated to be stunted —i.e. too short for their age (World Bank, 2020).

It is generally understood that an inadequate diet and a disease environment are important immediate causes of low mean height (Bozzoli et al., 2009; Smith and Haddad, 2015; Deaton and Drèze, 2009). Deaton (2007)'s thesis claims that the contribution of genetics and maternal influence on height is much smaller when analysing the variation in mean height across countries with different environmental risks. However, knowledge is still limited with respect to the key drivers affecting these mediating factors. Although research has documented links between the adoption of sanitation facilities and a disease environment in historical populations (Cutler and Miller, 2005; Kesztenbaum and Rosenthal, 2017; Alsan and Goldin, 2019), few have explored the role of sanitation in explaining the international heterogeneity in height in LMICs today. In these countries, there is great variation in the sanitation environment, which can be a key determinant of human capital beyond income. Pathogens from faeces cause infectious diseases that consume energy and impair the physical growth of young children (Guerrant et al., 1992; Humphrey, 2009) as well as of the mothers who nurture them in pregnancy and early life (Behrman et al., 2009; Prendergast et al., 2014).

Achieving safe sanitation environments in LMICs is, however, not a trivial task. It depends on three key factors: the adoption level, the population density and the quality of the sanitation solution. First, even when infrastructure is available, adoption levels are far from universal. This has been recognised as one of the main reasons that interventions entailing the construction of latrines have no effect on the disease environment (Patil et al., 2014; Clasen et al., 2014; Gertler et al., 2015). With open defecation as a natural alternative, the adoption of sanitation facilities not only protects individual families from faecal pathogens, but also entails positive health externalities for neighbouring families. Therefore, the average cost of sanitation infrastructure is less than the total social benefits, but frequently greater than the private willingness to pay (Ashraf et al., 2016).

Second, high population density, a common feature of cities and town in LMICs, imposes additional health challenges, given that people living closer together are more likely to encounter their neighbours' germs. In addition, the available infrastructure in LMICs' overcrowded cities is stressed beyond capacity and fails to protect citizens from infectious diseases (Hathi et al., 2017; Marx et al., 2013).

Third, the quality of the sanitation facility denotes the extent to which it can improve the disease environment. The Joint Monitoring Program WHO-UNICEF (2017) classifies sewerage infrastructure as one that can safely remove excreta away from human contact. Yet, most of the evidence regarding the effectiveness of sanitation facilities in improving child health comes from the adoption of rudimentary on-site latrines, where the status-quo is the practice of open defecation (Spears, 2020; Geruso and Spears, 2018; Augsburg and Rodríguez-Lesmes, 2018). Understanding these key factors and their link with human capital is thus of utmost importance for the development agenda.

In this paper, I aim to bring together these three factors by exploring the relationship between child height and the local connectivity density of sewerage: the interaction between the local share of households connected to sewerage and the population density. I present three complementary analyses. The first is a cross-country analysis that establishes the broad importance of sewerage connectivity density for predicting child height in LMICs. For this analysis, I construct a new international dataset from 89 Demographic and Health Surveys (hereafter, DHS) collected in 52 countries between 1991 and 2015, and match it to country-level population density data.

The second provides further evidence of this relationship. I focus specifically on Latin American countries because: (i) they have lower levels of connectivity relative to other countries with a similar income level, so this region is a special case in which economic development is not accompanied by an improvement in disease environment; and (ii) there is significant variation within countries both in child height and connectivity. I combine the last rounds of the DHS for nine Latin American countries, with height measures for more than 78,000 children surveyed between 1996 and 2015, and construct a fine-grained measure of sewerage connectivity at the community level, using the primary sampling unit (PSU) as proxy. I finally match the DHS to the country-level population density. This dataset allows the measure of local connectivity density to be more precise than is possible in the international dataset and to control for higher-resolution geographic fixed effects.

Finally, the third analysis supports the internal validity of the association of interest. For this I focus on Peru, one of the special cases in Latin America where the recent economic development has not been followed by greater adoption of a basic good such as sewerage and has left 14 per cent of children under the age of five stunted (World Bank, 2020). I construct a pooled cross-sectional dataset of more than 86,000 children surveyed between 2007 and 2015 living in 1,383 districts. I match this dataset to district-level population density to compute an even finer measure of local sewerage connectivity density by both PSU and district. In this analysis, I attempt to improve the identification by using an instrumental variable strategy. Relying on two census rounds and spatial data, I use as an instrument for connectivity density the average two-year lag connectivity density of adjacent districts. The identification assumption is that adjacent connectivity density only affects a given district's child height through the district's sewerage connectivity. I argue that the relevance of the instrument occurs through a "keeping up with the Joneses" effect: trying to emulate or not be outdone by the neighbours.

Across the analysis, I focus on three different types of heterogeneity. The first is age in months. Height-for-age is well-understood to be correlated with age during the first few months. A focus on younger ages has the advantage that the local environment recorded at the time of the survey matches more closely the environment in younger children's infancy if sewerage connectivity density has been changing over time (Spears, 2020). Another advantage of focusing on younger children is that impaired growth has been proven to have adverse functional consequences during the first 24 months of life (Prendergast et al., 2014). A focus on older ages has the advantage that age is not mechanically correlated with height-for-age. Furthermore, older children are more likely to be exposed to the environment given their increased mobility (Buttenheim, 2008). Younger and older children also differ in their nutritional patterns —i.e. breastfeeding for infants and solid food for children. Second, I look at heterogeneity by gender. As height-for-age is affected by net nutrition (diseases and nutritional intake), biological traits and social norms that systematically differ across the genders may moderate the association between height and local sewerage connectivity. For instance, evidence in India shows that improvements in the sanitation environment and socio-economic status benefit girls' more than boys' anthropometrics (Augsburg and Rodríguez-Lesmes, 2018; Duflo, 2003). Third, I look at heterogeneity by parity. Favouritism by birth order may affect parents' resource allocation across children. Evidence in India shows that favouritism towards eldest sons generates a steep birth-order height gradient (Jayachandran and Pande, 2017). Height disadvantage in girls (younger children) may decrease (increase) if they are now (not) able to take advantage of the improvements in the local environment and parents' investment in health.

I show that sewerage connectivity density positively predicts children's height-for-age in all three complementary strategies. This association remains robust when accounting for income, child characteristics and maternal input. Notably, connectivity density increases child height beyond the sewerage connectivity of the child's household, which serves as evidence of a positive externality. I find that a 10 per cent increase in the country-level sewerage connectivity density predicts an average increase in the country's average child height-for-age of 1.4 standard deviation units. Within Latin American countries, I find that a 10 per cent increase in the local-level sewerage connectivity density predicts an average increase in child height-for-age of 0.4 standard deviation units. The association is concentrated at the bottom of the height-for-age distribution, suggesting that stunted children benefit most from greater connectivity density. I also show that improvements in the current sanitation environment can affect child height beyond maternal inputs: the mother-child correlation is a function of connectivity density.

In Peru, I find that the association is stronger for children above six months of age — the age when exclusive breastfeeding is not recommended anymore and children are in turn more exposed to the environment through drinking water, food and soil. The association in Peru is twice as strong for boys than for girls. Moreover, there is a non-linear relationship between connectivity density and height: a greater magnitude of the association above the middle of the connectivity distribution and declining at the top. Finally, the instrumental variable strategy reveals that the estimated positive association can be interpreted as a causal one. The two-stage least-square estimates reveal that a 10 per cent increase in the district-level sewerage connectivity density increases child height by 1.4 standard deviation units, on average. This increase is almost equivalent to the negative deviation in height from the WHO reference category in districts with no sewerage connectivity. I also find that the effect is driven by the oldest group of children aged 25 to 59 months. The results also reveal that the increase in child height is accompanied by a decrease in the mortality of children under the age of five, which suggests that the effects on height are underestimated if the probability of survival increases for potentially shorter children.

The mechanisms behind the findings are twofold. First, the local sanitation environment apparently improved with greater sewerage connectivity density, reducing the burden of diseases (other than diarrhoea, such as enteric diseases) that affect nutritional status in the short-run. Second, there was a change in parental investment, particularly that affecting nutritional intake. While infants below six months of age were less likely to be exclusively breastfed, dietary diversity was greater for those children in communities with greater connectivity density. These mechanisms explain why the positive association between sewerage density and child height is concentrated in older children —those that eat food and are more mobile outdoors.

This paper makes several contributions to the literature on economics, human capital, and health. First, it contributes to the literature exploring the drivers of international disparities in human capital, specifically height (Deaton, 2007; Bozzoli et al., 2009; Deaton and Drèze, 2009; Jayachandran and Pande, 2017; Spears, 2020). It proposes and analyses a hypothesis to resolve an important puzzle regarding international height disparities across LMICs, which has attracted attention in the historical economics literature focused on advanced economies: the role of sewerage connectivity (Kesztenbaum and Rosenthal, 2017). Second, it contributes to the literature focused on early-life human capital accumulation (Cunha et al., 2010; Maluccio et al., 2009; Gertler et al., 2014; Campbell et al., 2014) by providing evidence on the determinants of child height. Height is a key variable in LMICs because it captures early-life health: an important dimension of children's human capital (Currie, 2000; Currie and Vogl, 2013).

Third, by advancing evidence on the importance of sanitation *adoption* on a higher-rung of the sanitation ladder and population density in LMICs, this paper contributes to the active and growing literature on sanitation and child health. While a number of studies have been able to rigorously show positive impacts of improved household sanitation (see for example Duflo et al. (2015); Pickering at al. (2015); Dickinson et al. (2015); Cameron et al. (2019)), many other recent randomised controlled trials (RCTs) have shown no health impacts (Patil et al., 2014; Clasen et al., 2014; Gertler et al., 2015). As stated above, the nil effects in these studies were possibly due to low levels of adoption. My study considers the impact of sanitation on child health, but instead of focusing on individual household sanitation ownership, I concentrate on sanitation adoption at an aggregate level. Specifically, I measure sanitation as the percentage of households connected to sewerage in the area of residence of a child (henceforth sewerage connectivity).

Recent studies have turned their attention to linking sanitation at the aggregate level to child health. The main motivation for this lies in the fact that household sanitation is unlikely to improve health when it is not used and neighbours are still contaminating the environment. Most relevant for the context of this study are Dickinson et al. (2015); Augsburg and Rodríguez-Lesmes (2018); Cameron et al. (2019). Using a randomised-controlled trial, Dickinson et al. (2015) estimates the effect of a community-led (known as CLTS) campaign in India, and finds that village- rather than individual-level interventions aimed at ending open defecation increased child height-for-age by 0.37–0.52 standard deviations. In contrast, Cameron et al. (2019) finds that a similar intervention in Indonesia had no effect on child height, which was attributable to the modest increase in the rate of latrine construction and adoption. Other studies that have achieved a greater first-stage, in the sense of greater adoption of latrines, show a better picture. Augsburg and Rodríguez-Lesmes (2018) find that a 10 percentage point increase in latrine adoption translates into an approximately 0.7 centimetre increase in height at age four. They exploit the village-level variation in sanitation investment prices, which determines the marginal cost of this investment, to induce exogenous variation in the sanitation environment. In a systematic review of field experiments, Spears (2020) shows that the positive effect of reducing village-level open defecation on height ranges between 0.3 and 0.55 standard deviation units. However, all of the studies in this literature stream have focused only on the eradication of open defecation and the adoption of on-site rudimentary latrines.

My study fills a gap in this literature by placing the analysis in the jump from on-site sanitation to sewerage systems. Finally, by moving beyond dichotomous rural and urban distinctions, this study explores the extent to which sanitation adoption interacts with population density to predict health (Hathi et al., 2017).

The paper proceeds as follows. Section 4.2 presents the data used in the three complementary analyses. Section 4.3 presents the cross-country evidence from the 52 LMICs, Section 4.4 presents the within-country evidence of nine Latin American countries and Section 4.5 expands the analysis for Peru. Section 4.6 discusses the conclusions of the study.

4.2 Data

In this study, I compile data from several sources, including the Demographic and Health Surveys (DHS), the World Bank's World Development Indicators and census and spatial data. I match and combine these data to compute indicators at the country, district, PSU and individual level.

For the cross-country analysis, I use all of the DHS that have ever collected data on child height and sewerage connectivity. These surveys are from 52 LMICs and the years spanning 1991-2015, a total of 89 DHS rounds. I use the country-level estimates for average child height and sewerage connectivity provided by the DHS's Statcompiler. Additionally, I use publicly available country year data from the World Bank's World Development Indicators on GDP per capita (PPP adjusted international dollars) and population density (people per sq. km of land area).

For the within-country analysis in Latin America, I use the latest round of DHS available for nine Latin American countries: Bolivia (2008), Colombia (2010), Dominican Republic (2013), Guatemala (2015), Guyana (2009), Haiti (2012), Honduras (2012), Nicaragua (2001) and Peru (2015). I construct a pooled cross-section of 78,117 children surveyed under the age of five, born between 1996 and 2015 and living in 11,613 PSUs . I match this dataset to country-level population density data (people per sq. km of land area) in the year of the survey obtained from the World Bank's World Development Indicators.

For the analysis in Peru, I use all of the annual DHS rounds measuring child height and access to sanitation facilities, spanning 2007-2015. I construct a pooled cross-section of 86,845 children under the age of five, born between 2000 and 2015, living in 9,376 PSU and 1,383 districts. I match these data to spatial data measuring district-level population density. I compute a measure of the population density at the district level using population forecasts provided by the National Institute of Statistics and Informatics (INEI for its Spanish acronyms) and district boundaries provided by the Ministry of Environment of Peru. To do so, I rely on a polygon overlay technique to compute yearly population by square kilometre of land for each Peruvian district. I match the DHS height data to the 2005 and 2007 Peruvian Censuses, which contain the share of households connected to sewerage in each district. Finally, I match the district-level mortality rates computed using vital statistics reports provided by the Ministry of Health of Peru.

The key dependent variable in this study is the height-for-age z-scores. The DHS provides height-for-age z-scores for children under the age of five obtained from the WHO's 2006 standardised age- and sex- specific growth reference group. This captures how short a given child is relative to the age- and sex-adjusted WHO reference group. The WHO reference group was formed through a population-based study that took place in the cities of Davis, California, USA; Muscat, Oman; Oslo, Norway; and Pelotas, Brazil; and in selected affluent neighbourhoods of Accra, Ghana and South Delhi, India between July 1997 and December 2003 (World Health Organisation, 2006). A caveat of using this reference group to determine impaired growth is that it may not be representative of the average height-for-age of affluent populations in LMICs. Because stunting indicators are sensitive to particular cut-offs, I use the mean height-for-age z-score for the cross-country analysis and the child-level height-for-age z-scores for the within-country analysis in Latin America and Peru. I also use mortality as an additional measure of child health. For the analysis in Peru at the district-level, I rely on vital statistics from which I compute the infant and under-five district mortality rate per 1,000 infants and children under-fives, respectively, as described in Chapter 1. Infant mortality data is also available in the DHS, but I do not use this source for two reasons. First, infant mortality is measured in the DHS as an indicator of children dying during the first year for every live birth that occurred at least one year before the date of the survey and no more than five years before the date of the survey. Thus, this measure of infant mortality may be affected by the sanitation environment not only of the survey year, but also of the previous five years. Second, infant mortality in the DHS is a low probability binary outcome, which poses power challenges.

The key independent variable used in this study is sewerage connectivity density. The DHS provides information on the sanitation facility typically used by a household. Although different categories of sanitation are used across countries and years, I use the broad classification of the Joint Monitoring Program WHO-UNICEF (2017) of sewerage connectivity: toilet connected to the public sewers. The log of sewerage connectivity density is computed as follows:

$$ln(\text{local sewerage connectivity} \times \text{population density} + 1),$$

where local *local sewerage connectivity* is the computed share of $[0, 1]$ of households connected to sewerage in a child's area (country, district or PSU) and *population density* is the population by square kilometre of land in a child's area (country or district). The sewerage connectivity density variable is measured at the time of the survey, meaning that it best describes the disease environment faced in that specific year by the youngest child, born at a time closest to the survey. Because the disease environment at the time of the survey may not have been similar to that a few years earlier, when the child was born, I am able to analyse the relationship between sewerage connectivity density and child height at different stages of the child's early life.

4.2.1 Descriptive statistics

Three tables in the Appendix present descriptive statistics of the three main datasets that are used for the analysis. First, Table 4.11 presents summary statistics of the sample of 52 LMICs by global region. The average height-for-age among LMICs is -1.29 standard deviation units, where children are taller in North-Africa/West-Asia/Europe (-0.94) and shorter in South and South-East Asia (-1.71). On average, LMICs' sewerage connectivity is 18 per cent and the average sewerage connectivity density globally is 1.93 connected per sq. km. North-Africa/West-Asia/Europe leads again (41 per cent connectivity and 3.36 connections per sq. km.) and Sub-Saharan Africa lags behind (5 per cent connectivity and 0.87 connections per sq. km).

Table 4.12 presents summary statistics of the study sample of Latin American countries. The average height-for-age in Latin America is -1.08 standard deviation units, where children are taller in the Dominican Republic (-0.29) and shorter in Guatemala (-1.89). Only 42 per cent of households are connected to sewerage systems in Latin America on average, with the Dominican Republic again leading (72 per cent), followed by Colombia (67 per cent) and Haiti lagging behind dramatically (less than 1 per cent). Although Haiti has the highest population density (371 people per square km), its average sewerage connectivity density (based on PSU connectivity and country-level population density) is of course one of the lowest in Latin America (0.23). Colombia and Peru, although fast growing large economies in South America, have a sewerage connectivity density comparable to that of a relatively poorer Central American country like Guatemala (lower than 3).

The table also shows that the average age in months is 29 across all countries. 33 per cent of the sample corresponds to children aged between 6 and 24 months and 58 per cent corresponds to children aged between 25 and 59 months. The remaining small share corresponds to infants born during the last 5 months. Because the DHS measures the height of the last children born to every women, only 30 per cent of the sample are first-borns and the average birth order is around 3 for all countries.

There is also great variation across Latin American countries in terms of socio-economic status. On average, the surveyed mothers had 7 years of education, with better educated mothers in Peru and the Dominican Republic (10 years) and worse educated ones in Guatemala and Haiti (5 years). Only 55 per cent of the households in Latin America use piped water as the main source for drinking, ranging from 4 per cent in Haiti to more than 80 per cent in Bolivia, Peru and Colombia. Notably, only 10 per cent of households drink piped water in the Dominican Republic, with the majority of households drinking bottled water (72 per cent). Households in Latin America are concentrated in the lowest wealth quintiles, with only 14 per cent located in the highest quintile (wealth quintile 5).

Finally, Table 4.13 presents summary statistics for Peru over time, specifically for the years 2007, 2011 and 2015. Height-for-age increased over time in Peru, starting with -1.34

standard deviation units up to -0.89. While the characteristics of the children in the sample remained similar over time, mothers' height and educational attainment improved. Between 2005 and 2015, there was also a great improvement in local sewerage connectivity density (from 3.36 to 4.69 connections per sq. km). Both sewerage connectivity and population density increased over time, but the increase was greater in the former. While there was no change in the upper tail of the wealth distribution, by 2015 a larger percentage of households were located in the first quintile and a smaller percentage in the second wealth quintile.

4.3 Evidence from 52 low- and middle-income countries

I start with the cross-country analysis, which reveals that countries' sewerage connectivity density is positively associated with child height, even after accounting for economic development. Figure 4.1 shows the relationship between average child height-for-age and the share of households connected to sewerage per square kilometre for 52 low- and middle-income countries (LMICs). The y-axis reveals that the average height-for-age in the LMICs is always lower than that of advanced economies (all values are lower than zero). Each circle corresponds to an LMIC and the radius of the circle denotes the total population of each country. The plots show a positive relationship between average child height and sewerage connectivity density (blue dashed line). Notably, the importance of sewerage connectivity density does not purely reflect general economic development, since the relationship remains positive even after controlling for GDP per capita and population density (solid red line). There are certain outliers in the plot, such as the case of India (largest circle at the lower bottom of the figure), which has a relatively high average sewerage density (almost 4 households connected to sewerage per square km) and yet a relatively low average height-for-age z-score (-2 standard deviations). Most Latin American countries are placed exactly on the linear prediction, with the Dominican Republic (furthest top-right circle) and Guatemala (furthest bottom-right circle) as outliers.

To formally show the association between average child height and country-level sewerage connectivity density, I estimate the following basic linear specification:

$$H_c = \beta S_c + \theta X_c + \sigma_r + \epsilon_c \tag{4.1}$$

where H_c is the average height-for-age z-score for children under five years old in country c and S_c is the country-level sewerage connectivity density based on the country's population density. X_c denotes a set of indicators that I include in a step-wise fashion: GDP per capita to capture economic development, population density to capture dense-settlement effects and the share of women with a height below 145 cm to capture the effect of maternal height. Moreover, the specification includes global-region fixed effects denoted by σ_r to control for any global-regional-specific height determinant and the standard errors are robust to heteroskedasticity.

Table 4.1 presents the results of the linear regression of the average height-for-age z-score of children on the log of the share of houses connected to sewerage per square kilometre. Column (1) shows that a 10 per cent increase in a country's sewerage connectivity density is associated with an increase of 1.4 standard deviation units in the average child height-for-age z-score. The estimated coefficient is statistically significant at the 1 per cent level. Given that the average country height-for-age is -1.4 for those with no sewerage connectivity density, a 10 per cent increase in a country's sewerage density could offset the deviation from the WHO's reference group, *ceterisparibus*, in these countries.

The estimated association remains robust to the inclusion of global-regional fixed effects (column 2). The association decreases slightly in magnitude, but remains positive and statistically significant at the 5 per cent level, when controlling for GDP, population density and the share of short women. The results are consistent with Deaton (2007)'s thesis that environmental risks play a key role when analysing the variation in mean height across countries.

4.4 Evidence from Latin America

I now focus the analysis on Latin American countries, which lag behind in their connectivity to sewerage, compared to other similar countries in terms of economic development. The average height-for-age z-score in Latin America is –1.08, indicating that the average child has a lower height-for-age than the reference population. Figure 4.2 shows the WHO height-for-age z-score for the sample of Latin American children by age in months and split by gender. It can be seen that the children are already slightly short for their age just after birth and that the z-score reduces, particularly in the first two years of life, after which children seem to catch up slightly again, but stay far the standard population. The drop in boys is greater than in girls, but the reverse is also greater for boys. The observed pattern is similar to the evidence in other LMICs like India (Augsburg and Rodríguez-Lesmes, 2018; Spears, 2020).

Figure 4.3 plots the individual-level data for nine Latin American countries to permit a visual analysis of the relationship between sewerage connectivity density (based on PSU sewerage connectivity and country-level population density) and child height. The many small dots plot the data non-parametrically by splitting the sample into 68 bins along the horizontal axis of connectivity density and computing the average height for each bin and the lines denote the linear fit for each Latin American country. The figure has four main take-aways. First, as the upward trend shows, children that are exposed to more and nearer sewerage connectivity are taller on average. Second, there is great variation in both the sewerage connectivity density and the average height-for-age, across and within countries. For instance, a small country like Guyana has a connectivity density comparable to a larger country like Bolivia, ranging between 0 and 1.5 per square kilometre. Central American countries like Guatemala and Haiti have a connectivity density, ranging between 0 and almost 5 per square kilometre and their height trends are similar. Yet, Guatemala has an average height lower than that of Haiti, although the former is richer than the latter. Third, the relationship between connectivity and height differs across countries. For instance, two comparable countries in Latin America in terms of economic development, such as Colombia and Peru, exhibit different trends. While the relationship is steeper in Peru than the general Latin American trend, the relationship in Colombia is flatter than the general trend (crossing paths when connectivity density is around two per square km). Finally, the between country differences in child height are far larger than the within-country differences. Although positive, the within-country slopes are not very steep. This observation complements the thesis of Deaton (2007) that there is a large genetic component to heights within populations, while the mean height across countries is predicted mostly by the disease environment.

To estimate the association between child height and local sewerage connectivity density, I use the following specification:

$$H_{ipc} = \beta_1 S_{pc} + \beta_2 S^h_{pc} + \theta X_i + \sigma_r + \epsilon_{ipc} \tag{4.2}$$

where H_{ipc} is the height-for-age z-score of children i in PSU p and country c. S_{pc} is the sewerage connectivity in PSU per square kilometre based on country-level population density and S^h_{pc} is an indicator equal to 1 if the household of the child is connected to sewerage. X_i denotes a set of child- and household-level controls, drawing closely on Spears (2020), including child's birth order, sex-by-age dummies, year-of-birth dummies, mother's height and educational attainment, household wealth, and an indicator of whether the household has access to piped water. Additionally, I control for country-level population density. σ_r denotes subnational-regional fixed effects. Standard errors are clustered at the PSU level to correct for intra-cluster correlation. The coefficient of interest is β_1, which captures the association between child height and sewerage connectivity density, even after controlling for own household connectivity.

Table 4.2 presents the estimated association between sewerage connectivity density and child height. Column 1 includes all children in the sample, while columns (2), (3) and (4) restrict the sample of analysis to the age group 0-5 months, 6-24 months and 25-59 months, respectively.

I find that, on average, a 10 per cent increase in connectivity density is associated with an increase in heigh-for-age of 0.4 standard deviation units at a 1 per cent significance level

(Panel A, column 1). Because the average height of children exposed to a sewerage connectivity density equal to zero is -1.37, this association translates into a 30 per cent increase. Notably, the magnitude of the association within-countries is half that across countries, as shown in Table 4.1. Thus, this observation suggests that the role of environmental quality is stronger when identifying cross-country differences in height, as opposed to within-country ones. The coefficients are slightly higher and are estimated with a greater statistical significance for children aged 6 months old or above. We cannot rule out, however, that the estimates lack statistical power for the age group 0-5 months old. The estimated coefficients are similar across birth order and gender.

Notably, the positive association is present even after controlling for the child's household connectivity to sewerage, possibly reflecting an externality. The estimated association is similar in magnitude to those found in the literature estimating the impact of eradicating open defecation (though with the opposite sign, as expected). The systematic review presented by Spears (2020) shows that the coefficients of the local area fraction of households defecating in the open predicting child height-for-age range between 0.3 and 0.55 standard deviation units. The negative association between household connectivity to sewerage and child height could be due to substitution effects. In their theory, Jalan and Ravallion (2003) posit that adopting piped water and sewerage can crowd-out parental investment in the child's human capital production function.

4.4.1 Quantile treatment effects

The association between sewerage connectivity density and child height is also likely to be heterogeneous depending on which part of the distribution of the height-for-age sex score children are in. Child height at the bottom of the height-for-age distribution may be more elastic with respect to connectivity density —i.e. stunted children have more space to "catch-up". I test for heterogeneity by estimating quantile treatment effects (QTE) as follows:

$$Quant_t(H_{ipc}) = \beta_t^i S_{pc} + \vartheta_t \eta_{ipc} \tag{4.3}$$

where t corresponds to the quantile of the height-for-age (H) distribution of children i in PSU p and country c.

Table 4.3 shows that the associations are slightly higher in magnitude for the percentiles at and below the median compared to the 75th and 90th percentile. The association at the bottom of the height-for-age distribution is one quarter higher than that at the top. Thus, this finding confirms the hypothesis that children lagging behind in terms of height benefit most.

When splitting by age group, the linear decreasing pattern is observed in the 0-5 months age group —i.e. stunted infants seem to benefit more from sewerage connectivity. However, this is not the case for the 6-24 months age group or the 25-59 months age group, where we observe a non-linear pattern. In the former, the association is slightly higher in the 25th, 75th and 90th percentile, while in the latter, it is the highest at the 10th percentile (equivalent to 0.5).

4.4.2 Maternal input

There are two mechanisms through which exposure to open defecation could impact child height: through the disease and net nutrition experienced by the child (Guerrant et al., 1992; Humphrey, 2009) and/or through the health of the mother, during and before pregnancy (Behrman et al., 2009; Prendergast et al., 2014). Besides direct exposure to the disease environment, children may be stunted due to intra-uterine restrictions imposed by stunted mothers (Martorell, 2012) and this stunting can be a result of the mother's own exposure to poor sanitation conditions previously. The important issue then is to understand whether the current sanitation conditions are capable of improving child height beyond maternal inputs. If this conjecture is true, we would expect the child-mother height correlation to be a function of the current sanitation environment.

This section presents suggestive evidence in support of this possibility, by showing that sewerage connectivity density predicts the mother-child height correlation. Figure 4.4 plots the mother-child height correlation as a function of sewerage connectivity density (per sq. km.). Panel (a) restricts the analysis to first children and Panel (b) to not first children. Three conclusions emerge from this figures. First, the mother-child height correlation is far below the computed correlation for US children at 0.41 (based on the U.S. from the National Longitudinal Study of Youth 1979) and in line with other correlations in the LMICs (Livson et al., 1962). The correlation is higher for older children than younger siblings when sewerage density is low. Second, the child-mother height correlation is a function of sewerage connectivity density. The current sanitation conditions improve child height beyond maternal height. Third, while the correlation is lower in PSU with greater sewerage density for first children, it is higher for subsequent children. These results mean that in Latin America, improvements in environmental quality play a greater role in predicting height than maternal input for eldest children, while the opposite is the case for children higher up the birth order. When splitting by age group, I find the same positive relationship between sewerage connectivity density and mother-child height correlation for younger siblings (not first child). This last finding is consistent with older-child favouritism (Jayachandran and Pande, 2017). Sanitation improvements and changes in parental investment in health apparently benefit first children more, to a point that the role of maternal input in height is relatively lower.

4.5 Evidence from Peru

Finally, I focus on Peru, a country that is classified as upper-middle-income and where still more than 40 per cent of households lack sewerage connectivity. Furthermore, 40 per cent of the under-five population are stunted, twice as many as the average of countries classified as upper-middle-income (World Bank, 2020).

Figure 4.5 shows that there were several improvements in Peru between 2007 and 2015 in terms of child height and sewerage connectivity. The sewerage connectivity density (blue bars), measured as the log of sewerage connectivity at the PSU level per square kilometre (based on the district's population density), sat at around 2.5 between 2007 and 2011 and increased progressively to up to 3.5 per square kilometre until 2015. During the same period spanning 2007-2015, the average child height-for-age z-score decreased from -1.5 to almost -1 standard deviation units (red line).

Figure 4.3 shows a steep height-for-age gradient by sewerage connectivity density for 2015 in Peru. In this section, I use a better measurement of sewerage connectivity density, computed using district-level population density for every year, as opposed to country-level population density. To formally evaluate the association between child height and connectivity density in Peru over time, I estimate the following specification:

$$H_{ipt} = \beta_1 S_{pt} + \beta_2 S^h_{pt} + \theta X_{it} + \sigma_d + \epsilon_{ipt}, \quad (4.4)$$

where H_{ipt} is the height-for-age z-score for child i in PSU p and survey year t. S_{pt} is the sewerage connectivity in PSU per square kilometre based on district-level population density and S^h_{pt} is an indicator equal to1 if the household of the child is connected to sewerage in survey year t. X_i denotes a set of child- and household-level controls similar to Equation 4.2. I additionally include district fixed effects σ_d. Standard errors are clustered at the PSU level to correct for intra-cluster correlation.

Table 4.4 presents the estimated association between sewerage connectivity density and child height. Similar to Table 4.2, column (1) includes all children in the sample, while columns (2), (3) and (4) restrict the sample of analysis to the age group 0-5 months, 6-24 months and 25-59 months, respectively. Panels B and C further split the sample of analysis by parity, for the first child and not the first child, respectively.

I find that, on average, a 10 per cent increase in connectivity density is associated with an increase in height-for-age of 0.1 standard deviation units at a 1 per cent significance level (column 1). Because the average height of children exposed to a sewerage connectivity density equal to zero is -1.44, this association translates into a 7 per cent increase. The estimated association is lost for the age-group 0-5 months and it is qualitatively similar across the age groups 6-24 months and 25-59 months (columns 3 and 4) and by parity. We cannot rule out, however, that this estimated association lacks statistical power for the 0-5 months age group. The positive association between connectivity density and child height for the age group 6-24 months is particularly relevant because impaired growth has adverse functional consequences during the first 24 months of life (Prendergast et al., 2014).

Interestingly, in the case of Peru, I find that the association between connectivity and height is twice as much for boys for the age groups 6-24 months and 25-59 months. This is contrary to the evidence observed in countries like India, where girls are systematically lagging behind and hence are those that benefit most from improvements in the local environment and disposable income (Duflo, 2003; Augsburg and Rodríguez-Lesmes, 2018). In Peru, perhaps the mechanism behind this finding is greater parental investment in nutrition, which tends to favour boys.[1] For the 25-59 months age group, another explanation is that boys are more exposed to outdoor hazards than girls (e.g. they play more outside and take greater risks) and improvements in environmental quality are more important drivers of height for them. The next section discusses these mechanisms in detail.

Again, the positive association is present even after controlling for the child's household connectivity to sewerage, which is likely to reflect an externality. Notably, for the case of Peru, the association between household connectivity and child height is positive and statistically significant at the 1 per cent level. Perhaps in this context, sanitation investments complement other parental investments.

4.5.1 Non-linearity

One may expect sewerage connectivity density to have a non-linear relationship with child height. On the one hand, gains at the lower end of the density distribution may improve environmental quality dramatically. On the other hand, due to the negative externalities from even one single household not being connected to sewerage, the gains may be greater at the upper end of the density distribution.

Table 4.5 presents the estimated association between child height and sewerage connectivity density in a non-linear fashion. I introduce variables that account for each additional two units of sewerage connectivity density. The associations are slightly non-linear, with greater magnitude above the middle of the distribution (between 6 and 8 households per square kilometre) and declining at the end (with 8 to 10 households per square kilometre). Note that the p-value of the joint significance test is 0, meaning that the hypothesis that the coefficients of each connectivity density measure are the same and equal to 0 can be rejected.

The predicted power of sewerage connectivity density is again concentrated in the groups of children between 6 and 24 months and 25 and 59 months old. While the association is linear for the age group 6-24 months, it is non-linear for the age group 25-59 months. The effect of connectivity density on child height is concentrated in the 25-59 age group.

[1] A traditional social norm in Peru is that "boys should eat more".

This non-linearity is similar to that observed by Kesztenbaum and Rosenthal (2017) when examining the association between sewerage connectivity and life expectancy in Paris neighbourhoods during the nineteenth century. The non-linearity may serve as evidence of externalities, but it might also simply be that important improvements in child height begin once a minimum adoption rate has been achieved for the whole of the local area.

4.5.2 Mechanisms

It is widely understood that height is a function of net nutrition: the difference between food intake and the losses to activities and diseases (Deaton, 2007). Hence, there are at least two mechanisms by which sewerage connectivity density might reduce average child height.

The first is through better environmental quality and the resulting reduction in disease burden in the first years of life. It has long been documented that chronic exposure to faecal contamination is the leading cause of water-borne diseases (Prüss-Ustün et al., 2014). Among these water-borne diseases, diarrhoea has been implicated as the main cause of poor growth. The medical literature have also documented that perhaps, most importantly, environmental enteric dysfunction plays a key role (Humphrey, 2009; Mbuya and Humphrey, 2016). This disease, also caused by repeated faecal contamination, increases the small intestine's permeability to pathogens while reducing nutrient absorption.

The DHS data provides a measure of diarrhoea incidence using the report of main caregivers on whether the child had an episode during the two weeks preceding the survey. Yet, the DHS do not measure biological pathways such as enteric dysfunction, or the contamination of the environment. To proxy for this, I use the standardised z-scores of weight-for-age and weight-for-height using the WHO's reference group. Weight-for-height is a measure of wasting or thinness, which indicates a recent and severe process of weight loss, associated with acute starvation, a severe disease or a chronic unfavourable condition. Weight-for-height is another measure of thinness, but it takes into account adiposity or greater lean body mass (World Health Organisation, 2010).

Table 4.6 shows that while sewerage connectivity density has no effect on the incidence of diarrhoea, it is positively associated with weight-for-age. On average, a 10 per cent increase in connectivity density is associated with an increase in weight-for-age of 0.1 standard deviation units at a 1 per cent significance level (column 2). Finding a reduction in wasting is consistent with the fact that sewerage connectivity improves the quality of the disease environment where children grow. The fact that diarrhoea is not a mechanism is not surprising. Humphrey (2009) argues that the effect of diarrhoea on permanent stunting is small because growth velocity can be faster than average for age between illness episodes, resulting in catch-up growth.

Another mechanism is parental investments, particularly those that affect nutritional intake. Greater sewerage connectivity may affect parental investment in factors, other than environmental quality, that affect the child's human capital production function. There are two main channels that can affect parental investments. The first channel is through an income effect. If sewerage connectivity increases the marginal health benefit for parents of spending more on their children's health, and such spending is a normal good, parents will spend more (Jalan and Ravallion, 2003). The second channel is through a substitution effect. Parents may spend more on other goods if the relative price of spending on a child's health is higher. Whether the income or substitution effect prevails is an empirical question.

I analyse the effect of sewerage connectivity density on four types of parental investment: (i) treating water to drink (e.g. boiling it, passing it through cloth, or adding chlorine to it); (ii) exclusively breastfeeding infants below 6 months of age (effort and time); (iii) dietary diversity and (iv) feeding sugar (expensive calories). Dietary diversity is measured as the number of different food groups consumed during the previous day by the child. The first two indicators are costly to parents (mostly mothers) due to the time and effort required. The last two require spending more on food.

Table 4.7 shows that the household's sewerage connectivity, rather than the local connectivity, is positively associated with the likelihood of treating drinking water. The local sewerage connectivity density, however, is negatively associated with the likelihood of exclusively breastfeeding infants. On average, a 10 per cent increase in connectivity density is associated with a decrease in exclusive breastfeeding of 0.1 percentage points (column 2). Perhaps lower contamination of the environment, food and water sources reduce the marginal benefit of exclusive breastfeeding and, hence, how much mothers "spend" on it. Non-exclusive breastfeeding during the first six months of life can increase the risk of infectious diseases and impair linear growth. This finding helps explain why there is no positive association between sewerage connectivity density and height in the first months of life (as seen in Table 4.4, column (2)).

Table 4.7 shows evidence that greater nutritional intake is a mechanism behind the positive association between sewerage and height of children above six months of age. On average, a 10 per cent increase in connectivity density is associated with an increase in dietary diversity of 0.2 food groups (column 3) and a greater likelihood of feeding the child sugary products of 0.1 (column 4). If the relative price of preventive and curative health care is higher, parents spend more on food. It seems that children are not only acquiring more calories through eating more food groups, but parents are also feeding their children more expensive calories (sugar and sweets). Ritter (2015) shows that the consumption of sugar-sweetened beverages (i.e. sodas) serves as a protective mechanism against infectious diseases for children in Peru. Even when sewerage connectivity density is high, only 30 per cent of wastewater is treated in Peru (Fay et al., 2017) and thus the consumption of liquids other than contaminated water can contribute to physical growth.

Another possible mechanism is the net nutrition of mothers, which could be influenced by near-term exposure to better environmental quality and/or higher caloric intake. While in the Latin American analysis I find that the mother-child correlation changes with sewerage density connectivity, this is not the case in Peru. Perhaps this latter result could be due to the fact that the mother's nutritional intake is also affected, and hence both mother and children have a better nutritional status. In this case, a mechanism explaining the positive association between sewerage and child height is greater intra-uterine space (Behrman et al., 2009). However, it is not possible to measure accurately whether this mechanism is at play because the DHS measures mothers' anthropometrics at the time of the survey, not during pregnancy or breastfeeding, and we do not observe mothers' childhood environments.

4.5.3 Extension: Instrumental Variable Strategy

The positive association between sewerage connectivity density and child height cannot be interpreted as a causal effect given potential endogeneity. For one, richer areas have both better connectivity and taller children, both of which may be driven by idiosyncratic factors: the PSU wealth-connectivity and -child height correlations are 0.25 and 0.1, respectively, and significant at the 1 per cent level. These richer areas are adopting sewers even though they already enjoy better nutrition and an improved health environment, as evidenced by taller children. Furthermore, one might worry that the areas that adopt sewers do so because of omitted unobservables that make sewers more efficient there than elsewhere. In the Peruvian analysis, such unobservables would need to vary over time within a district, since either spatial or time invariant factors would be controlled for by our district and year of birth fixed-effects. Another potential concern is reverse causality because good child health may create incentives to invest in goods that help sustain it.

The ability to successfully induce an exogenous large increase in sewerage connectivity is a necessary first stage to infer causality. Field experiments have not managed to generate large enough first stages to learn from interventions aimed at inducing latrine adoption and move away from open defecation (Patil et al., 2014; Clasen et al., 2014; Gertler et al., 2015; Cameron et al., 2019) and few studies have exogenously induced the adoption of sewers (Norman et al., 2014). This limitation could be overcome once we develop strategies to rapidly increase connectivity, permitting statistically powerful experimental studies to estimate the long-term effects on child health. Yet, even then, effects through accumulated maternal exposure to better environmental quality may require a long duration of changed exposure to fully reverse. As Spears (2020) states, at least until such strategies are available, there will be uncertainty about the exact size of the effect of sewerage connectivity on child height and population-level observational analysis will continue to play a big role.

In order to improve identification, I rely on an instrumental variable strategy to deal with endogeneity in sewerage connectivity. I use as an instrument the two-year lag of the average sewerage connectivity density in adjacent districts. By construction, this instrument is independent of both time- and district-specific health outcomes, so it addresses the reverse causality concern. The exclusion restriction of this instrument is satisfied if sewerage connectivity in adjoining districts affects child height only through an increase in sewerage connectivity in the own district. This spatial correlation may happen through supply- and/or demand-side channels. Through the supply-side, installing sewerage lines in neighbouring districts may increase the probability of a given district experiencing the same due to economies of scale, as equipping several adjacent districts with sewerage lines reduces materials and transaction costs. It also enables the given district to take advantage of treatment plants constructed to serve neighbouring districts.

The spatial correlation in adoption is hence more likely to come from the demand-side. As argued by Kesztenbaum and Rosenthal (2017), high sewer connectivity among neighbouring districts causes the district under consideration to adopt more sewer connections via a "keeping up with the Joneses" effect and learning about the benefits of adopting sewers. However, one might worry that sewer adoption in a given district is related to changes in adjacent districts' health because of contamination fears. In this scenario, neighbouring districts adopt more sewers because of a negative health shock, which may spur on the district under consideration. Contaminated individuals may directly infect their neighbours as they move in the city or through local sources of water. The second possibility is unlikely given that very few Peruvian households rely on local ground sources of water for drinking purposes (recall from Table 4.12 that as of 2015, more than 80 per cent of households relied on piped-water). Unfortunately, I cannot exclude the first possibility as movement between districts occurs frequently.

Using the two Census rounds of 2005 and 2007, I compute the sewerage connectivity density as the sewerage connectivity in a given district times the population density of that district in each year. Relying on the district-level connectivity provides a better measure for local environmental quality than using PSU connectivity, as in previous analyses, given that the DHS is not representative at the PSU level. Figure 4.6 shows that there is great variation in sewerage connectivity density across districts in Peru. The yellow-shaded districts are those with very low connectivity density, the green-shaded districts are those in the middle of the density distribution, and the blue-shaded districts are those at the upper end.

I exploit this variation across districts and within provinces to evaluate the effect of connectivity density on child height and infant and under-five mortality. I compute the average sewerage connectivity density of neighbouring districts in 2005, which I use as an instrument for connectivity density in 2007. I match these dataset to two sources of data for child health. First, I match the district-level data on sewerage connectivity to the DHS individual-level data on children surveyed in 2007. I get a cross-sectional dataset of surveyed 4,374 children in 366 districts within 159 provinces for the height outcome. Second, I match the district-level data on sewerage connectivity to the district-level mortality rate computed from vital statistics for the year 2007. I get a dataset of 1,005 districts within 165 provinces for the mortality outcome.

The results in Table 4.8 confirm the relevance of the instrument. A per cent increase in the average connectivity density of neighbouring districts (two-years lag) increases the connectivity density of the district under consideration by 1.1 per cent for the height-for-age sample and by 1.71 per cent for the mortality rate sample, both at the 1 per cent significance level. The F-stat of excluded instruments is sufficiently high, demonstrating the relevance of the instrument.

I first explore the effect of sewerage connectivity on the child height-for-age z-score. Table 4.9 presents the results from the OLS (Panel A) and a two-stage least square (2SLS) estimation (Panel B), which are consistent with the main results we presented in the previous sections. A 10 per cent increase in connectivity density, on average, increases child height-for-age by 1.4 standard deviation units (column 1) at a 5 per cent significance level. The effect is concentrated in older children (25-59 month group), as a 10 per cent increase in connectivity density increases child height-for-age by 2.2 standard deviation units. The magnitude of the effect is so large that it completely offsets the mean (negative) deviation in height-for-age of children in areas with zero sewerage connectivity. Therefore, large gains can result from pushing sewerage connectivity in areas with low connectivity rates, even if universal adoption is not achieved. I find no heterogenous effects by gender or parity.

Comparing across the OLS and 2SLS specifications we see that the 2SLS estimates are larger in magnitude. This could be due to the fact that those that comply with the instrumental variable strategy —i.e. districts that connect only because their neighbours did so— are different from the average district whose connectivity density is affected by other factors, say socio-economic ones. For instance, compliers may not adopt other public goods that affect child health, as always-takers would, and thus the returns from adopting sewerage may be greater.

I next estimate the effect of sewerage connectivity on the infant and under-five mortality rates. Table 4.10 presents the results from the OLS (columns 1 and 2) and two-stage least square (2SLS) estimation (columns 3 and 4). I find that, on average, a 1 per cent increase in connectivity density decreases the deaths per 1,000 children under the age of five by 4.3. This is equivalent to an 8 per cent decrease compared to the mortality rate of children living in districts with zero sewerage connectivity. Interestingly, this decrease is qualitatively similar to the increase in under-five mortality caused by an additional unfinished sewerage project, as estimated in Chapter 1. In other words, the social cost created by one additional unfinished sewerage project is similar to the social benefits generated when a district increases by only 1 per cent its sewerage connectivity density. This confirms the fact that large gains can be achieved from increasing connectivity, no matter how small the increase is. The results are stronger on the under-five than the infant mortality rate, perhaps due to the fact that older children are those that, in the absence of connectivity, are more exposed to environmental hazards.

4.6 Conclusions

This paper measured the contribution of adopting public infrastructure to increases in child height in LMICs. The study was motivated by the fact that the adoption of sewerage systems is far from universal and that the interaction of local connectivity with population density moderates the relationship between location and early-life health outcomes. The results presented in this article improve our understanding of this interaction, while investigating its external and internal validity. In three separate analyses, representing different points in a trade-off between external and internal validity, I find that greater sewerage connectivity density is positively associated with child height.

The first analysis focuses on LMICs as a whole because cities in these countries still face great challenges to the widespread adoption of public infrastructure. Citizens in LMICs often find it difficult to finance the investment needed to connect their dwellings to sewers and face information asymmetries that lower their willingness to pay. Furthermore, the collection of fees for providing sanitation services is extremely difficult in these countries, particularly in informal settlements, because of the lack of land titles. Although there is evidence that the sewerage revolution played a key role in improving public health in today's high-income countries in the nineteenth and early twentieth centuries (British Medical Journal, 2007), these countries had two advantages over LMICs: citizens had access to financing and greater security of property rights (Kesztenbaum and Rosenthal, 2017), both of which are the foundation for investing in dwellings and charging citizens for using public services.

The second analysis zooms into the Latin American region, which faces an additional challenge: stark inequality. Citizens in these countries face an extraordinary range of living conditions. Latin American countries have lower connectivity levels to public sewers than other middle- and upper-middle income countries, as well as a greater prevalence of child stunting. In Latin America, being a poor child means being less likely to achieve your full height and cognitive potential and being excluded from labour markets as an adult. This destiny is not only due to income inequalities, but also because of inequalities in access to basic infrastructure. In the extreme version of this inequality, a large fraction of the urban population lives in overcrowded informal settlements, where the burden of preventable diseases is exacerbated and public infrastructure has collapsed beyond capacity. Providing evidence on improvements in children's health that can be achieved by local level connectivity improvements is hence of direct policy relevance, especially for the agenda focused on breaking the inter-generational transmission of poverty.

Finally, this paper focuses on Peru, a special case in Latin America of a country that has experienced dramatic economic development in the last decade, accompanied by an increase in inequality. Peru is now classified as an upper-middle income country and is on its way to joining the advanced economies club — the Organisation for Economic Cooperation and Development (OECD). Yet, four out of ten households are still not connected to sewerage, meaning that they rely on rudimentary sanitation solutions, and at the same time one in every ten children is physically stunted.

Controlling for income, household characteristics and maternal inputs, sewerage connectivity density is a predictor of child height disparities across all LMICs, and specifically Latin American countries. My findings are consistent with Deaton (2007)'s claim that environmental risks play more of a key role when explaining the mean height variation across countries than that within countries. The estimated association is greater across countries, suggesting that there is a large genetic component to heights within populations.

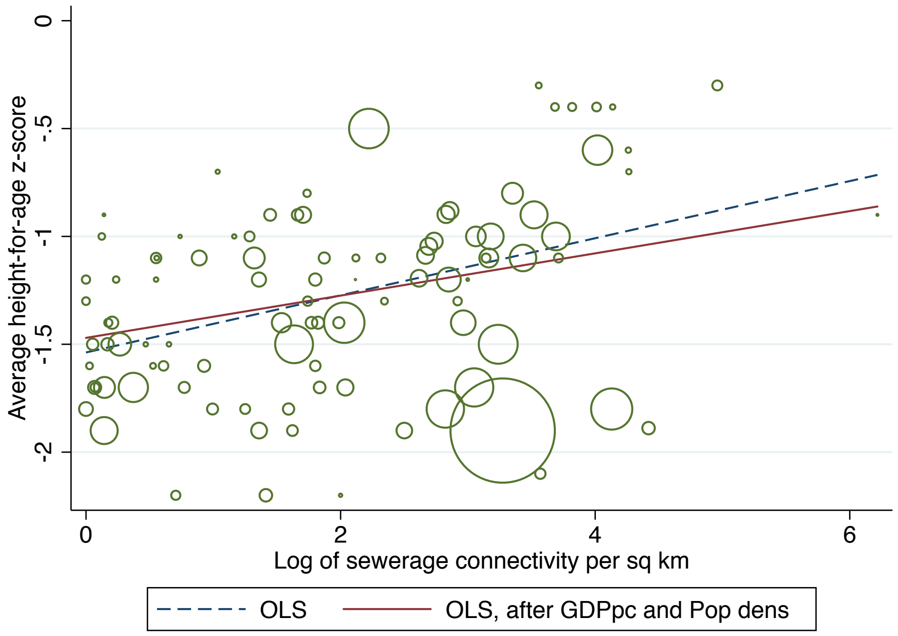
My estimated association between sewerage connectivity density and child height is consistent with those of Hathi et al. (2017), Spears (2020) and Dickinson et al. (2015), who find impacts of an improved sanitation environment on height-for-age of around 0.2–0.4 standard deviations in rural areas of India. Yet, the instrumental variable estimation (in Table 4.9) reveals that the impact of sewerage connectivity density on child height can be as high as three times larger than the one predicted for a reduction in open defecation density, such as the one estimated by Hathi et al. (2017) in Bangladesh. This result suggests that jumping from the use of on-site sanitation facilities to sewerage has greater impacts on child health than jumping from open defecation to on-site sanitation. It also underlines the need to gain a comprehensive understanding of the potential of sanitation to promote child development on different rungs of the sanitation ladder.

The mechanisms behind the findings are twofold. First, the local sanitation environment apparently improved with greater sewerage connectivity density, reducing the burden of diseases (other than diarrhoea, such as enteric diseases) that affect nutritional status in the short-run. Second, there was a change in parental investments, particularly those that affect nutritional intake. While infants below six months of age were less likely to be exclusively breastfed, dietary diversity was greater for those children in communities with greater connectivity density. In particular, the consumption of sugary products was greater, a mechanism consistent with Ritter (2015)'s findings that sugary beverages protect children against infectious diseases in Peru. These mechanisms explain why the positive association between sewerage density and child height is concentrated in older children (those that eat food and are more exposed to outdoors) and those that enjoy parental preference in resource allocation (boys and elder siblings).

To consider how substantial the gain in child height is from increasing sewerage connectivity density, I estimate a counterfactual scenario: what would child height have been if districts in Peru had achieved their 2007 sewer connection rate two years earlier? The acceleration in connectivity density would have increased it, on average, by 15 per cent — equivalent to 2 standard deviation units. This acceleration would have propelled the average height for children in areas with no sewerage connectivity all the way to the level of the WHO reference group.

My results have four important implications for policymakers. First, as discussed above, there are large gains to child health when promoting the adoption of sanitation facilities, and even more so when these facilities are on a higher rung of the sanitation ladder (i.e. safer technologies). My cross-country estimates reveal that increasing sewerage connectivity density is associated with half as much improvement in child height as increasing GDP by the same level —having policymakers greater control over the former factor. Second, for a given level of connectivity, policymakers should concentrate their efforts on improving connectivity where population density is high. Including population density as a factor in allocation decisions can improve targeting compared to restricting the focus to urban areas or certain levels of the total population. Several areas in the developing world are classified as rural, despite having greater population density than places classified as urban. Third, the results of this paper support the case that incentivising connectivity to a public good with positive health externalities, such as sewerage systems, should be a policy priority in the development agenda. Different policy approaches are currently being tested to increase adoption levels, but with mixed results (Guiteras et al., 2015; Pickering at al., 2015), so more research is needed to gain a comprehensive understanding of the policy options. Finally, sewerage connectivity density seems to be particularly relevant for older children (i.e. 25-59 months old), suggesting that it may be particularly fruitful to target areas with small children to increase awareness of how important the adoption of sewerage will be for their growing children in the future.

FIGURE 4.1: Child height and connectivity density, by country-round



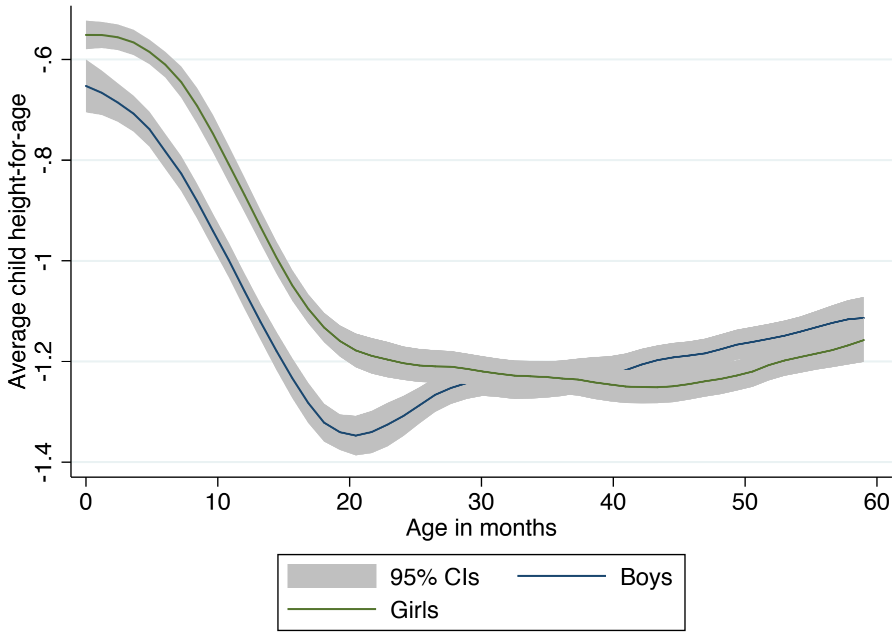
Notes: Circles denote country-year observations weighted by population. The dashed blue line denoted a linear fit and the solid red line denotes a linear fit after controlling for GDP per capita and population density.

TABLE 4.1: Robust association between sewerage connectivity density and child height, across LMICs

	(1)	(2)	(3)	(4)	(5)
Connectivity density (ln)	0.14***	0.15***	0.08**	0.10**	0.08**
	(0.03)	(0.04)	(0.04)	(0.05)	(0.04)
GDP per capita (ln)			0.20***	0.18**	0.19***
			(0.05)	(0.07)	(0.07)
Population density (ln)				-0.01	0.01
				(0.04)	(0.04)
Women with height below 145 cm					-4.00***
					(1.24)
Regional FE	No	Yes	Yes	Yes	Yes
Adjusted R square	0.18	0.49	0.56	0.55	0.65
Country-year	89	89	89	89	89
Countries	52	52	52	52	52

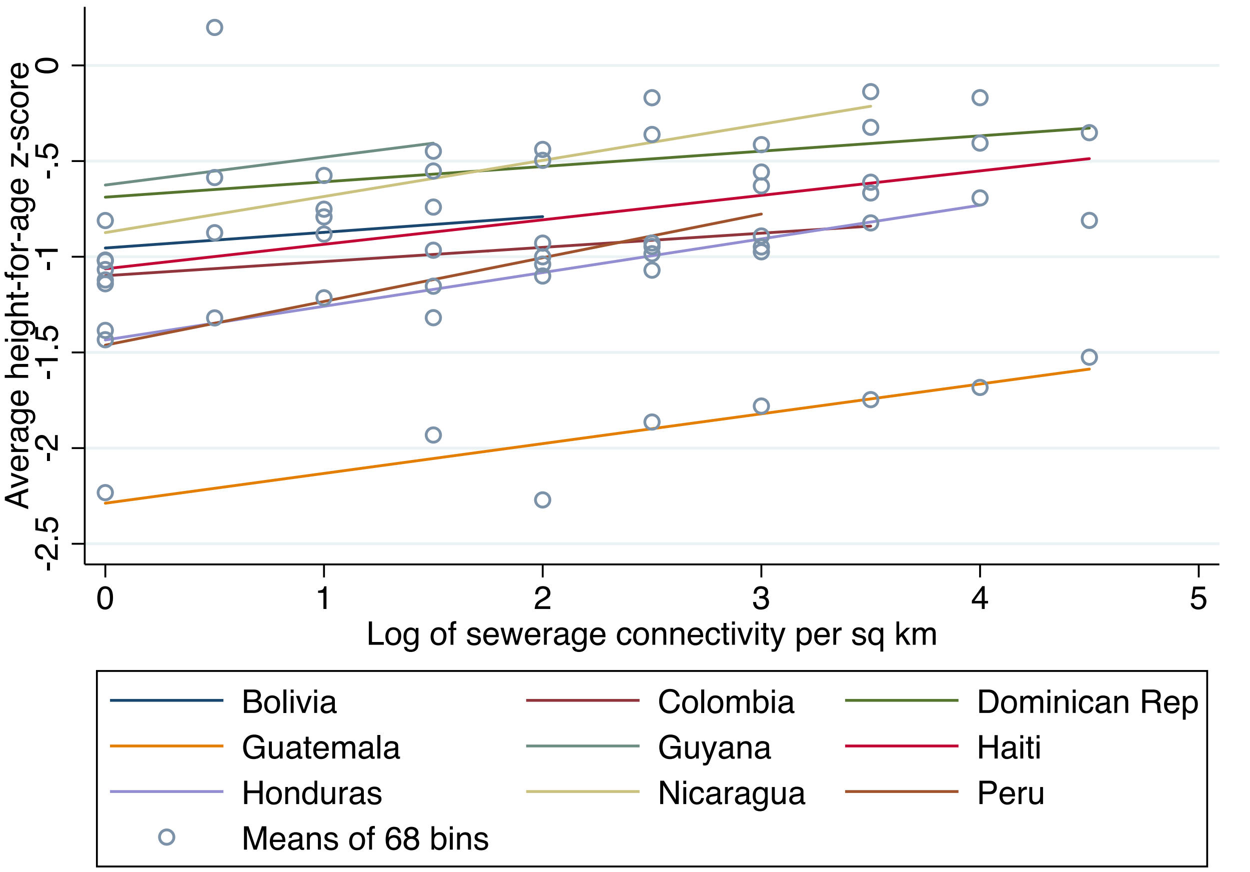
Notes: Sewerage connectivity density computed as ln(sewerage connectivity ∗ population density +1) at the country level. Columns (2) to (5) include global-region fixed effects. There are 4 global-regions: (1) Sub-Saharan Africa; (2) North-Africa/West-Asia/Europe; (3) South and South-East Asia and (4) Latin America. Robust standard errors in parenthesis. Statistical significance denoted by: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

FIGURE 4.2: Child height-for-age by age in months in Latin America



Notes: Local linear polynomials (blue for boys and green for girls) with 95 percent confidence intervals.

FIGURE 4.3: Child height and sewerage connectivity density, by Latin American country



Notes: Circles denote the mean height-for-age and sewerage connectivity density for 68 bins. Each line denotes the local regression for each country of Latin America in the sample. Sewerage connectivity density computed as ln(sewerage connectivity ∗ country population density +1) at the PSU level.

TABLE 4.3: Quantile regression estimates for connectivity density and child height in Latin America

	(1)	(2)	(3)	(4)	(5)
Percentile	10th	25th	Median	75th	90th
Panel A: All children					
Connectivity density (ln)	0.04***	0.04***	0.04***	0.03***	0.03***
	(0.01)	(0.01)	(0.00)	(0.00)	(0.01)
Children	78,117	78,117	78,117	78,117	78,117
Panel B: 0-5 months					
Connectivity density (ln)	0.04***	0.04**	0.03**	0.02*	0.00
	(0.01)	(0.02)	(0.01)	(0.01)	(0.02)
Children	6,945	6,945	6,945	6,945	6,945
Panel C: 6-24 months					
Connectivity density (ln)	0.03***	0.04***	0.03***	0.04***	0.04***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Children	25,950	25,950	25,950	25,950	25,950
Panel D: 25-59 months					
Connectivity density (ln)	0.05***	0.03***	0.04***	0.04***	0.04***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Children	45,222	45,222	45,222	45,222	45,222

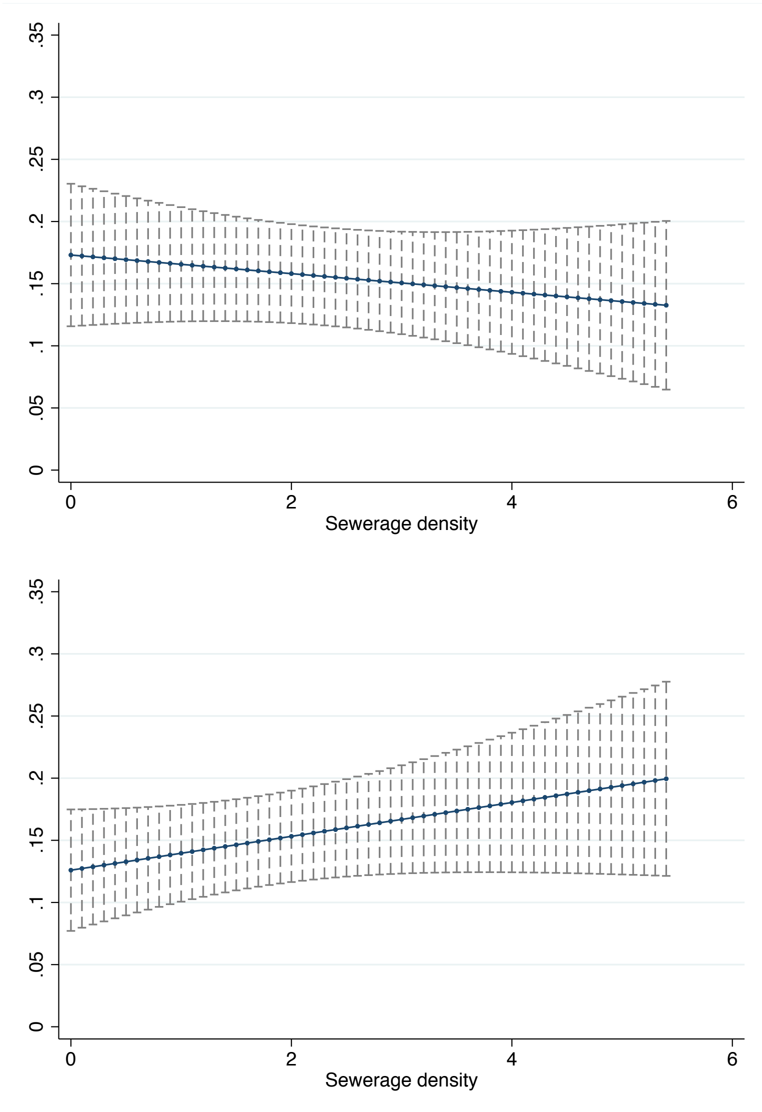
Notes: Dependent variable: height-for-age z-score. Sewerage connectivity density computed as ln(sewerage connectivity ∗ country population density +1) at the PSU level. All estimates include region fixed effects for the DHS sub-national regions, sex-by-age fixed effects and year-of-birth fixed effects. Additional controls include: child's birth order, mother's height and educational attainment, household wealth quintile, an indicator of whether household has access to piped-water and country-level population density. Robust standard errors in parenthesis. Statistical significance denoted by: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

TABLE 4.2: Sewerage connectivity density predicts child height disparities in Latin America

	(1)	(2)	(3)	(4)
	All	0-5 months	6-24 months	25-59 months
Connectivity density (ln)	0.04***	0.03*	0.04***	0.04***
	(0.01)	(0.02)	(0.01)	(0.01)
Household connectivity	-0.06***	-0.05	-0.08***	-0.05***
	(0.02)	(0.05)	(0.03)	(0.02)
Mean (initial)	-1.37	-0.68	-1.28	-1.54
Children	78,117	6,945	25,950	45,222
PSU	11,613	5,071	9,825	11,114

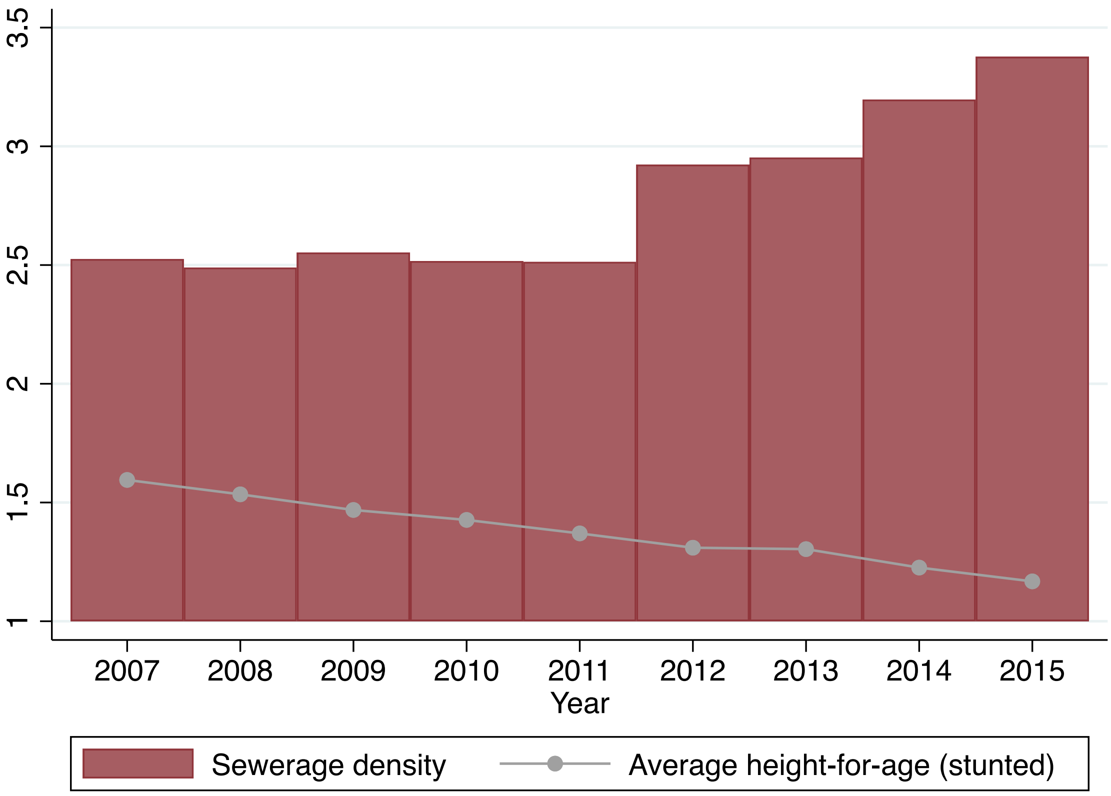
Notes: Dependent variable: height-for-age z-score. Sewerage connectivity density computed as ln(sewerage connectivity ∗ country population density +1) at the PSU level. All estimates include region fixed effects for the DHS sub-national regions, sex-by-age fixed effects and year-of-birth fixed effects. Additional controls include: child's birth order, mother's height and educational attainment, household wealth quintile, an indicator of whether household has access to piped-water and country-level population density. Standard errors clustered by PSU. Statistical significance denoted by: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

FIGURE 4.4: Mother-child height correlation as a function of sewerage connectivity density



Notes: The upped figure corresponds to women's first child and the lower map corresponds to subsequent children. For reference, the U.S. (1979) average mother-child height correlation is 0.4. These figures plot the child-mother height correlation in Peru, estimated as the marginal effect of the interaction term = PSU sewerage connectivity density (ln) $*$ mother height on child height. Marginal effects estimated for the whole range of sewerage density, increasing by 0.05 households connected to sewerage per square km. All estimates include region fixed effects for the DHS sub-national regions, sex-by-age fixed effects and year-of-birth fixed effects. Additional controls include: child's birth order, mother's height and educational attainment, household wealth quintile, an indicator of whether household has access to piped-water and sewerage connectivity and country-level population density.

FIGURE 4.5: Sewerage connectivity density and child height improves over-time in Peru



Notes: The red line connects the annual mean height-for-age in absolute terms, where each level is a negative value. Each bar denotes the PSU's sewerage connectivity per square kilometers, based on the district's population density. Sewerage connectivity density computed as ln(sewerage connectivity $*$ district population density $+1$) at the PSU level.

TABLE 4.4: Sewerage connectivity density predicts child height in Peru

	(1)	(2)	(3)	(4)
	All	0-5 months	6-24 months	25-59 months
Connectivity density (ln)	0.01***	-0.01	0.01**	0.01***
	(0.00)	(0.01)	(0.01)	(0.00)
Connectivity density (ln) × Boys	0.01***	0.00	0.01**	0.01***
	(0.00)	(0.01)	(0.00)	(0.00)
Boys	0.46***	0.21**	0.15**	-0.12**
	(0.08)	(0.09)	(0.07)	(0.06)
Household connectivity	0.04***	0.07	-0.01	0.06***
	(0.01)	(0.05)	(0.02)	(0.02)
Mean (initial)	-1.44	-0.73	-1.38	-1.62
Children	86,845	7,673	27,061	52,111
PSU	9,376	4,681	8,395	9,179

Notes: Dependent variable: height-for-age z-score. Sewerage connectivity density computed as ln(sewerage connectivity $*$ district population density +1) at the PSU level. Included DHS survey rounds spanning 2007-2015. All estimates include district fixed effects, sex-by-age fixed effects and year-of-birth fixed effects. Additional controls include: child's birth order, mother's height and educational attainment, household wealth quintile, an indicator of whether household uses piped-water to drink and district-level population density. Standard errors clustered by PSU. Statistical significance denoted by: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

TABLE 4.5: Sewerage connectivity density predicts child height in non-linear fashion

	(1) All	(2) 0-5 months	(3) 6-24 months	(4) 25-59 months
Connectivity density 2-4	0.08***	-0.01	0.06**	0.09***
	(0.01)	(0.06)	(0.03)	(0.02)
Connectivity density 4-6	0.09***	-0.07	0.08**	0.10***
	(0.02)	(0.07)	(0.04)	(0.02)
Connectivity density 6-8	0.10***	0.01	0.12**	0.11***
	(0.03)	(0.10)	(0.05)	(0.03)
Connectivity density 8-10	0.07*	-0.01	0.13*	0.06
	(0.04)	(0.15)	(0.07)	(0.05)
Household connectivity	0.04***	0.07	-0.01	0.06***
	(0.01)	(0.05)	(0.02)	(0.01)
Joint test p-value	0.00	0.84	0.04	0.00
Mean (initial)	-1.44	-0.73	-1.38	-1.62
Children	86,845	7,673	27,061	52,111
PSU	9,376	4,681	8,395	9,179

Notes: Dependent variable: height-for-age z-score. Sewerage connectivity density computed as ln(sewerage connectivity $*$ district population density +1) at the PSU level. Included DHS survey rounds spanning 2007-2015. All estimates include district fixed effects, sex-by-age fixed effects and year-of-birth fixed effects. Additional controls include: child's birth order, mother's height and educational attainment, household wealth quintile, an indicator of whether household uses piped-water to drink and district-level population density. Standard errors clustered by PSU. Statistical significance denoted by: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

TABLE 4.6: Child's health and nutritional status

	(1) Diarrhoea	(2) Weight-for-age	(3) Weight-for-height
Connectivity density (ln)	0.00	0.01***	0.00
	(0.00)	(0.00)	(0.00)
Household connectivity	-0.01	0.01	-0.01
	(0.01)	(0.01)	(0.01)
Mean (initial)	0.16	-0.39	0.63
Children	86,793	86,026	85,458

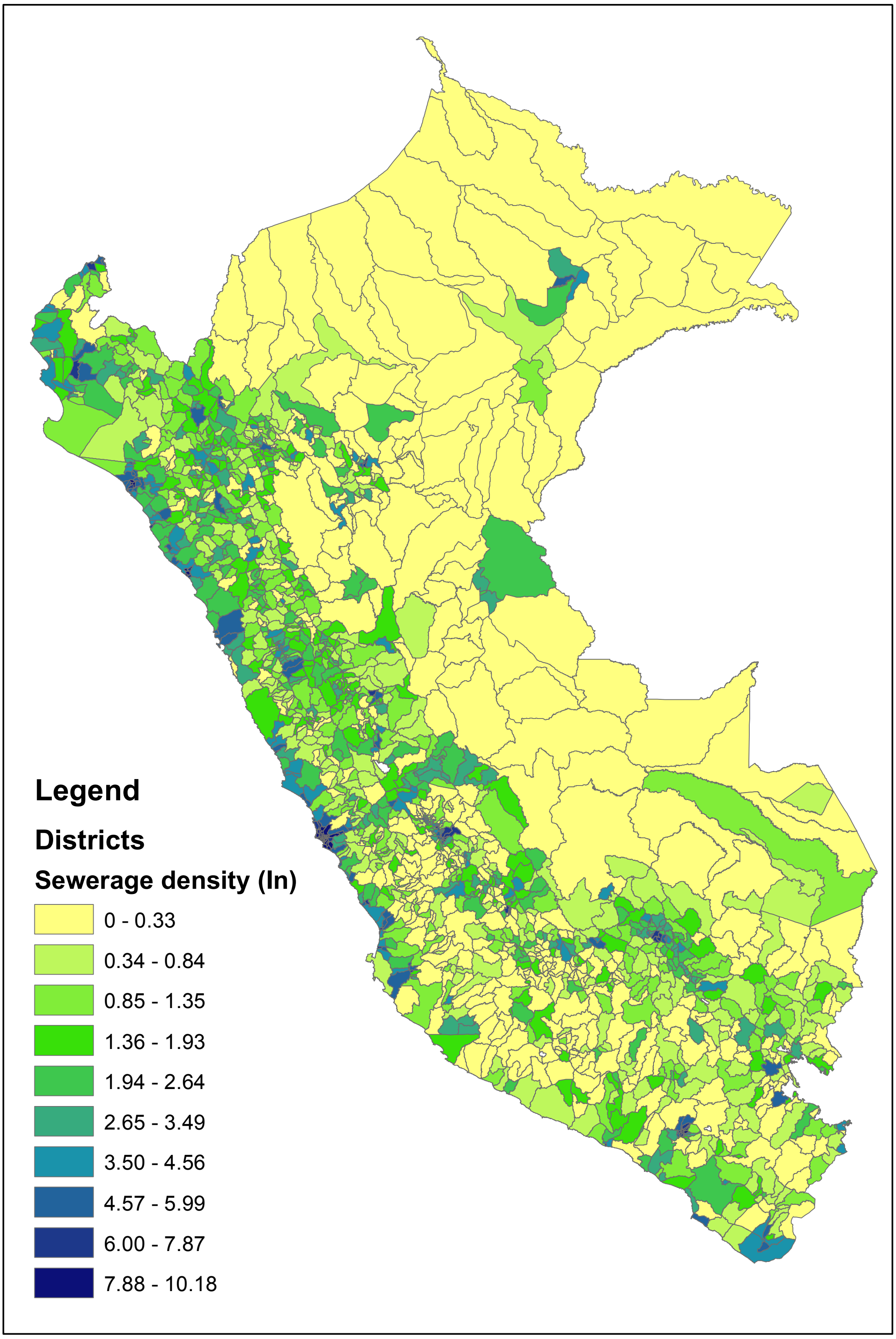
Notes: The dependent variable in column (1) is an indicator capturing whether the child had diarrhoea in the last 2 weeks, as reported by the main caregiver; in column (2) is the weight-for-age z-score and in column (3) the weight-for-height z-score. Sewerage connectivity density computed as ln(sewerage connectivity ∗ district population density +1) at the PSU level. Included DHS survey rounds spanning 2007-2015. All estimates include district fixed effects, sex-by-age fixed effects and year-of-birth fixed effects. Additional controls include: child's birth order, mother's height and educational attainment, household wealth quintile, an indicator of whether household uses piped-water to drink and district-level population density. Standard errors clustered by PSU. Statistical significance denoted by: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

TABLE 4.7: Parental investments

	(1) Treat water	(2) Exclusively breastfed	(3) Dietary diversity	(4) Fed sugar
Connectivity density (ln)	0.00	-0.01*	0.02**	0.01***
	(0.00)	(0.00)	(0.01)	(0.00)
Household connectivity	0.01*	0.02	-0.03	-0.01
	(0.01)	(0.02)	(0.03)	(0.01)
Mean (initial)	0.79	0.62	4.26	0.29
Children	86,837	9,097	61,211	61,211

Notes: The dependent variable in column (1) is an indicator capturing whether the household of the child treats the drinking water; in column (2) is an indicator capturing if the infant is exclusively breastfed; in column (3) is dietary diversity index and in column (4) an indicator capturing whether the child was fed sweets and sugar. Sewerage connectivity density computed as ln(sewerage connectivity ∗ district population density +1) at the PSU level. Sample in column 2 restricted to infants between 0 and 6 months old (months were exclusive breastfeeding is recommended by WHO). All estimates include district fixed effects, sex-by-age fixed effects and year-of-birth fixed effects. Additional controls include: child's birth order, mother's height and educational attainment, household wealth quintile, an indicator of whether household uses piped-water to drink and district-level population density. Standard errors clustered by PSU. Statistical significance denoted by: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

FIGURE 4.6: Sewerage connectivity density across Peruvian districts (2007)



Notes: This map shows the district boundaries of Peru and the distribution across districts of sewerage density per square kilometer. Light-shaded districts are those with lower sewerage connectivity density and dark-shaded districts are those with higher sewerage connectivity density. Sewerage connectivity density computed as ln(sewerage connectivity $*$ population density +1) at the district level. Author's calculation using data from the 2007 Census.

TABLE 4.8: First stage, adjacent predicts district's connectivity density

	(1)	(2)
Sample:	Height-for-age	Mortality rate
Adjacent connectivity density t-2 (ln)	1.09***	1.71***
	(0.27)	(0.21)
Fstat	15.89	89.64
Children	4,374	
Districts	366	1,005
Provinces	159	165

Notes: Sewerage connectivity density computed as ln(sewerage connectivity ∗ population density +1) at the district level. Sample restricted to year 2007, when data on district's and neighbour's (t-2) sewerage connectivity are available. All estimates include province fixed effects, sex-by-age fixed effects and year-of-birth fixed effects. Column 1 includes additional controls: child's birth order, mother's height and educational attainment, household wealth quintile, an indicator of whether household uses piped-water to drink and sewerage connectivity and district-level population density. Standard errors clustered by district in column (1) and province in column (2). Statistical significance denoted by: *** p<0.01, ** p<0.05, * p<0.1.

TABLE 4.9: Sewerage connectivity density increases child height

	(1)	(2)	(3)	(4)
	All	0-5 months	6-24 months	25-59 months
Panel A: OLS				
Connectivity density (ln)	0.02	0.16***	-0.02	0.02
	(0.01)	(0.05)	(0.03)	(0.02)
Panel B: 2SLS				
Connectivity density (ln)	0.14**	0.06	0.00	0.22**
	(0.06)	(0.17)	(0.08)	(0.09)
Fstat	15.89	9.65	16.37	11.93
Mean (no sewer)	-1.92	-1.27	-1.90	-2.10
Children	4,374	426	1,396	2,552
Districts	366	214	337	359
Provinces	159	125	156	158

Notes: Dependent variable: height-for-age z-score. Sewerage connectivity density computed as ln(sewerage connectivity ∗ population density +1) at the district level. Sample restricted to year 2007, when data on district's and neighbour's (t-2) sewerage connectivity are available. All estimates include province fixed effects, sex-by-age fixed effects and year-of-birth fixed effects. Additional controls include: child's birth order, mother's height and educational attainment, household wealth quintile, an indicator of whether household is connected to sewerage and uses piped-water to drink and district-level population density. Standard errors clustered by district to deal with intra-cluster correlation. Statistical significance denoted by: *** p<0.01, ** p<0.05, * p<0.1.

TABLE 4.10: Sewerage connectivity density decreases child mortality

	(1)	(2)	(3)	(4)
	OLS		2SLS	
	Infant	Under-5	Infant	Under-5
Connectivity density (ln)	-0.00	-0.21**	-0.00**	-0.43**
	(0.00)	(0.09)	(0.00)	(0.20)
Fstat			89.64	89.64
Mean (no sewer)	0.02	5.14	0.02	5.14
Districts	1,005	1,005	1,005	1,005
Provinces	165	165	165	165

Notes: Dependent variable: infant (IMR) and under-five (U5MR) mortality rate. Sewerage connectivity density computed as ln(sewerage connectivity $*$ population density +1) at the district level. Sample restricted to year 2007, when data on district's and neighbour's (t-2) sewerage connectivity are available. All estimates include province fixed effects, total population and population density. Standard errors clustered by province to deal with intra-cluster correlation. Statistical significance denoted by: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

4.7 Appendix

TABLE 4.11: Sample means and standard deviation, by global-region

	(1)	(2)	(3)	(4)	(5)
	All	Sub-Saharan Africa	North-Africa/West-Asia/Europe	South and South-East Asia	Latin America
Average height-for-age z-score	-1.29	-1.39	-0.94	-1.71	-1.07
	(0.45)	(0.30)	(0.54)	(0.31)	(0.39)
Sewerage connectivity	0.18	0.05	0.41	0.09	0.38
	(0.22)	(0.08)	(0.17)	(0.12)	(0.24)
Connectivity density (ln)	1.93	0.87	3.36	2.69	2.62
	(1.39)	(0.75)	(0.75)	(1.35)	(1.06)
Population density (per sq. km)	146.48	96.26	78.43	469.97	90.90
	(246.84)	(110.81)	(23.63)	(503.68)	(114.25)
GDP per capita (ln)	8.10	7.69	8.79	7.88	8.66
	(0.81)	(0.75)	(0.46)	(0.51)	(0.68)
Population density (ln)	4.24	3.96	4.31	5.53	3.89
	(1.22)	(1.24)	(0.34)	(1.19)	(1.16)
Women with height below 145 cm	0.04	0.02	0.02	0.10	0.07
	(0.05)	(0.02)	(0.02)	(0.04)	(0.07)
Country-year	89	43	17	13	16

Notes: Coefficients denote means and standard deviations in parenthesis.

TABLE 4.12: Sample means and standard deviation, by Latin American country

	(1) All	(2) Bolivia	(3) Colombia	(4) Dom Rep	(5) Guatemala	(6) Guyana	(7) Haiti	(8) Honduras	(9) Nicaragua	(10) Peru
Dependent variable										
Height-for-age z-score	-1.08	-0.98	-0.83	-0.29	-1.89	-0.87	-0.94	-1.11	-0.94	-0.87
	(1.27)	(1.25)	(1.11)	(1.21)	(1.18)	(1.43)	(1.41)	(1.22)	(1.35)	(1.07)
Independent variable										
Household connectivity	0.42	0.41	0.67	0.72	0.31	0.04	0.00	0.27	0.12	0.65
	(0.49)	(0.49)	(0.47)	(0.45)	(0.46)	(0.20)	(0.07)	(0.44)	(0.32)	(0.48)
PSU connectivity	0.42	0.42	0.67	0.72	0.32	0.03	0.01	0.26	0.13	0.65
	(0.45)	(0.45)	(0.43)	(0.28)	(0.38)	(0.12)	(0.04)	(0.40)	(0.29)	(0.43)
Connectivity density (ln)	2.00	1.06	2.70	4.85	2.41	0.08	0.23	1.48	0.69	2.27
	(1.87)	(1.05)	(1.55)	(0.77)	(2.10)	(0.23)	(0.88)	(1.88)	(1.28)	(1.33)
Population density (per sq km)	88.71	8.97	40.76	207.99	151.66	3.80	371.95	77.22	42.76	23.81
	(90.87)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Demographics										
Age in months	29.35	29.05	30.11	29.78	29.38	30.31	27.38	28.22	29.40	29.90
	(17.04)	(17.17)	(16.85)	(17.29)	(17.17)	(16.91)	(17.17)	(17.21)	(16.90)	(16.79)
0-5 months	0.09	0.10	0.07	0.09	0.10	0.07	0.11	0.11	0.09	0.08
	(0.29)	(0.30)	(0.26)	(0.28)	(0.30)	(0.26)	(0.31)	(0.31)	(0.29)	(0.27)
6-24 months	0.33	0.34	0.33	0.34	0.32	0.33	0.36	0.35	0.33	0.33
	(0.47)	(0.47)	(0.47)	(0.47)	(0.47)	(0.47)	(0.48)	(0.48)	(0.47)	(0.47)
25-59 months	0.58	0.56	0.60	0.57	0.58	0.60	0.53	0.55	0.58	0.59
	(0.49)	(0.50)	(0.49)	(0.49)	(0.49)	(0.49)	(0.50)	(0.50)	(0.49)	(0.49)
First child	0.34	0.31	0.40	0.37	0.31	0.30	0.32	0.34	0.31	0.33
	(0.47)	(0.46)	(0.49)	(0.48)	(0.46)	(0.46)	(0.47)	(0.47)	(0.46)	(0.47)
Birth order	2.65	2.88	2.24	2.25	2.89	2.81	3.03	2.64	3.21	2.42
	(1.97)	(2.13)	(1.56)	(1.40)	(2.16)	(2.02)	(2.28)	(1.96)	(2.56)	(1.61)
Socio-economics										
Mother's education (years)	7.46	8.60	8.69	10.10	5.03	8.47	4.97	6.56	5.31	10.02
	(4.65)	(4.63)	(3.96)	(4.02)	(4.28)	(3.99)	(4.19)	(4.19)	(4.27)	(4.31)
House piped water	0.55	0.87	0.80	0.09	0.54	0.30	0.04	0.11	0.55	0.81
	(0.50)	(0.34)	(0.40)	(0.29)	(0.50)	(0.46)	(0.19)	(0.31)	(0.50)	(0.39)
Wealth quintile 1	0.24	0.10	0.26	0.24	0.27	0.27	0.25	0.26	0.26	0.22
	(0.43)	(0.30)	(0.44)	(0.43)	(0.44)	(0.45)	(0.43)	(0.44)	(0.44)	(0.42)
Wealth quintile 2	0.22	0.16	0.24	0.22	0.22	0.22	0.22	0.21	0.22	0.22
	(0.41)	(0.37)	(0.43)	(0.42)	(0.42)	(0.41)	(0.42)	(0.41)	(0.41)	(0.41)
Wealth quintile 3	0.21	0.27	0.22	0.20	0.20	0.20	0.20	0.20	0.19	0.21
	(0.41)	(0.45)	(0.42)	(0.40)	(0.40)	(0.40)	(0.40)	(0.40)	(0.39)	(0.41)
Wealth quintile 4	0.19	0.27	0.17	0.18	0.18	0.16	0.20	0.20	0.18	0.18
	(0.39)	(0.44)	(0.38)	(0.38)	(0.38)	(0.36)	(0.40)	(0.40)	(0.38)	(0.39)
Wealth quintile 5	0.14	0.20	0.11	0.16	0.13	0.16	0.14	0.14	0.15	0.17
	(0.35)	(0.40)	(0.31)	(0.37)	(0.34)	(0.36)	(0.34)	(0.35)	(0.35)	(0.38)
Observations	78117	5075	15188	3169	11702	1540	3943	9802	5795	21903
Survey year		2008	2010	2013	2015	2009	2012	2012	2001	2015

Notes: Coefficients denote means and standard deviations in parenthesis. Sampling weights are used in this table, unlike other results in this paper that intend to document associations.

TABLE 4.13: Sample means and standard deviation, by year in Peru

	(1) All years	(2) 2007	(3) 2011	(4) 2015
Child characteristics				
Height-for-age z-score	-1.08	-1.34	-1.08	-0.89
	(1.13)	(1.22)	(1.09)	(1.07)
Male	0.51	0.51	0.51	0.51
	(0.50)	(0.50)	(0.50)	(0.50)
Birth order number	2.54	2.82	2.56	2.41
	(1.76)	(2.03)	(1.78)	(1.57)
0-5 months	0.09	0.09	0.09	0.08
	(0.29)	(0.29)	(0.29)	(0.27)
6-24 months	0.31	0.32	0.30	0.31
	(0.46)	(0.46)	(0.46)	(0.46)
25-59 months	0.60	0.59	0.61	0.61
	(0.49)	(0.49)	(0.49)	(0.49)
Mother characteristics				
Mother's height	1515.22	1511.53	1514.46	1520.62
	(55.65)	(56.84)	(54.78)	(55.82)
Mother's highest educational attainment	3.17	2.88	3.16	3.48
	(1.46)	(1.53)	(1.49)	(1.39)
Household characteristics				
Household sewerage	0.53	0.42	0.51	0.63
	(0.50)	(0.49)	(0.50)	(0.48)
Access to piped-water	5.61	6.09	5.64	4.95
	(20.92)	(22.03)	(21.00)	(19.43)
Wealth quintile 1	0.23	0.18	0.24	0.23
	(0.42)	(0.38)	(0.43)	(0.42)
Wealth quintile 2	0.24	0.27	0.23	0.22
	(0.43)	(0.44)	(0.42)	(0.42)
Wealth quintile 3	0.22	0.22	0.23	0.20
	(0.41)	(0.42)	(0.42)	(0.40)
Wealth quintile 4	0.17	0.17	0.18	0.18
	(0.38)	(0.37)	(0.38)	(0.38)
Wealth quintile 5	0.14	0.16	0.13	0.16
	(0.34)	(0.37)	(0.33)	(0.37)
District				
Sewerage density (ln)	4.04	3.36	3.87	4.69
	(3.67)	(3.65)	(3.66)	(3.62)
Pop density (sq. km)	3028.74	2580.08	2923.24	3574.38
	(5478.86)	(5339.66)	(5328.69)	(5834.64)
Child-year	86845	4374	8456	22232

Notes: Coefficients denote means and standard deviations in parenthesis. Sampling weights are used in this table, unlike other results in this paper that intend to document associations.

Chapter 5

Conclusions

The provision and adoption of public infrastructure plays a central role in social policy, particularly in that of LMICs. Crucial advances are being made in areas such as improving health, making human settlements resilient and promoting inclusive and sustained economic growth (World Bank, 2020).

This thesis evaluates both the supply and demand around public infrastructure, with a particular focus on the sanitation market and its contribution to public health and human capital. SDG 6 introduced the challenge of "Ensuring Availability and Sustainable Management of Water and Sanitation for All by 2030". Poor sanitation has recently been identified as one of the main causes of early-life mortality and stunted physical growth, leading to the loss of human capital and productivity in LMICs (Fay et al., 2017; World Bank, 2018).

Each empirical chapter addresses a different, but inter-linked, type of enquiry into public infrastructure delivery. Chapter 2 focuses on the supply of sanitation infrastructure. This chapter identifies inefficiencies in public expenditure and their unintended consequences for early-life mortality. Chapter 3 looks at how to promote demand for sanitation infrastructure. Finally, Chapter 4 explores the effectiveness of sanitation infrastructure, when supply and demand meet, in improving early-life human capital. Altogether, this thesis pushes our frontier of knowledge about the effective delivery of public infrastructure.

In the first section of this chapter I summarise the main findings and contributions of each of the papers. Next, I discuss the most important implications and policy recommendations coming out of this thesis. The third section describes the main limitations of my research. The final section elaborates on future avenues of my research.

5.1 Main Findings and Contributions

Taken together, the three papers in this thesis make three contributions to the literature. First, this thesis amplifies our empirical knowledge of where infrastructure projects may go wrong, by analysing the "forgotten middle" — the implementation phase and its consequences. Second, it provides useful, empirically informed guidance for overcoming obstacles to the demand for public infrastructure. Finally, through this detailed analysis of sanitation infrastructure, I also provide a more nuanced understanding of the human capital production function in LMICS, where public health is a key factor.

The Forgotten Middle

Chapter 2 addresses a noticeable gap in the public infrastructure literature. Previous literature has shown how vital effective public infrastructure is to improve living standards, but only when it is completed and already in use (Dinkelman, 2011; Rud, 2012; Lipscomb et al., 2013; Donaldson, 2018). In contrast, and in line with Rasul and Rogger (2018) and Williams (2017), I document how the implementation of public infrastructure projects suffers from mid-construction abandonment and severe delays. But I show that these inefficiencies are more than just a waste of public resources. Unfinished infrastructure projects generate high social costs: they can kill children.

Specifically, I find that unfinished sewerage projects, as opposed to not starting projects, increase infant and under-five mortality in Peru. The mechanisms behind this result are threefold. First, water cuts are needed during the installation of sewerage lines, which force the population to rely on unsafe sources of water and deteriorate their hygiene and sanitation practices. Second, in order to install public sewers, extensive excavations are required. This digging creates open ditches that get filled with stagnant water and become pools of infection. Third, large building sites pose hazards to children who are used to roaming freely and are at risk of accidents. In line with these mechanisms, my results show that the mortality caused by water-borne diseases and accidents increases. Supporting the internal validity of these results, I find no effects on mortality caused by other underlying conditions.

This chapter provides a full picture of the implementation of public infrastructure. In addition to exploring the health effects of unfinished projects, this chapter also shows that completed projects decrease early-life mortality, in keeping with findings that sewerage systems increase the probability of child survival and improved life expectancy in today's advanced economies during the previous centuries (Watson, 2006; Alsan and Goldin, 2019; Kesztenbaum and Rosenthal, 2017). I also show that providing access to public sewers does not ensure universal connectivity of households to sewerage systems in the short-run, which may prevent the social benefits of sewerage systems from fully manifesting. This finding is evidence of the last mile problem — the inability of governments to connect costly infrastructure to the final user (Ashraf et al., 2016).

How to Promote Demand

Chapter 3 contributes to the literature exploring how to promote the demand for public infrastructure in general, and in particular of goods with health benefits (Kremer et al., 2011; Devoto et al., 2012; Ben Yishay et al., 2017; Guiteras et al., 2015; Gertler et al., 2015;

Greenstone and Jack, 2015). I study this in the context of slums in India and community toilets, a type of sanitation where coordination problems are salient. While considered an important public health solution for the foreseeable future in slums, our data reveals rampant free-riding and remarkably low valuation for CTs, which are in turn of very bad quality. Burgess et al. (2020) and Mcrae (2015) have already demonstrated how non-payment and subsidies distort the supply of public infrastructure. In this chapter, I demonstrate that they also distort demand.

We find that a marginal improvement in CT quality achieved by the one-off supply push —a typical public intervention when rehabilitating infrastructure— is not sustained over time. Surprisingly, externally funding public infrastructure rehabilitation backfires. We find reductions in willingness to pay, a deterioration in attitudes towards paying a user fee and greater demand for public intervention in the maintenance of CTs. Altogether, these findings provide evidence that external funds crowd-out private contributions in our study context. Importantly, we find that an information campaign increasing awareness of the importance to pay the fee and externalities from unsafe sanitation behaviour is ineffective in counteracting any of these effects, despite having left a lasting impression on households.

Sanitation and Human Capital

Chapter 4 contributes to the literature on the drivers of international disparities in human capital (Deaton, 2007; Deaton and Drèze, 2009; Bozzoli et al., 2009; Spears, 2020). I provide evidence to show that local sewerage connectivity density is a driver of child height disparities in LMICs. The results remain robust across three separate analyses, representing different trade-offs between external and internal validity.

The mechanisms behind the findings are twofold. First, the local sanitation environment apparently improves with greater sewerage connectivity density, reducing the burden of diseases (other than diarrhoea, such as enteric diseases) that affect nutritional status in the short-run. Second, parental investments change, particularly those that affect nutritional intake. While infants below six months old were less likely to be exclusively breastfed, dietary diversity was greater for those children in communities with greater connectivity density. This finding is in line with Ritter (2015)'s study, which shows that the consumption of sugar-sweetened beverages protects against infectious diseases.

In addition, this paper also advances evidence on the importance of sanitation *adoption* at an aggregate level (Augsburg and Rodríguez-Lesmes, 2018; Spears, 2020), at the top rung of the sanitation ladder (Duflo et al., 2015; Pickering at al., 2015; Dickinson et al., 2015; Cameron et al., 2019) and when interacted with population density in LMICs (Hathi et al., 2017). The chapter expands the frontier of knowledge in the literature focused on early-life human capital accumulation (Maluccio et al., 2009; Cunha et al., 2010; Gertler et al., 2014; Campbell et al., 2014) by adding sanitation as a determinant in LMICs.

5.2 Policy Implications and Recommendations

Governments and Multilateral Development Banks invest billions of dollars every year in developing public infrastructure, with the aim of promoting economic and social development. The findings in this thesis can inform them on how those funds are spent.

The results in Chapter 2 stress the importance of obtaining a comprehensive understanding of the cost-effectiveness of supplying public infrastructure. This understanding must extend from the implementation of projects to their delivery to the final user. Moreover, cost-effectiveness analyses should include social costs in addition to private costs.

The inclusion of social costs will incentivise agents to mitigate these costs in the implementation of public infrastructure projects. For example, project delivery could be complemented by policies that mitigate the negative consequences of the construction works. Low-hanging fruit, such as stricter health and safety measures, complementary healthcare and the provision of alternative safe sources of water and sanitation during construction, could compensate the affected population and prevent child deaths.

Furthermore, any institutional arrangement (public or private) will have to deal with the lumpy nature of finance and construction of infrastructure. Mid-construction abandonment and unnecessary delays, which exacerbate health hazards to the population, must move up the ladder of policy priorities. As a minimum, LMIC governments must improve the monitoring of the physical progression of infrastructure projects. A reform of the contractual system could help finish projects that are started, such as leaving a large lump of the contractual payment for when projects are finalised and including a penalty for not completing infrastructure.

The literature provides additional useful insights into the determinants of project non-completion, which can guide policy actions. Rasul and Rogger (2018) stress the importance of improving managerial practices in local bureaucrats, including the use of external rewards. Williams (2017) highlights the need to impose a rule that districts must finish existing projects before starting new ones. Robinson and Verdier (2013) reveals that better government accountability, particularly during electoral years, can help reduce mid-construction abandonment when political leaders strategically delay unfinished projects.

The results in Chapter 2 also reveal that, even when public infrastructure is available, demand is not guaranteed. Chapter 3 adds to this challenge by showing that promoting demand for shared public infrastructure is not a trivial task. A one-off push to rehabilitate infrastructure, coupled with financial rewards to providers, is not enough to achieve sustained improvements in quality, valuation and usage. The traditional policy approach of supporting providers to rehabilitate public infrastructure with the aim of stimulating demand, regardless of the level of private contribution, backfires. Private contributions and usage decrease, while the demand for public intervention to operate and maintain shared infrastructure increases. Furthermore, the results in Chapter 3 show that intense information campaigns, a typical policy tool, are not effective at inducing payment for and increasing usage of shared infrastructure.

Exploring other solutions in a similar setting to ours, Coville et al. (2020) shows that hard threats of disconnection decrease non-payment. Yet, disconnecting/preventing usage of sanitation facilities may not be socially desirable in a high disease burden and low environmental quality setting such as slums, so there is a need to explore policy alternatives. Policies range from fully subsidising usage to removing explicit subsidies while continuing to support the poor through ear-marked transfers (Guiteras et al., 2015; Attanasio et al., 2011).

To change the social norm tolerating free-riding, while not deterring safe behaviour, encouraging collective action may be an effective avenue. Community Total Sanitation Campaigns (CLTS), which use psychosocial levers of shame and disgust and appoint a local monitoring committee, have proven to be effective to improve sanitation behaviour in poorer settings (Abramovsky et al, 2018). Though evidence of CLTS mainly comes from rural areas, an approach adapted to urban areas could be effective at reducing free-riding in shared infrastructure in slums.

The results in Chapter 4 provide a silver lining to the effective delivery and adoption of public infrastructure and its effects on well-being. When infrastructure projects are completed and their adoption ensured at an aggregate level, they can contribute to human capital formation. This chapter provides three main policy recommendations. First, there are large gains to child health when promoting the adoption of sanitation facilities at an aggregate level, and even more when these facilities are on a high rung of the sanitation ladder (i.e. safer technologies). Second, for a given level of connectivity, policymakers should concentrate their efforts on increasing connectivity where population density is high. Including population density as a factor in allocation decisions can improve targeting compared to restricting the focus to urban areas or certain levels of the total population. Several areas in the developing world are classified as rural, despite having greater population density than places classified as urban.

Third, the results of this paper support the case that incentivising connectivity to a public good with positive health externalities, such as sewerage systems, should be a policy priority in the development agenda. Policymakers need to run the last mile, ensuring that users are connecting to costly public infrastructure. Ashraf et al. (2016), for example, argues that this could be achieved by finding a "sweet spot" between fines and subsidies for users. Of course, this is a long-run policy approach, as it depends heavily on the institutional quality of legal and executive bodies.

5.3 Limitations

Acknowledging the limitations of the three different chapters is essential to provide a basis for future research.

Regarding Chapter 2, although one of its great strengths is the collection and assembly of several novel sources of administrative data, this also poses great limitations. The main data challenge is measuring physical project completion. The government of Peru does not keep records of the physical progress of infrastructure projects over time, only financial ones. Given this limitation, in this paper I use financial progress as a proxy for physical progress. Of course, financial progress may reveal corruption instead of physical progress. Yet, the concern lies in my measure of project completion being underestimated —i.e. greater financial expenditure than physical progress means that some projects will be categorised as completed, even when they were not. For monitoring purposes, the Ministry of Economy and Finance of Peru shared with me that, since 2019, they have started measuring the physical progress of infrastructure projects. Systematising these data will offer a great opportunity for future research.

Another limitation of the data is that it is available at an aggregate level, namely district level. In an ideal world, each infrastructure project would be geo-coded and I would be able to match them to households in the catchment area. Even more ideal would be to have access to geo-coded data of the physical progress of sewerage projects over time. I therefore face a limitation in the analysis of behavioural responses to the development of sewerage infrastructure projects.

Related to the last limitation, the aggregate nature of the project data means that many projects are happening at the same time and in different stages in a given district. There are very few districts in which only one project has taken place, which allows me to identify the different stages of implementation. It is therefore not possible to disentangle the effects of a project completed on time vs. one temporarily delayed vs. one abandoned. Focusing on the effects of all types of unfinished projects in a given district (underway, delayed and abandoned) is the cleanest way to deal with this limitation.

Finally, due to the high prevalence of unfinished projects, I am underpowered to estimate the effect of completed projects on connectivity rates, and subsequently on child health. This is key to disentangling the effects of completed and unfinished projects. Yet, the literature has already estimated the effects of completed projects, and hence the focus on unfinished projects is a key strength of this paper.

The main limitations of Chapter 3 are those typically ascribed to randomised controlled trials (RCTs) (Deaton and Cartwright, 2018). While the main advantage of RCTs is strong internal validity, this does not come with a "free lunch". A first limitation is the external validity of the findings because the study takes place in only two cities of urban India. Yet, the findings in this chapter are relevant to all urban slums in India, where 24 per cent of the total population lived as of 2014, and in other LMICS, particularly in South Asia (where 30 per cent of the population lived in slums as of 2014). India shares many key characteristics with other countries that face similar challenges of urbanisation and poor sanitation, including GDP per capita (close to the South Asian regional average), population growth and life expectancy at birth (World Bank, 2020). Within India, Lucknow and Kanpur are comparable to other growing cities within its state (Uttar Pradesh) and in other states, in terms of the population living in slums, literacy rates and poverty rates (IndianMinistryofHomeAffairs, 2011).

A second limitation is related to scaling-up. The fact that an intervention might work differently at scale has long been noted in the economics literature (Banerjee and Duflo, 2009). The estimated effects in Chapter 3 come from an intervention implemented in a semi-controlled environment. Of course providing this intervention at the national level poses greater challenges. It is not clear ex-ante, for example, if the improvements in quality and salience of the intervention would be greater or lower. Furthermore, when thinking about scaling-up, it is important to think about "general equilibrium effects". For instance, if the government gives a one-off push to improve the quality of all community toilets in India, the prices of the factors of production will increase due to the greater demand. If the supply of community toilets is price elastic, the maintenance costs will increase dramatically and the quality could instead be deteriorated.

A third limitation is linked to the average treatment effect (ATE). An RCT delivers an ATE for the trial population but, in general, that average does not apply to everyone. Of course, the ATE from an RCT is only an estimate, not the infallible truth, and, like other estimates, it has a standard error.

However, there is no consensus as to how to deal with these limitations. In Chapter 3, I make an attempt to improve the credibility of the results by detailing the mechanisms through which they operate and conducting heterogenous analysis. Of course, a judicious use of theory, such as structural models, could improve the credibility and transferability of the results even further (Attanasio et al., 2011).

Regarding Chapter 4, its main limitation is internal validity. The aim of this paper is to provide separate analyses representing different points in a trade-off between external and internal validity. While the former is achieved by using country-level data from 52 LMICs and within-country data from nine Latin American countries, the latter suffers from weak identification. A naive ordinary least square (OLS) estimate, even after the inclusion of fixed effects, is not consistent. Thus, we can only interpret the estimates as associations, rather than causal effects of sewerage connectivity density on child height. In an attempt to increase the internal validity of the results, I use an instrumental variable strategy in the analysis of Peru. Yet, I acknowledge that the instrument may not comply with the exclusion restriction. The adjacent connectivity density may not only affect a given district's child height through the district's sewerage connectivity. One might worry that sewer adoption in a given district was related to changes in adjacent districts' health because of contamination fears. With this limitation in mind, the credibility of the results rests on the fact that they remain robust across different analyses.

Another limitation of Chapter 4 is the availability of population density data only at an aggregate level. Only in the case of Peru am I able to use population density data from the lowest jurisdictional level (districts), which allows for getting better insights into the magnitude of the association. Systematising and harmonising population density data across different census rounds in several countries could be of great value for future research.

5.4 Future Research

The methodologies, limitations, results and policy implications of this thesis open avenues for future research.

Chapter 2 stresses the need to investigate the determinants of public expenditure inefficiencies in the development of public infrastructure. The institutional arrangement of the provision of sewerage systems requires further investigation. The fact that sewerage systems are provided by a monopolistic government that deters competition may be a key determinant of inefficiencies in the implementation of infrastructure projects.

Private participation in the provision of public goods has increased in Latin America and around the world. We must understand if alternative arrangements with greater private participation, such as outright privatisation or a public-private partnership, can improve the quality of public infrastructure provision. Galiani et al. (2005), for example, find large gains in connectivity and performance linked to the privatisation of sewerage services in Argentina, which ultimately decrease child mortality. Such alternative institutional arrangements could be a viable solution for the government of Peru to increase sewerage connectivity. Nonetheless, Granados and Sánchez (2014) find that municipalities that have privatised sewerage services exhibit a slower reduction in child mortality rates and lower increases in coverage. Differences in institutional quality may be behind this mixed evidence. Besley and Ghatak (2006) predict that privatised solutions are only viable in the presence of strong legal systems and effective regulation. Whether or not greater private participation can improve the provision of public infrastructure is therefore an empirical question.

Two other potential determinants of project completion require wider investigation. The first is the political economy of infrastructure supply. Further research can help us get a better understanding of the role of political dynamics, including changes to the incumbent political party and gender, as well as term times and possibilities for re-election. the second is the role of government capacity. Investigating exogenous shocks to municipal revenue and public employment can help us gain insights into the extent to which capabilities are binding constraints to the efficient supply of public infrastructure.

Chapter 3 stresses the need to continue investigating how to promote demand for public goods in general, and shared infrastructure with positive health externalities in particular. The findings, however, raise a key question: how to effectively break the vicious cycle around non-payment and low-quality infrastructure.

Further research is needed to answer this question and I have identified three key areas. First, it is important to understand which policy option is cost-effective to achieve sustainable improvements in the sanitation environment of urban slums. Alternatives range from fully subsidising shared infrastructure, to removing explicit subsidies while continuing to support the poor. That said, there remains a need for more evidence from high free-riding environments and when coordination problems are salient. Second, we need to understand how to change social norms that make free-riding acceptable, while not deterring safe behaviour. Third, we must explore the effectiveness of different technologies to make shared infrastructure excludable, making it possible to link payment with supply.

Chapter 4 stresses the need to successfully induce an exogenous large increase in sewerage connectivity as a necessary first stage to infer causality. Field experiments have not managed to generate large enough first stages to learn from interventions aimed at inducing latrine adoption and move away from open defecation (Patil et al., 2014; Clasen et al., 2014; Gertler et al., 2015; Cameron et al., 2019) and few studies have exogenously induced the adoption of sewers at an aggregate level (Norman et al., 2014). Different policy approaches are currently being tested to increase adoption levels, but with mixed results and on a lower level of the sanitation ladder (Guiteras et al., 2015; Pickering at al., 2015). Further research is needed to gain a comprehensive understanding of the policy options to induce households to connect to public sewers.

Moreover, there is a need for statistically powerful experimental studies to estimate the long-term effects on child height. Yet, even then, the effects from accumulated maternal exposure to better environmental quality may require a long duration of changed exposure to fully reverse. Therefore, long-term follow-up studies are required to understand better the role of the sanitation environment in the human capital production function of LMICs.

5.5 Concluding remarks

I conclude this thesis with a reminder that access to public infrastructure remains out of reach of the majority of the population in LMICs. Millions of children die every year because of lack of access to and adoption of (by their house and neighbours) sanitation infrastructure. This situation will not change as long as we do not identify supply- and demand-side constraints and discover effective policy approaches to release them. The aim of this thesis is to advance knowledge in this domain and provide practical guidance to policymakers. My findings open an active research agenda in this topic.

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