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Does Access to Better Water and Sanitation Infrastructure Improve Child Outcomes? Evidence from Latin America and the Caribbean

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Abstract¹

I review the evidence on access to water and sanitation infrastructure and child outcomes in Latin America. I show that there are large differences in access across countries and, within countries, between households living in urban and rural areas. Many papers in the public health literature show associations between access to clean water sources or improved sanitation, on the one hand, and child outcomes like the incidence of diarrhea or child development, on the other. These papers provide only weak evidence of causality. Stronger evidence comes from a handful of papers that exploit historical accidents in the extension of coverage of water and sanitation infrastructure, although the evidence is limited to child mortality, rather than morbidity, nutritional status, and development. Also, it has generally not been possible to separately estimate the effects of changes in quantity and quality of water because piped water frequently improves both. Given the paucity of the evidence to date, there would be large returns to evaluations that had credibly exogenous sources of variation in access to piped water or sanitation, and traced out the benefits to children, including surviving children, over time.

JEL Classification: I12, I31, J13, O1, O12, O15

Keywords: Sanitation, Water supply, Child development, Children Health and hygiene, Latin America, the Caribbean.

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1. Introduction

“Clean water technologies are likely the most important
public health intervention of the 20th Century”

(Cutler and Miller, 2005, p 2.)

It is widely believed that the lack of access to improved water and sanitation services has serious, negative consequences for child mortality, morbidity, nutrition and development. Inadequate sources of water supply and sanitation can result in high levels of ingestion of various microbes transmitted from human or animal feces.

One consequence of microbial ingestion is diarrhea. Diarrhea is one of the most important causes of under-five mortality in the developing world, accounting for 0.75 million deaths of children under five (10 percent of the total) in 2010 (Liu et al., 2012). Excluding neonatal mortality from these calculations increases the fraction of mortality that can be attributed to diarrhea because death in the first month is usually a result of congenital anomalies or complications that arise during birth, including prematurity. Globally, 16.2 percent of all deaths between month 1 and month 59 of age in 2012 were attributed to diarrhea, although in Latin America and the Caribbean the proportion is substantially lower, 8.9 percent of all deaths for that age group (World Health Organization, 2014).

Young children are particularly vulnerable to dehydration and nutritional losses associated with diarrhea. The World Health Organization (WHO) attributes the majority of diarrhea deaths in developing countries to unimproved water supply and sanitation. Frequent episodes of diarrhea in early childhood can have long-term consequences, even when they do not result in death. Diarrhea can prevent the absorption of key nutrients and, therefore, may result in anemia, inadequate growth, and impaired child development. Malnutrition, in turn, makes children more susceptible to diarrhea, creating a vicious cycle (Fewtrell et al., 2007). By one estimate, as much as 61 percent of childhood deaths due to diarrheal illness may be attributed to underlying malnutrition (Ahs et al., 2010).

There are other ways in which microbial ingestion at early ages can have a negative effect on child development. An unclean environment may result in a subclinical condition known as environmental enteropathy (EE). EE involves chronic, asymptomatic inflammation of the small intestine which interferes with intestinal absorptive and immunologic functions (Korpe and Petri, 2012; Ngure et al., 2014). No clinical manifestations (such as diarrhea) are apparent. EE may be as important, or more important than diarrhea as a pathway from poor sanitation and hygiene to impaired growth and child development (Humphrey, 2009, cited in Ngure et al., 2014).

In this paper, I review the evidence on access to water and sanitation infrastructure and child outcomes in Latin America and the Caribbean. The focus of the paper is on water

and sanitation “hardware”, rather than on interventions that seek to change household behaviors with regard to hygiene (for example, handwashing, boiling or chlorinating water at point of use, before it is consumed). Also, I primarily review the evidence from at-scale interventions (rather than small-scale efficacy trials or pilots) in middle-income countries, including the historical US.

2. Access to piped water and sanitation in Latin America and the Caribbean

The 7th Millennium Development Goal for 2015 is to reduce by half the proportion of people without sustainable access to safe drinking water and basic sanitation. The indicators for this goal are the proportions of the population that use an “improved” drinking water source and sanitation facility, respectively.² The WHO/UNICEF Joint Monitoring Programme (JMP) estimates that, in 2011, 94 percent of the population of Latin America and the Caribbean had access to an improved drinking water source (up from 85 percent in 1990); and 82 percent had access to improved sanitation facilities (up from 68 percent in 1990) (United Nations, 2013).

Although the MDG definitions are useful, there is in practice no general agreement of what is and is not “improved” water and sanitation. Below, I present stylized facts for the Region on the proportions of the population that have access to piped water and (separately) sanitation within the home. This has some advantages. For one thing, questions about access to piped water and sanitation are asked in a reasonably comparable manner across household surveys for different countries.³ Also, as I discuss below, the evidence that links access to

² The definitions used to measure progress towards MDG 7 are as follows. With regard to “improved drinking water source”: “An improved drinking water source is a facility that, by nature of its construction, is protected from outside contamination in particular from contamination with fecal matter. Improved drinking water sources include: piped water into dwelling, plot or yard; public tap/standpipe; borehole/tube well; protected dug well; protected spring; rainwater collection and bottled water. Users of bottled water are considered to have access to improved sources only when they have a secondary source which is of an otherwise improved type. Improved drinking water sources do not include unprotected wells, unprotected springs, water provided by carts with small tanks/drums, tanker truck-provided water and bottled water (if the secondary source is not improved) or surface water taken directly from rivers, ponds, streams, lakes, dams, or irrigation channels. Drinking water is defined as water used for ingestion, food preparation and basic hygiene purposes.” With regard to “improved sanitation facility”: “An improved sanitation facility is defined as a facility that hygienically separates human excreta from human, animal and insect contact. Improved sanitation facilities include flush/pour-flush toilets or latrines connected to a sewer, septic tank or pit; ventilated improved pit latrines; pit latrines with a slab or platform of any material which covers the pit entirely, except for the drop hole; and composting toilets/latrines. Unimproved facilities include public or shared facilities of an otherwise improved type; flush/pour-flush toilets that discharge directly into an open sewer or ditch or elsewhere; pit latrines without a slab; bucket latrines; hanging toilets or latrines; and the practice of open defecation in the bush, field or bodies of water.”

³ That said, because the precise way in which the questions are asked and the response categories can differ a little across countries, some caution should be taken in making cross-country comparisons. Specifically, there are two differences across countries that should be borne in mind. First, in some surveys households are asked whether they have piped water, whereas in others they are asked about the main source of water for drinking. In three countries where the question asks about the main source of drinking water, Colombia, Jamaica, and Paraguay, 0.83 percent, 16.6 percent, and 8.6 percent of households, respectively, respond “bottled water”. I have assumed that these households do not have access to piped water inside their home; if some do, I will be underestimating the coverage

pipled water and sanitation to child outcomes is arguably stronger than that which attempts to link access to other means of improving water and sanitation with child outcomes. Finally, the provision of pipled water has other benefits—for example, it reduces the amount of time that is spent collecting and carrying water, which frees up time for other activities.

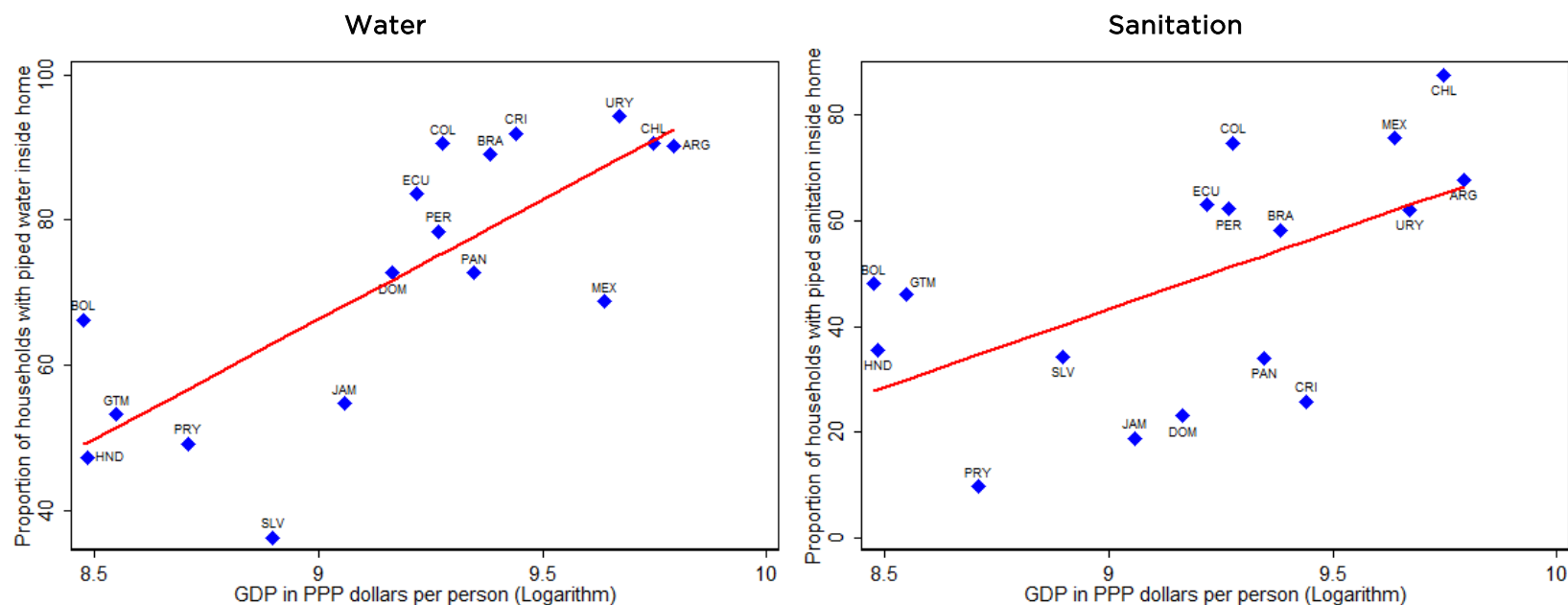
Figure 1 shows the relationship between GDP per capita and access to pipled water and sanitation. Figures 2 and 3 focus on differences between urban and rural areas, and over time, in six Latin American countries where questions about access have been asked in a consistent manner in surveys for at least two decades (Brazil, Chile, Colombia, Honduras, Mexico, and Uruguay). (Prior to 2006, household surveys in Uruguay covered urban areas only; the panel for Uruguay therefore only includes urban areas.) The figures show that there is considerable variation in Latin America both *within* and *across* countries. I note four stylized facts.

First, (and with the caveat that response categories are not always fully comparable across countries, see footnote 3), there are substantial differences in coverage across countries. Countries with higher income levels generally have better coverage of pipled water and sanitation. However, there are marked differences across countries of similar income levels. Access to pipled water is 25 percentage points higher in Honduras than in Bolivia, and access to both pipled water and pipled sanitation is 20 points higher in Brazil than in Panama. In Uruguay, one of the richest countries in the Region, only 70 percent of the population is connected to the sewerage system, well below what is found in Chile, Colombia, and Mexico, among a number of countries.⁴

of pipled water in these countries, in particular in Jamaica. Also, in about half of the countries I analyze (Chile, Cost Rica, Guatemala, Honduras, Jamaica, Mexico, Panama, Paraguay, Peru, and El Salvador), household responses for access to pipled water have separate response categories for water pipled inside the home, and outside the home. In these countries, I only consider access to pipled water *inside* the home. Insofar as some of the households who report having access to pipled water in the other countries (Argentina, Bolivia, Brazil, Colombia, Dominican Republic, Ecuador, Uruguay) only have pipled water *outside* the home, I will over-estimate the coverage of pipled water in this second group of countries relative to those in which the question has two response categories. Within countries, the definitions have generally remained the same over time.

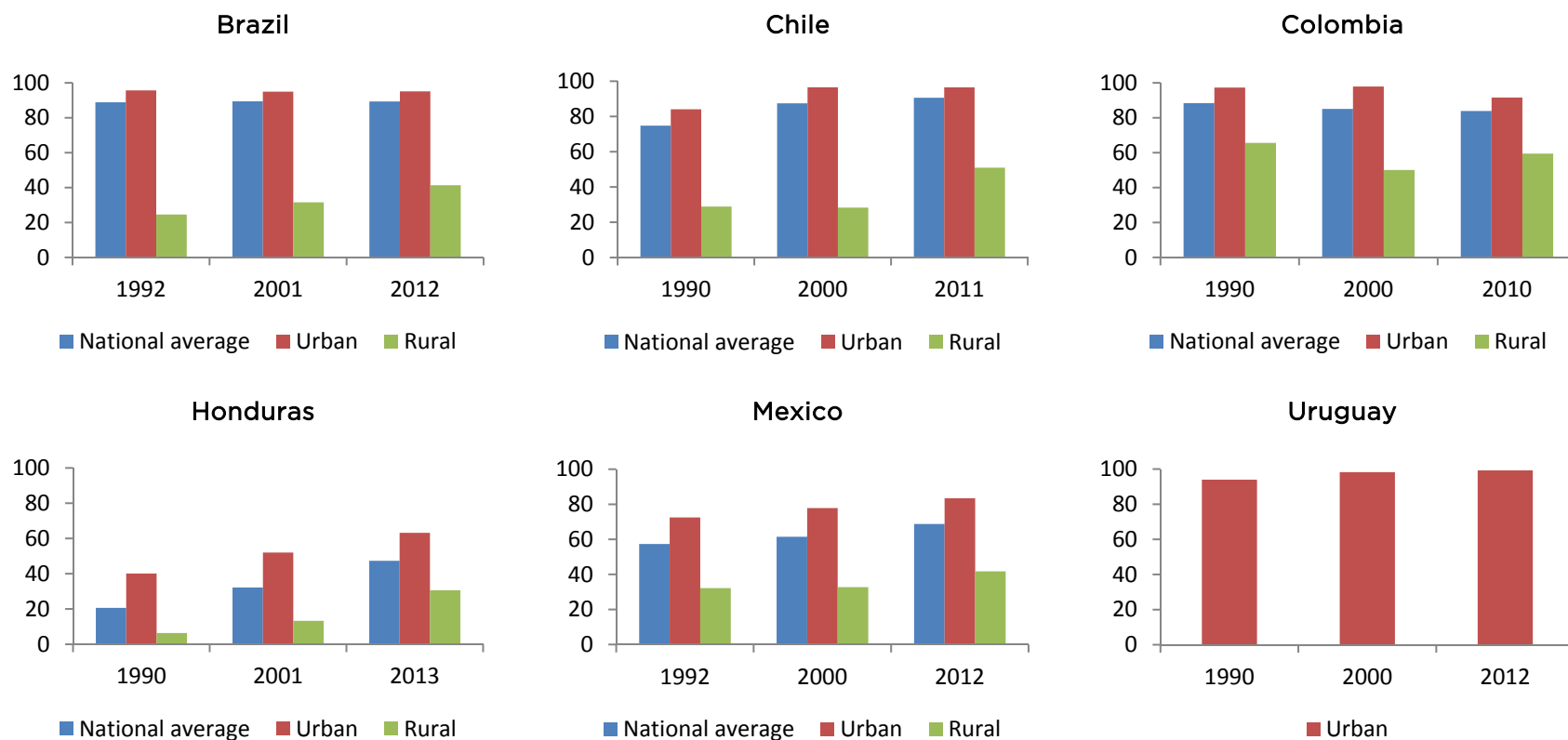
⁴ Low levels of pipled sanitation infrastructure in Uruguay do not seem to be an artifact of the data. A recent paper that analyzes Uruguay's experience with privatization, and subsequent re-nationalization of water and sanitation services, writes: "Studying Uruguay's water services is interesting because household access to Uruguay's pipled sewerage network is particularly low compared to countries at similar levels of development. With an access rate below 50 percent, Uruguay performs poorly relative to other Latin American countries, such as Chile, Colombia, Mexico, and some comparable Brazilian states, in terms of income per capita." (Borraz et al., 2013, p. 391)

Figure 1. Access to Piped Water and Sanitation
(by GDP per capita)



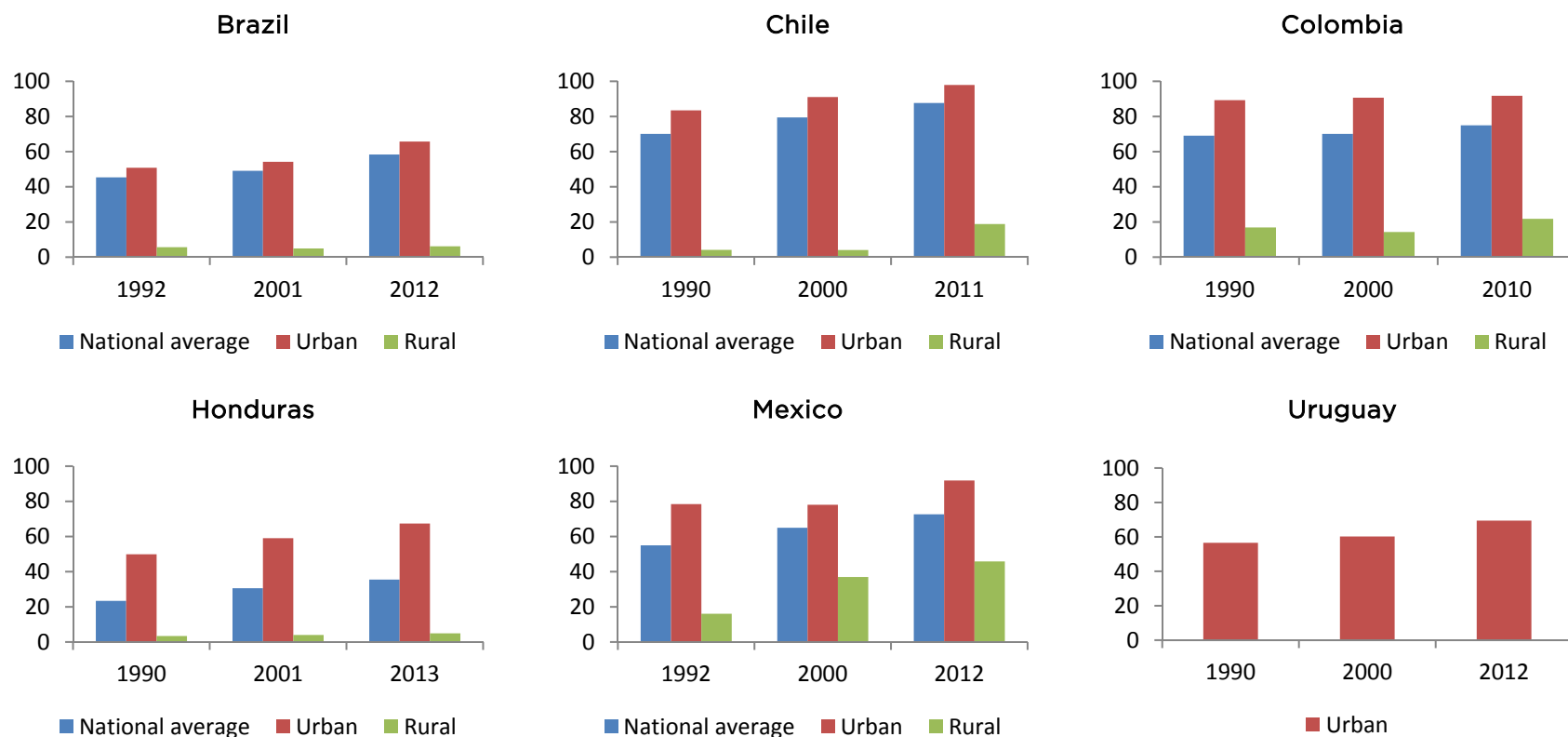
Source: Argentina, Encuesta Permanente de Hogares Continua (EPHC), 2012. Bolivia, Encuesta Continua de Hogares (ECH), 2011. Brazil, Pesquisa Nacional por Amostra de Domicílios (PNAD), 2012. Chile, Encuesta de Caracterización Socioeconómica Nacional (CASEN), 2011. Colombia, Gran Encuesta Integrada de Hogares (GEIH), 2012. Costa Rica, Encuesta Nacional de Hogares (ENAH), 2012. Dominican Republic, Encuesta Nacional de Fuerza de Trabajo (ENFT), 2012. Ecuador, Encuesta Nacional de Empleo, Desempleo y Sumempleo (ENEMDU), 2013. Guatemala, Encuesta Nacional de Empleo e Ingresos (ENEI), 2012. Honduras, Encuesta Permanente de Hogares de Propósitos Múltiples (EHPM), 2013. Jamaica, Jamaica Survey of Living Conditions (SLC), 2010. Mexico, Encuesta Nacional de Ingresos y Gastos de los Hogares (ENIGH), 2012. Panama, Encuesta de Niveles de Vida (ENV), 2008. Peru, Encuesta Nacional de Hogares (ENAH), 2012. Paraguay, Encuesta Permanente de Hogares (EPH), 2012. El Salvador, Encuesta de Hogares de Propósitos Múltiples (EHPM), 2012. Uruguay, Encuesta Continua de Hogares (ECH), 2012.

Figure 2. Access to Piped Water in Home



Source: Brazil, Pesquisa Nacional por Amostra de Domicílios (PNAD), 1992, 2001 y 2012. Chile, Encuesta de Caracterización Socioeconómica Nacional (CASEN), 1990, 2000, y 2011. Colombia, Demographic and Health Survey (DHS), 1990, 2000, y 2010. Honduras, Encuesta Permanente de Hogares de Propósitos Múltiples (EPHPM), 1990, 2001, y 2013. Mexico, Encuesta Nacional de Ingresos y Gastos de los Hogares (ENIGH) 1992, 2000 y 2012. Uruguay, Encuesta Continua de Hogares (ECH), 1990, 2000, y 2012.

Figure 3. Connected to Sanitation Network



Source: See note to Figure 2

Second, access to piped water and sanitation is substantially higher in urban than in rural areas. Access to piped water in urban areas is above 80 percent in all six countries; in rural areas, it is much lower, between 40 and 70 percent. In the case of sanitation, differences between urban and rural areas are also marked. In many countries, a substantial fraction of the population of rural areas, ranging from 16 percent in Colombia, 17 percent in Honduras, and 20 percent in Peru have no sanitation infrastructure at all, and practice open defecation.⁵ However, even in urban areas there are many households without access to piped sanitation services (in particular, in Brazil, Honduras and Uruguay, where coverage rates are between 60 and 70 percent).⁶

Third, there has been some progress in increasing access to piped services, especially in countries where coverage was initially low. This is particularly apparent in Honduras (for both sanitation and, especially, water), but also in Brazil, Chile, and Mexico (for access to piped sanitation services).

Fourth, and unsurprisingly, poorer households are much less likely than richer households to have access to piped water and sanitation. This can be seen in Table 1, which gives the proportion of households in the first (poorest) and fourth (richest) income quartiles with access to piped water (left-hand panel) and piped sanitation (right-hand panel) within their homes. The biggest differences in access between households in the poorest and richest quartiles are in countries in Central America and Mexico, and the smallest are in countries in the Southern Cone. At the two extremes are El Salvador, where the differences in access are more than 50 percentage points, and Chile, where these differences are less than 15 points.

A logical question is whether differences in access are largely a result of residential sorting—in other words, whether poorer households have less access to piped water and sanitation primarily because they live in areas where these services are not available.

To provide some evidence on this question, I estimate three sets of regressions.⁷ First, I run regressions of a dummy for access to piped water and (separately) sanitation on a dummy for households in the poorest quartile; the coefficient on the dummy for the poorest quartile in these regressions is equivalent to the difference in means reported in Table 1, and serves as a benchmark. Next, I include a dummy for living in rural areas; the coefficient on the dummy for the poorest quartile in this regression is an estimate of the extent to which poorer households living in the same area as richer households have less access to piped water and sanitation, where “area” means rural or urban. Finally, I also add dummies for the most

⁵ Own calculations based on the Demographic and Health Surveys (DHS) for 2010 in Colombia, 2011 for Honduras, and 2012 for Peru.

⁶ Of course, the definition of “rural” varies from country to country. This may affect cross-country comparisons of the differences in access between urban and rural areas, even if it does not affect the calculation of the national averages.

⁷ All regressions are weighted by the expansion factors given in the household surveys.

disaggregated residential location available in each survey—this corresponds to states in some countries, like Brazil, and municipalities in other countries, like Mexico; the regression coefficients on the dummy for households in the poorest quartile in these regressions are an estimate of the extent to which poorer households living in the same area have lower access to water and sanitation services, where “area” is now a finer disaggregation for place of residence (comparing, for example, poorer and richer households living within urban or rural areas in the same state in Brazil).⁸

Table 1. Proportion of Households with Access to Piped Water and Sanitation
(by Quartile 1 and 4)

Country	Water		Sanitation	
	Quartile 1	Quartile 4	Quartile 1	Quartile 4
Argentina	87.19	92.74	47.81	82.08
Bolivia	37.12	80.21	21.56	64.00
Brazil	84.44	93.52	42.43	72.42
Chile	84.41	94.47	79.01	93.85
Colombia	79.37	96.25	45.16	93.37
Costa Rica	84.35	97.08	15.25	36.34
Dominican Republic	59.18	85.91	15.23	31.64
Ecuador	68.50	93.67	38.32	84.89
El Salvador	8.88	61.89	6.68	63.19
Guatemala	37.32	70.70	23.98	72.88
Honduras	26.10	72.60	9.30	63.76
Jamaica	33.72	72.59	10.69	28.62
Mexico	38.29	90.55	52.02	89.65
Panama	7.42	35.97	6.19	57.10
Paraguay	28.66	56.48	1.78	20.02
Peru	64.08	88.53	31.31	84.23
Uruguay	94.36	96.30	42.60	78.83

Source: Author's calculations, based on data from household surveys

⁸ In Brazil, the geographic unit is the state; there are 27 states in the country (and the survey), and the median number of households in the survey in each state is 2,653. In Chile, the geographic unit is the commune; there are 324 communes in the survey, and the median number of households in the survey in each commune is 104. In Colombia, the geographic unit is the “Departamento”; there are 24 Departamentos in the survey, and the median number of households in the survey in each is 2442. In Honduras, the geographic unit is the village or city block; there are 113 such units in the survey, and the median number of households in the survey in each village or city block is 12. In Mexico, the geographic unit is the municipality; there are 377 municipalities in the survey, and the median number of households in the survey in each municipality is 19. In Uruguay, finally, the geographic unit is the neighborhood; there are 63 neighborhoods in the survey, and the median number of households in the survey in each neighborhood is 257.

The results from these estimations are in Figure 4 (for piped water) and Figure 5 (for sanitation). I present the results for the same six countries (Brazil, Chile, Colombia, Honduras, Mexico, and Uruguay).⁹ For each country, there are three bars—the first bar corresponds to the raw difference between households in the first and fourth quartile, the second bar to this difference adjusting for urban-rural location, and the third bar corresponds to the additional adjustment for smaller geographic areas. The results show that simply adjusting for urban-rural location substantially reduces the access “penalty” associated with being poor. In some countries, this “penalty” falls by more than two-thirds. As can be seen by the third bar in each graph, adjusting for place of residence more finely further reduces the coefficients on the income quartile dummy.

This analysis shows that poor households have less access to piped water and sanitation largely because they live in places where the coverage of these services is limited or nonexistent, rather than because of income differences in access *within* geographic areas.¹⁰ This is not surprising—there are substantial economies of scale with the provision of water and sanitation infrastructure. It therefore makes sense for entire neighborhoods or villages to be covered or uncovered.¹¹ Also, because there is generally some attempt at cost recovery, the expansion of services invariably occurs first in richer areas.¹²

I conclude this section with some caveats that should be kept in mind in reviewing the evidence above. The first, and most important, is that the data I present on “access” simply refer to the proportion of households in a particular country, region, or income quartile who report in the survey that they have piped infrastructure within the home. This is an imperfect measure of access. In many countries, even when households are connected to the piped network, water is only available for a few hours a day. Even when it is “available”, water pressure is often too low for households to carry out tasks like bathing, showering, or washing dishes. The figures therefore overstate real, or effective, “access” to piped water. Moreover, insofar as these problems are more likely to be an issue in poor neighborhoods, as seems likely, I will be understating the socioeconomic gradients in access.

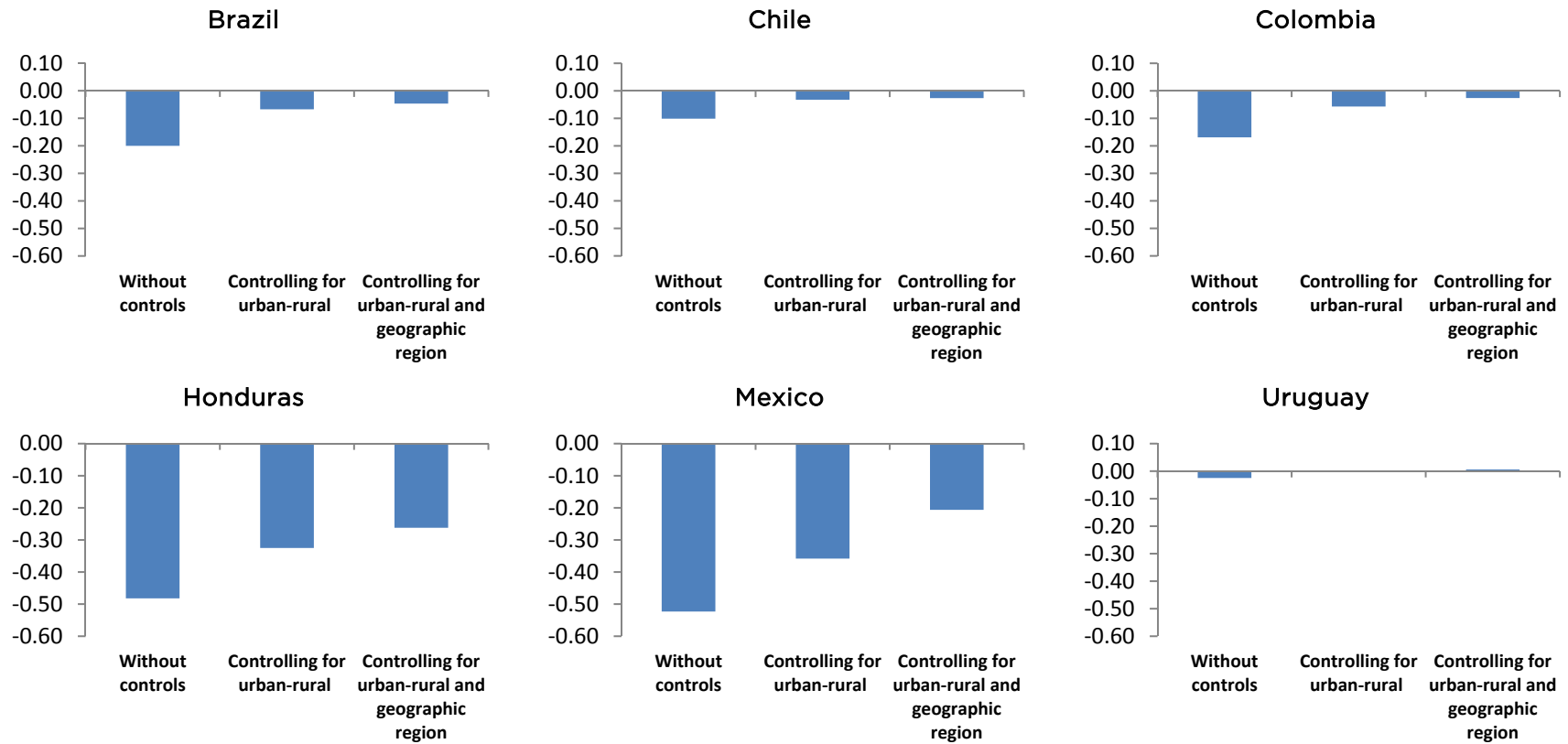
⁹ The latest household surveys for Uruguay, but not those before 2006, also collect information from households in rural areas.

¹⁰ This observation does not rule out that there could be a feedback loop from inadequate access to water and sanitation to poverty, for example through adult health status.

¹¹ These decompositions of the differences in access to water and sanitation into across- and within-area stand in contrast with similar calculations for other indicators of housing quality. For example, I conducted the same calculations as those in Figures 4 and 5, but focusing instead on the fraction of households that have dirt floors. The material of the floors is a privately provided good. There are no economies of scale. Unsurprisingly, then, a much smaller fraction of the total variation in the quality of floors is explained by within-area differences than is the case with water and sanitation infrastructure. These results are available from the authors upon request.

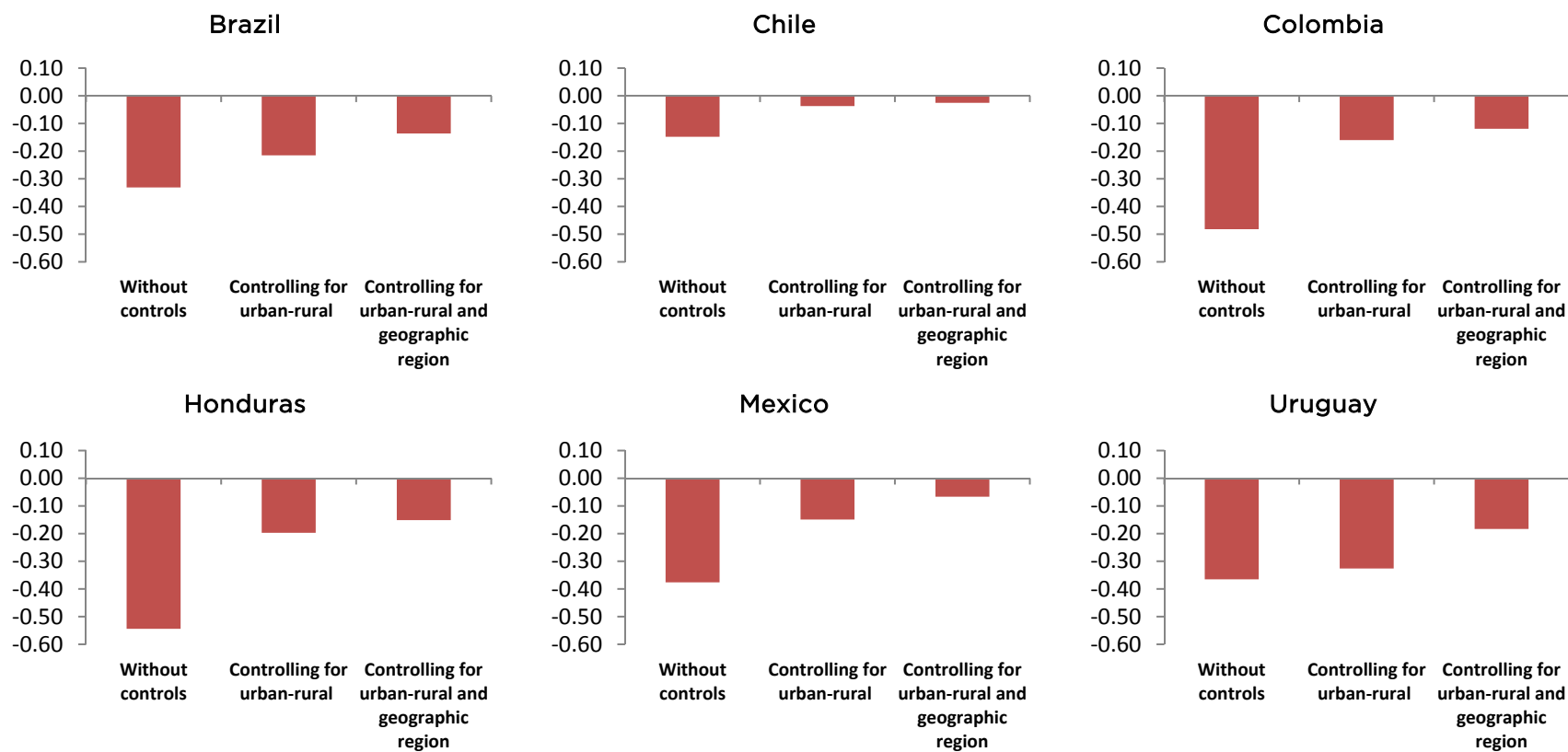
¹² In many countries, user fees do not cover the full costs of delivery, and water and sanitation services are subsidized. Depending on how much cost recovery there is, and how any budget shortfall is financed, this could have the perverse effect that poor households, who live in areas without service, subsidize others that are better off.

Figure 4. Difference Between Quartile 1 and Quartile 4 for Piped Water



Source: See note to Figure 2

Figure 5. Difference Between Quartile 1 and Quartile 4 for Sanitation



Source: See note to Figure 2.

Second, the figures say nothing about the quality of the water that is delivered—for example, about the concentration of pathogens of various sorts. Nor are they informative about traces or concentrations of heavy metals (for example, arsenic, mercury), which can have serious long-term consequences for child health and development. Moreover, interruptions in access generally result in a deterioration in the quality of the water that is *consumed*. When access is only intermittent, households will be forced to store water, and much of this water will be recontaminated—even if the water was relatively clean when it came out of the tap, it will have pathogens by the time it is drunk. The benefits of piped water are therefore negated, at least in part.^{13,14}

Third, individuals (including children) do not spend all of their time inside their homes. A better measure of access for an individual would incorporate whether there is safe water and sanitation at the workplace and, in the case of young children, in preschool or school. The figures I report are therefore likely to be noisy measures of access in a more general sense.

Finally, in the case of sanitation, there is the separate issue of how residue is disposed of. An *individual* may only care about whether sewage is removed from her home. From a *social* point of view, however, it matters whether this waste is treated, and how it is disposed of. In most countries in the Region, sewage is disposed of without any effective treatment, and is simply dumped into nearby water bodies. This, too, can have serious consequences for child (and adult) health. It is of course particularly a problem for households who live in close proximity to where the sewage is disposed of—especially, if these households use water for drinking from these same sources (for example, a river or stream).

3. Causal evidence of effects of access to water and sanitation infrastructure on child outcomes

I next turn to a review of papers that attempt to identify a causal effect of better water or sanitation infrastructure on child mortality, health, and development. A key message from this section is that many of these papers share important methodological weaknesses.

It is useful to begin by considering *why* and *how* access to better water and sanitation, in particular piped infrastructure, could improve child outcomes. There are two potential transmission channels. First, clean water and a more hygienic sanitary environment could reduce the ingestion of fecal microbes. Second, holding quality constant, water that is readily available may reduce the need for storage within the home (where it gets recontaminated),

¹³ A number of papers show that contamination of water once it is stored is a serious problem. For example, Ahuja et al. (2010) discuss a spring protection program in Kenya which reduced fecal contamination, as measured by *E. coli* bacteria, by two-thirds for water at the source, but by only 25 percent for water stored (and consumed) in the home.

¹⁴ Another issue is that when access to piped water is interrupted, the water that first comes out of the pipe when the service is restored is generally dirty because it picks up much of the residue from the pipes.

and may increase the frequency with which a variety of hygienic activities, such as bathing, hand washing, and general cleaning, are carried out. In either case, an improved water source could break the fecal-oral transmission chain. This, in turn, could have positive effects on child health and development.

A number of studies have attempted to link frequent episodes of diarrhea in early childhood with poor child outcomes at later ages. Three papers use data collected in a shantytown in Ceará, Brazil and report significant associations between diarrhea before age 2 years and growth faltering (Moore et al. 2001), cognitive functioning (Niehaus et al., 2002) and verbal fluency (Patrick et al., 2005) later in childhood. Another set of studies is based on a sample of children in San Juan de Miraflores, a shantytown in Lima, Peru. Here too, the authors report associations between diarrhea incidence before age 2 years and later child height (Checkley et al., 2004) and cognition (Berkman et al., 2002). All of these studies, and many others from the public health literature, share the same methodological weakness. Although they attempt to control for a variety of potential “confounders”, such as parental education or household assets, they leave open the possibility that there could be a host of unobservables that are correlated both with diarrhea and later outcomes (and that are not soaked up by the controls). These studies therefore provide only weak evidence of a *causal* effect of diarrhea on subsequent child outcomes.¹⁵ Moreover, the evidence, such as it is, comes from very small samples of children (often, fewer than 100).

Many of the studies that link access to water and sanitation infrastructure with child outcomes suffer from similar methodological weaknesses, in particular a concern with omitted variable bias. The most ambitious of these studies is Fink et al. (2011). In this paper, the authors use all available Demographic and Health Surveys (DHS) (171 surveys) to construct a dataset with information on 1.1 million children under the age of five years in 70 low- and middle-income countries over the period 1986-2007. They construct three dependent variables: whether a child died in her first five years of life, whether she had diarrhea in the two weeks preceding the survey, and whether a child is chronically malnourished (stunted). These variables are then regressed on variables for the quality of water and sanitation (both coded as “high”, “medium” or “low” quality) and, in some specifications, a set of controls.¹⁶ The authors conclude that both higher quality water and higher quality sanitation are associated with a reduced probability of death and better child

¹⁵ Other papers have attempted to link the disease environment generally, or the prevalence of parasitic infections that cause diarrhea specifically, with the distribution of IQ across states in the United States (Eppig et al., 2011), or across countries (Eppig et al., 2010). Of course, these studies are, if anything, even more exposed to concerns about omitted variables than those that compare children in a given setting.

¹⁶ These controls include the sex and age of the child, whether the child was the result of a multiple birth, the education of the mother and her partner, usual type of place of residence, the number of household residents over the age of 5 years, and ownership of specified assets (radio, television, and bicycle). See Fink et al. (2011), pp. 3-4.

health outcomes. However, the fact that the coefficients on water and sanitation infrastructure are reduced substantially when controls for household socioeconomic status (parental education, assets, household size) are included in the regressions suggests that omitted variables may be a serious concern.

Much stronger causal evidence comes from a handful of papers that exploit historical data, or data based on what are plausible natural experiments. The best known of these is Snow's (1855) analysis of the London cholera epidemic of 1853-54.¹⁷ Snow observed that households in much of London were supplied with water from two different companies, the Lambeth water company, whose water intake came from a point on the Thames above the city's main sewage discharge, and the Southwark and Vauxhall company, whose intake was below the discharge.

Using data on the addresses of cholera victims, Snow showed that there were 8.5 times as many cholera fatalities per thousand among households served by Southwark and Vauxhall than those that received their water from the Lambeth water company. What made Snow's analysis so convincing is that household characteristics were, in modern-day parlance, orthogonal with the company that delivered water to them.¹⁸ His analysis of the cholera epidemic was critical in giving credence to the oral-fecal theory of disease transmission, and is regarded as one of the seminal advances in the history of public health.

Cutler and Miller (2005) also use historical data. Their paper analyzes the introduction of water filtration and chlorination systems on mortality in the United States. The identification is based on the fact that these technologies were adopted at different times in different cities, for reasons that appear to be idiosyncratic (and are plausibly exogenous).¹⁹ Cutler and Miller begin by noting that mortality rates in the United States fell dramatically in the late 19th and early 20th centuries, in particular in urban areas.²⁰ They then use differences-in-differences to estimate that the introduction of clean water accounted for nearly half of the mortality reduction in major cities between 1900 and 1936, and three-quarter of the reduction in infant mortality. The effects were largest in cities with a higher fraction of the population that was illiterate (suggesting that clean water technologies helped reduce socioeconomic

¹⁷ I draw heavily on Deaton (1997, pp. 112-13) for a discussion of Snow's work.

¹⁸ As Snow writes (again, quoted in Deaton): "The mixing of the supply is of the most intimate kind. The pipes of each Company go down all the streets, and into nearly all the courts and alleys ... The experiment, too, is on the grandest scale. No fewer than three hundred thousand people of both sexes, of every age and occupation, and of every rank and station, from gentlefolks down to the very poor, were divided into two groups without their choice, and in most cases, without their knowledge; one group supplied with water containing the sewage of London, and amongst it, whatever might have come from cholera patients, the other group having water quite free from such impurity."

¹⁹ Cutler and Miller write: "Although probably not complete historical accidents, there was a large random component to the timing of clean water technology adoption in American cities." Most importantly, the authors show that there were no pre-existing differences in mortality trends in cities that adopted filtration and chlorination earlier.

²⁰ In the 19th century there was a substantial mortality 'penalty' associated with living in urban areas. In 1880 infant mortality was 140 percent higher in cities than in rural areas in the United States. As late as 1900, life expectancy at birth for white males was 10 years greater in rural than in urban areas (Cutler and Miller, 2005).

gradients in mortality). Cutler and Miller estimate the rate of return to clean water technologies to have been about 23 to 1, and the cost per life-year saved to have been about \$500 in 2003 dollars.²¹

Two other papers that use plausibly exogenous changes in water quality are Watson (2006) and Galiani et al. (2005). Watson focuses on the introduction of water and sanitation projects on Indian reservations in the United States, beginning in 1960. She notes that, between 1960 and 1998, the infant mortality rate of Native American infants in reservation counties fell from 53 to 9 per 1,000, while White infant mortality declined from 26 to 6 per 1,000. The convergence in infant mortality between Native Americans and Whites was particularly dramatic in post-neonatal deaths and deaths from gastrointestinal diseases—those causes of death that are most likely to have been affected by the provision of clean water and sanitation. Using a difference-in-difference framework, Watson estimates that a 1 percentage point increase in the fraction of homes with water or sanitation infrastructure reduced infant mortality by 0.05 per 1,000 births, or by 2.5 percent. She also finds some positive externalities from the program on the infant mortality of white children living near the treated Indian reservations, although these externalities are modest in magnitude.

Galiani et al. (2005) analyze the impact of the privatization of water and sanitation services in Argentina on under-five mortality, also using a differences-in-differences identification strategy. They exploit the fact that, in Argentina, local governments are responsible for delivering water and sanitation. During the 1990s, some, but not all, municipalities privatized these services. Their analysis compares mortality trends in two groups of municipalities—those that privatized water and sanitation, and those that did not. Galiani et al. show that, prior to privatization, the two groups of municipalities were on a similar downward trend in child mortality rates. Following the privatization, however, mortality reductions accelerated in municipalities that had privatized services. Galiani et al. estimate that privatization of services resulted in a 0.33 point reduction in child mortality, which amounts to 5.3 percent of the baseline rate.²²

²¹ Other papers that use historical data from the United States are Bleakley (2007; 2010). Bleakley (2007) analyzes the effect of hookworm eradication in the American South. He concludes that eradication resulted in increases in school enrollment, attendance, literacy and income. Bleakley (2010) analyzes the effect of malaria eradication in the United States, Colombia, and Mexico. He concludes that cohorts in malarial areas born after eradication campaigns saw substantial increases in incomes relative to the previous generation.

²² It is of course not clear whether we would in general expect privatization to improve child mortality and health outcomes, or the reverse to be the case. Kosec (2014) analyzes the effects of private sector participation in the water sector in Africa. To get around endogeneity concerns, she uses the fact that developed country firms are significantly more likely to work in African countries that are former colonies of the country where a firm is headquartered. Specifically, Kosec instruments private sector privatization in water in an African country with the former colonizing country's time-varying share of the world market for private, piped water (ignoring contracts covering African countries). Echoing the results in Galiani et al. (2005), she estimates that private sector participation in the urban piped water sector in Africa increased use of piped water by 14 percent, and reduced diarrhea among urban-dwelling children under the age of 5 by 2.6 percentage points (16 percent of the mean). She also concludes that the benefits were largest for children in the poorest households, again echoing Galiani et al. On the other hand, Borraz et al.

Galiani et al. (2005) report three other findings that are noteworthy. First, they show that the mortality declines were largest in the *poorest* municipalities that privatized their services (a result that echoes Cutler and Miller 2005, who find that improvements in the quality of water in the US led to larger declines in infant mortality in cities with a higher proportion illiterate). Second, and echoing the results in Watson (2006), they show that the mortality decline in municipalities that privatized services was concentrated in water-related diseases (infectious and parasitic diseases, perinatal deaths), but not in other causes of deaths (for example, accidents, congenital malformations). This gives greater credibility to their identification strategy. Finally, Galiani et al. (2005) argue that privatization led both to improvements in *access* (more households with piped water), and to better *quality* of water services. For example, they show that the transfer from a public to a private provider in the capital city of Buenos Aires resulted in increases in the percentage of clients with appropriate water pressure, and in declines in a measure of water turbidness.

A number of papers focus on access to water and sanitation in Brazil. Gamper-Rabindran et al. (2010) use the population censuses of 1970, 1980, 1991 and 2000 to construct municipality-level estimates of the proportion of households with access to piped water and sanitation, and municipality-level infant mortality rates. They use a differences-in-differences approach to see whether mortality fell more quickly in municipalities which had larger increase in access to water and sanitation.²³ Gamper-Rabindran et al. conclude that a one-percentage point increase in the number of households with piped water resulted in declines in infant mortality of 0.48 points (0.38 percent) in the 1970-80 period, of 1.36 points (1.57 percent) in the 1980-91 period, and of 0.20 points (0.41 percent) in the 1991-2000 period. They find no effects of increased access to sanitation infrastructure on mortality. Further, they use a quantile regression approach to show that reductions in infant mortality were generally larger in municipalities with higher baseline mortality rates.

The effects estimated by Gamper-Rabindran et al. (2010) are very large—even the lowest estimate, corresponding to the 1991-2000 period, is roughly four times the magnitude reported in Watson’s (2006) analysis of Native American reservation counties in the United States. By other metrics, their estimate also appears to be very large. The WHO (2012) estimates that almost three-quarters (72 percent) of all child deaths in Latin America and the

(2013) argue that privatization in Uruguay resulted in a deterioration of water quality, and that the subsequent renationalization improved it. Indeed, in many cases, governments in Latin America have reversed the privatization reforms of the 1990s. For the discussion in this paper, the important point is not whether supply by a regulated private provider is better or worse than direct public provision. Rather, what matters is that Galiani et al. identify one policy reform that appears to have improved access to, and the quality of, water in Argentina, and that this reform also appears to have reduced child mortality.

²³ Note that, while the approach is reasonable, Gamper-Rabindran et al. (2010) provide little evidence of *why* it is that changes in access were larger in some municipalities than in others. Insofar as changes in access were correlated with the underlying counterfactual trends in mortality, the results they report could be biased.

Caribbean are a result of complications surrounding birth and non-infectious diseases—causes that cannot plausibly have been affected by improved water supply.²⁴ Simple back of the envelope calculations indicate that, if the estimates reported in Gamper-Rabindran et al. are accurate, the *entire* decline in the proportion of infant mortality in Brazil between 1991 and 2000 that is not accounted for by complications at birth or non-communicable diseases would have to be eliminated as a result of the provision of piped water. In earlier decades, this proportion would have had to be even larger.²⁵ More generally, this highlights one of the weaknesses in the analysis by Gamper-Rabindran et al.—namely, that the paper does not break down the change in mortality by cause of death. This stands in contrast with Galiani et al. (2005) and Watson (2006), both of who show that the declines in mortality that coincided with the increase in access to piped water and sanitation happened precisely in the mortality categories where we would expect them to occur (diarrhea and other infectious diseases), and not others.

Rocha and Soares (2012) analyze the impact of rainfall fluctuations experienced during the gestational period on child outcomes in the semiarid region of Northern Brazil. They combine high frequency gridded information on precipitation with birth and mortality registration records to create a municipality-by-month dataset. Rocha and Soares conclude that negative rainfall shocks during pregnancy result in shorter gestation periods, lower birth weight, and higher infant mortality. A one standard deviation increase in rainfall leads to a reduction in infant mortality of 2.14 points (7 percent of the sample average of 31.3 deaths per thousand in the period they analyze, 1996 through 2008). Importantly, Rocha and Soares also show that piped water and sanitation protect child health during rainfall shocks: In a municipality with 20 percent coverage of piped water and sanitation, a decline in rainfall from the 90th to the 10th percentile results in an increase in infant mortality of 6.3 points, whereas in a municipality with 100 percent coverage the increase in mortality is only 2.3 points. Finally, Rocha and Soares conduct some back-of-the-envelope calculations and argue that

²⁴ Specifically, of every 1000 deaths to children under 5 in Latin America and the Caribbean, 95 were a result of birth asphyxia and birth trauma; 199 were a result of prematurity; 197 were a result of congenital anomalies; 71 were a result of sepsis and other conditions of birth; 69 were a result of injuries; 19 were a result of meningitis or encephalitis; and 86 were a result of other non-communicable diseases. WHO 2012.

²⁵ Gamper-Rabindran et al. (2010) show that, between 1991 and 2000, the percentage of households with piped water in Brazil increased by 20 percentage points (from 42.2 percent to 62.4 percent), while infant mortality fell by 15.5 per 1,000 children born (from 49.2 per 1,000 to 33.7 per 1,000). By their estimates, the change in access to piped water over the period should have resulted in a reduction in infant mortality of 4 per 1,000 (0.20×20), which is more than a quarter of the entire decline in infant mortality. Between 1980 and 1991, infant mortality fell from 86.8 per 1,000 to 49.2 per 1,000, while the fraction of households with access to piped water increased from 24 to 42.2 percent. The calculations in Gamper-Rabindran et al. (2010) suggest that 70 percent ($1.36 \times (42.2 - 24)$) of the entire decline in infant mortality in Brazil would have to be accounted for by the extension in the coverage of piped water. Of course, these back-of-the-envelope calculations are somewhat crude, for a number of reasons. First, the WHO estimate refers to 2012, and the proportion of deaths accounted for by communicable diseases would have been higher in earlier periods; second, the WHO numbers refer to all of Latin America and the Caribbean, and the causes of child mortality in Brazil may not be the same as in the region at large; and third, there is considerable uncertainty about the quality of the cause-of-death data that are used and reported by the WHO.

expansions in the coverage of piped water are much more cost-effective than expansions in the coverage of sanitation services—the cost per saved life is more than three times as high for increases in sanitation as it is for increases in access to piped water.²⁶

We next discuss improvements in infrastructure *other than* piped water and sanitation. Providing piped water and sanitation in rural areas can be expensive. In some cases, therefore, priority has been given to cheaper alternatives. In the case of water, these include wells, boreholes, or spring protection. In the case of sanitation, they include the provision of latrines. It is not clear whether these interventions consistently improve child outcomes. A number of recent reviews (Clasen et al., 2006; Clasen et al., 2010; Zwane and Kremer, 2007) discuss the evidence of effects on the incidence of diarrhea, and conclude that the quality of the studies is generally poor. One (Clasen et al., 2010) notes that none of the available studies are based on a randomized trial. Another (Zwane and Kremer, 2007) plainly states that there is insufficient evidence to advocate for infrastructure improvements, short of the provision of piped water and sanitation, as a way of reducing diarrhea.²⁷

Finally, a recent paper by Cattaneo et al. (2009) evaluates the impact of a program that replaced dirt floors with cement floors in Mexico. Dirt floors may contribute to the transmission of disease if they are a vector for parasites, and if they are more difficult to clean than floors made from cement or other material. Ngure et al. (2014) stress that children in developing countries frequently ingest fecal matter from humans or animals (for example, chickens) when they play on dirt floors.

Identification in Cattaneo et al. (2009) comes from the fact that the program, *Piso Firme*, was implemented in one state, Coahuila, but not in another, neighboring state, Durango. The authors compare outcomes in a set of matched households in two twin cities (Gómez Palacios-Lerdo in Durango, and Torreón in Coahuila) that straddle the two states. Cattaneo et al. argue that these cities are split administratively, but are effectively part of a single urban area. Households in the evaluation sample, drawn from both cities, appear to be very similar at baseline on a large number of outcomes. Prior to the implementation of *Piso Firme*, the states of Coahuila and Durango also appear to be on similar trajectories on a variety of measures (including child mortality, household infrastructure, income and consumption levels). Cattaneo et al. then use an Intent-to-Treat identification strategy to

²⁶ This is consistent with earlier work by Soares (2007), who applies an Arellano-Bond estimator to municipality-level data and finds that access to clean water explains a substantially larger proportion of the increase in life expectancy in Brazil between 1960 and 2000 than increased access to sanitation. See also Guanais (2013) and Macinko et al. (2006) for other results for Brazil, which also point to the importance of access to clean water as a determinant of infant mortality.

²⁷ A separate review (Dangour et al., 2013) focuses on effects on child nutrition, rather than diarrhea. It discusses the (very mixed) evidence from a number of interventions that seek to change behaviors, or improve the quality of water at the point-of-use (for example, through chlorination, solar disinfection, or boiling). However, none of the interventions sought to improve the physical infrastructure for water provision or the disposal of excreta.

compare a large number of outcomes for households in Torreón who were offered the *Piso Firme* intervention (the treatment group) and households in Gómez Palacios-Lerdo (the comparison group). They conclude that the program had substantial effects on child health (as measured by parasite counts, anemia, and the incidence of diarrhea), and child development (in particular, language development).²⁸

4. Conclusions and research priorities

There are a number of papers that provide credible evidence that access to, and the quality of, water reduce child mortality. In some cases, the reductions in mortality appear to be substantial. Moreover, improvements in water infrastructure have generally had larger effects on child mortality among the poor, and thus reduced socioeconomic mortality gradients.

Often (as in Galiani et al., 2005; and Watson, 2006), it is not possible to separate the effects of improved water from that of improved sanitation. In other cases (as in Gamper-Rabindran et al., 2010; Rocha and Soares, 2012; Soares, 2007, all of which analyze data from Brazil; Kosec, 2014 on a large set of countries from Africa), the authors attempt to separate these effects, and conclude that the impact of clean water on mortality is substantially larger than that of improved sanitation.

In general, it has not been possible to separately estimate the effects of changes in quantity and quality of water because piped water frequently improves both.²⁹ The distinction between access and quality may not matter all that much when the policy being considered is an expansion of piped water to areas that were previously unserved. It matters a great deal, however, for policies that seek to make access to water more convenient, but do not alter the quality of the water (for example, increasing the number of pipe stands in a neighborhood), or those that seek to improve quality, without changing access (for example, spring protection in rural areas). In many periurban or rural areas, these are realistic policy options.

Plausibly, by improving the disease environment, access to better water and sanitation infrastructure could also improve child outcomes other than mortality. However, the research on this point to date suffers from important methodological weaknesses, and is inconclusive.

²⁸ One concern is that the estimated effects are so large that they may perhaps appear to be implausible. For example, in their instrumental variables estimates, Cattaneo et al. (2009) estimate that “a complete substitution of dirt floors by cement floors would lead to a 78 percent reduction in parasitic infestations, a 49 percent reduction in diarrhea, an 81 percent reduction in anemia, and a 36 to 96 percent improvement in cognitive development among young children” (see p. 97, footnote 21).

²⁹ One exception is Devoto et al. (2011), who use a randomized evaluation in Tangiers, Morocco, to show that shifting households from use of communal piped taps to piped water within the home increased the use of water, but did not reduce the incidence of child diarrhea. On the other hand, provision of piped water within the home freed up time for leisure and social activities, and overall measures of social integration and welfare improved, even if these effects were not found on child health or income.

It is useful to analyze the coverage of piped water and sanitation services in Latin America and the Caribbean. Analysis of household surveys shows that a substantial fraction of households in the Region, in particular in rural areas, do not have access to piped water and sanitation infrastructure. Deficits in access are larger among poor households, although this appears to be, in large measure, because the poor live in areas where these services are unavailable (as opposed to differences in access between poor and less poor households living in the same area).

In light of these patterns, a good case can be made for the continued expansion of piped water and sanitation services as a way of improving child outcomes. Of course, there are important questions of how best to do this—for example, whether provision should be public or private, and how to set prices. These questions are beyond the scope of this paper. I note, however, that recent evidence suggests that the demand for improvements in water *quality* appears to be extremely price elastic. For example, in Kenya, households are unwilling to pay for even very small user charges for chlorine kits that kill the majority of pathogens in water (Ahuja et al., 2010). This may be because households are not well aware of the risks of contaminated water, especially for children, because they are imperfect agents for children (the principals), or because they value other features of the water, such as its taste. Regardless, as Ahuja et al. argue, these findings are a powerful argument for free distribution of this very simple technology. On the other hand, Devoto et al. (2011) show that households in Tangier, Morocco, were willing to pay substantial prices for access to piped water within the home (as opposed to shared stand pipes), even though this improvement in access had no effect on child health. Piped water inside the home freed up time for leisure or other activities and improved household welfare.

Among the many issues that would benefit from future research for Latin America and the Caribbean, three seem particularly important. First, although a strong case can be made for a biological chain, from access to clean water or improved sanitation, to better nutritional status (through reductions in diarrhea or EE, or both), and to improved child development, the evidence from well-identified evaluations is scarce. Indeed, only for one early link in the chain (from access to clean water to reduced mortality) is there well-identified evidence from a number of studies.³⁰ There would be large returns to an evaluation that had a credibly exogenous source of variation in access to piped water or sanitation, and traced out the benefits to children, including surviving children, over time.

³⁰ One consequence of this is that it is hard to include the benefits to child development (and, eventually, education and labor market outcomes) in calculating the rate of return to investments in piped water or sanitation, without relying on assumptions, rather than actual estimates, of these benefits.

Second, we do not know enough about the extent to which the returns to water and sanitation investments depend, at least in part, on the degree of development (for example, on pre-existing nutritional status, or education levels). In their work on Brazil, Gamper-Rabindran et al. (2010) speculate that both the time series results (larger effects in 1980-91 period than in the earlier or later periods) and the quantile regression results (larger effects in municipalities with higher initial infant mortality rates) suggest there is an S-shaped relationship between access to piped water and mortality. Below a threshold of socioeconomic development, increased access to piped water has only small effects on mortality because individuals may have low disease resistance due to very poor nutrition and personal hygiene. At high levels of development, above a “saturation point” in coverage, the marginal effect of increased access to water on mortality is also low.³¹ Arguments about an S-shaped relationship between access to piped water and child outcomes are essentially about whether water and sanitation investments are complements with other investments. Using data from India, Jalan and Ravallion (2003) also argue that piped water only reduces child diarrhea for households where at least one member has more than completed primary education. In the case of sanitation, the relationship between coverage and child outcomes may be highly non-linear—plausibly, full (or close to full) coverage of some sanitation may be necessary to reduce the transmission of pathogens. These are important issues but, to date, there is insufficient evidence on this point.

Third, because piped water and sanitation may not, in the short run, be a viable choice in rural areas in many countries, it is important to identify other options that improve the quality of the water that is *consumed* in these settings. There are a variety of interventions that seek to reduce microbial ingestion without changing water and sanitation hardware. These include handwashing, boiling water before drinking it, or solar purification, all of which in principle hold promise. In this paper, I do not review these interventions. Many of the evaluations of these interventions are of poor quality. In those cases where the identification strategy is more credible, the results have often been disappointing, in particular when programs are taken to scale (see, for example, Galiani et al., 2012 on handwashing in Peru). There is of course compelling biological evidence that handwashing, or boiling water before drinking it, reduces the number of pathogens in water that is ingested. However, there is a large gap between what the “science” shows, and what policies and programs are able to accomplish. Many of these interventions depend on behavioral changes by households. Effecting behavioral change is remarkably difficult, and water, sanitation and hygiene are no

³¹ In making this argument, Gamper-Rabindran et al. (2010) cite a variety of authors, including Shuval et al. (1981), Briscoe (1984), and Esrey et al. (1992).

exception. These challenges are likely to become ever more important as policy-makers attempt to take these interventions from small, intensive efficacy trials to at-scale programs.

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