Early Life Exposure to Tap Water and the Development of Cognitive Skills

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Abstract

To improve drinking water accessibility and safety in rural China, the Chinese government launched the rural drinking water program in the 1980s. As part of the program, tap water infrastructure has been constructed in rural areas to supply tap water to rural residents. This policy intervention provides a unique opportunity to examine the impact of early life exposure to tap water on children's cognitive achievement in later life. Using data extracted from the China Family Panel Studies (CFPS), we find that one additional year of exposure to tap water in early life increases average cognitive test score by 0.109 standard deviations for a sample of rural children aged 10-15 in 2010. The effect is larger for children whose fathers are less-educated. Event study estimates confirm that the beneficial impacts are concentrated in early life with limited additional impact after the time window.

Keywords: Early life; Water infrastructure; Human Capital; Cognitive skills

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1 Introduction

Cognitive skills are closely associated with long-term educational attainment, labor market outcomes, and overall wellbeing (Heckman et al., 2006; Lindqvist and Vestman, 2011). The skill formation theory suggests that, taking parental environment and other investment as inputs, cognitive skills can be produced at different stages of childhood into adulthood (Cunha et al., 2010; Attanasio, 2015). Emerging evidence has pointed to the fact that early life, usually covering the prenatal period and early childhood, is the most critical window in the process of cognitive development.[1] Although many studies in developed countries have linked early life conditions with cognitive development over the life-cycle, relatively few studies have provided such evidence in a developing country context.[2]

There are significant implications for understanding the determinants and mechanisms of cognitive skill formation in a developing country context. Empirical evidence suggests that some of these determinants are very similar to those in the developed world, such as household wealth, parental socio-economic background and parental involvement in the child bearing activities (Zhang et al., 2014; Schady et al., 2015). However, young children in developing countries are also subject to many other risk factors. Previous studies show that nutritional status, immunization status and the overall physical health in early childhood are all closely linked to cognitive skills in later life (Glewwe and King, 2001; Maluccio et al., 2009; Barham, 2012; Bloom et al., 2012; Bierman et al., 2017).

To enrich the understanding of the development of cognitive skills in developing countries, we analyze how early life access to tap water - one of the most important and basic public infrastructures - affects children's cognitive development in rural China. Since the construction of tap water infrastructure requires building water treatment plants (with water purification technology and equipment) and water pipelines that link directly to end users, connecting households to tap water may reduce the time burden of water collection and improve drinking water quality. A large number of studies have

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[1] For example, Case and Paxson (2008) observe that poor health and inadequate nutrition in early life is associated with long-term deficits in cognitive skills. Cunha et al. (2010) advocate that investment in cognitive development in early childhood will generate disproportionately large returns relative to investment in later childhood. A survey of this literature is provided by Almond and Currie (2011).

[2] Attanasio (2015) reviews recent studies on human capital formation during the early years of life in the context of developing countries.

investigated the effects of improved access to tap water on a variety of outcomes, including children's and adults' health and education, female labor supply, and perceived quality of life (Mangyo, 2008; Devoto et al., 2012; Zhang, 2012; Koolwal and van de Walle, 2013; Meeks, 2016; Zhang and Xu, 2016).

The development of tap water infrastructure in rural China during the past three decades provides a unique opportunity to evaluate the impact of early life exposure to tap water on children's cognitive development. In 1990, merely 11% of households in rural China had access to on-premise tap water (WHO and UNICEF, 2015). Aiming to raise the accessibility of safe drinking water in rural areas, the Chinese government has gradually rolled out the rural drinking water program since the 1980s. The program focuses largely on building water plants and pipelines to supply tap water to rural residents. There has been significant progress in access to safe drinking water: In 2015, 55% of rural households had access to on-premise tap water (WHO and UNICEF, 2015).

In this paper, we examine the effect of improved access to tap water in early life, which covers the period in utero and early childhood, on cognitive achievement in adolescence (10-15 years old). The data used for the analysis are extracted from the baseline survey of China Family Panel Studies (CFPS) conducted in 2010. The level of cognitive skills is measured by scores from the word and math tests administered among children aged 10 or above in CFPS. Because tap water keeps operating and does not "turn off" once introduced, when combined with data on children's birth year, we are able to identify both the timing of initial exposure and the length of early life exposure for each child. As the program has gradually been rolled out among rural communities, we use the difference-in-differences (DID) approach with community and birth year fixed effects to exploit the variation in outcomes across cohorts within a given community.

We find that exposure to tap water in early life significantly improves children's cognitive achievement in adolescence. One additional year of early life exposure to tap water increases the average cognitive test score of 10-15 year-old children by 0.109 standard deviations. Heterogeneous analysis reveals that the effect might be larger for children whose father is less educated. Our estimates remain robust in a series of sensitivity analyses, including using a sample of children from communities sharing similar trends in pre-intervention characteristics, conducting a placebo test using older cohorts, controlling for other governmental programs, and considering the impact of sample attrition. An event study confirms that the beneficial impacts of tap water exposure on children's cognitive development are concentrated in early life with limited additional impact after the time window.

Using the same data set, we discuss the mechanisms through which tap water access could have affected the development of cognitive skills. We find that early life tap water exposure may raise adolescent cognitive achievement through improving early childhood health. Our findings also suggest that for women with young children, the time saved from improved accessibility of domestic water may have been converted to increased time spent on caring for young children, which gives rise to improved cognitive development.

Our paper mainly contributes to three strands of literature. The first contribution is to the broad literature on the effects of early life interventions on human capital development. Early life interventions that are designed to improve children's welfare and development, such as in-kind or cash transfers, health interventions and preschool programs, have been causally linked with human capital accumulation over the life-cycle.[3] Interventions that target cognitive development specifically, both at the individual child and parental level, are also found to be influential (Gertler et al., 2014; Bierman et al., 2017; Lomanowska et al., 2017). However, there is little research on the link between early life access to public infrastructure and later life outcomes, although each year a significant amount of money is spent on the construction of public infrastructure.[4] Our paper extends the literature by showing that early life exposure to one of the most basic and important public infrastructures, tap water, contributes positively to the accumulation of cognitive skills.

The second is the literature on the effects of improved access to treated water on human capital development. Access to treated water is generally found to have a contemporaneous impact on children's health and educational outcomes (Jalan and Raval-

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[3] It has been documented that early life health or nutritional status (Case and Paxson, 2008, 2009; Currie et al., 2010), exposure to health shocks such as infections (Bleakley, 2007; Cutler et al., 2010) or drought (Hoddinott and Kinsey, 2001), nutrition and health interventions (Maluccio et al., 2009; Barham, 2012), access to better sanitation (Spears and Lamba, 2016), and maternal employment (Ruhm, 2004; Bernal, 2008; Ruhm, 2008; Baker and Milligan, 2010) have long-term effects on cognitive function, health and labor market outcomes. See Almond and Currie (2011) and Attanasio (2015) for extensive surveys of the literature.

[4] About 3.8% of world GDP has been spent on economic infrastructure over the last 20 years, *i.e.*, an annual amount of around 2,400 billion USD (applied to 2010 GDP) (Inderst, 2016). It is estimated that the annual infrastructure spending in developing countries in 2008 was 800-900 billion USD, of which 600-650 billion USD was by the public sector (Fay et al., 2011).

lion, 2003; Galiani et al., 2005; Mangyo, 2008; Gamper-Rabindran et al., 2010; Zhang, 2012; Koolwal and van de Walle, 2013; Kosec, 2014; Zhang and Xu, 2016). Our findings suggest that the effect of early life access to treated water can be long lasting. We show that tap water exposure in early life leads to better cognitive achievement in adolescence. Since the development of cognitive skills are considered to become relatively stable in adulthood, the disparity observed in adolescence would have a large impact on the overall economic well-being of these children over their course of life.

The third strand of literature documents the microeconomic effects of public infrastructure construction and expansion on human capital development in developing countries. Previous studies have investigated the effects of access to schools (Duflo, 2001, 2004; Li and Liu, 2014), electricity (Dinkelman, 2011; Grimm et al., 2015; Salmon and Tanguy, 2016), health facilities (Gruber et al., 2014; Lu and Slusky, 2016), and roads (Banerjee et al., 2012) on various household- and individual-level outcomes. Our paper adds to this line of literature by examining how constructing tap water infrastructure in less-developed areas affects human capital building. In particular, we speak to the impact of a health-oriented infrastructure (*e.g.* safe drinking water) on non-health outcomes (*e.g.* cognitive achievement).

The paper is structured as follows. Section 2 introduces the conceptual framework that will guide our discussion, and Section 3 provides the basic background information about the rural drinking water program in China. Section 4 details the data we use for estimation and the identification strategy. Section 5 presents the main findings and results of cost-benefit analysis, event study, and heterogeneous analysis. Section 6 shows the results from sensitivity analyses. Section 7 discusses potential mechanisms, and Section 8 concludes.

2 Conceptual Framework

In this section we discuss the link between tap water exposure in early life and the development of cognitive skills. We follow the theoretical model of human capital formation outlined in Attanasio (2015) to guide our discussion. This model is an extension of earlier work by Attanasio et al. (2015) and Cunha et al. (2010). The skill formation theory suggests that cognitive skills can be produced at different stages of childhood into adulthood, taking parental environment and other investments as inputs. The production function of human capital for individual i at time t is given by

$$H_{i,t+1} = g_t(H_{i,t}, X_{i,t}, Z_{i,t}, e^H_{i,t}), \tag{1}$$

where $H_{i,t}$, $Z_{i,t}$, $X_{i,t}$ and $e^H_{i,t}$ represent the stocks of human capital, parental background, investment inputs, and random human capital shock at time t, respectively.

Based on the skill formation theory outlined in Attanasio et al. (2015) and Attanasio (2015), suppose human capital at time t comprises of two dimensions: cognitive skills θ^c_t and health θ^h_t.[5] Parental background Z_t depends on mother's background (θ^m_t), father's background (θ^f_t), and all other (θ^r_t). Investment inputs X_t consists of monetary inputs (θ^M_t) and time inputs (θ^T_t). To summarize, we can write each component in the production function in equation (1) as follows:

$$\begin{aligned} H_t &= \{\theta^c_t, \theta^h_t\}, \\ Z_t &= \{\theta^m_t, \theta^f_t, \theta^r_t\}, \\ X_t &= \{\theta^M_t, \theta^T_t\}. \end{aligned} \tag{2}$$

Exposure to tap water can affect the development of cognitive skills directly through environment factor θ^r. Evidence in the public health and economics literature suggests that unimproved sources of drinking water with toxic chemicals such as fluoride, manganese and arsenic are associated with worse cognitive outcomes. Children exposed to these chemicals are more likely to have lower IQ scores, cognitive dysfunction and other behavioral problems (Zoni and Lucchini, 2013; Tyler and Allan, 2014; Choi et al., 2015).

Tap water exposure also has an indirect effect on the development of cognitive skills through its impact on θ^h_t and θ^T_t. Evidence suggests that early childhood diarrhea is associated with poorer cognitive functions in later childhood (Niehaus et al., 2002). As many incidences of diarrhea in developing regions are caused by water-borne bacteria, exposure to tap water could therefore enhance cognitive development by improving general physical health in early childhood. Accessibility of water also affects the time investment of main caregivers θ^T_t. In developing countries, households without sustain-

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[5] Other variations of this model include cognitive skills, noncognitive skills, and health as different dimensions of human capital. For simplicity, we suppress the individual subscript i in the subsequent discussions.

able access to water spend considerable amount of time collecting water for domestic use, and this task is often designated to women (Devoto et al., 2012). As mothers are usually the primary caregivers of young children, access to tap water could free up mothers' time from water collection to more productive child rearing activities, and hence enhance children's cognitive development.

Because our data set does not include data on the chemical contents of drinking water before and after the program, we cannot evaluate the direct impact of exposure to the chemicals discussed above. Instead, we analyze the indirect channels in which tap water may affect the development of cognitive skills using child health and mothers' time use data in Section 7.

3 Background

3.1 Drinking water in rural China

China as a whole is a water-stressed country. Its annual per capita freshwater resources, about $2,156\,m^3$ in 2007, are among the lowest for a major country (Xie et al., 2009). The problem is made worse by uneven distribution, both spatially and temporally, and the severe deterioration in water quality from industrial, domestic, and agricultural sources that has accompanied China's unprecedented economic boom in the past thirty years (Xie et al., 2009). Data from China's water monitoring system shows that in 2004, of all 745 monitored river sections, 28% were unsafe for any use (below Grade V standard on a six-grade scale), and only 32% were safe for industrial and irrigation use (Grade IV-V standards)) (Xie et al., 2009).

The development of the public water supply in rural China lags greatly behind that of urban areas. According to WHO and UNICEF (2015) estimates, in 1990, 92% of urban residents had access to on-premise treated water from water plants, while 88% of rural residents had no access to on-premise tap water, and 44% had difficulty in obtaining drinking water from improved sources.

Lack of access to safe drinking water exposes rural residents to enormous health risks. It is estimated that the risk for diarrhea in households with tap water is 0.66 times less than households without tap water (World Bank, 2007). Ebenstein (2012) found that a deterioration in water quality by a single grade (on a six-grade scale) increases the incidences of digestive cancer by 3.3% in counties with higher tap water coverage, but by 13.1% in counties with lower coverage only. Besides health outcomes, the time use of rural households might be constrained by poor accessibility of safe drinking water. For rural residents who rely on surface water - such as rivers, lakes, and ponds - as the primary source of drinking water, tremendous time and efforts may be required to fetch and/or treat water. For instance, Meng et al. (2004) estimated that rural households without piped water spend an average of 20 to 60 minutes every day to fetch water, and the time may go up significantly during dry seasons.

Aiming to improve households' access to safe drinking water in rural China, the Chinese government initiated the rural drinking water program in the 1980s. As part of the program, water plants (with water purification technology and equipment) and pipeline systems have been constructed in qualified areas to supply drinking water to rural residents. The drinking water produced by the water plants has to meet the *Sanitary Standards for Drinking Water Quality* set by the Ministry of Health in 1985. As stated in the *Interim Provision on Rural Drinking Water* issued in 1984, the rural drinking water program targets areas with poor accessibility to drinking water, specifically those with (1) horizontal distance to drinking water source longer than one kilometer, and/or (2) vertical distance to drinking water source deeper than 100 meters. In 2000, the promulgation of the *Regulations on Construction of Rural Drinking Water Projects* kicked off the second phase of the program by adding in a third criteria: concentration of fluoride in drinking water source higher than 1.1 mg/L. While the central government stipulates the program guidelines, local governments are taking responsibility in program financing, planning, constructing, and management. In general, the central government, local government, rural residents, and other sponsors collectively bear the cost, with the contribution ratios of the parties varying across regions. Through the end of 2010, the program had incurred a total cost of 182.5 billion yuan (USD 27.4 billion) and covered 815.8 million rural residents (Meng et al., 2004; National Development and Reform Commission, 2007, 2012).

3.2 Probability and timing of tap water connection

Figure 1 plots the number of new communities connecting to tap water each year and the cumulative distribution of the community level tap water roll-out during 1980 and 2010 among 404 rural communities in CFPS 2010. In 1980, less than 5% of the communities had access to tap water. By 2010, over 55% of the communities had received a connection. As we will explain in Section 4.1, the treated communities in our study are those who first received a tap water connection in 1995 and 2005. This period covers both the first and the second phases of the program. Therefore, the estimated effects of the tap water exposure may stem from the improvement in water access or the improvement in water quality, or both.

As the program has been designed, the distance to and quality of the nearest drinking water source determine the probability and the timing of tap water access.[6] Other factors may have also affected the probability and timing of tap water access – for example, a community's location, population, size, level of economic development, and topographic characteristics. We employ a province fixed-effects model to show the correlation between community characteristics in 2010 and the probability and the timing of community-level tap water connection. Table 1 presents the regression results. We find that the location of a community is among the most important determinants for both the placement of tap water connections as well as the timing of construction: a community closer to a town or city is more likely to have access to tap water in 2010 and would have a tap water connection earlier than other communities located in the same province.[7] We do not find any significant results for population, size, average years of schooling of the 25-55 year-olds, or topographic characteristics.[8]

4 Empirical strategy

4.1 Data

We use data extracted from China Family Panel Studies (CFPS) survey. The CFPS survey was launched in 2010 by the Institute of Social Science Survey (ISSS) of Peking University, China (Xie, 2012). It is a longitudinal study of a nationally representative

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[6] The information on the communities' proximity to water source or the quality of drinking water is not available from the CFPS.

[7] Among the 404 rural communities, 90 are located in suburban areas, and the rest are located in rural areas.

[8] Population and area are proxies for the scale of a community, and average years of schooling is a proxy for the economic development of a community. Topographic characteristics capture the difficulty of constructing a tap water supply in the community.

sample of Chinese communities, families and individuals. The target sample of CFPS consists of 16,000 households in 25 regions in China, excluding Hong Kong, Macao, Taiwan, Xinjiang, Tibet, Qinghai, Inner Mongolia, Ningxia and Hainan. A total of 14,798 households and 42,590 individuals from 645 communities were successfully interviewed in the baseline survey, the source of the data for the main part of our analysis.

The survey provides detailed information at the community, household and individual level that is essential for our analysis.[9] Specifically, two tests of cognitive achievement were administrated to every respondent aged 10 or above, with which we construct the outcome variables. We use the information on timing of tap water connection at the community level, combined with respondent's year of birth, to construct our treatment variable. One concern is that the treatment variable may fail to measure the correct amount of exposure if households are attracted to move to communities that have recently obtained access to tap water. This may bias our estimates if the immigration decision is systematically related to both the timing of tap water connection and the outcomes. To rule out the potential bias caused by immigration, we restrict the sample to children whose place of birth, place of residence at age three, place of residence in 2010, and place of *hukou* (household registration) in 2010 coincide, so that our sample consists of children who are most likely to have resided in the community in utero and throughout early childhood.

The sample for analysis includes 2,246 children who were born between the year 1995 and 2000 and aged 10-15 in 2010. As cognitive tests in CFPS 2010 are administrated for children who are at least 10 years old, age 10 is chosen as the starting point. We choose age 15 as the ending point because in general children complete the 9-year compulsory education at age 15, at which point many rural children may choose to leave home for purposes such as studying or working after completing compulsory education.[10]

A child's cognitive achievement is measured by standardized scores from a word recognition test and a math test administrated by CFPS to children 10 years and older.[11]

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[9] The community questionnaire was administrated to a knowledgeable individual who has access to statistical materials in the community, such as the director or the accountant of the community committee, or the secretary of the Party branch.

[10] Extending the age range to 17 years old produces similar results. The results are available upon request from authors.

[11] Although we mainly look at the impact of tap water on the development of cognitive skills in this

Our main outcome is the average cognitive test score obtained by standardizing the weighted average of the word and math test scores to have a mean of zero and a standard deviation of unity within each cohort.[12] We also look at the effects on standardized word and math test scores separately. Panels A and B of Table 2 report the summary statistics of outcome variables and basic characteristics of the sample.

The treatment variable that we are interested in is a child's years of exposure to community-level tap water connection in early life, spanning from the prenatal period to early childhood. Health at birth that can be affected by in utero conditions is an important predictor of long-term outcomes (Aizer and Currie, 2014). Early childhood, which is usually defined as the period from birth to the age of five or six years, is also believed to be a critical period for human capital accumulation (Cunha et al., 2006; Almond and Currie, 2011). We therefore expect that if tap water exposure has any impact on child development, the largest magnitude of the effect should take place in utero and during early childhood.

Specifically, the years of early life exposure to tap water is jointly determined by the timing of receiving tap water connection at the community level and the child's year of birth.[13] In the absence of exact month of receiving the connection, we define the period of interest as that from one year before birth to the year before turning age six (spanning 7 years) and assume that the treatment starts counting from the first year of the community's access to tap water. To illustrate this, consider a child born in 1999 in a community that received a tap water connection in 2000, the child's exposure to tap water starts counting since 2000, and the child is considered to receive five years of exposure during the period of interest.[14]

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study, it is possible that tap water exposure can affect children's educational attainment and health outcomes as well. We examine the impact of early life tap water exposure on educational attainment in Section 7.3. In Appendix A.1, we discuss the effect of early life exposure to tap water on children's later life health outcomes.

[12] More detailed information on the approaches to construct the outcomes and their definitions is presented in Table A.2.

[13] The community survey asks "whether your village has been connected to tap water". If the answer is yes, the survey further asks what year tap water was first available at the community level.

[14] Calculating the treatment variable in this way may raise the concern of measurement error. For example, if the first connection took place in December, 2000, the child born in 1999 actually receives four years of exposure. In another case, if a child was born in December, 2000 in a community that connected to tap water in January, 2000, the child actually receives seven years of exposure but is taken as receiving six years in our analysis. This measurement error would attenuate the estimated impact of exposure to tap water. Since we find tap water exposure has a significant positive effect on children's test

scores, controlling for the measurement error would strengthen our results.

As our sampled children were born between 1995 and 2000, the variation in the treatment comes from the children residing in the communities that first received the connection between 1995 and 2005, who constitute the treatment group of our study. The control group consists of children from communities that did not experience any change in the availability of tap water connection during 1995 and 2005. Children from communities that had not connected by 2005 had no exposure to tap water in early life. For children from communities that received tap water connection before 1995, their early life exposure to tap water is seven years. As shown in Figure 1, the fraction of communities with tap water connection increases by around 20 percentage points during 1995-2005, providing substantial variation in the treatment variable. Panel C of Table 2 shows the summary statistics of the treatment variable, as well as the tabulation of years of exposure. Around 72% of the sampled children lived in communities that had no access to tap water during their early life, while 18% were fully exposed since one year prior to birth. The treatment status of the remaining 10% varies from one to seven years.

Without information on household access to tap water in early life, the estimated effect of years of exposure is actually an intention-to-treat (ITT) estimate. Since we find positive ITT estimates and some children may not have access to tap water even though their communities had a connection, the average effect of treatment on the treated will be larger than the ITT estimates.[15]

4.2 Empirical specification

The human capital indicator Y_{ict} in 2010 for child i from rural community c and born in year t can be expressed as

$$Y_{ict} = \phi \text{Exposure to tap IU-5}_{ct} + X_{ict}\beta + g_c + \gamma_t + \theta_t W_c + \epsilon_{ict}, \tag{3}$$

where $\text{Exposure to tap IU-5}_{ct}$ measures the years of exposure to tap water in early life (from one year before birth to the year before turning to age six) for children from rural com-

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[15] We briefly discuss the household take-up in Appendix A.2.

munity c born in year t. It takes discrete values from zero to seven.[16] X_{ict} is a vector of basic individual and household characteristics, including gender, number of siblings, mother's age at birth, number of household members, whether the household engages in agricultural production, and parents' years of schooling.[17] g_c is community fixed effects that control for time-invariant community-level characteristics that may be associated with both the timing of tap water connection and the outcomes. γ_t is the unrestricted cohort effects at the national level. $\theta_t W_c$ represents the interactions of community characteristics and birth year dummies, capturing the cohort effects varying by community characteristics. ϵ_{ict} is the random error term.

This empirical specification is essentially a difference-in-differences (DID) model, where we identify the impact of exposure to tap water, represented by ϕ, from the variation across birth cohorts within communities. If cohort trends are the same for all communities conditional on observables X_{ict}, the difference in outcomes of children from communities that experienced a new connection to tap water during 1995 and 2005 (the treatment group) captures the joint impact of tap water connection and the cohort fixed effects. Cohort fixed effects can be identified from the control group, consisting of children from communities that had a tap water connection before 1995 or had not received a connection by 2005. Taking into account the possibility that cohort effects may vary across provinces, we additionally control for province-specific cohort fixed effects. To acknowledge the possible differences in cohort or time trends across communities with different characteristics, we follow Gentzkow and Shapiro (2008) and Hoynes et al. (2016) and include a set of community characteristics W_c interacted with a cohort-specific coefficient vector θ_t.[18]

The validity of our identification strategy relies on the parallel trend assumption that in the absence of tap water exposure, the changes in cognitive achievement across cohorts would be the same for communities of similar pre-treatment characteristics within

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[16] The baseline specifications assume a linear relationship between cognitive achievement and years of exposure to tap water. We explored non-linear specifications by adding the square of years of exposure in the regression. The quadratic term is not statistically significant at conventional levels, rendering support to the baseline linear specification. The results are available from the authors upon request.

[17] We attempted to add household income in 2010 in the regressions and found the estimates unaffected. Considering the endogeneity of household income in 2010, we do not control for it in the baseline specifications. The results are available from the authors upon request.

[18] The same set of community characteristics as the explanatory variables in Table 1 are used to construct interaction terms. The community characteristics capture location, population, size, economic development, and topographic features of the communities.

a given province. To test this assumption, we compare the trends in pre-intervention characteristics of communities that received a tap water connection earlier with communities receiving the connection later. Our analysis in Section 6.1 finds similar pre-intervention trends in these two types of communities. To further rule out the possibility that other sources of unobserved trends may have driven the results, we conduct a placebo test using groups of individuals over 15 years old in 2010 in Section 6.2. We find no effect of the placebo treatment status on these older cohorts.

The DID estimator ϕ could still be biased if tap water exposure varies simultaneously with other factors that affect children's cognitive development. For example, other concurrent government programs might have driven the effects instead of tap water exposure. We address this issue in Section 6.3 by additionally controlling for early life access to roads, electricity, health facilities and landline phones to our preferred specification. Our results are not sensitive to accounting for the effects of other facilities.

There exists sample attrition caused by rural-to-urban migration or household emigration across communities by the time of survey. If the sample attrition is systematically related to the treatment variable, our estimates might be biased. In Section 6.4, we show that although there is sample attrition prior to 2010, it is unrelated to early life exposure to tap water, and therefore is unlikely to bias our estimates.

To keep our sample size reasonable, observations with missing individual and household characteristics are included in the regressions. Sample means are assigned to the missing values, and a set of dummy variables is created with each variable being equal to one if the corresponding information is missing. To account for any serial correlation across different cohorts within the same community, standard errors are clustered at the community level (Bertrand et al., 2004).

5 Results

5.1 Baseline results

Table 3 reports the estimation results for average cognitive test score, as well as the individual scores of the word recognition and math tests. The average test score is the standardized weighted average score of the word recognition and math tests, with a higher average score indicating a higher level of cognitive achievement. The treatment variable, Exposure to tap IU-5, measures the number of years a child had access to tap water at the community level in early life, varying from zero to seven years. Assuming common time trends nationwide, column (1) reports results from the specification with individual and household characteristics, cohort effects and community fixed effects controlled for. Column (2) allows the time trends to vary by province and presents results from the augmented specification with province-specific cohort effects added in as controls. Columns (3)-(5) report results from our preferred specification where the time trends could vary across communities with different characteristics by additionally controlling for interactions of community characteristics and cohort dummies.

Exposure to tap water in early life is found to have positive and significant effect on a child's cognitive achievement in adolescence. When only cohort effects and community fixed effects are controlled for in column (1), one additional year of early life tap water exposure increases children's average cognitive test score by 0.100 standard deviations. When we relax the assumption of nationwide common trends, the estimated effects in both columns (2) and (3) show little change, suggesting that latent cohort or time trends in cognitive achievement may not vary across provinces and across communities with different characteristics. In our preferred specification in column (3), the point estimate suggests that one additional year of early life exposure to tap water leads to a 0.109 standard deviation increase in average cognitive test score.

Looking at the word recognition test and math test separately, we find that tap water exposure has positive effects on both test scores. One more year of early life tap water exposure raises a child's word test score by 0.066 standard deviations and math test score by 0.133 standard deviations, although only the latter increase is statistically significant. Here, one standard deviation increase in standardized test score is equivalent to correctly answering 5 more questions in the math test or 7.5 questions in the word test. Taking the math test as an example, one additional year of early life exposure results in correctly answering 0.7 more questions in the test. It also means that a child receiving full exposure in early life would correctly answer around 5 more questions than an otherwise similar child with zero exposure.

Our findings have profound policy implications. In China, the gap between urban and rural human capital per capita is large and still widening (Human Capital in China, 2016). Using data from CFPS 2010 to compare the average cognitive test score of rural children aged 10-15 with that of their urban counterparts, we find that for each cohort the urban children outperform their rural counterparts by around 0.5 standard deviations. Since our study reveals that full exposure to tap water in early life increases average cognitive test score by 0.763 standard deviations, improving access to tap water would have significant potential to raise rural children's cognitive achievement and eventually narrow down or mitigate the enlarging human capital gap between rural and urban children in China.

5.2 Cost-benefit analysis

In addition to showing that early life exposure to tap water has significantly raised rural children's cognitive achievement, we also examine whether the rural drinking water program initiated by the Chinese government is cost-effective. In the past thirty years, China's fiscal expenditures have experienced a dramatic increase: total government expenditures soared to roughly 9 trillion Chinese yuan (equivalent to 1.34 trillion U.S. dollars) in 2010 from 601 billion yuan (89.7 billion U.S. dollars) in 1980 (National Bureau of Statistics of the People's Republic of China, 2011).[19] In view of this significant growth in government spending, it is essential to understand whether the fiscal expenditures have been cost-effective. To this end, we conduct a back-of-the-envelope calculation of the cost effectiveness of the rural drinking water program.

Following the method proposed by Lindqvist and Vestman (2011), we estimate the return to cognitive skills using a sample of rural residents aged 25 to 35 in CFPS 2010. The average annual income for these individuals is 13,600 yuan (2,030 U.S. dollars) in 2010. A simple OLS regression reveals that one standard deviation increase in cognitive achievement is associated with an increase of 1,216 yuan (181 U.S. dollars) in annual income for these individuals.[20]

As one additional year of early life tap water exposure is found to increase average test score by 0.109 standard deviations, together with the estimated return to cognitive skills, we find that one additional year of exposure to tap water in early life would lead to an increase of 133 yuan (20 U.S. dollars) in annual income.[21] Since the average

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[19] All numbers here are in 2010 values.

[20] Other explanatory variables we control for in the regression include gender, whether holding agricultural *hukou*, whether living in rural area, whether doing farm work, whether having a wage job, number of siblings, parents' years of schooling, birth year dummies, and county fixed effects.

[21] In robustness tests, the estimated effect of one additional year of tap water exposure on average

cost of the program is less than 30 U.S. dollars per capita (Meng et al., 2004), for an individual receiving merely one year of early life exposure, the income increase would cover the cost in two years. For another individual receiving full exposure, *i.e.* 7 years, in early life, the average test score could be 0.763 standard deviations higher than her/his counterpart without any exposure, which would in turn generate a rise of 928 yuan (139 U.S. dollars) in annual income, easily covering the per capita cost of the program in one year. Considering the durability of the community water supply system and the benefits associated with the program on health (Zhang, 2012) and educational attainment (Zhang and Xu, 2016), the total benefits should be significantly larger. Thus the program is shown to be highly cost-effective.

5.3 Does the timing of treatment matter?

The treatment thus far is the number of years that community-level tap water supply system is available in early life, *i.e.* the period between one year before birth and the year before turning six. However, in the setting of this study, when a child receives any exposure in early life, she/he is definitely exposed to tap water in later life if the child stays in the same community. Therefore, our estimates may also pick up treatment effects beyond early life. In this section, we show that the timing of the treatment is crucial in terms of cognitive development, in the sense that exposure in early life matters more than exposure during later childhood.

We use an event study model to explore how the timing of treatment matters. Event time is defined as the difference between the first year of tap water connection at community level and the year of birth. For example, a child born in 2000 in a community that first got a tap water connection in 2002 would have an event time of 2. The child would have event time of -2 if tap water was first connected to their birth community in 1998. A negative event time indicates full exposure in early life, and a positive event time indicates partial or no exposure.

We generate a series of dummies based on two-year intervals of event time. We re-estimate Equation 3 but replace the treatment variable $\text{Exposure to tap IU-5}_{ct}$ with the dummies and use event time of 8-9 as the base group. The end points are open brackets

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cognitive test score is between 0.106 and 0.132 standard deviations, which would translate into an income increase between 129 yuan (19 U.S. dollars) and 161 yuan (24 U.S. dollars) annually.

(event time below −4 on the left, and event time over 9 on the right), which helps reduce the collinearity between event time and birth year. Because the sample is unbalanced in event time, we follow Hoynes et al. (2016) and focus on the event study coefficients inside these unbalanced endpoints. We present the results in Figure 2. Each dot on the solid line is the coefficient of interest and a 95-percent confidence interval is plotted by dash lines.

We test three hypotheses in the event study. The first hypothesis is that if tap water exposure starts before birth, regardless of the actual timing, it exerts the largest impact on cognitive development. If this hypothesis is true, we expect all negative event times to have similar estimates, and the estimates are the largest among all. Second, if the exposure starts after birth, the impact becomes smaller as the timing of initial exposure increases. To support this hypothesis, the estimate would get smaller as the event time increases. Finally, tap water exposure in later life exerts little impact as compared to that in utero and during early childhood. This hypothesis would be supported if the estimate for any event time beyond 5 is close to zero.

The event study results shown in Figure 2 support our hypothesis very well. The impact of tap water on cognitive achievement accrued to those with negative event times (full exposure) is largest and flat. The line shows an overall declining pattern in early life, suggesting that the later a child is exposed to tap water, the smaller the improvement in cognitive achievement. After event time of 5, the line becomes flat, indicating that exposure after the period of interest has minimal impact on cognitive development. Overall, the event study confirms that timing of tap water exposure is crucial for cognitive development.

5.4 Heterogeneous effects

The effect of early life tap water exposure on children's cognitive development may depend on the gender of the child or on household socioeconomic status (SES). In this section, we investigate the heterogeneous effects of early life tap water exposure. We first run separate regressions for boys and girls. Results are reported in columns (1) and (2) of Table 4. One additional year of early life exposure to tap water is found to increase average cognitive test score by 0.155 standard deviations for boys and 0.167 standard deviations for girls, and the effects are significant for both genders. Hence, no gender difference in the treatment effects is detected.

Next, we use father's education as a proxy for household SES. The children are divided into two groups: those whose father has at least nine years of schooling (high SES) and those whose father has less than nine years of schooling (low SES). We run separate regressions for the two groups and report results in columns (3) and (4), respectively, of Table 4. It is shown that early life tap water exposure has a positive and significant effect on the cognitive achievement of children from low SES households: one more year of exposure raises the average cognitive test score by 0.176 standard deviations. Although the effect on children from high SES households is also positive, the effect is smaller in magnitude (0.117 standard deviations) and not significant. It is likely that before the communities receive a tap water connection, lower SES households have poorer access to safe drinking water than higher SES households, so that children from lower SES households may benefit more from the tap water exposure.

6 Sensitivity analysis

6.1 The comparability between treatment group and control group

In the main analysis, children from communities that first obtained a tap water connection during 1995 and 2005 serve as the treatment group, and those from communities that connected before 1995 or after 2005 constitute the control group. Although we have controlled for a rich set of explanatory variables and fixed effects in our preferred specification, our DID specification may still fail if the unobserved trends of outcome variables are different across treatment and control groups in the absence of tap water connection. To address this issue we compare the trends in pre-intervention characteristics across communities receiving tap water connections at different timing. In particular, we derive from CFPS 2010 the average years of schooling of males, average years of schooling of females, sex ratio, and fertility rate at the community level by every two adjacent cohorts born between 1950 and 1989.[22] The comparison is done across two types of communities: those gaining access between 1995 and 2005, and those gaining access after 2005. We do not include communities that received access to tap water be-

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[22] The calculation is done by every two years. For example, the value in 1986 is in fact the average for individuals born between 1986 and 1987.

fore 1995, as the trends for cohorts born between 1950 and 1989 in those communities may actually reflect post-intervention trends. For communities receiving tap water connections in or after 1995, when the tap water connection starts kicking in, the youngest cohort was already six years old, and the cohort trends we are plotting should reflect the pre-intervention trends.

Figure 3 shows that the two types of communities share very similar pre-intervention trends in education, fertility rate and sex ratio. It is therefore reasonable to believe that these two types of communities experience the same trends in other unobservable dimensions. In other word, communities that had not obtained tap water connection by 2005 could serve as a suitable control group.

We re-run the regressions using children from these two types of communities to see if the choice of control group matters for our estimates. Column (1) of Table 5 reports the regression results. The effect of early life tap water exposure remains positive and significant on average cognitive test score. This exercise suggests that our conclusion still holds after excluding children from communities that first obtained a tap water connection before 1995.

6.2 Time-shifted placebos

In order to rule out the possibility that other sources of unobserved trends drive the results, we conduct a placebo test using five groups of individuals who were 16-21, 18-23, 20-25, 22-27, and 24-29 years old, respectively, in 2010. We uniformly shift their birth year backwards by 6, 8, 10, 12, and 14 years, respectively, so that they were of the same "age" as the children in our main analysis, 10-15 years old in 2010. A pseudo Exposure to tap IU-5 is calculated using the shifted birth year and the actual first year of tap water connection in the community. We re-run the regressions for each group with Exposure to tap IU-5 replaced by pseudo Exposure to tap IU-5. If our results were driven by unobserved trends, we would detect a correlation between the pseudo exposure and the outcome variables for the older cohorts as well.

The estimates from the placebo tests are plotted in Figure 4 by shifted birth years. Consistent with the main results, the only positive and significant coefficient is where birth year is not shifted (birth year shifted being "0" in the graph), which corresponds to the main specification. For all the other groups, the pseudo tap water exposure in early life is found to have little or no effect on average cognitive test score. Overall, the findings from the placebo tests suggest that the main results are unlikely to be driven by unobserved trends.

6.3 Effects of other simultaneous government programs

To check if the estimated effect of tap water exposure on cognitive development was driven by other governmental programs, we include in the regression children's exposure to electricity, cable/satellite TV, roads, health facilities, and landline phones in early life. The reasons for controlling for exposure to these specific facilities are as follows. First, improving access to these basic public facilities might be part of an integrated government program aimed to promote growth in poor rural areas. Therefore, the connections to tap water, electricity, TV, roads, health facilities, and landline phones can be triggered simultaneously by raising public expenditure. Second, previous work has causally linked these facilities to household and individual outcomes. For example, economists have established causal relationship between electricity and labor supply (Dinkelman, 2011), roads and economic growth (Banerjee et al., 2012), health facilities and health care utilization (Lu and Slusky, 2016), and landline phones and migration (Lu et al., 2016). Such casual links suggest that the increase in children's cognitive achievement could be attributable to early life exposure to public facilities other than tap water.

To construct the years of exposure to other public facilities in early life, we use the same method as that used to construct years of exposure to tap water, described in Section 4.1. The regression results are reported in column (2) of Table 5. Our results are highly robust after adding controls for other public facilities. The effect of early life tap water exposure remains positive and significant. The findings suggest that our estimates are unlikely to be biased by other concurrent government programs in early life.[23]

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[23] We have attempted to control for exposure or accessibility to other public facilities, such as train stations and mobile phone signals. Controlling for exposure to other public facilities does not change the coefficients on the treatment variable, exposure to tap water. Results are available from the authors upon request.

6.4 The impact of sample attrition

Sample attrition may be caused by household emigration, children leaving home for study or work, or other reasons. It may bias our estimates if the absence of the children in the survey is affected by the introduction of tap water in the community. For instance, having access to tap water may raise children's school performance, which in turn may increase their probability of being admitted to prestigious middle schools outside the communities and consequently their probability of leaving home.

Since CFPS does not track children who have moved out of the community, we cannot test the above possibility directly. Instead, we rely on the existing data to shed some light. Among 2,417 children aged 10-15 in CFPS 2010, there were 171 children whose families were surveyed in CFPS 2010 but themselves were not surveyed. For these children, we are able to construct their actual exposure to tap water based on their parents' reporting of their basic information, such as gender and birth date. We estimate the effect of early life exposure to tap water on the likelihood of the children themselves not being surveyed in 2010. Column (1) of Table 6 shows that early life exposure to tap water does not affect children's probability of absence in CFPS 2010.

Children could also be absent in the survey because of household emigration. To check this, we examine the sample attrition between two adjacent CFPS waves, 2010 and 2012. We choose children who were aged 0-13 and participated in the survey in 2010. The starting point is chosen to be zero, because the information on fetuses is absent in 2010. The oldest child included was 13 in 2010, who turned 15 in 2012. Among 4,979 children who were aged 0-13 and surveyed in 2010, 739 were not surveyed in 2012. Column (2) of Table 6 shows that for the children who were surveyed in CFPS 2010, the possibility of absence in CFPS 2012 is not affected by years of exposure to tap water in early life. Overall, we find no evidence of sample attrition due to early life tap water exposure. Therefore, our findings are unlikely to be affected by sample attrition.

7 Potential mechanisms

As discussed in Section 2, exposure to rural drinking water program could directly or indirectly affect child development through a variety of channels. In this section, we examine two of the most well-known channels documented in the literature: childhood health and maternal time investment.

7.1 Childhood health

Better access to clean water is found to have first-order effects on childhood health by reducing the incidence of waterborne disease and improving nutritional status (Jalan and Ravallion, 2003; Zhang, 2012). It has also been documented that childhood health and circumstance has continuing and lasting effects on later outcomes (see *e.g.* Case et al. (2005)). Hence, we would like to know whether better access to tap water raises children's cognitive achievement by improving childhood health.

As the childhood health status of the 10-15 year-old children in 2010 is not available from CFPS 2010, we instead examine the effects of tap water connection on health status of the 0-5 year-old children in 2010.[24] We only include communities that received tap water connection before 2005 or after 2010, to focus on the children who are either fully exposed since the year prior to birth or are never exposed.[25] We estimate the following equation:

$$Y_{ic} = \phi \text{Tapwater}_c + X_i\beta + W_c\gamma + g_s + \epsilon_{ic}, \tag{4}$$

where Y_{ic} denotes health outcomes of child i living in community c. It takes six measures of health status, including number of illness incidences and number of doctor visits the previous month; number of doctor visits the previous year, and whether total health expenditure for the previous year fell in the top quintile; and number of illness incidences and number of doctor visits in the first 12 months after birth. Tapwater_c is a dummy indicating whether community c is connected to tap water before 2005.[26] X_i is a vector of variables measuring individual and family characteristics. g_s is the vector of county-year fixed effects.[27] To reduce the probability that the coefficient ϕ is confounded by unobserved difference between communities with tap water and those without, we control for a series of community characteristics and the availability of many other public facilities, denoted by W_c (see table notes of Table 7).

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[24] Unfortunately, health status in utero is not available.

[25] Our results are robust to including the communities getting access between 2005 and 2010.

[26] We do not use years of exposure, as it is highly correlated with age for 0-5 year-old children.

[27] Here we are comparing the health status of children from communities having tap water with that of their same-county counterparts from communities without tap water, so our estimates in fact reveal the correlation between tap water exposure and childhood health outcomes.

Table 7 reports the effect of having access to tap water on the health status of children aged 0-5 in 2010. We find that children from communities with a tap water connection are better than those without on all six health measures: fewer illness incidences and doctor visits, and lower total health expenditure. The findings suggest that early life tap water exposure may raise cognitive achievement through improving health at childhood.

7.2 Time use

Devoto et al. (2012) find that in developing countries providing easy access to water reduces the burden of water collection, which is borne primarily by women and girls. The time freed up from water management could be spent on additional production, such as taking care of young kids, doing domestic duties and/or doing self-employed or paid work. As maternal time is a key input for child development (Ruhm, 2008; Miller and Urdinola, 2010), if access to tap water could increase maternal time investment, it might indirectly improve children's short- and long-term development. Therefore, we would like to find out whether mothers' time use pattern has been altered by improved access to tap water.

As historical time use data of mothers of the sampled children in our baseline analysis are not available from CFPS 2010, we examine the effect of community-level tap water connection on time use for a sample of rural women aged 20-45 years in CFPS 2010. We divide them into two groups: those who have at least one 0-5 year-old child in 2010, and those who do not. We divide each woman's time use into four sections: family care (inclusive of maternal time investment), paid work, housework, and others (inclusive of time spent on water collection).[28] We estimate Equation 4 with Y_{ic} replaced with three time use outcomes: number of hours spent taking care of family members in a week, number of hours spent on paid work in a week, and number of hours spent on housework in a week. A series of individual, household, and community characteristics are controlled for in the regressions (see table notes of Table 8). The hypotheses we would like to test are: (1) having tap water connection in the community of residence would reduce the time spent on fetching water, (2) for women with one or more 0-5 years old children, the saved time would be spent on taking care of young children, and

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[28] For the details of the time use module, please refer to China Family Panel Studies (2010) User's Manual (Xie, 2012).

(3) for women without a 0-5 years old child, the saved time would be spent on other activities, such as paid work and housework. The second and the third hypotheses could be tested directly through individual regressions, and the first hypothesis could be indirectly tested by checking if the total time spent on family care, work, and housework increases.

The results presented in Table 8 are consistent with all the three hypotheses. We find that for both groups of women access to tap water increases the time spent on family care, paid work, or housework and the time spent on none of the three activities drops significantly. It suggests that community-level access to tap water may reduce women's time spent on water collection. Column (1) of Table 8 shows that when having one or more 0-5 year-old children, mothers living in communities with tap water spend more hours on taking care of family members than others in communities without tap water. In contrast, for women who have no 0-5 year-old children, the amount of time spent on family care does not depend on tap water availability (see column (4) of Table 8). This comparison also suggests that the time spent on taking care of young children may represent a large proportion of the time spent on taking care of family members by these mothers. The results shown in column (2)-(3) of Table 8 suggest that in the presence of very young children, the amount of time spent on paid work or housework does not depend on tap water accessibility. However, for those having no young children, the amount of time spent on paid work or housework is significantly higher with community-level access to tap water.

By comparing the time use pattern across women living in communities with or without tap water connection, we show that no matter these women have young children or not, access to tap water significantly increases the total amount of time spent on family care, paid work and/or housework. For women with young children, the time saved from improved access to tap water may have been converted to increased time spent on caring for young children, which gives rise to enhanced human capital development. For women without 0-5 year-old children, the time saved from improved tap water access may have been used for labor supply or housework instead.

7.3 Alternative explanation

In this study, we use cognitive test scores to measure one's cognitive skills, rather than educational attainment, which is often used as a proxy for cognitive skills. The cognitive test score has two advantages over educational attainment as a measure of cognitive development. First, educational outcomes such as completed years of schooling or enrollment status are indirect measures of cognitive skills, which may not reflect what people really know that may vary by school quality or out-of-school learning (Maluccio et al., 2009). Second, 91% of the children in our sample are currently enrolled in school. Therefore, the estimated effect on completed years of schooling does not reflect the impact of tap water exposure on one's ultimate educational attainment, but only the impact on early dropout and/or delayed enrollment.

Nevertheless, improvement in one's educational attainment may still function as one of the channels via which cognitive test scores are increased (Carlsson et al., 2015). To test this, we estimate the treatment effects of early life exposure to tap water on children's educational attainment, measured by completed years of schooling, grade-for-age status and school enrollment status in 2010. Grade-for-age status is measured by a dummy indicator that takes value one if the child was enrolled in the supposed grade for her/his age and zero otherwise. School enrollment status is measured by a dummy indicator which equals to one if the child was enrolled in school at the survey time and zero otherwise. The results are shown in Table 9. We find no significant impact of early life access to tap water on later educational attainment. This finding implies that the positive effect of tap water exposure on cognitive test scores is unlikely due to increased educational attainment.

Hansen et al. (2004) suggest that manifest ability, as reflected by achievement test scores, is affected by latent ability and schooling. By ruling out the possibility that the positive impact on cognitive test scores comes from an improvement in education, we can conclude with more confidence that early access to tap water indeed enhances one's latent cognitive skills.

8 Conclusion

In this paper, we study the impact of access to tap water in early life (from one year before birth to the year before turning six) on the cognitive achievement of rural children observed at ages 10-15. Using community fixed-effects models, we find that early life exposure to tap water has a positive and significant effect on rural children's cognitive test scores. An additional year of exposure to tap water in early life is found to raise a rural child's average cognitive test score by 0.109 standard deviations. This indicates that children who are fully exposed from one year before birth answer four more questions correctly in the math test, or read six more words correctly in the word recognition test, than children with no exposure during the same period. Results from heterogeneous analysis suggest that the effect is larger for children whose father has less education.

Event study reveals that the timing of first exposure to tap water is crucial. The impact of tap water on cognitive achievement is largest for those children whose exposure starts at least one year before birth, and gets smaller as the first year of tap water connection lags behind of the birth year, finally diminishing if the first exposure begins six years after birth. Our results survive a series of robustness tests: comparing the pre-trends across different types of communities, conducting a placebo test using older cohorts, controlling for other governmental programs, and considering the impact of sample attrition. Mechanism analysis suggests that early life exposure to tap water may raise cognitive achievement by improving childhood health and increasing maternal time investment.

The urban-rural gap in human capital is large and widening in China (Human Capital in China, 2016). Our results suggest that improving access to tap water among rural residents has great potential to enhance rural children's cognitive development, especially for those from low SES households, and consequently narrow down or mitigate the gap in human capital between urban and rural children, which would eventually contribute to reducing urban-rural income inequality. More important, the back-of-envelope cost-benefit analysis proves that the rural drinking water program is highly cost-effective.

Our study reveals the essential role of early life exposure to tap water in the development of cognitive skills. A tap water supply system is one type of public infrastructure. Similarly, cognitive development, though crucial, is just one dimension of human capital development. As the construction of public infrastructure always involves large fiscal expenditures, future work should examine the effects of exposure to various types of public infrastructure on the development of multiple dimensions of human capital in children, and at different growth stages. This would not only reveal the role of public infrastructure in human capital development and the importance of intervention timing, but would also provide guidance for distributing fiscal resources across regions or customizing government spending according to local conditions to achieve maximum benefits for society.

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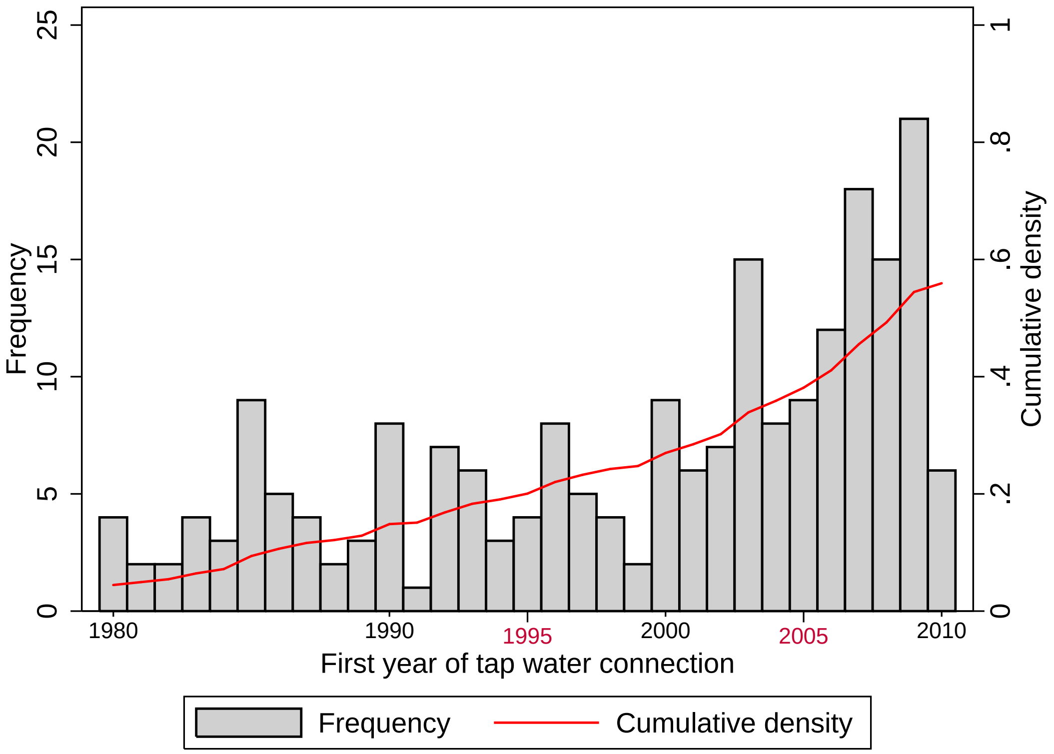
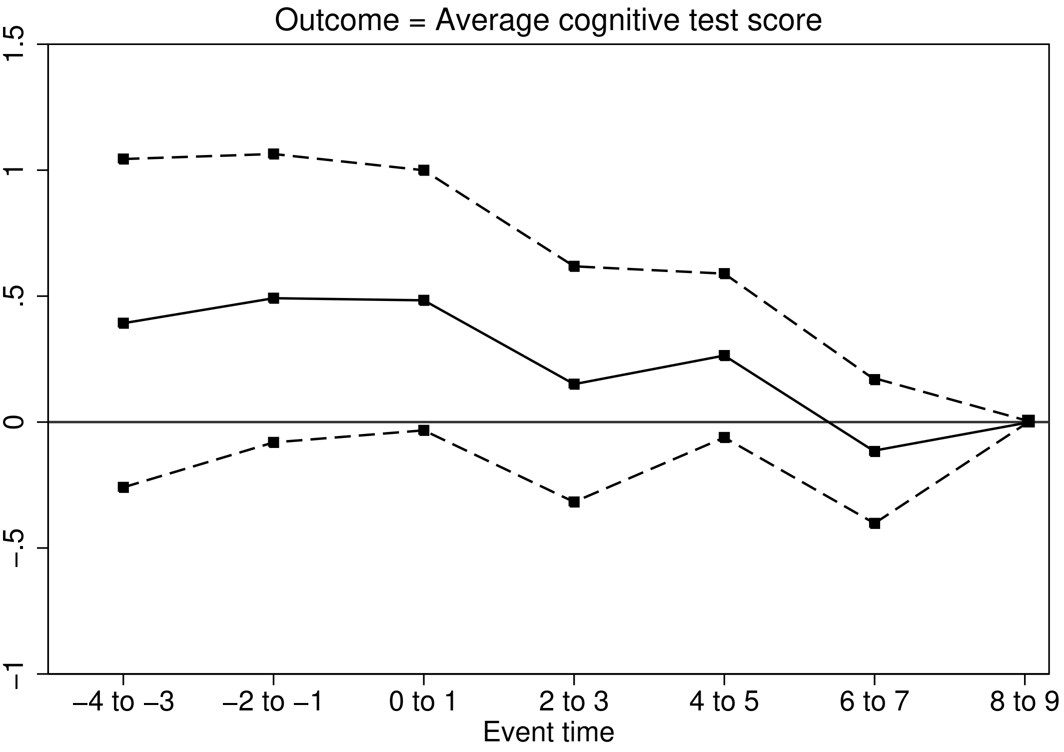


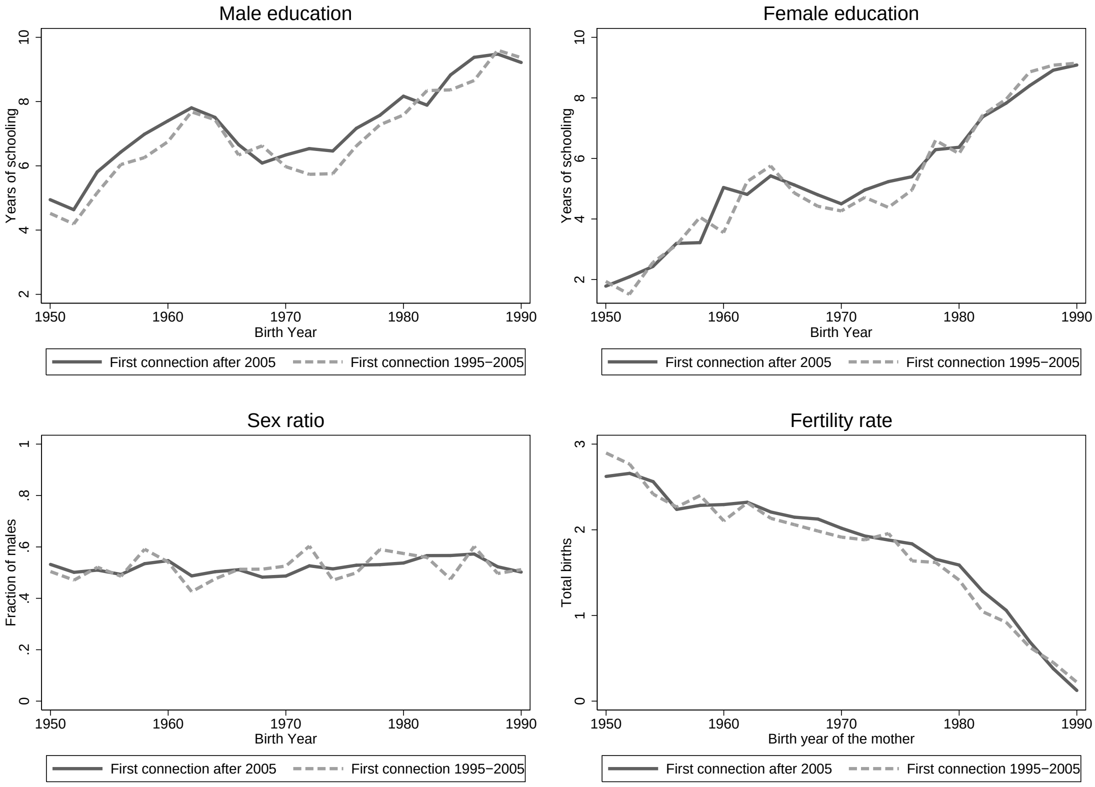
Data source: China Family Panel Studies 2010.

Figure 1: Roll-out of the rural drinking water program in China



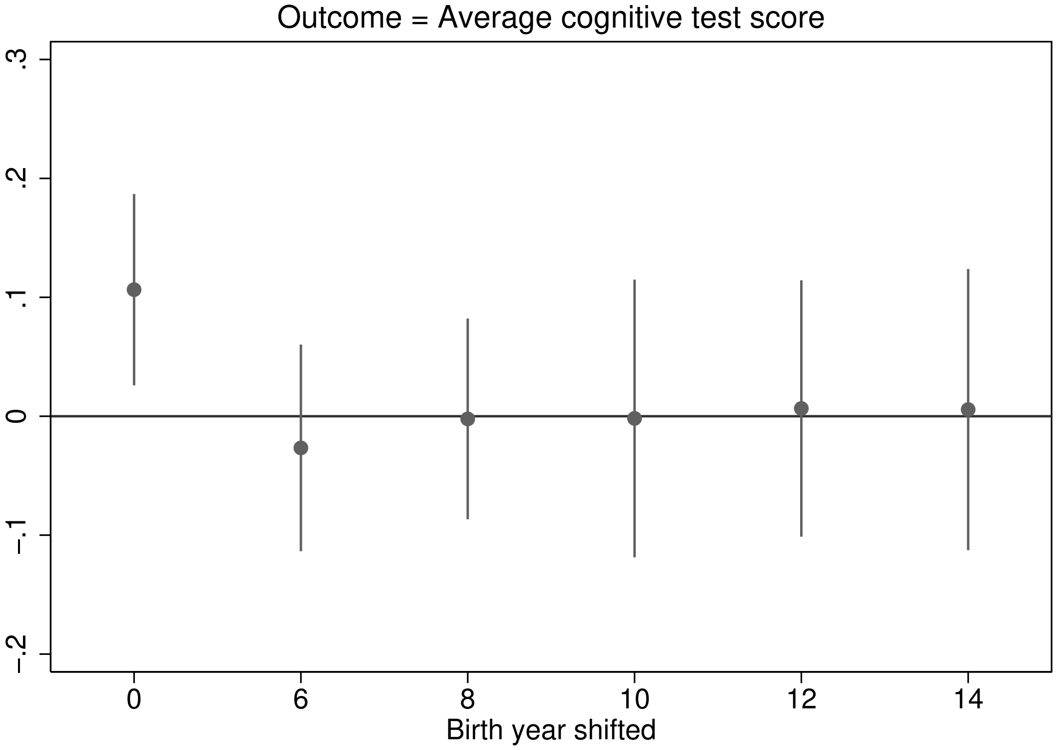
Notes: The figure plots coefficients and 95-percent confidence intervals from an event-study analysis. Event time is defined as the difference between the first year of tap water connection at community level and the year of birth. For example, a child born in 2000 in a community that first got a tap water connection in 2002 would have an event time of 2. The child would have event time of -2 if tap water was first connected to the birth community in 1998. A negative event time indicates full exposure in early life. The event time of 8-9 is taken as the base group so estimates for other age groups are relative to that point. See the text for a description of the model.

Figure 2: Event study estimates of the impact of tap water exposure



Notes: The figure contains plots of pre-intervention characteristics by birth cohort for males and females between the ages of 25 and 45 from communities receiving tap water connection between 1995 and 2005 and communities receiving tap connection after 2005.

Figure 3: Pre-intervention community characteristics by tap water connection year



Notes: In the placebo test, we uniformly shift the birth year of five groups of individuals who were 16-21, 18-23, 20-25, 22-27, and 24-29 years old in 2010 backwards by 6, 8, 10, 12, and 14 years, respectively, so that they were of the same "age", 10-15 years old in 2010, as the children in our main analysis. We generate pseudo Exposure to tap IU-5 for the individuals and estimate the effect for each of the five groups. Each dot on the solid line is the coefficient of interest and the 95-percent confidence interval is plotted by solid line. The estimates for the birth year shifted by "0" come from column (3) in Table 3.

Figure 4: Placebo test using older cohorts

Table 1: Regression analysis of tap water connection at community level

VARIABLES	Connected to tap water in 2010 (1)	Year first getting connection (2)
Suburban village (0/1)	0.109*	-3.319***
	(0.064)	(1.105)
Log (distance to nearest town or city (hours))	-0.077**	1.732***
	(0.033)	(0.541)
Log (population)	-0.023	-0.909
	(0.041)	(0.632)
Log (area)	0.007	-0.018
	(0.012)	(0.197)
Average years of schooling of 25-55 year-old	0.018	-0.191
	(0.015)	(0.258)
Hills	-0.079	0.446
	(0.066)	(1.075)
Mountains	0.041	-0.478
	(0.097)	(1.460)
Plateaus	-0.054	-0.530
	(0.135)	(1.843)
Others	-0.012	-0.534
	(0.078)	(1.321)
Observations	404	404
R^2	0.198	

Notes: * means significant at 10%, ** significant at 5%, and *** significant at 1%.
We categorize the communities into five types by topographic characteristics: hills, mountains, plateaus, plains, and others. The type of plains is taken as the omitted group. Column (1) is estimated with OLS regressions. Column (2) is the marginal effects from Tobit regressions, conditional on community first getting tap water access no later than 2010. Robust standard errors are in parentheses.

Table 2: Summary statistics

	N	Mean	S.D.
Panel A: Outcomes			
Standardized average cognitive test score	2,163	0.029	0.987
- Standardized word score	2,163	0.028	1.001
- Standardized math score	2,163	0.021	0.969
Panel B: Control variables			
Number of siblings	2,145	1.282	0.986
Mother's age at birth	2,225	25.74	4.588
Father's years of schooling	2,203	5.814	3.974
Mother's years of schooling	2,194	3.906	3.961
Household size	2,246	5.100	1.634
Farm household	2,246	0.836	0.371
Panel C: Treatment variable			
Exposure to tap IU-5	2,246	1,584	2.775
- Exposure = 0	2,246	0.722	0.448
- Exposure = 1	2,246	0.024	0.152
- Exposure = 2	2,246	0.013	0.113
- Exposure = 3	2,246	0.016	0.126
- Exposure = 4	2,246	0.016	0.126
- Exposure = 5	2,246	0.015	0.120
- Exposure = 6	2,246	0.013	0.115
- Exposure = 7	2,246	0.181	0.385

Notes: Raw means and standard deviations are calculated using data from CFPS 2010.

Table 3: The impact of tap water exposure on cognitive achievement

	Average cognitive test score			Word	Math
VARIABLES	(1)	(2)	(3)	(4)	(5)
Exposure to tap IU-5	0.100***	0.099***	0.109***	0.066	0.133***
	(0.034)	(0.037)	(0.041)	(0.048)	(0.043)
Boy	-0.119**	-0.124**	-0.113**	-0.176***	-0.002
	(0.049)	(0.052)	(0.053)	(0.055)	(0.049)
Number of siblings	-0.056	-0.064	-0.061	-0.029	-0.088*
	(0.040)	(0.040)	(0.042)	(0.041)	(0.045)
Mother's age at birth	0.001	0.003	0.004	0.005	0.001
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Father's years of schooling	0.035***	0.035***	0.036***	0.037***	0.025***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.008)
Mother's years of schooling	0.009	0.009	0.009	0.005	0.011
	(0.007)	(0.007)	(0.008)	(0.008)	(0.008)
Number of household members	0.006	0.005	0.006	-0.002	0.017
	(0.018)	(0.019)	(0.020)	(0.019)	(0.022)
Farm household	-0.115	-0.128*	-0.146*	-0.114	-0.149*
	(0.072)	(0.075)	(0.076)	(0.093)	(0.084)
Observations	2,163	2,163	2,163	2,163	2,163
R^2	0.410	0.434	0.449	0.443	0.395
Cohort FE	Yes	Yes	Yes	Yes	Yes
Community FE	Yes	Yes	Yes	Yes	Yes
Cohort-province FE	No	Yes	Yes	Yes	Yes
Cohort*community Controls	No	No	Yes	Yes	Yes

Notes: * means significant at 10%, ** significant at 5%, and *** significant at 1%.
"Boy" equals one for boys and zero for girls. Farm household equals one if the household was engaged in farm work and zero otherwise. Community fixed-effects model is applied in all specifications. In columns of (3)-(5), the community characteristics used to construct interactions with birth year dummies are suburban village (=1 if yes, =0 if not), distance to nearest town (city), log(population), log(area), average years of school of 25-55 year-old, and topographic characteristics (hills, mountains, plateaus, plains, and others). Standard errors in parentheses are clustered at community level.

Table 4: Heterogeneous effects

	Average cognitive test score			
	Gender		Father's schooling	
	Boys	Girls	>= 9 years	< 9 years
VARIABLES	(1)	(2)	(3)	(4)
Exposure to tap IU-5	0.155**	0.167**	0.117	0.176**
	(0.076)	(0.078)	(0.106)	(0.069)
Observations	1,087	1,076	865	1,262
R^2	0.597	0.602	0.617	0.538

Notes: * means significant at 10%, ** significant at 5%, and *** significant at 1%. Each coefficient is estimated from a separate regression with the same specification applied as in column (3) of Table 3. Standard errors in parentheses are clustered at community level.

Table 5: Robustness checks

	Average cognitive test score	
VARIABLES	(1)	(2)
Exposure to tap IU-5	0.113**	0.132***
	(0.039)	(0.045)
Observations	1,846	1,935
R^2	0.442	0.462

Notes: * means significant at 10%, ** significant at 5%, and *** significant at 1%. Each coefficient is estimated from a separate regression with the same specification applied as in column (3) of Table 3. In column (1), we exclude communities getting tap water connection before 1995. In column (2), we additionally control for early life exposure to other public facilities. Standard errors in parentheses are clustered at community level.

Table 6: Sample attrition

	Dep. Var. = 1 if not surveyed in 2010	Dep.Var. = 1 if not surveyed in 2012
VARIABLES	(1)	(2)
Exposure to tap IU-5	0.002	-0.004
	(0.014)	(0.004)
Observations	2,417	4,979
R^2	0.399	0.436

Notes: * means significant at 10%, ** significant at 5%, and *** significant at 1%.
Each coefficient is estimated from a separate regression with the same specification applied as in column (3) of Table 3. Standard errors in parentheses are clustered at community level.

Table 7: Tap water access and health of children aged 0-5

	Last month		Last year		First 12 months after birth	
	# illness	# doctor visits	# doctor visits	Top 20% expenditure	# illness	# doctor visits
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Tap water in community	-0.378***	-0.217**	-1.005**	-0.068*	-1.397**	-1.328**
	(0.114)	(0.098)	(0.484)	(0.040)	(0.615)	(0.519)
Observations	2,036	2,049	1,952	1,996	1,641	1,635
R^2	0.425	0.435	0.429	0.436	0.423	0.449

Notes: * means significant at 10%, ** significant at 5%, and *** significant at 1%.
The sampled children are from communities that either received tap water before 2005 or after 2010 and were aged 0-5 in 2010. Tap water in community is equal to one if the community first got tap water connection before 2005, and zero if otherwise. Each coefficient is estimated with a separate regression. Individual-level control variables include the child's gender, age, and number of siblings, mother's age at birth, parents' years of schooling, number of household members, and an indicator of farm household. Community-level controls include an indicator of suburban village, log (distance to nearest town or city), log (population), log (area), average years of schooling among the 25-55 years old residents, topographic characteristics of the community, and community accessibility to other facilities (kindergarten, primary school, health facility, electricity, road, cable/satellite TV, landline phone, and mobile signal). County-year fixed-effects model is applied. Standard errors in parentheses are clustered at community level.

Table 8: Tap water access and mothers' time use

	Have 0-5 year-old child			Have no 0-5 year-old child		
	Family care	Work	Housework	Family care	Work	Housework
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
Tap water in community	6.240**	-2.878	0.713	-0.101	3.975**	1.480**
	(2.659)	(2.818)	(0.870)	(0.510)	(2.015)	(0.693)
Observations	1,233	1,238	1,232	3,127	3,138	3,124
R^2	0.269	0.293	0.282	0.199	0.215	0.251

Notes: * means significant at 10%, ** significant at 5%, and *** significant at 1%.
The sample women were at 20-45 years old in 2010. Each coefficient is estimated with a separate regression. Individual-level control variables include age of the respondent and its quadratic form, years of schooling, an indicator of living with the spouse, number of household members, and an indicator of farm household. Community-level controls include an indicator of suburban village, log (distance to nearest town or city), log (population), log (area), average years of schooling among the 25-55 years old residents, topographic characteristics of the community, and community accessibility to other facilities (kindergarten, primary school, health facility, electricity, road, cable/satellite TV, landline phone, and mobile signal). County fixed-effects model is applied. Standard errors in parentheses are clustered at community level.

Table 9: The impact of tap water exposure on educational attainment

	Years of schooling	Grade-for-age	School enrollment
VARIABLES	(1)	(2)	(3)
Exposure to tap IU-5	-0.016	0.003	0.001
	(0.054)	(0.028)	(0.010)
Observations	2,184	2,246	2,246
R^2	0.807	0.432	0.356

Notes: * means significant at 10%, ** significant at 5%, and *** significant at 1%.
Each coefficient is estimated from a separate regression with the same specification applied as in column (3) of Table 3. Grade-for-age status is measured by a dummy indicator that takes value one if the child was enrolled in the supposed grade for her/his age and zero otherwise. School enrollment status is measured by a dummy indicator which equals to one if the child was enrolled in school at the survey time and zero otherwise. Standard errors in parentheses are clustered at community level.

Appendix

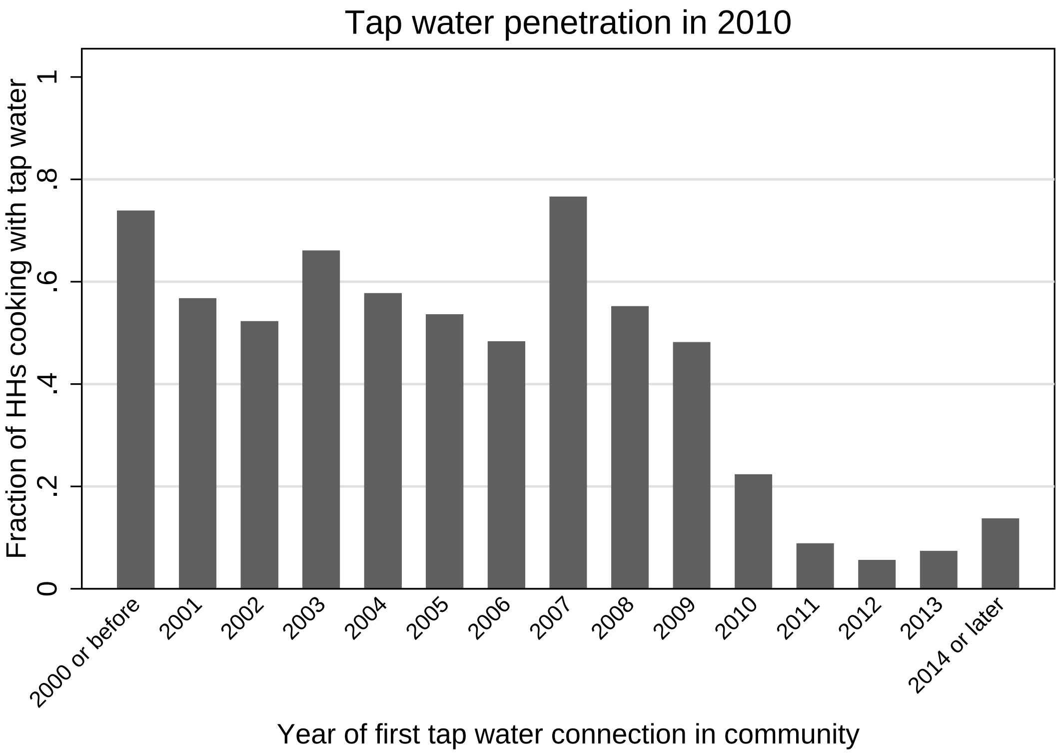
A.1 Early life tap water exposure and later life health

Using the same sample as in Section 5.1, we also examine the impact of early life tap water exposure on health status of 10-15 year-old children. We draw the information on health status from six questions in CFPS 2010: whether in very good health, whether any illness incidence last month, number of times visiting doctor last month, number of times visiting doctor last year, and whether total health expenditure last year in the top 20% by cohort.

Table A.1 presents estimation results from the preferred specification (as in column (3) of Table 3). We find that early life tap water exposure has minor and insignificant effect on all six health outcomes for the 10-15 year-old. It implies that although early life tap water exposure may improve childhood health status, its effect on physical health may be transient, while its effect on cognitive development is long-lasting.

A.2 Household take-up of tap water

To shed some light on the program take-up rate, we plot the ratio of households using tap water as the main source of water for cooking in 2010 by the first year of tap water connection at community level. The data on first year of community tap water connection in or before 2010 is extracted from CFPS 2010 community survey, and that after 2010 is extracted from CFPS 2014 community survey. As shown in Figure A.1, among households residing in communities that had not obtained tap water connection by 2010, less than 10% of them were using tap water for cooking in 2010. Among households residing in communities that newly received tap water connection in 2009, around 50% of them reported using tap water for cooking in 2010, while for communities that got connection before 2009, the percentage of households using tap water for cooking falls in the range of 50% and 80%. It suggests that once the tap water becomes available in the community, households take it up rapidly, and the penetration rate does not depend on the cumulative years of tap water availability at community level.



Data source: China Family Panel Studies 2010 and 2014.

Figure A.1: Tap water penetration in rural China by first year of connection

Table A.1: The impact of tap water exposure on health

		Last month		Last year	
	General health	# illness last month	# doctor visits last month	# doctor visits last year	Health exp. in top 20%
VARIABLES	(1)	(2)	(3)	(4)	(5)
Exposure to tap IU-5	0.001	-0.004	-0.003	-0.004	0.014
	(0.025)	(0.039)	(0.030)	(0.108)	(0.021)
Observations	2,242	2,240	2,240	2,204	2,200
R^2	0.299	0.281	0.286	0.407	0.329

Notes: * means significant at 10%, ** significant at 5%, and *** significant at 1%.
Each coefficient is estimated from a separate regression with the same specification applied as in column (3) of Table 3. Standard errors in parentheses are clustered at community level.

Table A.2: Construction of main outcome variables

Variable name	Definition
Word test score	A word recognition test was administrated by CFPS, including 34 questions with the final score ranging from 0 to 34, and a standardized score is obtained.
Math test score	A math test was administrated by CFPS, including 24 questions with final score ranging from 0 to 24. The standardized score is obtained by subtracting the mean and divided by the standard deviation of the same-cohort comparison group, who live in communities that had not obtained access to tap water by 2005. All standardized outcomes and measures are obtained through the same method if not otherwise stated.
Average cognitive test score	The standardized test score is obtained by standardizing the weighted average of math and word test scores.