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(中国の水ガバナンスに関する実証研究)

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Chapter 1

General Introduction

The nature of the relationship between humans and water has become more complex with time because of increasing uncertainties in rapidly changing socioeconomic and climatic conditions (Wang et al., 2018). In many countries, growing population, increased irrigation areas and economic development have led to a rapid increase in water demand, whereas available water resources mostly depend on geographic and climatic factors. As a result, water governance plays an important role in balancing supply and demand for sustainable economic and social development worldwide (Udimal et al., 2017; Wang et al., 2018).

China has several water issues to cope with in the twenty-first century: municipal water demand conflicts between sectors; delays in construction of new water infrastructures; increasing water scarcity and water pollution; frequent water-related disasters. Additionally, climate change is predicted to further decrease available water resources, aggravating water vulnerability in semi-arid and arid regions, or even turn non-vulnerable regions to vulnerable ones (Zheng et al., 2016). China's overall mean annual temperature has significantly increased over the past five decades and most regions have experienced a decrease in the annual number of raindays, particularly in the southwest and northeastern part. Long-term investment and comprehensive water management are crucial, since water availability has become a key factor to China's sustainable development.

This dissertation is intended to give a glimpse into China's water governance from three aspects: urban water allocation, rural water provision, and water-energy nexus under extreme drought. We have three main objectives. First one is to investigate how rural-urban migration policy affects water distribution and allocation. China's cities have grown faster than the public service capacity. Although tapped water access is relatively high in urban areas, deficiencies in urban water supply are likely to affect migrant population disproportionately. Rapid urbanization under hukou system has limited migrants' access to adequate urban services such as housing, sanitation, health and education, which will distort their water consumption. Furthermore, most long-term migrants stay in suburban and city villages rather than center areas. China's migration policy can control population mobility to adjust their consumption of water-related public goods and durable goods, which will affect water use in different sectors.

The second objective is to find out whether the current water reform and water provision system improve water access and health inequality in rural areas. Tapped water access in rural areas is still low, and most households use unmanaged ground water as main drinking water source. Same as other developing countries, the main barriers to innovation and implementation of improved water and sanitation in China's rural areas are insufficient supply, demand constraints of free riding and institutional constraints. Building large-scale infrastructure will be an important part of the long-term solution, and China's has started to reform water sector nationwide since 2002 through two ways: improving access to existing large-scale infrastructure by corporatization, and providing smaller scale investment at county level or community level by privatization. Improved water provision was found associated with better health and education outcomes for children and this study aims to shed light on the pathways.

Third one is to examine how water-related disaster affects economic activities and energy mix. Industrialization under increasing water scarcity has tighten the relationship between water and electricity. Although development of hydropower in water abundant regions is a cost-effective way to balance energy demand and lower the energy mix of fossil source, it also causes water vulnerability concerns. Extreme drought will change the socio-economic dynamics of water use through affecting industrial activities and power production. Adaptive measures to improve water and energy sustainability deserves more efforts during hydropower development to mitigate this impact.

The remainder of this dissertation is organized as follows. Chapter 2 estimates the impact of internal migration on urban water use through 2SLS and FE models, aiming to capture the urban water allocation features in the household and public service sector. Municipal level data including province characteristics and sector characteristics are obtained to explore how water use patterns vary across different population groups. Chapter 3 examines the social impact of SOE reform in water supply. Two main water reform types, private sector participation and corporatization, are designed as treatment indicators to deploy DID models. Detailed child data and community data between 1989 and 2015 are collected to analyze the effects of different types of water reform on child health and piped water access in rural areas. Chapter 4 focuses on the association between water-energy nexus and economic activities during extreme drought. A firm level panel data for 8 years, which contains extensive information, is used to investigate the impact of a severe drought on the production of energy-intensive industries in southwestern China. The southwest drought in 2010 caused long-term water shortage, which makes it possible to investigate power firms' responses during and after the drought. Further, heterogeneous effects of drought across industries, ownership types, drought-hit provinces and years are also estimated through DDD models. Chapter 5 concludes the findings and research implications.

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Chapter 2

Internal Migration and Urban Water Stress

2.1 Introduction

Urbanization in China has entered a stage of rapid development since the reform and opening policy started in 1978. In the 30 years from 1979 to 2009, China's urban population grew by about 440 million. Internal migration contributed to half this increase (Chan, 2008). In 2011, 271 million people in China lived away from home. By the end of 2015, urban residents had more than doubled and 56% of the total population lived in urban areas.

Increased urban population, living standards, and dynamic industrial activities could lead to increased pressure on water sources (Zheng and Kahn, 2013). Although water withdrawals for domestic and municipal use account for a modest part of total water use, they are growing rapidly, especially as a result of population growth in urban areas of developing countries (UNDP, 2006). In China, it is predicted that the average water availability will decline to 1507 cubic meters per capita by 2030 from 2,691 cubic meters in 2005 (Dinar and Tsur, 2014). From 1997 to 2007, the share of annual freshwater withdrawals for domestic use of total freshwater withdrawals increased more than 7%, which is more rapid growth than that of other countries. The challenge of supplying adequate water resources will become even greater given China's massive ongoing urbanization (Zheng and Kahn, 2013).

Researchers have found connections between urbanization level and water use (White, 1999; Shalizi, 2008; Bao and He, 2015). It is suggested that urbanization may cause rapid growth in water use, leading to increased pressure on water resources (Bao and He, 2015; White, 1999). As PAI (2012) notes, fast population growth could limit the amount of water available per person, driving people into marginal areas that are already water stressed. Population forecasts, changes in the composition of the urban–rural population, and changes in the per capita water demand are all key variables for analyzing changes in China's water use (Shalizi, 2008). Since migration accounts for roughly half of urban growth in most cities of a developing country, it is important to consider the impact of migration on water demand (White, 1999). Using mathematical estimation, some researchers have proved that rural-to-urban migration would save consumptive domestic water use in China, because the purely consumptive domestic water use per capita in rural areas is higher than that in urban areas (Wu et al., 2012). However, there is sparse empirical literature to date on the link between internal migration and urban residential water use.

This chapter fills this gap by looking at the impact of internal migration on urban residential water use in China. A significant demographic change during urbanization is expected to be associated with an increase in urban water use. Since internal migration data are not yet sufficient, the floating population is adopted as a proxy for estimation. Furthermore, residential water use in two sectors—household and public service—is estimated, considering their differences in purpose and water pricing. Thus, this chapter provides implications for policy by considering the connection between population composition change in urbanization and urban water use.

The rest of this chapter proceeds as follows. The next section provides institutional background and develops the hypothesis used in this study. Section 3 presents the empirical framework, estimation methods, and data employed. Section 4 reports the estimation results and discussion. The conclusions from our findings are presented in the final section.

2.2 Background

To understand demographic change in China, it is important to note the comprehensive household registration system, known as the hukou system. China opted for an industrialization strategy after the communist revolution, which centered on heavy industries in cities and extraction of agricultural surplus from the peasantry (Chan, 2010). Therefore, in order to control population mobility, especially the rural exodus, the hukou system was established in 1958. Under the system, each person has a hukou registration and is classified as rural or urban in a specific administrative unit (Chan, 2010). Changing a hukou residence within the same city or town is generally permitted, but changing a hukou from a rural area to an urban area or from a small city to a big city is tightly controlled and permitted only under very limited conditions (Chan, 2008, 2010). However, China's market reform at the end of the 1970s and labor-intensive, export-oriented growth strategy in the mid-1980s have encouraged rural labor into cities to meet labor demand (Chan, 2010). By the mid-1980s, rural-hukou labor had become the backbone of the manufacturing sector; in some coastal cities, migrant labor accounted for 70% to 80% of the labor force. Significant disparities in wages between the urban and rural areas are the most important driver of migration.

[Figure 2.1]

Migrants are classified into two categories by their household registration status: hukou migrants and non-hukou migrants. On the one hand, hukou migrants are those with all types of officially approved changes in hukou within a particular year (Chan, 2008). On the other hand, non-hukou migrants are those moving on a voluntarily and without official permission for the transfer of residential status (Gu and Ma, 2013). According to the unique concept of the "floating population" in China, a person is considered "floating" as long as his or her usual place of residence differs from the hukou location, regardless of when actual migration occurred (Fan, 2008). Therefore, non-hukou migrants are known as the floating population, characterized by temporary migration with no state-designated residency rights or social benefits (Chan, 2008; Gu and Ma, 2013).

After decades of criticism, from the mid-1990s, provincial governments gained administrative power to offer local urban hukou to rich and highly educated people. In addition, some neighboring rural-hukou populations are given local urban hukou in exchange for their land-use rights for urban expansion (Chan, 2010). Most migrants in China are the floating population and internal migration is concentrated in a small number of province pairs (Luo et al., 2016). There is no available public data series on the migration inflows and outflows of each province every year before 2011. Therefore, the floating population staying for 6 months or more[1], rather than flow migration data, is used to estimate the effect of internal migration in our empirical analysis.

[Figure 2.2]

---

[1] Floating population is not flow migration but a stock measure, and there are different series of the floating population according to the different purposes, geographic boundaries, and minimum length of stay. The series used in this chapter is published by the National Bureau of Statistics, but is not the broadest and most widely used definition of floating population, which is difficult to detect (Chan, 2008).

Figure 2.2 shows per capita water resources and internal migration status in China. According to the Falkenmark Water Stress Indicator[2], a region experiences water stress when the annual natural water supply is below 1,700 m^3 per person; water scarcity when it is below 1,000 m^3; and absolute scarcity when it is below 500 m^3 per person. Central regions in China are physically water scarce. Beijing, Tianjin, Shanghai, Chongqing, and cities along the southeastern coast face water scarcity mainly caused by rapid economic growth and urbanization (Rijsberman, 2006). Migration flows are directed primarily toward coastal provinces, such as Guangdong and the Shanghai region, while the origins of these flows are mostly low-income inland provinces (Chan, 2008). These areas have always had very low rates of natural population increase, and consequently, internal migration contributes a substantial fraction of their total population growth. They hold only 5% of the country's water resources but 40% of the country's population (NBS, 2012a). Therefore, there is a clear overlap between areas facing water stress and areas with a net population inflow, as revealed in Figure 2.2.

In this chapter, the linkage between the floating population and the change in urban residential water use is explored. In China, urban total water use refers to the total consumption of water provided by water supply facilities. According to the National Bureau of Statistics of China, urban total water use includes water for productive use and water for residential use. The latter is composed of water use for household and public service, which is illustrated as water use in the household and public service sectors.

Many studies have investigated the determinants of household water consumption in developed countries and found that water price, income, and household composition are the main factors. Water demand is proved to be price inelastic in earlier studies (Arbués et al., 2003). In addition, the influence of conservation attitudes and water-saving devices is emphasized (Baumann et al., 1998; Grafton et al., 2011). Meanwhile, some studies concluded that in developing countries, socioeconomic characteristics and water accessibility, rather than income and water price, are more important in determinants of household water use and consumption (Zhang and Brown, 2005; Domene and Saurí, 2006; Ogunbode and Ifabiyi, 2014). For residential users, efficiency of water use can be improved by promoting the use of water-efficient home appliances, reducing leakage, and increasing the use of

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[2] The Falkenmark indicator is the most widely used measure of water stress. Multiple countries were surveyed and the water usage per person in each economy was calculated. Based on the per capita water usage, the water conditions in an area can be categorized as: no stress, stress, scarcity, and absolute scarcity.

recycled water (Cosier and Shen, 2009).

[Figure 2.3]

China's water use in the public service sector is the subject of far less research than its water use in the household sector for several reasons. First, water use in the public service sector has various purposes and is less relevant to the preferences and behavior of consumers. According to China's classified standard for urban water consumption, water use in the public service sector includes water use for public facilities; social services; wholesale and retail sales; catering services and the hotel industry; health services; culture, recreation, sports, and telecommunications; education; and public institutions and social organization. As reported by the Beijing Water Authority, Beijing's urban water use for public service increased at an average rate of 5% per year from 908 million m^3 in 2006 to 1272 million m^3 in 2013. Figure 2.3 illustrates Beijing's water use by purpose in the public service sector in 2013. Administrative institutions, schools, hotels, and hospitals accounted for more than 50% of the total water use in the public service sector. In other words, water use in the public service is diverse. Second, innovations occur in all aspects and stages of public services, alongside China's economic development (Jiang and Osborne, 2017), and these complex transformations sharpen the difficulty of exploring the factors affecting water use in the public service sector. By considering the differences in socioeconomic status and consumption patterns between established population and the floating population, this chapter investigates the impact of the floating population on water use for public service through comparison.

China's residential water use varies across regions. Populations in the northwestern and southwestern regions have higher access to water resources as well as more water use. Urban populations consume more water than do rural populations, while people living in urban areas tend to have different water-use patterns depending on their income level and personal behavior. The floating population's impact on water demand can be influenced by their social status and consumption pattern. Gu and Ma (2013) study the floating population's environmental concerns, possible migration choices, and sociodemographic features in Shenzhen. The authors find, on one hand, that living conditions for the temporary population are poor owing to their low socioeconomic status, and a large number of them live in dormitories supplied by their companies. Furthermore, most rural migrant workers are still employed in low-paid jobs in manufacturing, construction, and services, even though their per capita net income is higher than that of farmers. They have to work long hours and except for necessary living expenses, rarely spend money on culture and entertainment (CLB, 2017; Gu and Ma, 2013). On the other hand, the local inhabitants had privileged access to resources, earning high income with little effort (Gu and Ma, 2013). Furthermore, according to the 2014 survey of migrant workers, only around 21% of long-distant migrant workers moved as a whole family unit, and migrants and their children still faced institutionalized discrimination, such as highly restricted access to local schools and healthcare (CLB, 2017).

With poor living standards and low incomes, the floating population may have relatively low water consumption in both the household and public service sectors, which means that more floating population may result in less average per capita water use. In addition, because of their limited access to public services, it can assumed that average per capita water use in the public service sector is more affected than is that in the household sector. However, from another aspect, although migrants from outside do not consume as much water as do natives, the considerable quantity of people, even with lower rates of consumption, still requires a lot of resource (Gu and Ma, 2013). Therefore, we assume that the increase in total water use is relevant to the floating population too. Based on these observations, the following hypothesis is formulated. An increase of urban total residential water use in China, especially in the household sector, is associated with floating population during urbanization, while more floating population is associated with less per capita water use in both the household and the public service sector.

2.3 Estimation Strategy

2.3.1 *Data*

We construct a balanced panel dataset of water use, water price, floating population, and other variables for 30 provinces (including four province-level municipalities and excluding Tibet) in China over the period from 2007 to 2012, except 2010[3]. Data of residential water use are from the National Bureau of Statistics (NBS), while data of water use in the household and public service sectors are from the China Urban Construction Statistical Yearbook

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[3] 2010 is the census year, and thus, some data on province-level are not available.

(CUCSY). Table 2.1 presents a detailed description of the variables and data sources.

[Table 2.1]

The water price data are collected from the E20 Environment Platform, which provides the water price by sector and city from 2007. The E20 Environment Platform reports water prices of the household sector and public service sector separately, and these two data subsets are used to obtain the real water price[4] of each sector. With regard to population data, we rely on a national sample survey on population changes[5], with a sampling fraction of 1‰. The national sample survey on population changes takes the whole country as the sampling population and the provincial units as the sampling sub-population. The samples are selected by adopting a stratified, multi-stage, clustered sampling method, with probability proportional to size. In total, 4800 villages (neighborhood) committees, 4420 townships (towns, streets), and 2133 counties (cities, districts) in 31 provinces (autonomous regions and municipalities) are selected, and nearly 1.5 million people interviewed, of which, permanent residents account for 1.15 million people. The data are collected by interviewing the selected households (NBS, 2012b). The population by registration status is composed of established population, floating population, population with permanent household registration unsettled, and population residing in Hong Kong, Macao, and Taiwan or abroad, with permanent registration in townships, towns, and street communities. The last two components comprise less than 0.5% of the sample population, and thus, they are omitted in the analysis.

Data on age and household size are also collected based on this survey from the database of the NBS. Average number of people in a family household is used to measure average household size in each province, which is calculated by multiplying the family household size (one, two, three, and four) by its share in the total number of family households. In addition, the NBS provides data on almost all the control variables. The numbers of hotels, restaurants, hospitals, and public toilets per 10,000 people are obtained by dividing them by the total size of the urban population. As weather is a significant determinant of water use, it is expected that hot weather could affect residential water use by increasing shower frequency (Rathnayaka et al., 2015). Temperature data are obtained from the NBS and the

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[4] The annual consumer price index is used to adjust prices for inflation, with 2007 as the base year. The water price does not include the wastewater treatment fee.

[5] Population data covered in this chapter are estimated based on annual national sample surveys on population changes.

average temperatures in June, July, and August are used to measure the temperature in summer.

2.3.2 Estimation Framework

As mentioned in section 2, water use in the residential sector consists of water use in the household and public service sectors. To investigate how the floating population influences urban residential water use, estimations for each sector were performed. These two sectors are denoted as sector j (j = household, public service) in our model, representing the household sector or public service sector. Since per capita income is the main drive of internal migration, per capita income and similar variables are excluded from the models to avoid multicollinearity. Based on the data and assumption, the following model was established for the analysis:

$$\begin{aligned} LogWater_{ijt} = {} & \beta_{0j} + \beta_{1j} Waterprice_{ijt} + \beta_{2j} LogFloating_{it} + \\ & \beta_{3j} Demographic_{it} + \beta_{4j} Control_{ijt} + \theta_i + \delta_t + \epsilon_{it} \end{aligned} \tag{2.1}$$

where $Water_{ijt}$ is the urban total residential water use and per capita water use in province i of sector j in year t. Total residential water use is divided by the population of residents with access to tap water to obtain per capita residential water use. The average water price of all cities in province i of sector j in year t is used to measure $Waterprice_{ijt}$ and all three sectors share the same floating population variable and demographic variables. $Floating_{it}$ is the floating population in province i in year t. $Demographic_{it}$ is demographic characteristics of population in each province, including established population, household size, and age structure variables. $Control_{ijt}$ is the set of control variables, including water-use pattern variables for water use in the household sector and public service capacity variables for water use in the public service sector.

Laundry, bathing, and kitchen use account for more than 80% of household water use (NBS, 2012a), and thus, the ownership of washing machine and water heater are used to control for the influence of water-use pattern. From 2007 to 2014, the average ownership of washing machines per 100 urban households in most areas was relatively constant at 95 units or above, while the average ownership of dish washers per 100 urban households was less than 1 unit, and even Beijing had only 1.3 units[6]. Ownership of washing machines is reaching saturation, whereas ownership of dishwashers is not yet common in China, therefore, we include only the ownership of washing machine and water heater in our analysis. The number of automobiles, hotels, restaurants, hospitals and areas of green land are included to control for the capacity of public service infrastructures. Regarding the public service sector, some divisions, such as schools are excluded for their high correlation with other variables. Our interest lies in β_{2j}, the coefficient of floating population. Based on our hypothesis, we expect $\beta_{2j} > 0$, $\beta_{2household} > \beta_{2public}$ for the estimation of total water use, and $\beta_{2j} < 0$ for the estimation of per capita water use, but it is difficult to compare $\beta_{2household}$ and $\beta_{2public}$. Table 2.2 lists the descriptive statistics of all the variables included in our estimation framework. China's urban total residential water use and per capita residential water use in provinces vary greatly by region, because of the time-invariant characteristics of each region. Accounting for the higher urbanization rates and economic development of Beijing, Tianjin, Shanghai, and Chongqing, a municipality dummy θ_i is added to control the effects of these province-level municipalities and to investigate the role of mega-cities in urban residential water in China. Year dummy δ_t is also included to control the effect of particular events occurring in each year.

[Table 2.2]

We run fixed effects models first, because the Hausman test result prefers fixed effects regression to random effects regression and OLS regression. However, the coefficients of water price in fixed effects models are positive and statistically significant at the 1%level, which is not reasonable in the water demand function. Although a fixed effects model can rule out unobserved heterogeneity, it is possible that the water price is positively correlated with unobserved time-variant variables $\left(\mathrm{cov}(Waterprice_{it}, \epsilon_{it}) \neq 0; cov(Waterprice_{it}, \theta_{it}) \neq 0\right)$, or that regions with higher water usage may have higher water tariffs, which leads to positive bias. To determine whether the water price is endogenous, a Durbin—Wu–Hausman test is applied with total amount of water resource as the instrumental variable, which is exogenous $\left(\mathrm{cov}(z_{it}, \epsilon_{it}) = 0; cov(z_{it}, \theta_{it}) = 0\right)$ and correlated with water price, since it is the determinant of water supply. In all models except total water use in the public service

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[6] The average ownership of washing machines and dish washers is calculated based on the data from NBS, 1994–2014.

sector, the test results reject the null hypothesis that there is no endogeneity. Consequently, endogeneity exists in the models for the estimation of total water use in the household and residential sectors; as well as in the models for the estimation of per capita water use in all three sectors. Two-stage least squares (2SLS) estimation is applied to solve the endogeneity problem, and the total amount of water resource is used as the instrument in 2SLS models. 2SLS estimation can provide estimates of city dummy variables and year dummy variables. To compare the results, fixed-effects models, 2SLS models, and ordinary least squares (OLS) regressions are applied for the estimation of water use.

2.4 Results

2.4.1 Effects on Total Water Use by Sector

The regression results of water price, demographic characteristics, sector control variables, and dummy variables for urban total water use are reported in Table 2.3. The coefficients of water price in the household sector are negative and statistically significant at the 5% level when we control for the endogeneity using the 2SLS fixed effects models. A water price increase of 1 yuan corresponds to a decrease of about 0.7% in water use for the household sector, but it has a smaller but significant negative impact in the public service sector as well. Average water price in the household sector ranges from 0.89 yuan to 3.8 yuan, and in the public service sector from 1.02 yuan to 6.65 yuan. Water price in the public service sector is lower on average, and it shows a smaller impact on water use than that in the household sector. A rough estimation of elasticity values are obtained for water price in the household sector, which are in a range of -0.002 and -0.0068 (i.e., almost 0). Previous studies have shown that the elasticity values of average price are roughly in a range of -0.05 and -0.96. Although this chapter obtains a far lower absolute value than those of the previous literature, as long as the elasticities of water price are different from zero, they can play a crucial role (Arbués et al., 2003).

[Table 2.3]

Household size is negatively correlated with total water use for the household sector and there is no significant correlation between household size and total water use for the public service sector. Having more children is associated with less total water use, and a 1% increase in the population share of people aged under 14 years could reduce total water use by 7%–9.7% in the household sector, and 11.2%–14.4% in the public service sector. These results are in contrast to the findings of some previous studies that families with larger family size and more children are expected to use more water, especially for outdoor water use (Arbués et al., 2003). There are two possible explanations. First, the dramatic growth in small families during the process of urbanization might have offset the influence of household size on water use. Second, housing typology in China is associated with little outdoor water use. Moreover, the coefficient of population aged under 14 years for the household sector is smaller in absolute value than that for the public sector in absolute value, which makes sense, because most public services are provided for adults. The water-use pattern can be revealed to a certain extent by the possession of washing machines, water heaters, and dish washers. A 1% increase in the ownership of water heaters per 100 households could increase total water use for the household sector by about 0.3%. Temperature is always positively correlated with total water use, and a 1% increase in summer temperature corresponds to a more than 1% increase in residential water use. Mega-cities have a big impact on urban total water use in different ways. For example, compared with other regions, Beijing uses more water in all sectors than other regions do, including total residential water use. Tianjin has more water use for household while Shanghai has more water use for public services.

2.4.2 *Effects on Per Capita Water Use by Sector*

The regression results of estimating equation (2.1) are reported in Table 2.4. Water price is negatively correlated with per capita water use at a significance level of 5% in the household sector, and 1% in the public service sector. The household sector is always more affected by water price than the public service sector is, and per capita water use is more price elastic than total water use is. A rise of 1 yuan in water price results in more than a 1% decrease in per capita water use for household and a 0.67% decrease in per capita water use for public service. Elasticity values of water price in the household sector are in a range of -0.012 and -0.013, and those of the public service sector are in a range of -0.004 and -0.067. In conclusion, the water price could be more effective at encouraging water saving in the household sector than in the public service sector, because households must pay the water bill themselves, which gives them more incentive to save water when the price increases. The coefficients of demographic variables (household size and age) and sector control variables for per capita water use in the household sector are insignificant. In the public service sector, the population aged under 14 years has negative and significant impacts on per capita water use. More green areas and higher temperatures cause more per capita water use while the effects of the control variables are not significant. Furthermore, the results of municipality dummy are positive and significant in both sectors, which shows that highly developed municipalities are likely to be more influential than provinces over urban water use.

[Table 2.4]

2.4.3 *Effects of Floating Population on Water Use by Sector*

Table 2.5 reports the results of estimating total water use and per capita water use in the residential sector. The accumulative effects of some variables become insignificant because they have opposite impact on water use in the household sector and public service sector. We summarize the results of floating population in Table 2.6 to compare its impacts on water use in different sectors. Furthermore, the coefficients of the floating population and permanent residents are also compared to obtain a clearer picture of how floating population affects urban water use differently to the long-term residents. Tables 2.3 and 2.4 show that permanent residents group has a positive impact on urban total water use in all the sectors. The result for the public service sector in Table 2.3 column (5) implies that a 1% increase in permanent residents is associated with a 0.39% increase in water use for public services. As for the results of per capita water use, more permanents residents are associated with less per capita water use in the public service sector, while the floating population has a larger negative and significant impact.

The coefficients in Table 2.6 column (1)–(3) reveal the correlation between floating population and total water use in each sector. The coefficients of floating population for the household sector are positive and statistically significant at the 1% level in the 2SLS models, but the coefficients for the public service sector show no significance. The result in column (2) shows that a 1% increase in floating population is associated with about a 0.26%

increase in total water use for households but has little influence on total water use for public services. The hypothesis for total water use, which states that an increase in urban total residential water use is associated with the floating population while the total water use for public services is less affected, is valid. In the residential sector, only the result of OLS regression result is statistically significant, and its coefficient is smaller than that of the household sector, suggesting that the impact of the floating population on urban total residential water use is derived from the household sector alone.

Our hypothesis for per capita water use is also valid. The estimates in the household sector show no significance, while they are statistically significant in the public service sector at the 5% level and negative in both 2SLS and OLS fixed effects models. This result implies that migrants keep moving to cities, but they do not increase the water use in the public sector. The floating population has no effect on per capita water use in the household sector, and neither does permanent residents, which is consistent with the conclusions of most previous studies. Per capita water use for household is more likely to be determined by personal level variables, such as consumers' socioeconomic status, water-use patterns, and environmental awareness.

[Table 2.5]

[Table 2.6]

2.5 Conclusions

This chapter examines the linkage between the floating population and urban residential water use by sectors during the urbanization process for 30 Chinese provinces from 2007 to 2010, and addresses the endogeneity of the water price. In the household sector, the floating population is positively correlated with total water use but has no influence on per capita water use, and the result is robust when demographic variables and water-use pattern variables are included.

On the contrary, our findings suggest that in the public service sector, the floating population is not associated with total water use growth but results in less per capita water use. Although the floating population makes up a smaller share of urban population, they affect per capita water for public services more than permanent residents do. This finding could be explained, on one hand, by the floating population's poor access to public services, which is restricted by their hukou status, and on the other hand, by the urban public service sector's possible lack of capacity to meet the surge in water demand caused by the large amount of floating population. In one aspect, the floating population contributes to total water use increase in the household sector, but the main consumers in all three sectors are established residents. The floating population may crowd public services, but their effect on the total water use increase in the public service sector is insignificant, and thus, the large amount of floating population only ends up with less per capita water use for public services. The income effect is not considered because of its high correlation with the floating population, which makes it difficult to determine which effect is stronger: the effect of income or the effect of floating population. As a result of these mixed effects, it is possible that the coefficients of floating population are biased. It should also be noted that data of the floating population might not fully capture internal migration. Instead of reflecting the real in-flow and out-flow of migrants, yearly aggregated data of floating population indicate only the change in registration status. It is very difficult to measure the floating population, let alone its seasonal variation due to tourism, making it difficult to capture the reality (Chan, 2008). The effects of the floating population on water use could be underestimated, and detailed survey data and better econometric methods would help to improve the results.

According to an annual survey of migrant workers conducted by the NBS in 2016 (NBS, 2017), even though the total number of migrant workers has increased steadily over the last decade, the growth rate has declined noticeably 4.4% in 2011 to 1.5% in 2016, and it is predicted that the migrant work population could peak in the next few years. Furthermore, migrant workers tend to move short distances toward smaller or medium-sized cities (CLB, 2017). However, unless the full benefits of urbanization are made available to their rural settlements, there is insufficient incentive for people to stay in rural areas (Laquian, 2011). The increasing demand for residential water use in the household sector may decline,following internal migration, to reach a plateau. Meanwhile, water use in the public service sector should be given more attention; it is less price elastic and has more room for growth than water use in the household sector. China's residential water use in the public service sector could be the subject of further research. Moreover, internal migration may be an important potential consideration for urban water-use planning and water resource management.

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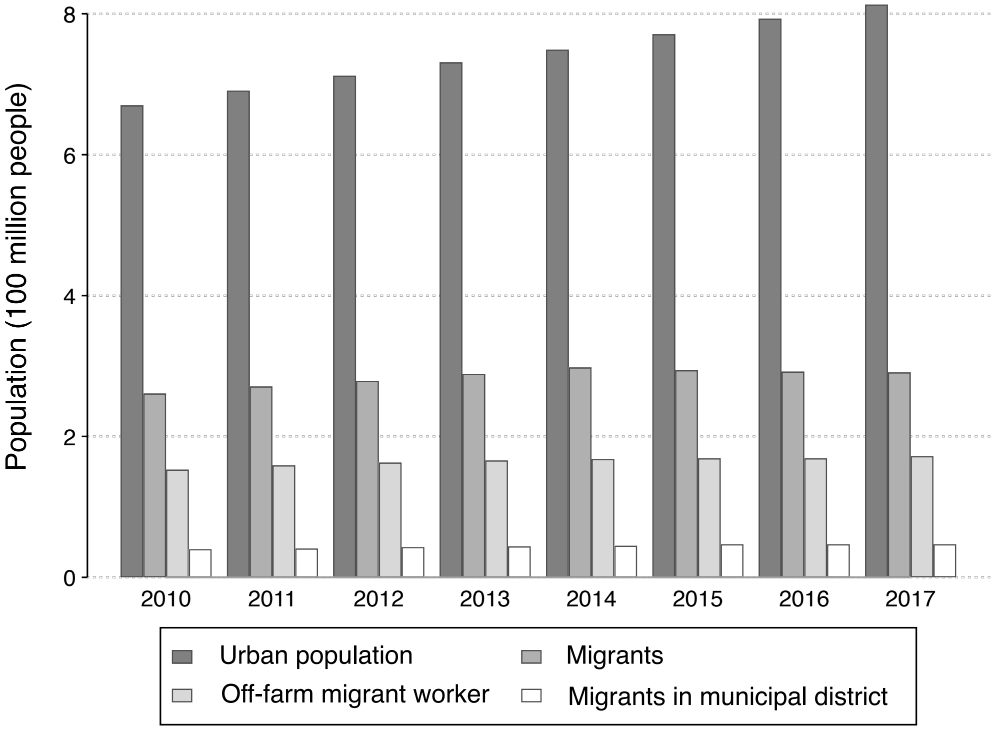
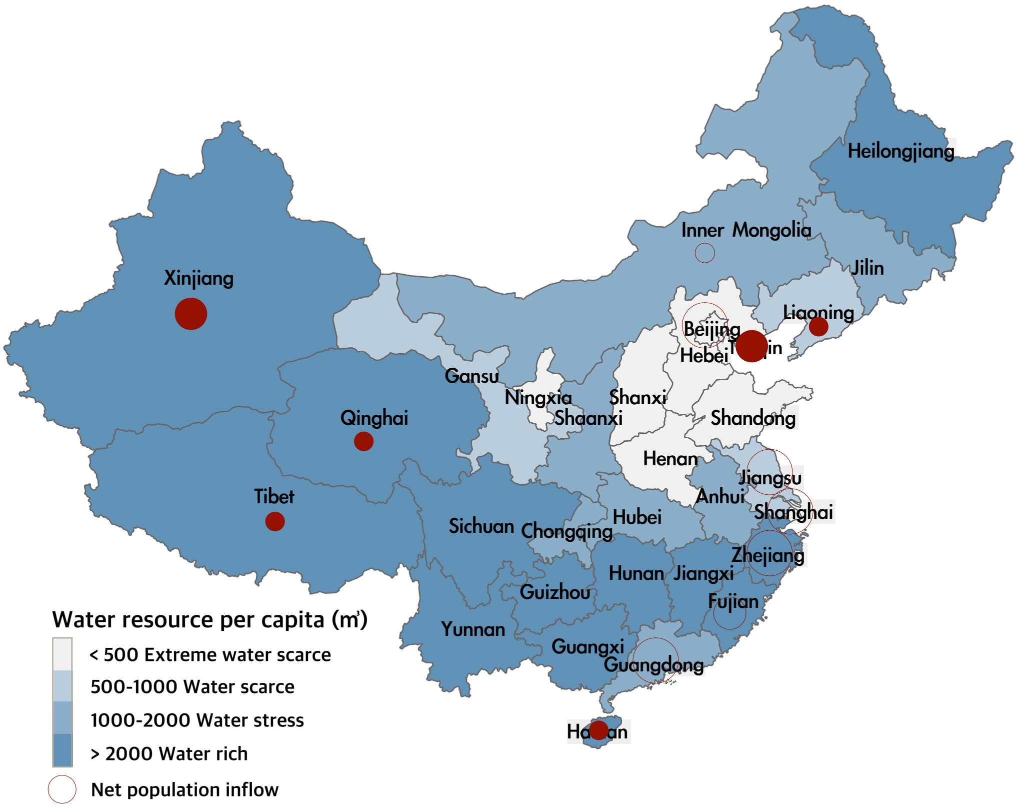


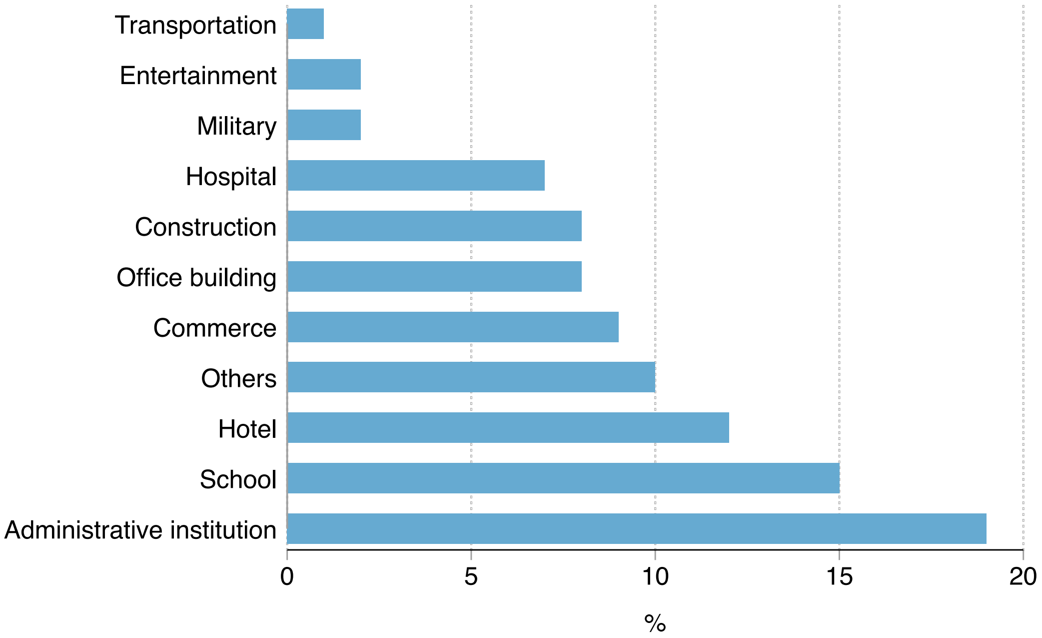
Source: NBS, 2010-2017. Migrants are floating population without local household registration status of one place through the Chinese Hukou system, but stay there for at least 6 months. Municipal districts are subdivisions of a municipality or a prefecture-level city.

Fig. 2.1. Change in population distribution



Data source of water resource: NBS, 2007-2017. Data source of internal migration: China Migrants Dynamic Survey, 2011-2016. Note: Size of the red circle shows the scale of net population inflow: large: > 10,000 people; medium: 1000-10,000 people; small: <1000 people.

Fig. 2.2. Per capita water resource and internal migration



Source: Che et al., 2015

Fig. 2.3. Breakdown of water use in public service sector in Beijing (2013)

Table 2.1 Variable descriptions and data sources

Variable Name	Variable Description	Data Source
Total residential water use	Total consumption of water for residential use	NBS
Total household water use	The quantity of water for household use	CUCSY
Total public service water use	The quantity of water for public service	CUCSY
Per capita residential water use	Per capita consumption of tap water for total residential use	NBS
Per capita household water use	Per capita consumption of tap water use for household	CUCSY, NBS
Per capita public service water use	Per capita consumption of tap water use for public service	CUCSY, NBS
Water price in the residential sector	Volume-weighted average price of water for total residential use	E20 Environment Platform
Water price in the household sector	Average price of water for household use	E20 Environment Platform
Water price in the public service sector	Average price of water for public service	E20 Environment Platform
Floating population	Population, residing in the townships, towns, and street communities with permanent household registration elsewhere having been away from that place for more than 6 months (sample survey)	NBS
Permanent residents	Population, residing in the townships, towns, and street communities with permanent household registration there (sample survey)	NBS
Household size	Average number of people in a family household (sample survey)	NBS
Aged under 14	Population aged 0–14 years (% of sample population)	NBS
Aged 65 and over	Population aged 65 years and over (% of sample population)	NBS
Ownership of washing machine	Ownership of washing machines per 100 urban households	NBS
Ownership of water heater	Ownership of water heaters per 100 urban households	NBS
Ownership of automobile	Ownership of automobiles per 100 urban households	NBS
Area of green land	Area of green land in cities	NBS
Number of hotels	Number of hotel enterprises	NBS
Number of restaurants	Number of catering service enterprises	NBS
Number of hospitals	Number of healthcare institutions	NBS
Number of hotels per capita	Number of hotel enterprises per 10,000 people	NBS
Number of restaurants per capita	Number of catering service enterprises per 10,000 people	NBS
Number of hospitals per capita	Number of healthcare institutions per 10,000 people	NBS
Number of healthcare institutions per 10,000 people	NBS	
Summer average temperature	Average temperature during summer months (June–August)	NBS
Total water resource	Total amount of water resources	NBS

Table 2.2 Descriptive statistics

Variable Category	Unit	Mean	Std. Dev.	Min	Max
Explained Variables					
Total residential water use	10,000 m^3	79423.33	73791.03	6500	411300
Total household water use	10,000 m^3	57470.58	54091.38	5195	297711
Total public service water use	10,000 m^3	21622.81	20662.05	1031	116880
Per capita residential water use	1,000 liter	61.73	16.18	31.26	106.67
Per capita household water use	1,000 liter	45.32	13.61	20.39	81.32
Per capita public service water use	1,000 liter	16.10	5.11	6.36	30.58
Water Price					
Water price in the residential sector	Yuan/m^3	1.80	0.68	0.93	4.56
Water price in the household sector	Yuan/m^3	1.64	0.53	0.89	3.77
Water price in the public service sector	Yuan/m^3	2.21	1.03	1.02	6.65
Demographic Characteristics					
Floating population	person	4924.15	5135.49	334	30606
Permanent residents	person	33296.95	20971.67	3842	83833
Household size	person	2.24	0.13	1.94	2.50
Aged under 14 years	%	0.17	0.04	0.08	0.27
Aged 65 years and over	%	0.09	0.02	0.05	0.14
Sector Control Variables					
Ownership of washing machine	unit	158.65	27.92	73.30	201.20
Ownership of water heater	unit	81.19	19.11	32	113.5
Ownership of automobile	unit	11.62	8.82	0.70	42.30
Area of green land	10,000 hectare	6.79	7.36	0.30	41.06
Number of hotels	unit	489.71	355.87	50	1861
Number of restaurants	unit	687.54	715.95	29	3780
Number of hospitals	unit	22514.22	19806.99	1530	80963
Number of hotels per capita	unit	0.24	0.13	0.09	0.82
Number of restaurants per capita	unit	0.29	0.24	0.58	1.44
Number of hospitals per capita	unit	10.91	6.96	1.46	28.39
Summer average temperature	°C	25.40	3.08	16.03	29.43
Instrument Variable					
Total water resource	100 million m^3	720.97	649.48	8.42	2892.36

Note: Data of demographic characteristics are obtained from the National Sample Survey on Population Changes. Number of hotels, restaurants, hospitals per capita are calculated by dividing the total number of these facilities by the urban total population. The sampling fraction for year 2007, 2008, 2009, 2011, 2012 are 0.9‰, 0.887‰, 0.873‰, 0.85‰, 0.831‰.

Table 2.3 Effects of floating population on total water use by sector

	Household sector			Public service sector		
	2SLS (1)	2SLS-FE (2)	OLS-FE (3)	2SLS (4)	2SLS-FE (5)	OLS-FE (6)
Water price	-0.760**	-0.688**	-0.196***	-0.367	-0.338*	-0.134***
	(0.339)	(0.315)	(0.042)	(0.232)	(0.199)	(0.040)
Floating population	0.180***	0.257***	0.287***	0.020	0.052	0.090
	(0.052)	(0.055)	(0.044)	(0.077)	(0.072)	(0.058)
Permanent residents	0.434***	0.609***	0.569***	0.478***	0.389**	0.306**
	(0.089)	(0.063)	(0.051)	(0.178)	(0.177)	(0.129)
Household size	-0.628	-1.199***	-1.665***	0.121	0.016	-0.319
	(0.458)	(0.419)	(0.268)	(0.499)	(0.477)	(0.398)
Aged under 14	-9.679***	-8.181***	-6.984***	-14.437***	-13.793***	-11.244***
	(1.857)	(1.312)	(0.787)	(3.459)	(2.902)	(1.169)
Aged 65 and over	-0.645	-6.284*	-2.880*	-4.598*	-7.959**	-5.541**
	(3.251)	(3.330)	(1.457)	(2.574)	(3.333)	(2.335)
Summer average temperature	1.326***	1.127***	1.159***	1.686***	1.691***	1.704***
	(0.377)	(0.365)	(0.282)	(0.349)	(0.302)	(0.285)
Ownership of washing machine	0.378	0.149	-0.012			
	(0.317)	(0.193)	(0.138)			
Ownership of water heater	0.666***	0.308*	0.270**			
	(0.249)	(0.165)	(0.119)			
Ownership of automobile				0.017	0.014	0.001
				(0.020)	(0.015)	(0.007)
Area of green land				0.025***	0.030***	0.030***
				(0.008)	(0.007)	(0.007)
Number of hotels				-0.108	-0.117	0.017
				(0.239)	(0.188)	(0.128)
Number of restaurants				0.095*	0.021	0.053
				(0.055)	(0.058)	(0.062)
Number of hospitals				-0.089	0.169*	0.124
				(0.060)	(0.101)	(0.089)
Municipality fixed effects	No	Yes	Yes	No	Yes	Yes
Year fixed effects	No	Yes	Yes	No	Yes	Yes
Observations	150	150	150	148	148	148
R^2	0.806	0.877	0.930	0.847	0.872	0.891

Note: Robust standard errors are in parentheses. Coefficients of water price in column (1)–(3) report the results of estimating water price in the household sector, and coefficients of water price in column (4)–(6) report the results of estimating water price in the public service sector. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 2.4 Effects of floating population on per capita water use by sector

	Household sector			Public service sector		
	2SLS (1)	2SLS-FE (2)	OLS-FE (3)	2SLS (4)	2SLS-FE (5)	OLS-FE (6)
Water price	-1.220***	-1.286**	-0.059	-0.612**	-0.665***	-0.042*
	(0.432)	(0.500)	(0.036)	(0.239)	(0.235)	(0.024)
Floating population	-0.031	-0.071	0.005	-0.265**	-0.322**	-0.132***
	(0.068)	(0.087)	(0.033)	(0.115)	(0.129)	(0.043)
Permanent residents	-0.235*	0.023	-0.078**	-0.139	-0.049	-0.147***
	(0.123)	(0.106)	(0.034)	(0.089)	(0.101)	(0.048)
Household size	-0.105	-0.154	-1.316***	0.581	1.063	-0.690***
	(0.607)	(0.705)	(0.184)	(0.627)	(0.855)	(0.261)
Aged under 14	-2.939	-2.536	0.449	-9.562***	-10.287***	-4.004***
	(2.508)	(2.285)	(0.642)	(3.115)	(3.103)	(0.655)
Aged 65 and over	3.522	-2.663	5.825***	-3.664	-6.286	1.996
	(5.255)	(6.238)	(1.003)	(3.277)	(4.530)	(1.673)
Summer average temperature	0.690	0.432	0.514**	0.932**	0.784*	1.353***
	(0.465)	(0.502)	(0.211)	(0.384)	(0.471)	(0.202)
Ownership of washing machine	0.435	0.054	-0.348***			
	(0.453)	(0.328)	(0.112)			
Ownership of water heater	0.594*	0.288	0.192*			
	(0.345)	(0.261)	(0.105)			
Ownership of automobile				0.027	0.027*	-0.001
				(0.018)	(0.014)	(0.004)
Area of green land				0.007	0.016**	0.012***
				(0.008)	(0.008)	(0.004)
Number of hotels per capita				-0.389	0.127	-0.113
				(0.570)	(0.535)	(0.248)
Number of restaurants per capita				0.160	-0.199	0.428**
				(0.241)	(0.381)	(0.167)
Number of hospitals per capita				-0.002	0.010	-0.004
				(0.007)	(0.012)	(0.006)
Municipality fixed effects	No	Yes	Yes	No	Yes	Yes
Year fixed effects	No	Yes	Yes	No	Yes	Yes
Observations	150	150	150	148	148	148
R^2	-	-	0.658	-	-	0.560

Note: Robust standard errors are in parentheses. Coefficients of water price in column (1)–(3) report the results of estimating water price in the household sector, and coefficients of water price in column (4)–(6) report the results of estimating water price in the public service sector. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 2.5 Effects of floating population on residential water use

	Total water use			Per capita water use		
	2SLS (1)	2SLS-FE (2)	OLS-FE (3)	2SLS (4)	2SLS-FE (5)	OLS-FE (6)
Water price for residential sector	-1.262*	-1.049**	-0.240***	-1.835*	-2.086*	-0.098***
	(0.666)	(0.456)	(0.040)	(0.996)	(1.116)	(0.031)
Floating population	-0.137	-0.053	0.111**	-0.432	-0.524	-0.062*
	(0.170)	(0.134)	(0.046)	(0.279)	(0.333)	(0.032)
Permanent residents	0.386*	0.348**	0.386***	-0.264	0.086	-0.093**
	(0.214)	(0.166)	(0.079)	(0.219)	(0.214)	(0.036)
Household size	0.676	0.433	-0.498*	1.128	2.920	-0.864***
	(0.953)	(0.726)	(0.266)	(1.550)	(2.640)	(0.200)
Aged under 14	-11.555***	-10.193***	-7.448***	-5.080	-5.406	-0.935
	(4.037)	(2.516)	(0.849)	(4.619)	(4.649)	(0.589)
Aged 65 and over	5.054	-2.680	-1.745	11.082	-0.420	4.518***
	(5.060)	(3.364)	(1.466)	(8.158)	(9.160)	(0.992)
Summer average temperature	2.144***	1.835***	1.211***	1.924*	1.606*	0.548***
	(0.814)	(0.587)	(0.222)	(1.056)	(0.971)	(0.183)
Ownership of washing machine	1.042**	0.636**	0.301**	1.084	1.624	-0.132
	(0.517)	(0.324)	(0.150)	(0.896)	(1.178)	(0.125)
Ownership of water heater	-0.042	-0.092	0.326**	-0.695	-0.710	0.247**
	(0.333)	(0.307)	(0.142)	(0.563)	(0.597)	(0.111)
Ownership of automobile	0.054	0.040	0.001	0.078	0.071*	-0.000
	(0.037)	(0.024)	(0.005)	(0.049)	(0.042)	(0.003)
Area of green land	0.021*	0.032***	0.028***	-0.002	0.032	0.007***
	(0.012)	(0.009)	(0.004)	(0.015)	(0.024)	(0.003)
Number of hotels	-0.078	-0.065	0.112			
	(0.286)	(0.189)	(0.071)			
Number of restaurants	0.030	-0.122	-0.059			
	(0.097)	(0.084)	(0.042)			
Number of hospitals	-0.088	0.327*	0.077			
	(0.096)	(0.179)	(0.052)			
Number of hotels per capita				0.126	2.784	0.217
				(1.033)	(2.078)	(0.215)
Number of restaurants per capita				0.210	-1.673	-0.071
				(0.552)	(1.171)	(0.100)
Number of hospitals per capita				-0.005	0.031	-0.003
				(0.012)	(0.027)	(0.003)
Municipality fixed effects	No	Yes	Yes	No	Yes	Yes
Year fixed effects	No	Yes	Yes	No	Yes	Yes
Observations	148	148	148	148	148	148
R^2	0.584	0.804	0.950	-	-	0.699

Robust standard errors are in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 2.6 Summary of the main results

	Total Water Use			Per Capita Water Use		
	2SLS (1)	2SLS-FE (2)	OLS-FE (3)	2SLS (4)	2SLS-FE (5)	OLS-FE (6)
Household Sector	0.180***	0.257***	0.287***	-0.031	-0.071	0.005
	(0.052)	(0.055)	(0.044)	(0.068)	(0.087)	(0.033)
Public Service Sector	0.020	0.052	0.090	-0.265**	-0.322**	-0.132***
	(0.077)	(0.072)	(0.058)	(0.115)	(0.129)	(0.043)
Residential Sector	-0.137	-0.053	0.111**	-0.432	-0.524	-0.062*
	(0.170)	(0.134)	(0.046)	(0.279)	(0.333)	(0.032)

Note: Each column shows the coefficients of floating population from above estimations. Column (1) and (4) report the results without municipality and year fixed effects.

Chapter 3

Water Reform and Child Health in Rural Areas

3.1 Introduction

China is experiencing a rapid increase in the demand for water in all sectors, accompanied by uneven distribution of water resources and water quality deterioration. The poor water condition and water infrastructure have caused great health concerns, particularly among young children in rural area. From 2003 to 2012, a total of 127,539 children aged under 5 years in China died from diarrhea, with 42% of the total deaths were from rotavirus diarrhea[7], and 93% of all rotavirus deaths occurred in rural areas (Zhang et al, 2015). Water has become a major constraint to China's sustainable development.

As in many other countries, the water supply sector in China was traditionally dominated by the state, which has been criticized for its inefficiency, a lack of innovation, and low levels of service coverage (Bai et al., 2006; Zhong et al., 2008; Koppenjan and Enserink, 2009; Jiang and Zheng, 2014). To finance water infrastructures and tackle inefficiencies of state-owned water utilities, China introduced pilot private sector participation (PSP) projects from 1992, and market-oriented reform of state-owned enterprises (SOEs) was formally allowed nationwide in the water sector from 2002. Meanwhile, the restructuring of SOEs has been facilitated by the Corporate Law introduced in 1993 to resemble modern corporations. The process of transforming SOEs into state-owned corporations without privatization, defined as corporatization, is expected to improve the performance of SOEs (Aivazian et al., 2005; Hsieh and Song; 2015). Although PSP and public-private partnerships (PPPs) in water have been actively encouraged by the government, state-owned water utilities still hold monopolies in the water supply sector.

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[7] The virus is found in water sources such as private wells that have been contaminated with the feces from infected humans, such as private wells. Waste can enter the water in different ways, including sewage overflows, sewage systems that are not working properly, and polluted storm water runoff.

From the outset, private sector provision of water supply systems has been a controversial topic since the very beginning, and this chapter is driven by two of the most debated questions. Does private sector provision conflicting with the human right to water? Are there policy alternatives to privatization? The human right to water[8] is defined as the right of everyone to sufficient, safe, acceptable and physically accessible and affordable water for personal and domestic use (UNDESA, 2019). Bayliss (2002) mentions in her study that low-income consumers may benefit from privatization if the private firm is willing to extend the service network, and only if is affordable and reliable enough. In many developing countries where there is no effective social safety net, public sector reform and corporatization are options other than privatization. Bakker (2007) suggests that human rights are compatible with PSP in water supply, and a human right to water does not imply that water should be accessed for free (Bullock, 2006).

Extensive research has shown that water, sanitation, and hygiene interventions can lead to better health outcomes. Access to piped water is suggested to be effective at reducing infant mortality rate and diarrhea illness, as well as increasing anthropometric z-scores among children from poor households in developing countries (Jalan and Ravallion, 2003; Fewtrell et al., 2005; Gamper-Rabindran et al., 2010; Koolwal and Van de Walle, 2013). Similar results are found in China—that improved drinking water source is associated with less illness incidence and better anthropometric outcomes among both children and adults (Mangyo, 2008; Zhang, 2012; Zhang and Xu, 2016). Moreover, access to water infrastructures can explain a substantial portion of the inequality in health outcomes through differences in service coverage (Fay et al., 2005).

Other studies have examined the impact of water reform, generally PSP, on social outcomes, such as health and education. Galiani et al. (2005) find that privatization in the water sector reduces child mortality from infectious and parasitic disease related to water condition in Argentina. Kosec (2014) shows that PSP decreases diarrhea among urban-dwelling young children and increases school attendance of children aged 7–17 in African countries. Both studies find that private sector involvement benefits the poorest population, and the potential channel is through increasing the share of households connected to the water net-

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[8] On July 28, 2010, through Resolution 64/292, the United Nations General Assembly explicitly recognized the human right to water and sanitation and acknowledged that clean drinking water and sanitation are essential to the realization of all human rights. The resolution calls upon states and international organizations to provide financial resources, help build capacity, and transfer technology to help countries, in particular developing countries, to provide safe, clean, accessible and affordable drinking water and sanitation for all (UNDESA, 2019).

work.

Although the above-mentioned studies have explored the effects of water reform on human welfare, little empirical work has been undertaken on how different types of water reform affect child health, particularly whether state-owned corporations in the water supply sector achieve better outcomes than those of traditional state-owned water utilities or PSP in water. To fill this research gap, the present study investigates the impact of water reform on health outcomes of children aged under 5 years in rural communities[9] based on an empirical study in China. We focus on the effects of two types of water reform—Corporatization and PSP—and run differences-in-differences (DID) estimations on child-level data and community-level data. It is found that PSP in water decreases the incidence of diarrhea among children aged under 5 years in rural communities, while no improvement effect in weight-for-height and height-for-age is observed. Furthermore, the health benefits of water reform are greater for children in less educated households. We also conduct placebo analysis to check the results, and shed light on the potential channel through which water reform influences child health.

The remainder of this chapter is organized as follows. Section 2 provides an overview of water reform, with a focus on reform types and how they influence health. Section 3 describes the estimation strategy and potential problems. Section 4 gives a description of the data used for the analysis and sampling procedure. Section 5 presents the empirical results and examines the potential channels. Section 6 concludes with a discussion and policy implications.

3.2 Background

3.2.1 SOE Reform in Water Supply Sector

Since 1978, China has initiated intensive reforms and privatization of SOEs in the industrial sector, which is regarded as a strategic adjustment to a transition to a market-oriented economy transition (Geng et al., 2009). The early SOE reform during 1978–1992 featured the appointment of SOE managers and enhancement of managerial incentives, without owner-

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[9] Rural community indicates county, town, neighborhood, or rural village, based on the variable "stratum" in CHNS Individual Roster Data 1989–2015 File and CHNS Survey File 1989–2015.

ship transfer (Guo, 2003; Xu, 2011). SOEs were given more autonomy in their operations, and restrictions on entry by non-SOEs were gradually relaxed (Bai et al., 2006). However, the early SOE reforms failed when firms faced fierce competition from the non-state sector. The financial performance of the state sector worsened rapidly and the total losses peaked in 1998 (Xu, 2011).

The reform from 1993 to 2002 featured the transformation of large SOEs into modern corporations and privatization of small SOEs, based on a policy known as "grasping the large and letting go the small" (Geng et al., 2009; Hsieh and Song, 2015). The Corporate Law was introduced in 1993 and after 1998, some large SOEs were gradually restructured and merged into state-funded corporations following a modern corporate structures after 1998 (Hsieh and Song, 2015). These large SOEs were transformed to improve economic performance and fulfill social responsibilities simultaneously. Meanwhile, privatization was expected to change the state sector from chronicle losses to profit (Xu, 2011). Small and medium-scale SOEs were leased out or sold off to private enterprises and foreign firms, and the ownership system was transformed into mixed structure with various types of ownership (Guo, 2003). Privatization in China is mostly developed through partial privatization, since the Chinese government still wants to maintain ultimate control of the economy. Li and Yamada (2015) suggested in their study that the government is more likely to control privatized SOEs that have higher levels of employment and greater firm values for both efficiency and political purposes.

SOE reform in the water sector started from the mid-1990s in China. The government at first attempted to introduce the build–operate–transfer (BOT) projects in the water sector to deal with the enormous demand for investment and maintenance of urban water infrastructure (Zhong et al., 2008; Wang et al., 2011; Jiang and Zheng, 2014). In 2002, the Opinions on Accelerating the Marketization of Public Utilities[10] was issued to formally allow PSP in the water sector (Zhong et al., 2008). In China, the main PSP model in the water supply sector is joint ownership, also known as partial divestiture of SOEs (Zhong et al., 2008; Jensen, 2017). Water utilities with partial or full private sector involvement and water utilities with partial or full foreign sector involvement are defined as PSP in water supply.

Figure 3.1 shows the distribution of water utilities by ownership types for 2000–2013. By the end of 2000, more than 95% water utilities remained collectively owned, state owned,

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[10] No.272 Policy Paper of the MOC, 2002.

or owned by its various agencies and entities. The share of water utilities with PSP shows a steady rise from 2000 and 2008, along with the increase in state-owned corporations. PSP in the water sector peaked in 2008 and stop increasing probably due to the global financial crisis in 2008, and China's infrastructure investment stimulus plans may have crowded out private investment (Jensen, 2017). The second PSP boom started in 2013, driven by PPP models. By 2013, 10% of the water utilities were state-owned corporations, and more than 40% had PSP.

[Figure 3.1]

[Table 3.1]

Table 3.1 summarizes the characteristics of different forms of PSP and solely state-funded corporations in China's water sector. BOT or build–own–operate–transfer (BOOT), joint ownership, and full divestiture[11] are the dominant models in China's water sector. The main PSP model in the water supply sector is joint ownership, also known as partial divestiture of SOEs (Zhong et al., 2008; Jensen, 2017). "Ideally, the public sector ensures that externalities are internalized, and takes account of social equity. The private party, meanwhile, brings management expertise, a concern for efficiency, and a willingness to adopt innovative approaches" (Jensen, 2017). According to Geng et al. (2009), profitable SOEs in a strategic market, such as infrastructure and energy, have been consistently maintained to increase the infrastructure network and keep the price of resources low.

Galiani et al. (2005) find that privatized firms in Argentina were more efficient, invested more, and provided better water service than public firms. Welfare increased more with PSP, because child mortality decreased more with PSP than with the public sector at the same level of water connections. McKenzie et al. (2003) investigate the distributional impact of privatization in Latin American. They show that privatization increases access to water and other infrastructures, but the distributional impact of the service expansion depends heavily on initial levels of access.

However, results from several studies suggest that privatization might not necessarily be welfare improving. Clarke et al. (2004) estimate household-level data in Latin American

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[11] The firm's legal registration is a common way to identify ownership in China. Joint ownership indicates limited-liability corporations or shareholding firms with private sector involvement. Full divestiture indicates domestic private firms or foreign firms. They are two forms of PSP.

countries (Argentina, Bolivia, and Brazil) and find that piped water connections increased following privatization, but the authors observe the same increase in cities that remained public. In addition, an empirical study in Africa shows that private utilities are not associated with better performance than state-owned utilities in lower-income economies (Kirkpatrick et al., 2006). The mixed results of PSP are also revealed in a literature review by Pérard (2009), which summarizes 51 case studies and indicates that PSP in water supply has no significant positive effect on efficiency. Therefore, the choice between public and private water delivery is probably not only a question of efficiency, it is also determined by the cost of funds, transaction costs, and the potential political cost of privatizing.

Most empirical studies in China have shown favorable effects of privatization. This is quite reasonable considering that China is one of the few countries that has continued to actively encourage PSP since the 1990s. Using panel data for 35 major cities in China, Wang et al. (2011) investigate the impact of PSP on performance of water utilities. They find that PSP has a positive impact on integrated production capacity and the participation of foreign companies significantly improves the performance of water utilities. Moreover, PSP contributes to narrowing the gap of the water coverage rate between developed and less developed cities. Furthermore, PSP outperforms state-run infrastructure monopolies by increasing investment and efficiency (Jiang and Zheng, 2014; Zheng et al., 2016). Several studies consider the impact of corporatization in China in general, although they do not focus on the impact in the water sector. For example, Aivazian et al. (2005) suggest that corporatization has a positive impact on SOE performance, but no impact on investment levels. Hsieh and Song (2015) find that state-owned corporations contributed to total factor productivity growth, but the capital productivity remained lower than that of private firms from 1998 to 2007.

Since PSP was initially introduced to finance urban water infrastructure, few studies have investigated its impact on county-level water utilities and whether it has health effect on children in rural areas. Delmon (2014) indicates that one of the challenges for water authorities is to meet water service delivery obligations in remote rural, peri-urban, and small town communities. Private operators may provide water delivery services to remote communities because they are located closer to and are potentially more accountable to users, and they may also attract additional sources of finance.

Based on the literature review, we develop two hypotheses. First, we assume that reformed water utilities outperform traditional water utilities, which leads to better health outcomes. Second, we assume that PSP in county-level cities or counties may improve the performance of water utilities, bring in investment and adding new services as in urban areas, while state-owned corporations might not be as efficient as PSP. This may be due to the potential political cost that limit their performance, or the fact that, larger water utilities mostly are located in more developed areas, where better piped water access is already available. This may result in different impacts on health outcomes among children served by these utilities.

3.3 Estimation Strategy

3.3.1 *Empirical Models*

The following linear regression model is used to examine the effect of water reform on health outcomes of children aged under 5 years in rural areas. We compose two samples for the estimation: child sample and rural community sample. The main outcome variable in the child sample is a binary indicator of diarrhea incidence in the last 4 weeks, and thus, we run logit and probit models to measure the effect of water reform on diarrhea. The rural community sample is constructed to address the potential endogeneity of the treatment assignment, and to estimate difference-in-differences models. We conduct fixed-effect estimations to investigate the impact of water reform on the prevalence of diarrhea, weigh-for-height z-score, and height-for-age z-score.

$$health_{ict} = \beta_1 T_{ct} + \beta_2 G_c + \beta_3 X_{ict} + \delta_c + \theta_t + \varepsilon_{ict} \tag{3.1}$$

where $health_{ict}$ is the health outcome of child i in community c in year t, including three health measures: the incidence of diarrhea in last 4 weeks, weight-for-height z-score, and height-for-age z-score. T_{ct} is the treatment indicator that takes a value of one if community c implemented water reform in year t between 2000 and 2015, and zero otherwise. X_{ict} is a vector of control variables, including child characteristics, household characteristics, and community characteristics. Child characteristics consist of both time-invariant and time-varying variables: ethnicity, gender, age, and mother's education level. Household and community characteristics are variables that vary across time and community, per capita household income, household cooking fuel type[12], and household toilet type[13], community population density, economic component score, community education category, sanitation score of community, transportation component score, and sanitation score on community level. Province dummy variable δ_c captures the unobservable heterogeneity across provinces. θ_t is a time effect common to all communities in period t, controlling the effects of policies and programs for health improvement over time. ε_{ict} is the error item.

3.3.2 Identification

As discussed in Section 2, water reform is possibly not assigned randomly to counties, and there may be observable or unobservable time-varying covariates that affect both treatment status and health of children aged under 5 years.

Endogenous treatment assignment occurs together with self-selection bias to water reform. Although the decision of water reform is not made by children and their households, counties' self-selection may correlate to both the location of the water reform and child health. There are several cases for which we cannot obtain unbiased estimates of the treatment effect. First, local governments may have more incentive to reform their water sector when they cannot afford a rapid increase in construction cost of water infrastructure or maintenance expenses. Simultaneously, child health in these counties may have already been affected as a result of urbanization or poor public service provision. Second, investment may favor relatively developed rural areas, for their business-friendly environment and huge profit potential through expansion of services. These areas are possibly engaged in improving their public service provision and the environment for political or economic reasons, which may also affect child health. Third, water reform, especially the transformation of large SOEs, is expected to promote integrated urban–rural water supply and management projects. Areas operating these projects may have better resources for health improvement at both the household and the community level. Another concern is

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[12] Household cooking fuel type is a dummy variable that takes a value of one if a household normally used clean fuel for cooking, including electricity, kerosene, liquefied petroleum gas, or natural gas, and zero if the fuel type is coal, wood, sticksstraw, charcoal, or other.

[13] Household toilet type is a dummy variable that takes a value of one if a household has an in-house toilet facility, including flush or no flush, and zero if the household's normally uses toilet facility is a public restroom, cement openpit, or earth openpit outside the house.

the unobservable time-invariant characteristics varying across regions that may confound identification, such as quality of bureaucracy, law enforcement, and the control of corruption.

Previous studies address these issues through instrumental variables, matching methods, or differences-in-differences regressions. Since child-level panel data are not available owing to the attrition problem, we construct a community panel dataset to deal with the potential bias. Moreover, the standard errors are clustered at community level to allow the unobservable factors at the individual level to be correlated within a community.

To obtain stable and unbiased specifications, we conduct both child-level and community-level analysis in this study. First, our main interest lies in child-level results, because we lose a lot of information during the panel data construction. Second, we rely on community-level data to address endogeneity and control for unobservable heterogeneity. Third, child data aggregated at community level can eliminate the influence of extreme values in z-score measures, and therefore, we use community panel data for the estimation of z-score health outcomes.

3.4 Data Description

3.4.1 Child Data and Health Outcomes

The main data source is the China Health and Nutrition Survey (CHNS), which includes 10 rounds of surveys collected in 1989, 1991, 1993, 1997, 2000, 2004, 2006, 2009, 2011, and 2015. The survey covers the nine provinces of Liaoning, Heilongjiang, Jiangsu, Shandong, Henan, Hubei, Hunan, Guangxi, and Guizhou. A multi-stage, random cluster process is used to draw the samples surveyed in each province. Counties in the nine provinces and villages and townships in the counties are selected randomly. Three municipalities (Beijing, Shanghai, and Chongqing) are added in 2011, but we exclude them from our sample owing to lack of information in the earlier rounds. The CHNS collects information on health, nutrition, income, assets, expenditure, employment, and education from the households. In addition, community-level data can be used to identify respondents' locations. To construct our child sample, we collect data of health outcomes, individual characteristics, household characteristics, and community characteristics.

Our child sample is a longitudinal dataset, comprising 1,168 children under 5 years of age living in rural areas and who have piped water access from local water utilities. A rural area indicates a county town neighborhood and rural village, based on the variable "stratum" in the CHNS Individual Roster Data 1989–2015 File and the CHNS Survey File 1989–2015. This variable helps us to spot the rural areas where children actually dwell, rather than the official urban or rural registration status. Children with piped water access are identified based on the survey question "Major Source of Drinking Water" in the CHNS Household Assets 1989–2015 File. We limit our sample to children who have access to piped water, which means their drinking water is delivered from water plants, to exclude the effect of other drinking water sources. We focus on children aged under 5 years for three reasons. First, young children are the first to become sick and die from waterborne and sanitation-related illnesses, including diarrhea diseases and malaria (UNICEF, 2019). Second, the nutritional status of children under the age of 5 years is considered to be a good reflection of the nutritional well-being of community in developing countries (Quinn, 1992). Last, a young child sample can avoid the influence of catch-up growth and uncertain environmental factors on health outcomes.

Water utility data are obtained from Annual Industrial Firm Surveys 1999–2013 conducted by the National Bureau of Statistics (NBS), including firm code certificate, name, date of commencement of business, administrative division codes, detailed location, and ownership type. The annual survey covers all registered industrial firms that are either state-owned or non-state-owned, with sales above 5 million yuan. There are three four-digit industries related to the water industry: water production and supply (4610); wastewater treatment and reuse (4620); and other water treatment, utilization, and distribution (4690). We build a firm-level panel dataset of water utilities during 1999–2013 in the nine provinces in which the CHNS surveys were conducted. We notice that more than half of the water utilities have changed their name or ownership type or simply disappeared. In terms of firms that changed their name, ownership type, or both, we track them down by cross-checking the firm code certificate and location. In addition, some firms disappeared because the latest operation status is not reflected in the survey. Thus, we acquire information from the National Enterprise Credit Information Publicity System (NECIPS) to ensure all the water utilities in our dataset are still in operation. Water supply utilities that are closed down, revoked, or canceled are removed.

We also collect information from a supporting data source. The Private Participation in Infrastructure (PPI) Project Database is the leading source of private participation in infrastructure trends in the developing world, covering projects in the energy, telecommunications, transport, and water and sewage sectors from 1990 to 2018. PSP in other sectors is considered because fiscally constrained counties that allow private financing of water utilities may also encourage private financing in other infrastructure sectors. We combine the information in the PPI database and NBS Annual Industrial Firm Surveys to create PSP variables in the sewage sector and energy sector for placebo tests.

[Table 3.2]

Table 3.2 presents the descriptive statistics of the child sample. The short-term health outcomes, incidence of diseases, and weight-for-height z-score are worse in the treatment group, while the long-term health outcome, the height-for-age z-score, is better in the treatment group. As for treatment status, 585 out of 1668 children aged under 5 years lived in communities affected by water reform during 2001 to 2015. In the treatment group, 60% of children live in communities with restructured state-owned water utilities, and almost 50% live in communities that adopted PSP in water supply. Some communities experienced PSP first, after which their water utilities were merged into state-owned corporates. For this reason, the total share of our two treatment variables is larger than 1.

The main dependent variables in our analysis are incidence of diarrhea, weight-for-height, and height-for-age among children aged under 5 years. We transform weight-for-height and height-for-age into z-scores[14], because they provide a better statistical assessment of nutritional status, which remains stable over different age groups as well as across the different indicators (Quinn, 1992).

Incidence of diarrhea is a binary health outcome, measuring the probability of diarrhea occurring to a child under 5 years of age in the 4 weeks before the survey. We focus on this indicator, because it reflects sanitation and safe water availability. Water supply, sanitation, and hygiene, given their direct impact on infectious disease, especially diarrhea, are important for preventing malnutrition (WHO, 2019). Since the diseases caused by poor water and sanitation, repeated or persistent diarrhea, or other chronic diseases usually lead to weight

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[14] We use the 2000 Centers for Disease Control and Prevention (CDC) Growth Reference in the United States to transform weight-for-height and height-for-age into standard deviation z-scores; the 1990 British Growth Reference is used to create height-for-age z-score for the robustness check.

loss and malnutrition[15] (Zhang, 2012; WHO, 2019), we use two anthropometric measures apart from diarrhea: z-score of weight-for-height and z-score of height-for-age. Weight-for-height is commonly accepted as a good indicator of a child's present nutritional status, and height-for-age as a good indicator for past nutritional status, reflecting overall socioeconomic conditions (Quinn, 1992). In our sample, most children have normal nutrition status, and 91.8% of children's weight-for-height z-scores and 93.5% of children's height-for-age z-scores are higher than -2 in the rural child sample. Furthermore, we collect data on the incidence of fever, sore throat, and cough in the last 4 weeks to examine the placebo effect of water reform.

3.4.2 Treatment Variables

To examine the health effect of water reform, we construct three treatment variables for this analysis: water reform; corporatization in water, and PSP in water. It takes five steps to identify the communities that undertook water reform between 1989 and 2015. First, we cross-reference the location information in the child data and water utility panel data, in order to match the counties where water supply utilities are located with the counties where children are living. Then, we keep the matched water utilities. Second, we cross-check the firm code certificate, firm location, and information collected from the NECIPS to track the operation status of water utilities and whether they have changed the firm name and ownership type[16] during the study period. This step is critical for identifying water utilities that are always public or reformed. Third, we draw such information as business, history, and service areas from the websites of water utilities and local governments, combining information from the second step to classify communities in each county by water reform types[17]. Fourth, the date of commencement of the business variable helps us to identify when the old water utilities were transformed as well as when the new water utilities participated. Last, we integrate all the four steps to create three treatment variables, which are interactions between time and treated communities. Basically, we conduct the matching on county level. However, in some cases there are more than one water utilities in one county,

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[15] Moderate malnutrition is defined as a weight-for-height z-scores of between -3 and -2 below the median of the WHO child growth standards. Weight-for-height z-scores of less than -3 indicate severe acute malnutrition and height-for-age z-scores of less than -3 indicate severe stunting (WHO, 2019).

[16] The change in firm name always follows the change in ownership type.

[17] Ownership types are used to define water reform type, as explained in Section 2.

therefore we match some of the locations on community level as well when this happens.

Table 3.3 summarizes the major drinking water sources of children aged under 5 years in rural are between 1989 and 2000. We use this period to capture the pretreatment water access status, since most communities started water reform after 2000. In the rural sample, only 21% and 25.1% children in the two groups use safely managed water as drinking sources. It is interesting that in the treatment group, piped water access in communities that sign PSP deals is almost 20% lower than that in communities that implement SOE transformation. Meanwhile, groundwater access is 23% higher in communities that adopt PSP than that in communities that implement SOE transformation. The representativeness of the child sample is doubtful, and thus, we also check the summary statistics of drinking water sources for the full household sample for all age groups, including 11,754 households in rural areas between 1989 and 2000. As a result, a similar trend is observed and the t-test results do not vary over different population groups. The above mentioned evidence supports the assumption in Section 2 that compared to SOE transformation, PSP in water is more likely to occur in less developed rural communities with lower piped water use.

[Table 3.3]

In summary, water reform indicates that communities with water utilities reformed through corporatization or PSP between 1989 and 2015. Corporatization is defined as communities with restructured water utilities, transformed from stated-owned enterprises to solely state-funded corporations. Meanwhile, PSP in water is defined as communities with all forms of private participation in the water supply sector between 1989 and 2015.

3.4.3 Rural Community Data and DID-PSM Method

In addition to child-level data, we also collect community-level data from the CHNS to identify treatment effects. We focus on rural communities and construct a balanced panel dataset consisting of 11 urbanicity components[18]. However, this dataset includes no health

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[18] Jones-Smith and Popkin (2010) construct a multi-component urbanicity scale in 2010 based on the CHNS community survey to measure urban features on a continuum in China. The scale is developed to predict the incidence of overweight/obesity populations in China, and it promises to be most useful for other economic, demographic, social welfare, and health outcomes. The authors consult references to find common defining and distinguishing features of urban places and synthesize them to define their urbanicity scale, identifying 12 components. These are: population density, economic activity, traditional markets, modern markets, transportation infrastructure, sanitation, communications, housing, education, diversity, health infrastructure, and social services

outcome variables, and thus, we construct community-level health indicators by aggregating the mean values of individual-level health data from the sample of children aged under 5 years[19]. The summary statistics of the rural community sample are presented in Table 3.4. The mean values of the health outcome variables are all very small, for instance, the average prevalence of diarrhea in the last 4 weeks is only 0.8% in both groups and left censored at 0. The large proportions of missing data at the individual level[20] could cause this, because we drop all the missing data to compose a balanced community panel dataset.

[Table 3.4]

Figure 3.2 depicts the trends of health outcomes by control group and treated group. Prevalence of diarrhea and weight-for-height z-score have similar common trends between control group and treatment group before 2000. On the contrary, the pretreatment trends of height-for-age z-score are very different between these two groups, despite that the mean difference is not significant. Apart from this, improvement effects are revealed at post-treatment period, but it is unknown if they are caused by water reform.

[Figure 3.2]

We test the mean difference of community characteristics between the control group and the treatment group in the pretreatment period. We choose 2000 as the baseline year, since most communities launched water reform after the year, and all the communities that started reform before 2000 were dropped. As revealed in Table 3.4, the mean values of community population density category and sanitation score between the two groups are statistically different at the level of 5% in the pretreatment period, whereas health outcome indicators show no significant difference.

[Table 3.5]

Therefore, we use the differences-in-differences–propensity score matching (DID–PSM) method to construct a community sample on common support. Conventional matching

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[19] In the community sample, the weight-for-height z-score and height-for-age z-score are aggregated from the child sample obtained piped water access. However, the prevalence of diarrhea is aggregated from the child sample with all types of water access, because no results are generated from the matching method if the child sample that obtained piped water access is used.

[20] According to the child sample we use, 56.4% of diarrhea data, 46.2% of height-for-age z-score data, and 39.2% of weight-for-height z-score data are missing.

methods are based on the conditional independent assumption to develop a valid counterfactual by finding controls that have similar observed covariates as the treatments. Rosenbaum and Rubin (1983) propose the construction of a control group by matching treated and untreated units based on a propensity score $P(x)$, which gives the conditional probability of receiving treatment given the pre-treatment values of the vector x, that is, $P(x) = Pr(D = 1|x)$. Heckman et al. (1998) develop a generalized DID–PSM estimator to extend conventional matching methods to longitudinal data, which controls for the confounding effects from both observable and time-invariant unobservable covariates.

The community characteristics in Table 3.5 are used to estimate the probability of a community implementing water reform after 2000 by a logit model. Then, we use the predicted propensity to match the control and treatment groups in the pretreatment period to identify a sample on common support. The t-test results in Table 3.5 show that the mean differences between the treatment and control groups in the pretreatment period are not statistically significant after matching. The sample on common support is well balanced, and all the observations that are off support are excluded for the following estimation. Then, we use Equation (3.1) to to conduct DID regressions. Because PSP was formally allowed in the water supply sector from 2002, and corporatization was adopted from 2003, we choose 2002 as the baseline year. The pretreatment period is 1989, 1991, 1993, 1997, and 2000, and the post-treatment period is 2004, 2006, 2009, 2011, and 2015.

3.5 Results

3.5.1 *Effects on Diarrhea: Child Sample*

Table 3.6 presents the results from logit regressions. Columns (1)–(8) examine the marginal effects of water reform, corporatization, and PSP in water on the possibility of diarrhea in children aged under 5 years in rural areas. Column (1)–(2) include no control variables; columns (3)–(4) control for individual characteristics, household characteristics, and community characteristics; columns (5)–(6) add only the province dummy, and columns (7)–(8) add only the year dummy. The coefficients of water reform are negative and statistically significant at the 1% level in columns (1), (3), and (5). The year dummy in column (7) seems to be significantly correlated with the incidence of diarrhea, but the impact of water reform remains significant at the 5% level.

The marginal effects of corporatization and PSP in water are also reported in Table 3.6. The impact of corporatization is negative and significant at the 10% level (columns (2) and (4)), but becomes insignificant when we introduce the province dummy or year dummy (columns (6) and (8)). PSP in water has a stable and significant negative effect on diarrhea, irrespective of the model specification. However, the impact of PSP in water becomes smaller when the year dummy is added in column (10), and a similar trend is shown in the coefficients of water reform. In all regressions, the coefficients of water reform and PSP in water are negative and statistically significant.

[Table 3.6]

To further investigate the effect of water reform on the incidence of diarrhea, we divide the child sample into two and estimate logit models and probit models. We run regressions with two different child samples to separate the effect of water plant from other drinking water sources. The estimation results are reported in Table 3.7. Again, the negative and significant effects of water reform and PSP do not change across different estimation models and samples. By contrast, all the estimated coefficients of corporatization lose significance.

Columns (1)–(4) in Table 3.7 present the results for children who gained access to piped water from water plants, and columns (5)–(8) present the results for children who obtained drinking water access from multiple sources[21]. We focus on the results from the probit models in columns (3)–(4) and columns (7)–(8) because of their lower standard errors. For children who obtained drinking water access from multiple sources, the coefficient of water reform in column (7) is -0.052, statistically significant at the 10% level, and the coefficient of PSP in water is -0.072, statistically significant at the 5% level. The results in columns (7)–(8) suggest that the effects of water reform and PSP in water are smaller because of unimproved drinking water sources. Nevertheless, the improvement effects are significant and robust in both samples.

[Table 3.7]

Overall, we find that water reform led to a decrease in the probability of diarrhea occurrence by 5.2% to 8.5% among children aged under 5 years in rural areas. Regarding the types

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[21] Drinking water sources include water plant, groundwater, deep well, and surface water.

of water reform, only PSP in water generates a significant effect, reducing the possibility of diarrhea incidence by 7.2% to 10.4%.

3.5.2 Heterogeneous Treatment Effects

In Table 3.8, columns (1)–(3) analyze the marginal effects of water reform, corporatization, and PSP in water, respectively, by gender and age. Panel A shows the results by children's gender, and panel B presents results for children aged 0–1, 1–2, 2–3, 3–4, and 4–5 years. In addition, marginal effects at various maternal education levels are reported in Table 3.9.

The results in Table 3.8 panel A show that the possibility of diarrhea incidence decreases 9.3% for girls and 7.4% for boys in treated communities. In panel B, for children aged 0–1 and 1–2 years, the results are similar and statistically significant at the 1% level. In addition, the probability of diarrhea is most reduced by PSP in water among young girls. The treatment effect of water reform varies according to maternal education levels. As shown in Table 3.9, water reform corresponds with a decrease of diarrhea incidence at each education level, and the effect almost doubles among children whose mothers receive no education compared to children of the most educated mothers. We exclude mother's education level from the models in Tables 4 and 5 owing to the insufficient number of observations, considering our limited sample size. Moreover, no predictors of PSP in water are generated in Table 3.9 as a result of complete separation. In other words, when PSP in water is 1, the incidence of diarrhea equals 0.

Despite the insignificant effects from the overall estimations, corporatization is significantly associated with a fall in the probability of diarrhea by 5.2% at the 10% level among boys. Young children aged 0–3 years living with poorly educated mothers also benefit from corporatization.

[Table 3.8]

[Table 3.9]

3.5.3 Placebo Tests

We estimate probit models in Table 3.10 with the child sample to examine the effects of water reform on the incidence of fever, sore throat, and cough in the last 4 weeks. Panel A in Table 3.10 reports the results for a sample of children with access to piped water. Column (1) in panel A reports the results for incidence of fever, sore throat, and cough. The coefficients in column (1) are not statistically significant. We find that the improvement effects of water reform are limited to diarrhea.

[Table 3.10]

We check the effects of PSP in other sectors as well. According to data from the World Bank (2019), 1314 private participation infrastructure projects reached financial closure in China from 1990 to 2015, of which 462 are in water and sewage[22], and 591 are in energy. Therefore, we construct two PSP variables from the PPI database: PSP in sewage treatment and PSP in energy. Columns (2)–(3) of Table 3.10 report the estimated effects of PSP in sewage treatment and PSP in energy on diarrhea, and neither has any statistically significant impact.

Furthermore, water reform benefits child health by delivering improved drinking water; thus, children drinking water from other sources should not be affected by water reform. Panel B in Table 3.10 is a sample of children drinking groundwater, which is the most widely used drinking water source for children aged under 5 years in rural areas. Column (4) estimates the effect of water reform on diarrhea with this sample. Again, all the coefficients show no significance. Consequently, all the results provide evidence that reduction in diarrhea incidence is caused by water reform in the water supply sector.

3.5.4 Effects on Diarrhea: Rural Community Sample

To mitigate the potential endogeneity, we run DID regressions with the sample on common support. We include community characteristics to capture the improvements in community education level, sanitation status, and health-related infrastructure. Year fixed effects allow for the correlated impact from national programs, such as a rural drinking water

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[22] Private participation in infrastructure in water and sewage includes projects in water supply and projects in sewage treatment, of which 88.7% are sewage projects.

treatment program[23] in China. The results of water reform are reported in columns (1) and (3) of Table 3.11, separately. Column (1) presents the baseline results estimated with the full sample. The coefficients are negative and statistically significant in both columns. The relationship between water reform and the prevalence of diarrhea among children aged under 5 years is stronger after matching. Columns (2) and (4) present the estimated impacts of corporatization and PSP in water. In line with the results in the child sample, corporatization still shows a negative but insignificant effect on the prevalence of diarrhea. PSP in water, however, is associated with a 0.9% reduction in the prevalence of diarrhea at the community level, and the impact does not change before and after matching.

[Table 3.11]

In summary, the results provide evidence that water reform can improve child health by reducing the possibility of diarrhea occurrence among children aged under 5 years in rural areas. Furthermore, corporatization and PSP in water have different effects on the incidence of diarrhea, and in our study, the overall impact of water reform mainly comes from PSP in the water sector. The results are robust regardless of sample, choice of control variable, and estimation method. Moreover, water reform, corporatization, and PSP in water are all connected to the decrease in the probability of diarrhea occurrence among the most vulnerable children, that is, younger girls and boys whose mothers have less education. Similar significant effects are revealed in all three treatment variables.

We also run DID fixed-effects models with the rural community sample for weight-for-height z-score and height-for-age z-score. For the following two reasons, we use only community-level data. First, z-score data follow a standard normal distribution, and the fixed-effects model could provide more reliable predictors than the pooled OLS model in this case. Second, aggregating child data to the community level eliminates the effect of extreme values. As discussed above, the trends of z-score indexes are different between the control group and the treated group at the pretreatment period, and thus, we estimate the effect of water reform with observations on common support in Table 3.8. However, we find no association between water reform and anthropometric health outcomes, although water reform seems to be more effective for short-term indicators. A possible reason is that short-

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[23] The Chinese government started the rural drinking water treatment program in the 1980s to build water treatment plants with installation of clean water technology and equipment to eradicate chemical pollutants and microorganisms and to enable government bodies to monitor water quality precisely and regularly.

term indicators can be recovered instantly through access to clean drinking water, while long-term indicators are stock measures reflecting accumulated impact of social status and environment.

3.5.5 *Potential Channels*

This subsection further explores the channels that may explain our findings. We collect unbalanced household panel data from the CHNS, keeping households that participated in at least seven rounds of the surveys to capture the change in their drinking water sources before and after water reform. The panel data includes 15,922 households in rural communities, of which 8011 were surveyed between 1989 and 2000, and 7911 were surveyed between 2004 and 2015. Three binary dependent variables are used to identify households' drinking water sources: piped water use, groundwater use, and surface water use. Piped water use indicates households using safely managed piped water delivered by water plants as the drinking water source. Groundwater use is defined as households using water from underground or open wells ($>$5 meters) as the drinking water source. Surface water use is defined as households using water from creeks, springs, rivers, or lakes as the drinking water source. Households drinking ice water, snow water, or other water sources are not considered owing to the small proportion (0.6%).

[Table 3.12]

Table 3.12 reports the results of fixed-effects logit models. According to columns (1)–(2), water reform has a positive and significant impact at the 1% level of a 3.1% increase in the possibility of using piped water. The marginal effect of corporatization is positive and significant at the 5% level, while PSP in water has a stronger effect in both magnitude and significance. They are associated with an increase in the possibility of piped water use by 2.4% and 4.2%, respectively. On the contrary, water reform leads to a decrease in access to groundwater and surface water, as reported in columns (3)–(6). The results are heterogeneous and water reform shows a much greater impact on the access to surface water (columns (3) and (5)). We find that corporatization has no significant effect on access to groundwater (column (4)) but reduces the possibility of using surface water by 26% (column (6)). Meanwhile, PSP in water is associated with a 2.2% (column (4)) decrease in the possibility of using groundwater, and a 23.9% (column (6)) decrease in the possibility of using surface water.

These results suggest that one possible channel for water reform improving child health is by expanding access to piped water for households using groundwater as the drinking water source. This could explain why PSP in water has a more significant impact than corporatization does, which has no substitution effect on households' choice of drinking water source. Households in treated communities are more likely than households in control communities to drink improved piped water when it is available, despite its higher cost than that of groundwater use.

3.6 Conclusions

This chapter investigates the effects of reforming state-owned water utilities in rural China. We find that water reform significantly decreases the possibility of diarrhea occurrence among children aged under 5 years in rural communities. Both corporatization and PSP in water benefit the most vulnerable population by reducing diarrhea occurrence among young children aged under 2 years. Furthermore, different samples and estimation methods are used to confirm that the results are robust and stable after an endogenous treatment assignment is considered. A placebo analysis is also conducted to confirm that the health improvement effects are driven directly by reform in the water supply sector.

In addition, we investigate the short- and long-term effect of water reform on child nutrition through weight-for-height z-score and height-for-age z-score. The results are not significant but water reform shows a positive impact on short-term health outcomes by reducing diarrhea and increasing the weight-for-height z-score. Anthropometric indicators, especially long-term health outcomes, such as height-for-age z-score, reflect the influence of overall factors. The effects of other diseases, environmental pollution, and households' accumulated decisions could offset the effect of water reform.

We also shed light on the service expansion effect of water reform, which is, increasing the proportion of improved piped water use and decreasing the proportion of groundwater use in households. The substitution effect is greater in communities that adopted PSP, which brings financial benefit for local governments and casually leads to better health. Since groundwater is the primary drinking water source for households in rural communities, expanding piped water service is a potential channel through which the health improvement effect is achieved.

This study has several limitations. First, our data are collected from eastern provinces and municipalities, and thus, the results might not be applicable to other regions of China. Second, we investigate only one potential channel concerning households' drinking water choices under water service expansion. Further research is needed to explore the key factors making PSP in water more effective than corporatization for health improvement, in terms of water utility-level or community-level determinants. Empirical studies on the social impacts of different PSP forms are also needed, although they are dependent on sufficient data.

Our results suggest that market-oriented water reform may contribute to child health improvement, and at the same time lead to more effective use of water resources. Reform also helps to achieve the Sustainable Development Goal "to ensure availability and sustainable management of water and sanitation for all," through narrowing the water provision gap between urban and rural areas. We find that PSP in water is more likely to be implemented in rural communities with lower piped water access, which results in a greater improvement effect than corporatization. The government's control on water tariff and payment schemes makes it possible to promote PSP without harming the high-risk population. Consequently, the division of tasks and responsibilities between the public and private sectors may play an indispensable role in sustainable and integrated urban–rural water management during the rapid urbanization process in China.

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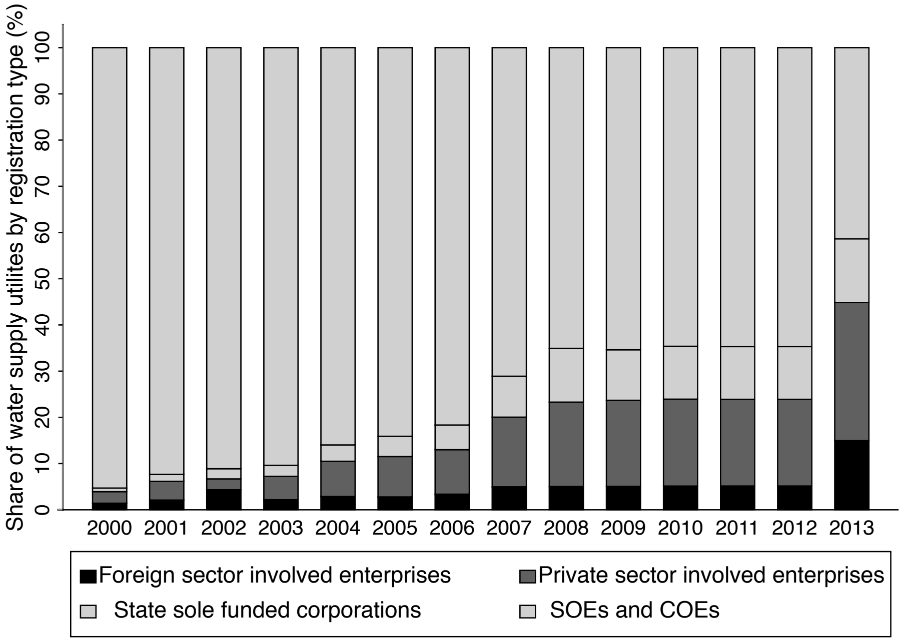
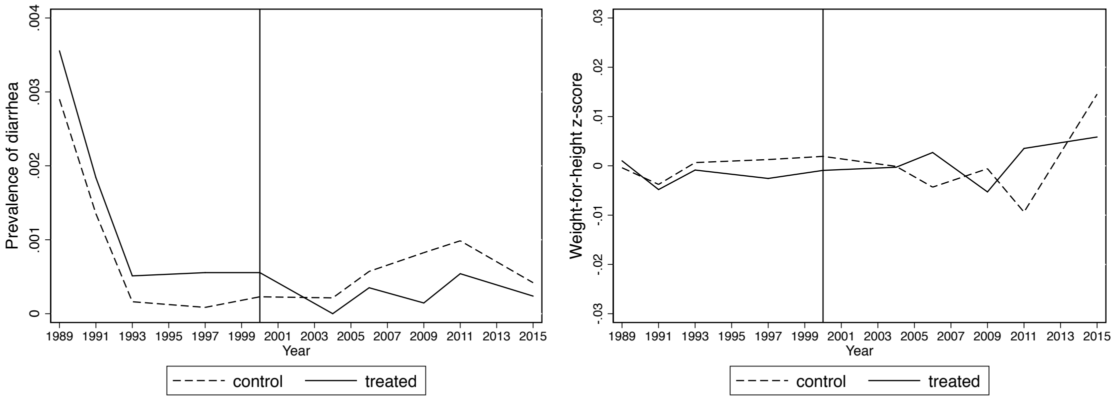


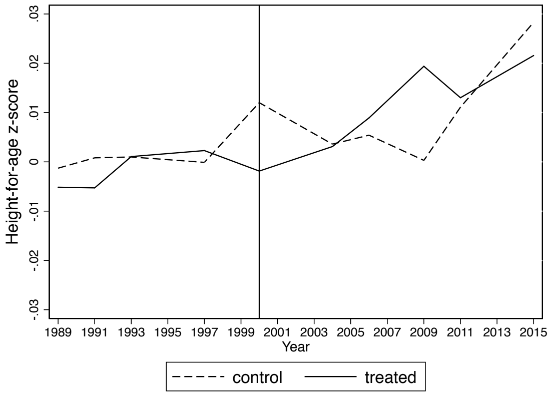
Source: NBS Annual Industrial Firm Survey, 1999–2013. Note: Foreign sector involved enterprises indicate partially or fully foreign-funded enterprises. Private sector involved enterprises indicate partially or fully private-funded enterprises. SOEs are state-owned enterprises; COEs are collective-owned enterprises.

Fig. 3.1. Trend of the share of water utilities by registration type



(a) Prevalence of diarrhea

(b) Weight-for-height z-score



(c) Height-for-age z-score

Source: China Health and Nutrition Survey between 1989 and 2015.

Fig. 3.2. Trends of health outcomes of children aged under 5 years

Table 3.1 Characteristics of water reform types

Option	Ownership	Operations	Revenue source	Duration
Different forms of PSP				
Service/Management contracts	Public	Some private	Tariffs/public budget	1–10 yr
Lease contract	Public	Private	Tariffs	5–25 yr
Concession	Public/Private	Private	Tariffs	10–50 yr
BOT/BOOT (China)	Public	Private	Tariffs/public budget	15–30 yr
Joint ownership (China)	Private&Public	Private&Public	Tariffs&public budget	Undetermined
Sale of full divestiture (China)	Private	Private	Tariffs	Undetermined
Corporatization				
State sole funded corporations	Public	Public	Tariffs&public budget	Undetermined

Source: Expanded from Delmon (2014); Jensen (2017).

Note: BOT indicates build-operate-transfer contracts and BOOT indicates build-own-operate-transfer contracts.

Table 3.2 Summary statistics of child sample

By treatment: water reform	Control group			Treatment group		
Variable	Mean	Std. dev.	N	Mean	Std. dev.	N
Health outcomes						
Last 4 weeks: diarrhea	0.040	0.190	629	0.060	0.230	297
Last 4 weeks: fever, sore throat, cough	0.180	0.380	628	0.240	0.430	299
Doctor's diagnosis of respiratory disease	0.640	0.480	114	0.700	0.460	66
Z-score of weight-for-height (2000 US CDC Growth Reference)	-0.0700	1.480	643	-0.130	1.320	356
Z-score of height-for-age (2000 US CDC Growth Reference)	0.220	1.580	551	0.420	1.540	306
Z-score of height-for-age (1990 British Growth Reference)	0.410	1.880	732	0.600	1.790	401
Child characteristics						
Calculated age in years	2.140	1.390	1083	2.090	1.370	585
Ethnicity (Hanzu=1)	0.730	0.450	1083	0.880	0.330	585
Gender (male=1)	0.550	0.500	1083	0.550	0.500	585
Mother's education level	2.037	1.104	807	2.201	1.071	437
Household characteristics						
Household size	5.320	1.700	1083	5.070	1.480	585
Log of per capita household income	8.310	1.080	1068	8.410	0.960	581
Use clean fuel for cooking (Clean fuel=1)	0.450	0.500	1083	0.410	0.490	585
Have in-house toilet (In-house toilet=1)	0.450	0.500	1083	0.370	0.480	585
Community characteristics						
Community population density category	5.870	1.330	1083	6.180	1.400	585
Economic component score	5.410	2.990	1083	5.470	2.860	585
Community education category	3.180	1.220	1083	3.010	1.120	585
Transportation component score	5.422	2.261	1083	5.539	2.081	585
Quality of health score	5.906	2.280	1083	5.720	1.921	585
Sanitation score	7.290	2.090	1083	8.020	1.710	585
Treatment variables						
Corporatization in water				0.603	0.490	585
PSP in water				0.497	0.500	585

Source: China Health and Nutrition Survey (1989, 1991, 1993, 1997, 2000, 2004, 2006, 2009, 2011, 2015), NBS Annual Industrial Firm Survey (1999–2013).

Note: Summary for children under 5 years of age living in town, county or rural village. All children gained piped water access supplied by water utilities.

Table 3.3 Summary of children's major source of drinking water

	Control group			Treatment group		
Variable	Mean	Std. dev.	N	Mean	Std. dev.	N
Rural sample by treatment: Water reform						
Piped water	0.214	0.410	2325	0.251*	0.434	892
Surface water	0.082*	0.275	2325	0.062	0.241	892
Groundwater (> 5 meters)	0.699	0.459	2325	0.685	0.465	892
Rural sample by treatment: Corporatization						
Piped water	0.207	0.405	2871	0.370*	0.483	346
Surface water	0.076	0.265	2871	0.081	0.273	346
Groundwater (> 5 meters)	0.714*	0.452	2871	0.543	0.499	346
Rural sample by treatment: PSP						
Piped water	0.234*	0.424	2671	0.176	0.381	546
Surface water	0.082*	0.274	2671	0.049	0.217	546
Groundwater (> 5 meters)	0.679	0.467	2671	0.775*	0.418	546

Note: Rural sample indicates children living in town, county, or rural village. The results show the proportion of children using piped water, groundwater, or surface water as the major drinking water source. Surface water indicates drinking water from creek, spring, river, or lake. * indicates mean value is significantly larger at 5% level, two-tailed using *t*-test.

Table 3.4 Summary statistics of rural community sample

By treatment: water reform	Control group			Treatment group		
Variable	Mean	Std. Dev.	N	Mean	Std. Dev.	N
Health outcome						
Last 4 weeks: diarrhea	0.008	0.025	650	0.008	0.035	300
Z-score of weight for height (US)	-0.000	0.258	550	-0.002	0.167	210
Z-score of height for age (US)	0.061	0.363	520	0.057	0.270	210
Z-score of height for age (UK)	0.074	0.358	540	0.064	0.286	210
Community characteristics						
Community population density category	5.580	1.240	650	5.760*	1.120	320
Economic component score	4.260	3.080	650	4.540	3.060	320
Community education category	2.710	1.090	650	2.600	1.020	320
Transportation component score	4.590	2.510	650	4.580	2.740	320
Quality of health score	4.690	2.003	650	5.020	2.190	320
Sanitation score	4.840	2.930	650	5.170*	2.860	320
Treatment variables						
Corporatization in water				0.440	0.500	320
PSP in water				0.560	0.500	320

Source: China Health and Nutrition Survey (1989, 1991, 1993, 1997, 2000, 2004, 2006, 2009, 2011, and 2015), NBS Annual Industrial Firm Survey (1999–2013).

Note: Summary for communities in town, county or rural village. * indicates mean value is significantly larger at the 5% level, two-tailed, using *t*-test at pretreatment period.

Table 3.5 Balancing t-test results by DID-PSM matching

Weighted variables	Mean control	Mean treated	Mean difference	t-value	p-value
Prevalence of diarrhea	0.010	0.014	0.004	1.17	0.2428
Community population density category	5.726	5.832	0.106	0.83	0.4075
Economic component score	2.755	2.906	0.151	0.72	0.4734
Community education category	2.126	2.176	0.050	0.75	0.4510
Diversity score	3.832	3.857	0.026	0.30	0.7619
Market component score	4.132	4.064	-0.068	0.20	0.8402
Modern markets component score	2.863	2.995	0.132	0.45	0.6547
Transportation component score	4.069	4.004	-0.064	0.24	0.8089
Quality of health score	4.952	4.789	-0.163	0.88	0.3786
Social services score	0.286	0.344	0.058	0.80	0.4262
Housing component score	2.684	2.785	0.101	0.53	0.5964
Sanitation score	4.339	4.469	0.130	0.49	0.6241

Note: The baseline year is 2000. A t-test is performed at period=0, before the water reform.

Table 3.6 Effects of water reform on diarrhea in children aged under 5 years

	Dependent variable: diarrhea in last 4 weeks							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Water reform	-0.099***		-0.079***		-0.094***		-0.061**	
	(0.033)		(0.030)		(0.028)		(0.031)	
Water reform · before	0.074***		0.052***		0.055**		0.046***	
	(0.022)		(0.016)		(0.026)		(0.017)	
Corporatization in water		-0.065*		-0.065*		-0.071		-0.040
		(0.036)		(0.039)		(0.045)		(0.037)
PSP in water		-0.163***		-0.108**		-0.122***		-0.094*
		(0.056)		(0.044)		(0.045)		(0.053)
Corporatization · before		0.062***		0.051***		0.044		0.050***
		(0.018)		(0.018)		(0.032)		(0.014)
PSP · before		0.098***		0.052**		0.052*		0.029
		(0.035)		(0.025)		(0.031)		(0.036)
Age			-0.013**	-0.013**	-0.013**	-0.013**	-0.013**	-0.013**
			(0.005)	(0.005)	(0.006)	(0.006)	(0.006)	(0.006)
Ethnicity			0.008	0.010	0.005	0.005	0.012	0.016
			(0.015)	(0.016)	(0.015)	(0.016)	(0.016)	(0.018)
Gender			-0.009	-0.009	-0.010	-0.009	-0.009	-0.009
			(0.012)	(0.012)	(0.012)	(0.013)	(0.012)	(0.013)
Household size			-0.010*	-0.010	-0.010	-0.010	-0.011*	-0.010
			(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Log of per capita household income			-0.008	-0.007	-0.009	-0.009	-0.003	-0.003
			(0.006)	(0.006)	(0.007)	(0.007)	(0.008)	(0.008)
Use clean fuel for cooking			-0.040**	-0.039**	-0.038**	-0.038**	-0.046**	-0.042**
			(0.017)	(0.016)	(0.017)	(0.017)	(0.021)	(0.020)
Have in-house toilet			0.001	-0.001	-0.012	-0.013	0.007	0.003
			(0.022)	(0.022)	(0.025)	(0.025)	(0.027)	(0.027)
Community characteristics	no	no	yes	yes	yes	yes	yes	yes
Province dummy	no	no	no	no	yes	yes	no	no
Year dummy	no	no	no	no	no	no	yes	yes
Observation	926	926	912	912	880	880	796	796
Pseudo R-squared	0.069	0.081	0.192	0.196	0.210	0.214	0.251	0.260

Note: Each column presents the average marginal effect from logit regression. Standard errors are in parentheses and clustered by community. * is p<0.1, ** is p<0.05, and *** is p<0.01.

Table 3.7 Effects of water reform on diarrhea by drinking water sources

	Access to piped water				Access to water from multiple sources			
	Logit model		Probit model		Logit model		Probit model	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Water reform	-0.080***		-0.085***		-0.055*		-0.052*	
	(0.027)		(0.025)		(0.032)		(0.027)	
Water reform · before	0.055**		0.062**		-0.007		-0.004	
	(0.026)		(0.028)		(0.018)		(0.019)	
Corporatization in water		-0.053		-0.060		-0.006		-0.013
		(0.041)		(0.038)		(0.041)		(0.037)
PSP in water		-0.101*		-0.104**		-0.080**		-0.072**
		(0.054)		(0.052)		(0.041)		(0.036)
Corporatization · before		0.052*		0.055*		-0.003		0.001
		(0.029)		(0.030)		(0.023)		(0.023)
PSP · before		0.030		0.042		-0.016		-0.015
		(0.041)		(0.048)		(0.021)		(0.023)
Community characteristics	yes	yes	yes	yes	yes	yes	yes	yes
Province dummy	yes	yes	yes	yes	yes	yes	yes	yes
Year dummy	yes	yes	yes	yes	yes	yes	yes	yes
Observation	768	768	768	768	2295	2295	2295	2295
Pseudo R-squared	0.268	0.275	0.267	0.273	0.231	0.235	0.228	0.233

Note: Each column presents the average marginal effect from separate regressions. Standard errors are in parentheses and clustered by community. * is $p<0.1$, ** is $p<0.05$, and *** is $p<0.01$.

Table 3.8 Treatment effects by gender and age

Dependent variable: diarrhea	(1) Water reform	(2) Corporatization in water	(3) PSP in water
Panel A: by gender			
Female	-0.093***	-0.065	-0.122**
	(0.029)	(0.041)	(0.057)
Male	-0.074***	-0.052*	-0.097*
	(0.023)	(0.030)	(0.051)
Panel B: by age			
Age 0-1	-0.104***	-0.074*	-0.139*
	(0.039)	(0.045)	(0.071)
Age 1-2	-0.103***	-0.074	-0.139**
	(0.036)	(0.045)	(0.068)
Age 2-3	-0.076***	-0.057*	-0.107**
	(0.026)	(0.034)	(0.052)
Age 3-4	-0.061***	-0.049	-0.092**
	(0.022)	(0.030)	(0.045)
Age 4-5	-0.044**	-0.037	-0.070*
	(0.019)	(0.024)	(0.038)

Note: The average marginal effect from probit regressions are reported, with individual, household, and community characteristics as well as year dummy and province dummy included. Standard errors are in parentheses and clustered by community. * is p<0.1, ** is p<0.05, and *** is p<0.01.

Table 3.9 Treatment effects across mother's education levels

	(1) None	(2) Primary school	(3) Lower middle school	(4) Upper middle school	(5) Technical degree	(6) College degree
Water reform	-0.181***	-0.113***	-0.117***	-0.095***	-0.076***	-0.089***
	(0.041)	(0.028)	(0.028)	(0.027)	(0.022)	(0.034)
Corporatization in water	-0.179**	-0.100**	-0.103**	-0.099**	-0.077**	-0.097**
	(0.076)	(0.042)	(0.043)	(0.046)	(0.036)	(0.049)

Note: The average marginal effect from probit regressions are reported, with individual, household, and community characteristics as well as year dummy and province dummy included. Standard errors are in parentheses and clustered by community. * is p<0.1, ** is p<0.05, and *** is p<0.01.

Table 3.10 Results of placebo tests

Dependent variables	Last 4 weeks: fever, sore throat, cough	Last 4 weeks: diarrhea		
	(1)	(2)	(3)	(4)
Panel A: Use piped water as drinking water source				
Water reform	-0.032			
	(0.050)			
Corporatization in water	-0.101			
	(0.064)			
PSP in water	0.134			
	(0.083)			
PSP in sewage treatment		-0.026		
		(0.027)		
PSP in energy			0.010	
			(0.036)	
Panel B: Use groundwater as drinking water source				
Water reform				-0.071
				(0.045)
Corporatization in water				0.006
				(0.059)
PSP in water				-0.058
				(0.049)
Includes child, household, community characteristics	yes	yes	yes	yes
Year dummy	yes	yes	yes	yes
Province dummy	yes	yes	yes	yes
Observation	907	768	768	1169

Note: Each column presents the results from separate regressions. Panels A and B are two subgroups of child sample by the type of drinking water source. Standard errors are in parentheses and clustered by community. * is $p<0.1$, ** is $p<0.05$, and *** is $p<0.01$.

Table 3.11 Effects of water reform on health with rural community sample

	Last 4 weeks: diarrhea				WHZ (US)		HAZ (US)		HAZ (UK)	
	Without matching		Sample on common support							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Water reform	-0.008*		-0.008**		0.014		0.057		-0.026	
	(0.004)		(0.004)		(0.037)		(0.059)		(0.058)	
Corporatization in water		-0.006		-0.007		0.032		0.010		-0.058
		(0.006)		(0.006)		(0.038)		(0.084)		(0.079)
PSP in water		-0.009*		-0.009*		0.004		0.083		-0.008
		(0.005)		(0.005)		(0.046)		(0.059)		(0.065)
Community characteristics	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Year dummy	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observation	950	950	879	879	621	621	597	597	619	619
R-squared	0.096	0.095	0.097	0.096	0.049	0.048	0.069	0.069	0.108	0.107

Note: Each column presents results from separate regressions. Dependent variables in column (7)–(8) use the 2000 CDC Growth Reference in United States, and in column (9)–(10) the 1990 British Growth Reference for the transformation of standardized z-scores. Standard errors are in parentheses and clustered by community. * is $p<0.1$, ** is $p<0.05$, and *** is $p<0.01$.

Table 3.12 Impact of water reform on access to drinking water

Dependent variables	Piped water use		Groundwater use		Surface water use	
	(1)	(2)	(3)	(4)	(5)	(6)
Water reform	0.031***		-0.011**		-0.260***	
	(0.012)		(0.005)		(0.041)	
Corporatization		0.024**		-0.003		-0.272***
		(0.010)		(0.004)		(0.051)
PSP in water		0.042***		-0.022**		-0.239***
		(0.016)		(0.009)		(0.062)
Includes household, community characteristics	yes	yes	yes	yes	yes	yes
Year dummy	yes	yes	yes	yes	yes	yes
Observation	10354	10354	10928	10928	4882	4882
Pseudo R-squared	0.210	0.211	0.195	0.196	0.076	0.076

Note: Each column presents the average marginal effects from separate fixed-effects logit regressions. Standard errors are in parentheses. * is $p<0.1$, ** is $p<0.05$, and *** is $p<0.01$.

Chapter 4

Impact of Southwestern Drought on Energy-Intensive Industries and Water–Energy Nexus

4.1 Introduction

Water and energy security are becoming China's two great challenges, due to the uneven distribution of both types of resources and geographical mismatch between demand and supply. Northern provinces hold only 16% of water resources but account for more than 60% of the national amount of coal, crude oil and electricity production in 2015 (Lin and Chen, 2017). Furthermore, hydropower resources in the western provinces account for 81.46% of the national total, while over half of the net electricity consumption is in eastern coastal provinces (Wei, 2014; Li et al., 2015). China's power demand is expected to rise 65% by 2030 from 2013 (IRENA, 2016), and nine 10-GW coal-power bases will be built in arid regions according to the Energy Development Strategy Action Plan 2014–2020, which will lead to more severe water scarcity (Shang et al., 2016). The Chinese government has proposed dual control actions to promote energy and water conservation in the 13th Five-Year plan. Meanwhile, much effort has been directed toward the development of renewable energy, especially hydropower for CO_2 emission mitigation, energy structure adjustment, and water utilization. However, climate change poses immediate risks to supplies of fresh water for the production of electricity as drought is becoming more frequent and more severe (Eyer and Wichman, 2018). The industrial sector has been the dominant energy consumer in China and accounted for 87% of national total consumption in 2013, of which secondary industry consumes 84% (Wei, 2014). How and to what extent climate change affects economic activities, directly or indirectly through the water–energy nexus, is becoming increasingly uncertain.

The water–energy–climate nexus has received much attention from researchers in recent years. Many comprehensive analyses has been undertaken on the trade-offs between water and energy, incorporating the future impacts of climate change. Through simulation models and life-cycle assessment, researchers have found that water-saving technologies, energy mix, coal consumption and water consumption control policies can reduce water vulnerabilities in the power industry associated with climate change (Koch and Vögele, 2009; Zheng et al., 2016; Zhang et al., 2018; Shang et al., 2018). Zheng et al. (2016) projected the regional water vulnerability of thermal power by a vulnerability index and find that the construction of mine-mouth power plants may aggravate existing vulnerability and turn non-vulnerable regions into vulnerable ones. Other researchers explore the connection between the water–energy–climate nexus and the industrial sector. Gu et al. (2016) use input-output analysis to test the water saving effects of energy conservation policy in the industrial sectors. They suggest that water saving technology application in energy-intensive industries can achieve big water saving effect. Further, Su et al. (2018) projected drought losses under global temperature increase and predicted a considerable reduce in GDP in the absence of climate change mitigation plans. Understanding the water–energy–climate nexus in industries is crucial for exploring the possible adaption measure to climate change.

Apart from simulation assessment, increasing empirical studies also have focused on the effects of weather fluctuations on the water–energy nexus and economic activities. Eyer and Wichman (2018) investigated the effect of water scarcity on the US electricity fuel mix using plant-level data and palmer drought severity index, and they indicated that drought is likely to decreases hydroelectric generation and increase CO_2 emissions and local pollutants in the US. McDermott and Nilsen (2012) provide an empirical evidence from Germany that electricity prices are significantly affected by both falling river levels and higher river temperatures. Furthermore, Zhang et al. (2018), Chen and Yang (2019) estimated the responses of industrial output to temperature changes in China. They find a non-linear relationship, and that high temperature has detrimental effects on output. Chen and Yang (2019) conclud that adaption to warming may have been undertaken in high-temperature regions. On the other hand, as to empirical analysis on drought, most researches focused on its impact on agriculture, ecosystem, or variation of drought patterns.

Very few researchers note the association between persistent drought and output of energy-intensive industries. Moreover, it is not clear how firms respond to long-term water and power shortages during drought. Our study fills this gap in the literature by estimating the linkage between the water–energy nexus and economic activities in the context of persistent drought. We compile a detailed firm panel dataset using the latest firm data from 2006 to 2013 to examine the impact of extreme drought on energy-intensive industries and power production in regions with a high share of hydropower. Second, we investigate the heterogeneity effects of long-term water shortage on firms' responses across industries, regions, and years using differences-in-differences-in-differences (DDD) models.

The remainder of this chapter is organized as follows. Section 2 provides an overview of China's western development policy and the southwestern drought. Section 3 describes the treatment design and estimation strategy. Section 4 explains the data and sampling procedure. Section 5 presents the empirical results and discussions. Conclusions based on our findings are presented in the final section.

4.2 Background

Severe drought of high frequency is one of the most devastating natural disasters to occur in China. Drought-affected areas have greatly increased, and extreme droughts have occurred frequently since 2000 (Xu et al., 2015). Figure 4.1 shows the number of people affected by droughts from 1983 and 2016. Extreme droughts impacted more than 10 million people only occurred five times between 1983 and 1999, however, the occurrence doubled between 2000 and 2016. In particular, the extreme droughts in 2010 and 2011 both caused severe water shortages in affected regions. Furthermore, the growing water scarcity and competition for water supply has transferred the impact of drought to distant cities. Even though extreme drought does not affect the industrial sector directly or immediately, it causes long-term water shortage, high temperatures, and eventually lowers productivity. Over the past 10 years, annual industrial losses from drought conditions have exceeded 230 billion yuan (Zhang et al., 2012). Climate change is predicted to further decrease precipitation and increase drought risks, and more frequent drought events of long duration are projected in the southwestern river basins (Xu et al., 2015; Huang et al., 2018).

[Figure 4.1]

Although the southwestern region is China's most water-abundant region, it is as vulnerable to extreme droughts as China's arid regions are. The southwestern region[24] holds most of the hydropower resources in China, comprising approximately 67% of the total exploitable hydropower resources of the nation (Liu et al., 2018). China has promoted hydropower development in the southwestern region and carried out the Western Development and the West-East Electricity Transmission Project since 2000. The West-East Electricity Transmission Project is designed to optimize the distribution of China's resources and electric power structure, so as to ease electricity shortages in China's developed regions by exploiting resources in the southwestern region (Ming et al., 2013). The southern route of West-East Power Transmission project transmits Guizhou's thermal power and the hydropower of Yunnan, Guizhou, and Guangxi to the Pearl River Delta (Guangdong, Hong Kong, and Macau). In 2010, both the transmission capacity and electricity amount of the southern route were 10 times than that of 2000, with the maximum power capacity of western electricity to Guangdong accounting for 27% of its maximum load, and 30% in the case of Guangxi (Ming et al., 2013). Moreover, as a cost-effective clean energy, hydropower plays a prominent role in China's 12th Five-Year Plan and 13th Five-Year Plan in order to achieve the commitments to reduce greenhouse gases.

The development of hydropower may make the southwestern regions more vulnerable to drought for several reasons. First, various supporting policies and cheap electric hydropower are attractive to firms in energy-intensive and water-intensive industries. Pollution-intensive industries are concentrated in the southwestern region, which may cause water scarcity due to water quality deterioration. According to Table 1, the share of energy-intensive firms in the southwestern region is 8% higher than other regions. Second, industrial agglomerations reliant on hydropower are more easily affected by drought-associated water scarcity. Third, climate change will increase drought risks and more thermal power plants are needed as alternative power of generation, which will further stress the water–energy nexus in this region. However, annual investment in water saving in the southwestern region is less than half of that in other regions, and the water resource fee is also much lower (MOHURD, 2006–2013).

This chapter focuses on the impact of the southwestern drought, referred to as the most severe drought event in a century in southwestern China. During the southwest-

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[24] The southwestern region includes five provinces and one municipality: Guangxi, Sichuan, Guizhou, Yunnan, Xizang, and Chongqing.

ern drought, precipitation dropped 90% and the summer growing season was 1.5 degrees Celsius hotter than normal (Zhang et al., 2012). The drought began in October 2009 and its impact lasted more than a year. It affected Yunnan, Guizhou, and Guanxi provinces and spread into parts of Sichuan Province and Chongqing, affecting 60 million people and 6.5 million hectares of agricultural land. As reported in the 2011 China Electric Power Yearbook, the hydropower generation of Guizhou and Guangxi in 2010 decreased 14% and 25%, respectively, from 2009 because of the drought. Moreover, the southwestern drought reduced the operating hours of hydropower considerably, and the electricity transmitted to Guangdong province also reduced 6 billion kWh by the end of 2010. Some of the provinces and cities had to implement power rationing to deal with the long-term power shortage.

The southwestern drought provides a good treatment for our analysis on the impact of persistent drought on the water–energy nexus and the economic activities of energy-intensive industries. We develop three hypotheses based on the above background information. First, we assume that energy-intensive industries will be more affected than non-energy-intensive industries, due to the damage caused to hydropower. Second, the accumulative effects on the power industry will be much lower than on other industries, because the drought will shift the electricity mix from hydropower generation to thermal power generation. Last, the effects of the southwestern drought may vary across ownership types, because private firms are more profit driven than state-owned enterprises (SOEs) are.

4.3 Estimation Strategy

4.3.1 *Treatment Indicators*

To examine the impact of drought on industrial activities and power mix, we construct two treatment indicators for the differences-in-differences-in-differences (DDD) analysis. We use the first treatment variable *Drought*, to capture the effect of being a province hit by the southwestern drought, and the second treatment variable *Energy*, to capture the effect of being a firm in energy-intensive industries. We interact these two treatments to identify the effect of being an energy-intensive firms in drought-hit areas.

Figure 4.2 shows the geographical division of the treatment group and the control group by *Drought*. The treatment group includes five southwestern provinces: Sichuan, Chongqing, Guizhou, Yunnan, and Guangxi. Regarding the control group, our primary concern is the impact of other severe droughts between 2006 and 2013. As mentioned in Section 2, two extreme droughts occurred during our study period, the southwestern drought and the 2011 drought in northern China, which both caused large damage and water shortages. However, the 2011 drought affected most of wheat-producing regions, and thus, the influence on the industrial sector was very limited. To consider the impact of the 2011 drought, we divide the control group into two to distinguish the provinces affected. We keep Tibet in control group 2 because only 1% of firms are located in Tibet. According to the EM-DAT database, the southwestern drought started in October 2009, and therefore, we set 2008 as the baseline year. Furthermore, we use province and year fixed effects to control for the impact of the 2008 Sichuan earthquake.

[Figure 4.2]

4.3.2 *Industrial Outcome Model*

We estimate the average effect of the southwestern drought on the industrial outcomes of energy-intensive industries using the following equation.

$$LogY_{ijt} = \sum_{e \in E \in n} \beta^e (Drought_j \times Post_t \times Energy_i^e) + \delta_{jt} + \theta_{nt} + \lambda_{nj} + \mu_i + \eta_t + \varepsilon_{ijt} \qquad (4.1)$$

where $LogY_{ijt}$ is the logarithm of industrial outcome of firm i in province j in year t. $LogY_{ijt}$ contains two outcome measures: log output and log revenue. $Drought_j$ is a province dummy that equals one if province j was struck by the southwest drought and zero otherwise. $Post_t$ is a dummy variable that indicates the post-drought period; it equals one if t>2008 and zero otherwise. $Energy_i^e$ is a dummy indicator for each firm's industry type e, which is included in the two-digit industry E (energy-intensive industries), E=10, 25, 26, 32, 33, 44 (See Table 4.9 on the detailed information of industry classification codes). n represents all two-digit industries, n=06, $\cdots$, 46. We include δ_{jt}, θ_{nt}, λ_{nj} to capture the effects of unobservable regional policy, industrial regulation, economic shock, etc. in a given province and year, industry and year, and industry and province. Firm fixed effect μ_i controls for unobservable time-invariant firm characteristics. η_t is a year effect common to all firms in period t, controlling for national energy policy and environmental regulation over time. ε_{ijt} is the error item. We allow for correlation within two-digit industries, and spatial correlation across industries within a given province and year by clustering the standard errors.

Our interest lies in the parameter of the triple term β^e. We examine the separate effects of drought on non-power industries (10, 25, 26, 32, 33) and the power industry (44). In our analysis, non-power industries are defined as five two-digit energy-intensive industries other than the power industry. The power industry in one region could be less damaged than non-power industries during drought, depending on the energy mix of that region. If the alternative electricity resource is sufficient enough, the power industry can continue the electricity production to meet the urgent needs. To shed light on the specific effects of the southwestern drought on the power industry [25], we further investigate the effects of drought on hydropower, thermal power, and the other electric power industries. We assume $\beta^{power} > \beta^{non-power}; \beta^{hydro} < 0; \beta^{thermal} > 0; \beta^{other} > 0$.

To examine how treatment effects vary across drought-hit provinces and years, we use the following equation (4.2) to estimate DDD models with multiple provinces or multiple time periods.

$$LogY_{ijt} = \sum_{j=1}^{5} \sum_{e \in E \in n} \beta^e (Drought_j \times Post_t \times Energy_i^e) + \delta_{jt} + \theta_{nt} + \lambda_{nj} + \mu_i + \eta_t + \varepsilon_{ijt} \quad (4.2)$$

where j=1, $\cdots$, 5, representing Guangxi, Chongqing, Sichuan, Guizhou, and Yunnan. For estimation with multiple time periods, we replace $\sum_{j=1}^{5}$ with $\sum_{t=-2}^{5}$, where t=-2, -1, 1, 2, 3, 4, 5, indicating the 2 years prior to the baseline—2006, 2007—and the 5 years after the baseline—2009 to 2013. Apart from logged output and revenue, two more dependent variables are added, namely, logged form of employment and log assets, for these two analyses. Employment indicates the average annual number of employees, which shows the scale and growth potential of a firm. Assets indicate the firm's total assets, including fixed assets and current assets. The estimation results are reported in Table 4.7 and Table 4.8.

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[25] The power industry includes six four-digit industries: hydropower industry, thermal power industry, nuclear power industry, other electric power industry, electricity supply industry, and heating power industry. We combine nuclear power with other power industry because of its limited size. In this analysis, we focus on electric power industries.

4.4 Data Description

We use several data sources for the empirical estimations. The main data source is the NBS Annual Industrial Firm Survey. We construct a balanced 8-year firm-level panel dataset from 2006 to 2013 to estimate the industrial outcome model. This firm sample includes 97,388 firms and 779,104 observations from 41 two-digit industries. Drought data are obtained from the EM-DAT database, which contains data on the occurrence, location, and effects of severe droughts in China from 1920 to 2019. We use this database to identify the provinces affected by other severe droughts other than the southwestern drought during our study period.

4.4.1 Firm Data

The NBS industrial firm survey covers all industrial enterprises above designated size from 1998 to 2013. The definition of industrial enterprises above designated size was changed twice in 2007 and 2011. The term was first used from 1996 to 2007 to refer to any SOE (no threshold), and non-SOE with main annual business revenue of 5 million yuan or more. From 2007 to 2010, SOEs under designated size were excluded. Then, the threshold was increased to 20 million yuan from January 2011 to be categorized as an industrial enterprise above designated size. Since we use a panel data from 2007 to 2013, firms in our sample are industrial enterprises with main annual business revenue of 20 million yuan or more.

Several variables can be used to identify a firm: unique matching identification (ID), firm ID, administrative code, industry code, firm name and legal representative. Each firm has a firm ID, but firms can change their IDs as a result of restructuring, acquisition, or merging (Zhang et al., 2018). We use the unique matching ID to merge firm data over time. Furthermore, to ensure that the matching ID does not change like the firm ID, we follow previous studies to match firms for double-checking (Zhang et al., 2018; Chen and Yang, 2019). This dataset includes three secondary industry sectors—Mining and quarrying; manufacturing; and utilities—and 41 two-digit industries, which is consistent with the China Industry Classification System GB/T4754-2011. Each firm has a four-digit Standard Industrial Classification (SIC) code, which is used to identify its specific industry sector.

Figure 4.3 (a) shows the distribution of firm numbers for two-digit non-energy-intensive industries and energy-intensive industries by province. Most of the energy-intensive industries are located in the eastern coastal provinces in the control group, and Sichuan province in the treatment group. We can observe a similar distribution of power firms in Figure 4.3 (b), which suggests that the agglomeration of energy-intensive industries is highly power-driven. Although nuclear power and renewable energies have developed rapidly in the last decade, thermal power and hydropower still dominate the market. Large thermal power firms are concentrated in the eastern coastal region and central China, while half of the large hydropower firms are in the southwestern region.

[Figure 4.3]

4.4.2 *Dependent Variables*

An inherent weakness of the dataset is that there is a large amount of missing data on the main information in the surveys after 2007. The survey in 2010 contains only very straightforward industrial outcome data of revenue, employment, and total assets. Moreover, we collect the data of annual average number of employees before 2010, but after 2010, only the total number of employees at the end of the survey year are available. We combine them to construct the measure of employment. Finally, we collect 7 years of data on output, and 8 years of data on revenue, employment, and total assets as dependent variables. We drop the unreasonable data, such as negative values for our dependent variables and firm age. The rest of the data are used to compile an 8-year balanced panel dataset for our analysis.

According to the summary statistics in Table 4.1, the average share of energy-intensive firms is 12.9% in the control group, among which 10.9% are non-power firms and 2% are power firms. In the treatment group, the average share of energy-intensive firms, non-power firms, and power firms is 21%, 14%, and 7%. The southwestern region has less energy-intensive firms in absolute value, but a larger share of firms in both non-power industries and the power industry. However, the share of thermal power firms is much lower in the treatment group than in the control group. According to the results, 40% of power firms are hydropower firms in the treatment group, compared to 10% in the control group.

[Table 4.1]

4.5 Results

4.5.1 *Baseline Results*

We report the baseline regression results in Table 4.2 by estimating equation (4.1) with full sample, including control groups 1 and 2. Table 4.2 reports the effects of the southwestern drought on logged output and log revenue. We control for province and year fixed effects, province and two-digit industry fixed effects, year and two-digit industry fixed effects, and year fixed effects in all the models. Firm fixed effects are included as well in models (2)–(4) and models (6)–(8).

The results in columns (1)–(4) show that the southwestern drought has a negative but insignificant impact on the output of energy-intensive firms, while the effect on non-power firms is negative and significant at the 5% level. In contrast to these two industries, in the power industry, the drought shows a positive but insignificant effect, which may offset part of the shock on energy-intensive industries. The southwestern drought affects four-digit power industries significantly in the opposite way: it reduces the output of hydropower firms by 19.7%, but increases the output of thermal power firms and other power firms by 34.9% and 52.7%, respectively.

Columns (5)-(8) presents the estimated effects on logged revenue across different types of energy-intensive firms. The losses in revenue are larger than those in output for non-power firms and hydropower firms, 9.8% and 21.3% respectively. Other power firms experience an increase of 21.6% in revenue. However, the southwestern drought is associated with a reduction of 8.6% in revenue of thermal power firms, despite the increase in output. Several reasons could explain this difference. First, the positive impact on revenue did not last, which we investigate later with multiple-period regressions. Second, electricity may have been primarily provided for disaster relief during drought, which may have led to a decrease in sales of thermal power firms. Last, energy market status such as seasonal change in thermal coal prices and lack of coal reserves, could also influence revenue.

[Table 4.2]

We run another estimation with control group 1 for robustness check. The results in Table 4.3 remain robust when we drop control group 2, which implies that the influence from the 2011 drought is too small to be taken into account.

[Table 4.3]

4.5.2 *Results after Matching*

Although the southwestern drought is a random shock, we are concerned about the potential self-selection bias in our firm sample. As mentioned above, the three most developed economic zones[26] in eastern coastal China have always been the first options for firms' location, especially large private firms. Meanwhile, the West Triangle Economic Zone is still under design, as a component of the Western Development policy. We have good reasons to believe that firms move to or start from southwestern China maybe somewhat different from firms in other regions at the firm level.

We use the nearest-neighbor matching method to address this issue. Three firm characteristics are selected as covariant variables for matching: firm age, total assets and employment. We keep firms from the baseline year 2008, and employ the one-to-one nearest neighbor matching with replacement using a 0.05 caliper to reduce the likelihood of poor matches. In addition, balancing tests after matching are performed to check whether firms in the treatment group and the control group are well balanced. Table 4 shows the t-test results and there is no statistically significant difference between treated mean and control mean after matching. Firms off support in the control group are dropped, and we compile a new panel data sample with the rest of the firms.

The estimation results are reported in Table 4.5. We find they are quite similar to the baseline results. Our results are robust across different samples. In conclusion, the southwestern drought is associated with an average decrease of 8.6% and 9.2% in output and revenue of non-power firms in drought-hit regions, that is, 3.87 million yuan and 4.31 million yuan, respectively, for each firm. In power industries, hydropower firms sustain the most severe damage. The southwestern drought reduces output and revenue by 19.7% and 21.4%, respectively, and the loss is 0.65 million yuan for output and 0.72 million yuan for revenue on average. By contrast, the drought increases output of thermal power firms by 34.9%, but it decreases revenue by 8.7%. As for other power firms, the drought is associated with a significant increase in both output and revenue, although the absolute size of the

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[26] The Yangtze River Delta Economic Zone, Jingjinji Metropolitan Region, and Pearl River Delta Economic Zone

increase is not so large, because of their low share in total output and firm number. Consequently, the accumulative effect on energy-intensive industries is negative, and larger than other industries in southwestern regions, while the accumulative effect on the power industry is insignificant. Our findings are consistent with Eyer and Wichman (2018). They find that water scarcity will likely shift the U.S. electricity mix from relatively water-intensive of generation towards alternative sources of generation. In our case, devastating drought, like the southwestern drought, will induce more thermal power production in China.

[Table 4.4]

[Table 4.5]

4.5.3 *Heterogeneity Across Firm Ownership Type*

To investigate heterogeneous impacts of drought on firms with different ownership, we collect information on firms' ownership type to perform more thorough estimations. There are six firm ownership types for firms, namely, SOE, collective-owned enterprise (COE), private firm, foreign firm, Hong Kong, Macao and Taiwan firm, and mixed-ownership firm (Chen and Yang, 2019). Our analysis does not include Hong Kong, Macao and Taiwan firms, and mixed-ownership firms owing to their lack of clarity. Several studies have shown that different firm types (ownership type specifically) tend to behave differently to external shocks.

Zhang et al. (2010) investigate how ownership affects corporate philanthropic disaster response decisions in the aftermath of the 2008 Sichuan Earthquake. They find that non-state-owned firms are more strategically motivated and economically driven to engage in corporate philanthropic disaster response than state-owned firms are. Cai et al. (2016) study firm heterogeneity in responding to environmental regulations. They find that private firms are cost sensitive and less environmentally conscious than SOEs and foreign firms are, and take more actions to avoid stringent policies. Zhang et al. (2018) examine the heterogeneity in temperature effects across firm ownership types, and suggest that the effects of high temperatures on output may be stronger in private firms than in state-owned firms, because of the weaker enforcement of labor regulations in private firms. Furthermore, the magnitude of temperature effects is linked to the sample share of each ownership type.

We examine the effects of the southwestern drought on output and revenue of SOEs, COEs, privates firms, and foreign firms to infer their possible responses to drought strike. The share of each type in the balanced firm sample is 6.84%, 4.55%, 66.11%, and 10.31%, respectively. In the treatment group, the observation percent for each type is 15.58%, 5.36%, 69.65%, and 3.09%, respectively. Private firms comprise largest share in both the control and the treatment groups for non-power industries. However, for the power industry in the treatment group, SOEs comprise the largest share: 56.41% for hydropower and 85.83% for thermal power.

We present the results in Table 4.6. Columns (1)–(8) show the estimated effects of the southwestern drought on output and revenue. In non-power industries, the drought reduces output and revenue of SOEs by 16.3% and 14.2% respectively, and the coefficients are statistically significant at the 1% level. The effects on COEs are insignificant. Private firms experience less damage in output and revenue, although they comprise the largest share in the sample. In the hydropower industry, both SOEs and COEs bear large losses of more than 20% in output and revenue. Meanwhile, in the thermal power industry, the drought increases the revenue of COEs by 25.9%, but decreases the revenue of SOEs by 12.3%. Compared to private firms and foreign firms, SOEs are less cost-sensitive (Cai, 2016) and more locally based. They may play the role of a social network during drought to adjust the energy market rather than make profits. COEs are also locally based, but they are more flexible and less responsible. Private firms experience less damage to the hydropower industry as well, but benefit the most from the thermal power industry. As implied in prior studies, private firms are more cost sensitive and profit driven, and thus, they may respond negatively to power rationing during drought. Another possible reason is that many private firms are located in less damaged urban areas. Foreign firms sustain the worst damage in all industries, even though their sample share is the smallest in the treatment group. They are more likely to follow the power rationing policy, and they do not have enough capacity to deal with extreme drought, which may lead to significant damage to their production.

[Table 4.6]

4.5.4 *Effects on Power Production by Province and Year*

The effects of drought may vary across provinces. Firms in worst-hit provinces may suffer more damage. Furthermore, energy mix, power plant scale, and infrastructures in one province may affect firms' responses to long-term droughts. We present the results in Table 4.7 and Table 4.8 by estimating equation (4.2). Figure 4.4 shows the heterogeneity effects of the southwestern drought on output, revenue, employment, assets. We find that the power industry is more affected by the drought in Guizhou and Yunnan, because they are the worst-hit provinces. The southwestern drought shifts the electricity mix of these two provinces from hydropower of generation towards thermal power of generation. However, hydropower share in Guizhou's energy mix is much smaller than in Yunnan, and thus, the southwestern drought induces a large increase in its thermal power production, 189.1% for output and 84.3% for employment. Although Chongqing sustains less damage from the drought, there is a significant increase of 52% in the employment of thermal power firms there, because of its lower hydropower share and large electricity demand. This shift is not observed in the other two provinces, but the output and revenue of their hydropower firms are all negatively and significantly affected. Sichuan province is very close to three largest hydroelectricity power stations in China, the Three Gorges Dam, Xiluodu Dam, and Xiangjiaba Dam, which makes it more adaptable to extreme droughts. The southwestern drought also decreases the assets of firms in all industries, and reduces long-term investment. The consumption of inventory for production during drought may could explain this.

[Table 4.7]

[Figure 4.4]

Figure 4.5 reveals the estimated effects on power production over time. Figures 4.5-(a) and 4.5-(b) show the effects on output and revenue of the power industry. We find a similar trend in these two figures. The negative effects on output and revenue of hydro firms lasted 5 years from 2009 to 2013, and the largest decreases of 20.8% for output and 27.6% for revenue are in 2011. On the other hand, the positive effects on output and revenue of thermal firms lasted 3 years, but the strongest effects are in 2009 then the effects become weaker. Figure 4.5-(c) shows that the southwestern drought decreased employment in hydropower firms, but employment was quickly restored right after the drought mitigated in

2011. The effects on employment of thermal power firms lasted longer and peaked in 2011. Finally, the negative effects on assets lasted for a long time and showed no sign of dissipating. The motivation of long-term investment in the power industry in the southwestern region could be influenced by the drought. We also explore the effects on the production of other power firms, but they are not shown, because their sample share is too small to reveal the long-term effects. The other power firms respond positively and quickly to the drought, and they could be good alternative source of power generation in the short-term.

[Table 4.8]

[Figure 4.5]

4.6 Conclusions

In this chapter, we examine the impact of the southwestern drought on the production of energy-intensive industries and power production. We use an 8-year firm level balanced panel dataset to employ specific estimations on the responses of energy-intensive firms to long-term water shortage and power shortage caused by extreme drought. We find that the southwestern drought affects energy-intensive firms from different industries in various ways. Firms in non-power industries sustained more damage during drought than firms in power industries in southwestern region. Meanwhile, the accumulative effects on the power industry depend on the regional energy mix. Since long-term water shortage devastated hydropower generation, the southwestern drought induced more thermal power generation. Our findings suggest that energy-driven industries are vulnerable to extreme climate changes, especially in regions with high drought-hit frequency. Drought adaptive measures may be more necessary in water abundant undeveloped regions, alongside development policies.

We also find that ownership type may affect firms' response to disasters. In this case, collective-owned firms and private firms in energy-intensive industries are damaged the least, and benefit the most from the southwestern drought. They may adopt two behavioral patterns in response to policies like powering rationing during drought. If they respond positively, they may have developed adaptive behaviors towards disasters like droughts. However, if they respond negatively, they may simply ignore the policy and cause more damage to the total welfare. Moreover, foreign firms sustain the largest damage during drought, and this could influence investments. SOEs, on the contrary, may play a more social role or political role during drought. The distribution of firms' ownership type in one region could also be an important consideration for disaster management policies.

This study has several limitations. First, the representativeness of this study is limited. We focus on an extreme drought in regions with a high share of hydropower. Future studies could explore the impacts of different disaster types on power industries and electricity mix. It is also possible that extreme droughts have different effects on energy-intensive industries in arid regions. Second, Missing data may result in estimation bias. The main dependent variables of output and assets include a large amount of missing data, while the employment variable is not unified before and after 2010. More thorough surveys are needed for more accurate analysis. At last, this study focuses only on the production activities, whereas future research is also needed on the association between extreme disasters and firm location choices or firm migration behaviors, to shed further light on the response decisions of firms towards disasters.

In conclusion, local governments maybe motivated to develop hydropower resources, but climate change has posed a challenging issue for water-intensive power firms. Our results suggest that the effects of extreme drought vary across regions and last a long time. Not only can hydropower be used for drawing capital and advanced technologies for local governments, but more policies should be implemented to support their roles in strengthening energy guarantees and fighting climate change.

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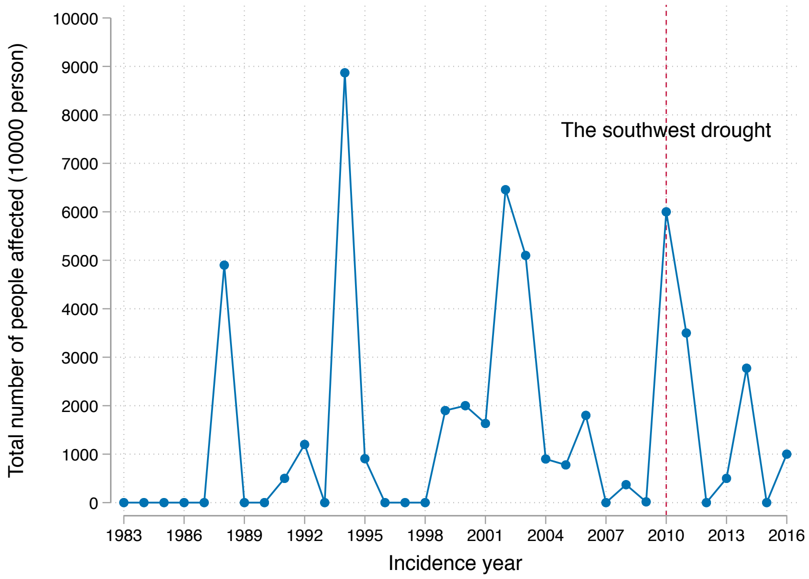
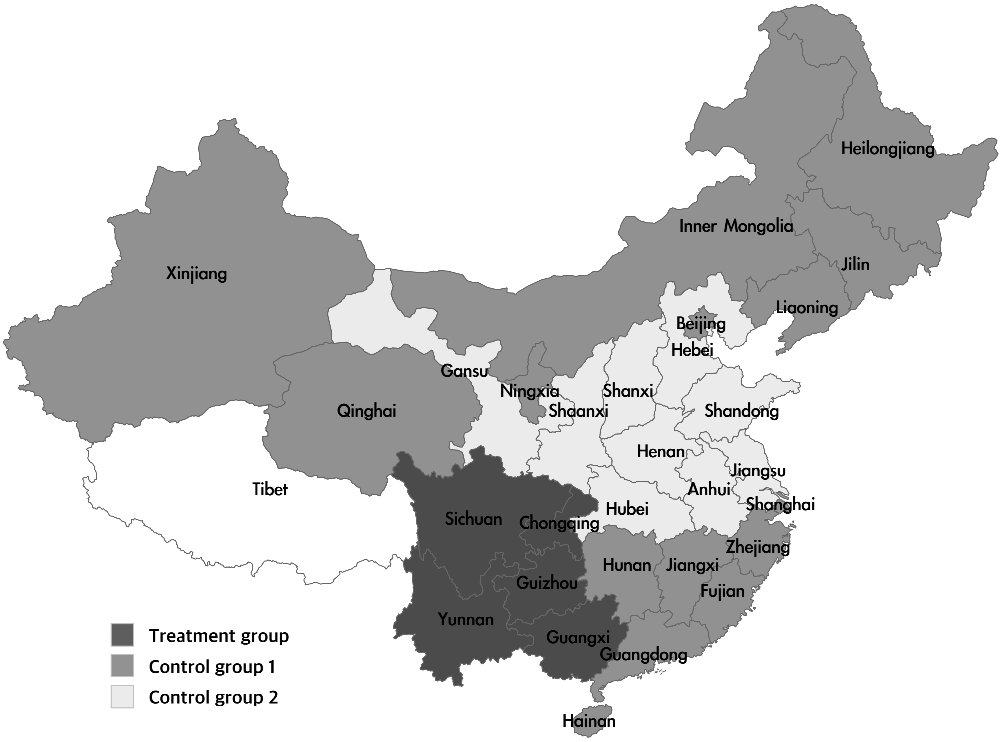


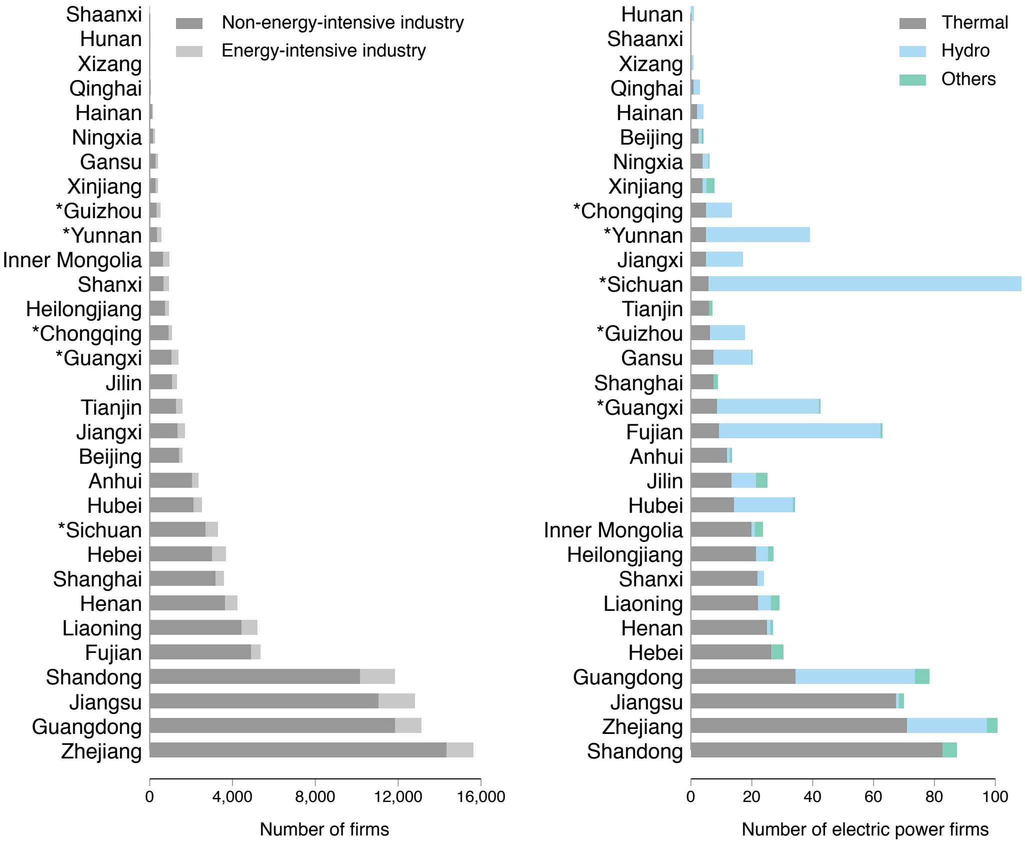
Source: EM-DAT Database, 1983–2016; China Meteorological Administration, 2013.
Note: The southwest drought lasted from October 2009 to April 2010.

Fig. 4.1. The trend in drought occurrence



Source: EM-DAT Database, 2006–2013. Note: Control group 2 includes provinces hit by the 2011 drought after the southwest drought. The 2011 drought affected most of wheat-producing regions over the middle and lower reaches of Yangtze River. Water shortage associated with the occurrence of both droughts.

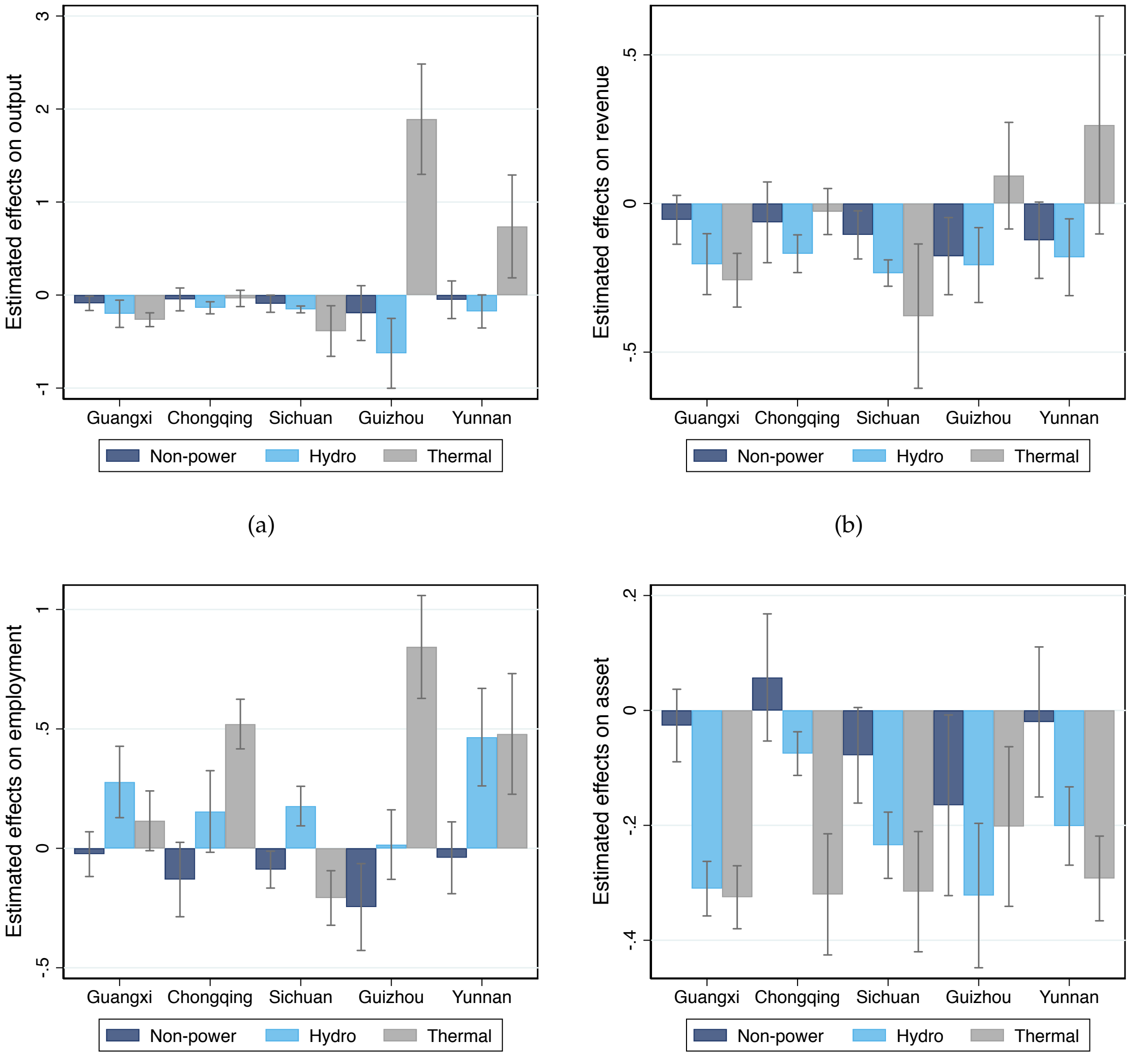
Fig. 4.2. Treatment group and control group



(a) (b)

Source: NBS Annual Industrial Firm Survey, 2006–2013. Note: Figure (a) shows the distribution of firm numbers for two-digit non-energy-intensive industries and two-digit energy-intensive industries. Figure (b) shows the distribution of firm numbers for four-digit electric power industries. The total number of firms is 97388, and * indicates treatment group.

Fig. 4.3. Distribution of firm numbers by province and industry

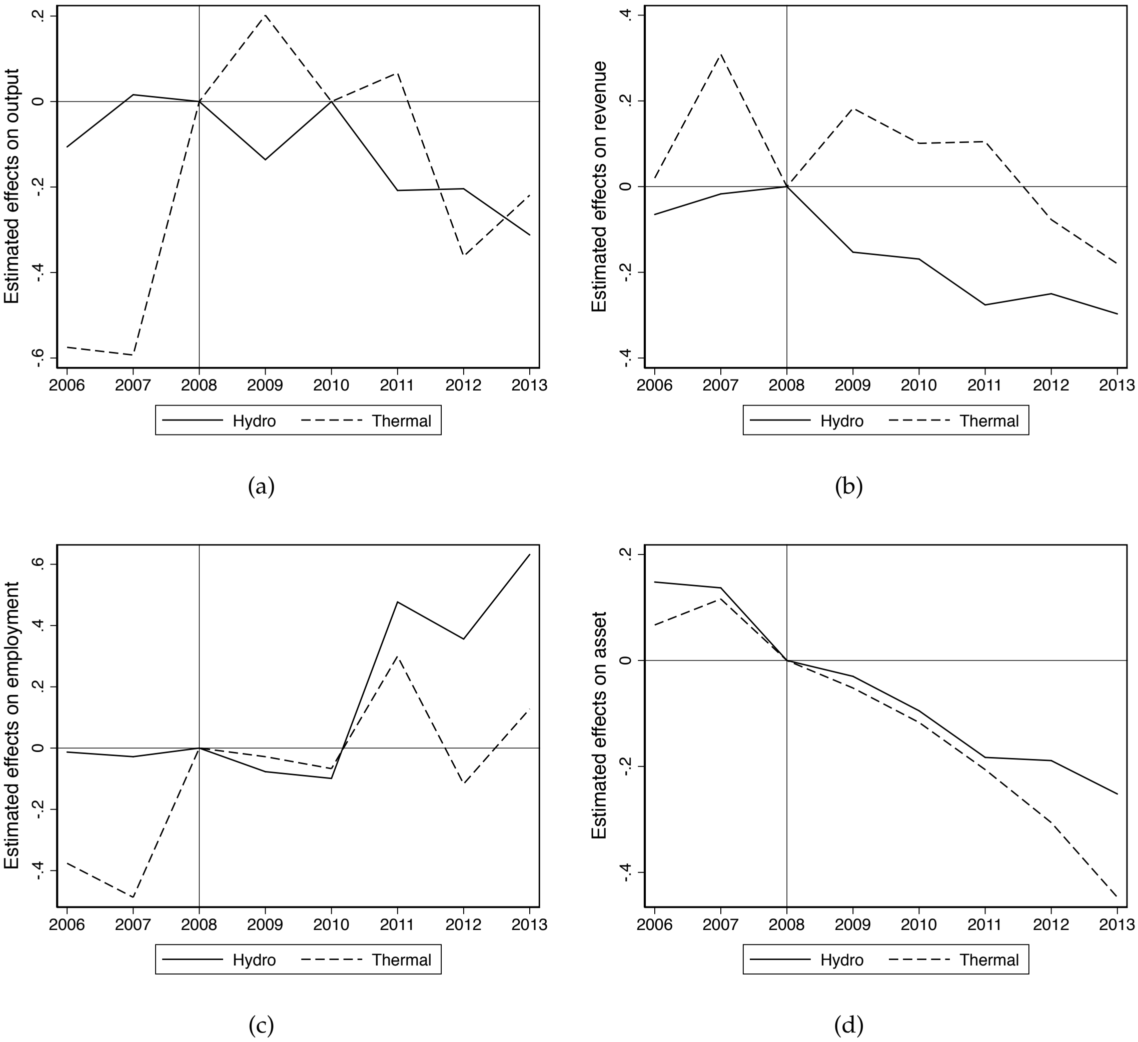


(a) (b)

(c) (d)

Note: The above figures plot the estimated effects of drought on log output, log revenue, log employment, log assets across drought-hit provinces. The 95% confidence bands are added as gray solid lines. Coefficients are obtained from estimating equation (4.2).

Fig. 4.4. Estimated effects on industrial outcomes by province



(a)

(b)

(c)

(d)

Note: The above figures plot the coefficients from estimating equation (4.2), DDD models with multiple time periods. 2008 is the baseline. Figure (a) shows the annual effects of southwest drought on log output of electric power firms, and the effect of 2010 is automatically generated by averaging the effects of 2009 and 2011.

Fig. 4.5. Estimated effects on power production over time

Table 4.1 Summary statistics

	Control group (1+2)			Treatment group		
Variable	Mean	Std. Dev.	N	Mean	Std. Dev.	N
Industrial outcome data						
Output (million yuan)	270.641	2238.737	593,809	255.032	1505.751	45,113
Revenue (million yuan)	284.572	2504.801	724,483	257.355	1604.025	54,534
Log output	11.164	1.357	593,809	11.202	1.390	45,113
Log revenue	4.327	1.281	724,483	4.340	1.300	54,534
Firm characteristics						
Age	12.277	9.249	724,458	13.953	11.831	54,544
Employment (person)	428.108	1847.109	684,525	431.402	1147.841	51,990
Assets (million yuan)	233.424	3128.126	724,501	257.084	1713.063	54,543
Energy-intensive industry data						
Energy-intensive firm	0.129	0.335	724,556	0.210	0.407	54,548
Non-power firm	0.109	0.312	724,556	0.140	0.347	54,548
Power firm	0.020	0.140	724,556	0.070	0.255	54,548
Hydropower firm	0.002	0.046	724,556	0.028	0.165	54,548
Thermal power firm	0.005	0.073	724,556	0.005	0.067	54,548
Other power firm	0.0004	0.019	724,556	0.00006	0.007	54,548

Source: NBS Annual Industrial Firm Survey (2006–2013). Note: All monetary variables are deflated to 2015 yuan using GDP deflator (2015=1; World Bank, 2019). We divide two-digit energy-intensive industries into non-power industries and the power industry; the power industry contains 6 four-digit industries, including: hydro electric power industry, thermal electric power industry, nuclear electric power industry, other electric power industry, electric power supply industry, and heat power industry. We focus on electric power generation firms in this study; nuclear power firms are combined with other power firms as other power.

Table 4.2 Baseline results with full sample

	Log output				Log revenue			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Drought × Post × Energy	-0.077	-0.053			-0.100	-0.070**		
	(0.062)	(0.047)			(0.062)	(0.032)		
Drought × Post × Non-power			-0.086**	-0.092**			-0.092***	-0.098***
			(0.037)	(0.036)			(0.026)	(0.026)
Drought × Post × Power			0.021				-0.018	
			(0.037)				(0.029)	
Drought × Post × Hydro				-0.197***				-0.213***
				(0.018)				(0.017)
Drought × Post × Thermal				0.349***				-0.086**
				(0.052)				(0.034)
Drought × Post × Other				0.527***				0.216***
				(0.024)				(0.025)
Firm FE	no	yes	yes	yes	no	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes	yes	yes
Year-province FE	yes	yes	yes	yes	yes	yes	yes	yes
Year-industry FE	yes	yes	yes	yes	yes	yes	yes	yes
Province-industry FE	yes	yes	yes	yes	yes	yes	yes	yes
Observations	638905	638905	638905	638905	778997	778997	778997	778997
Adjust R^2	0.221	0.844	0.844	0.844	0.222	0.885	0.885	0.885

Note: Dependent variables are logged form of output and revenue. Each column presents the results from DDD model estimated by high-dimensional fixed-effects regressions. The constant term is included but not reported. Standard errors are in parentheses clustered at two-digit industry, and year-province levels. * is $p<0.1$, ** is $p<0.05$, and *** is $p<0.01$.

Table 4.3 Estimated effects on energy-intensive industry with control group 1

	Log output				Log revenue			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Drought × Post × Energy	-0.042	-0.045			-0.073**	-0.073***		
	(0.039)	(0.039)			(0.034)	(0.026)		
Drought × Post × Non-power			-0.066**	-0.071**			-0.081***	-0.085***
			(0.032)	(0.031)			(0.025)	(0.024)
Drought × Post × Power			0.006				-0.053	
			(0.040)				(0.033)	
Drought × Post × Hydro				-0.217***				-0.246***
				(0.017)				(0.018)
Drought × Post × Thermal				0.330***				-0.120***
				(0.060)				(0.034)
Drought × Post × Other				0.527***				0.201***
				(0.030)				(0.026)
Firm FE	no	yes	yes	yes	no	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes	yes	yes
Year-province FE	yes	yes	yes	yes	yes	yes	yes	yes
Year-industry FE	yes	yes	yes	yes	yes	yes	yes	yes
Province-industry FE	yes	yes	yes	yes	yes	yes	yes	yes
Observations	383830	383829	383829	383829	468835	468833	468833	468833
Adjust R^2	0.222	0.885	0.885	0.885	0.212	0.884	0.884	0.884

Note: Dependent variables are logged form of output and revenue. Each column presents the results from DDD model estimated by high-dimensional fixed-effects regressions. The constant term is included but not reported. Standard errors are in parentheses clustered at two-digit industry, and year-province levels. * is $p<0.1$, ** is $p<0.05$, and *** is $p<0.01$.

Table 4.4 Balancing test results

Variable	Unmatched/Matched	Treated mean	Control mean	%Bias	%Reduct bias	T-test (P-value)
Age	U	12.511	10.796	16.4		0.000
	M	12.511	12.517	-0.1	99.7	0.977
Assets	U	183.93	173.33	0.7		0.667
	M	183.93	231.87	-3.0	-351.8	0.435
Employment	U	383.43	389.55	-0.4		0.787
	M	383.43	394.19	-0.7	-75.9	0.533

Table 4.5 Estimated effects on industrial outcomes with balanced sample

	Log output		Log revenue	
	(1)	(2)	(3)	(4)
Drought × Post × Non-power	-0.086**	-0.092**	-0.092***	-0.098***
	(0.037)	(0.036)	(0.026)	(0.026)
Drought × Post × Power	0.022		-0.019	
	(0.037)		(0.029)	
Drought × Post × Hydro		-0.197***		-0.214***
		(0.018)		(0.017)
Drought × Post × Thermal		0.349***		-0.087**
		(0.052)		(0.034)
Drought × Post × Other		0.528***		0.217***
		(0.024)		(0.024)
Firm FE	yes	yes	yes	yes
Year FE	yes	yes	yes	yes
Year-province FE	yes	yes	yes	yes
Year-industry FE	yes	yes	yes	yes
Province-industry FE	yes	yes	yes	yes
Observations	638314	638314	778293	778293
Adjust R^2	0.843	0.843	0.884	0.884

Note: Dependent variables are logged form of output and revenue. Each column presents the results from DDD model estimated by high-dimensional fixed-effects regressions. The constant term is included but not reported. Standard errors are in parentheses clustered at two-digit industry, and year-province levels. * is p<0.1, ** is p<0.05, and *** is p<0.01.

Table 4.6 Estimated effects on industrial outcomes by ownership type

	Log output				Log revenue			
	SOE (1)	COE (2)	Private (3)	Foreign (4)	SOE (5)	COE (6)	Private (7)	Foreign (8)
Drought × Post × Non-power	-0.163***	0.043	-0.056	-0.272***	-0.142***	0.022	-0.062**	-0.230***
	(0.052)	(0.100)	(0.041)	(0.070)	(0.049)	(0.085)	(0.029)	(0.080)
Drought × Post × Hydro	-0.219***	-0.245***	-0.015	-0.165***	-0.225***	-0.219***	-0.062***	-0.112
	(0.033)	(0.051)	(0.012)	(0.058)	(0.029)	(0.034)	(0.021)	(0.084)
Drought × Post × Thermal	0.277***	0.396***	0.000	-0.247***	-0.123***	0.259***	0.266***	-0.196**
	(0.079)	(0.058)	(0.000)	(0.083)	(0.026)	(0.064)	(0.032)	(0.097)
Firm FE	yes	yes	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes	yes	yes
Year-province FE	yes	yes	yes	yes	yes	yes	yes	yes
Year-industry FE	yes	yes	yes	yes	yes	yes	yes	yes
Province-industry FE	yes	yes	yes	yes	yes	yes	yes	yes
Observations	44315	29026	423245	62421	52628	33963	512958	79080
Adjust R^2	0.907	0.883	0.832	0.870	0.946	0.912	0.871	0.916

Note: Dependent variables are logged form of output and revenue. Each column presents the results from DDD model estimated by high-dimensional fixed-effects regressions. The constant term is included but not reported. Standard errors are in parentheses clustered at two-digit industry, and year-province levels. * is $p<0.1$, ** is $p<0.05$, and *** is $p<0.01$.

Table 4.7 Estimated effects on power industries across drought-hit provinces

	e=Hydropower				e=Thermal power			
	Output (1)	Revenue (2)	Employment (3)	Asset (4)	Output (5)	Revenue (6)	Employment (7)	Asset (8)
Guangxi × Post ×$Energy^e$	-0.201***	-0.204***	0.278***	-0.310***	-0.265***	-0.258***	0.115*	-0.325***
	(0.072)	(0.051)	(0.074)	(0.023)	(0.037)	(0.045)	(0.062)	(0.027)
Chongqing × Post ×$Energy^e$	-0.137***	-0.169***	0.154*	-0.075***	-0.036	-0.027	0.520***	-0.320***
	(0.032)	(0.031)	(0.085)	(0.019)	(0.043)	(0.038)	(0.051)	(0.052)
Sichuan × Post ×$Energy^e$	-0.154***	-0.234***	0.177***	-0.235***	-0.387***	-0.379***	-0.208***	-0.315***
	(0.018)	(0.022)	(0.041)	(0.029)	(0.135)	(0.120)	(0.056)	(0.052)
Guizhou × Post ×$Energy^e$	-0.626***	-0.207***	0.016	-0.322***	1.891***	0.094	0.843***	-0.202***
	(0.186)	(0.062)	(0.072)	(0.062)	(0.293)	(0.089)	(0.107)	(0.069)
Yunnan × Post ×$Energy^e$	-0.176*	-0.181***	0.466***	-0.201***	0.738**	0.264	0.479***	-0.292***
	(0.088)	(0.064)	(0.101)	(0.034)	(0.274)	(0.181)	(0.125)	(0.036)
Firm FE	yes	yes	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes	yes	yes
Year-province FE	yes	yes	yes	yes	yes	yes	yes	yes
Year-industry FE	yes	yes	yes	yes	yes	yes	yes	yes
Province-industry FE	yes	yes	yes	yes	yes	yes	yes	yes
Observations	638285	778259	735782	778064	638285	778259	735782	778064
Adjust R^2	0.843	0.884	0.813	0.923	0.843	0.884	0.813	0.923

Note: Note: 2008 is the baseline year. We restrict the sample to observations on common support in this analysis. The dependent variables are logged form of output, revenue, employment, and assets. This table shows the effects of drought on industrial outcomes of power industries across provinces by the southwestern drought. The constant term is included but not reported. Standard errors are in parentheses clustered at two-digit industry, and year-province levels. * is $p<0.1$, ** is $p<0.05$, and *** is $p<0.01$.

Table 4.8 Estimated effects on power industries over time

	e=Hydropower				e=Thermal power			
	Output	Revenue	Employment	Asset	Output	Revenue	Employment	Asset
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Drought $\times Energy^e \times$ 2006	-0.106***	-0.065**	-0.013	0.148***	-0.575***	0.020	-0.376***	0.067***
	(0.026)	(0.027)	(0.022)	(0.008)	(0.097)	(0.063)	(0.043)	(0.017)
Drought $\times Energy^e \times$ 2007	0.016	-0.017	-0.028	0.137***	-0.593***	0.309***	-0.487***	0.116***
	(0.013)	(0.017)	(0.029)	(0.009)	(0.092)	(0.022)	(0.050)	(0.017)
Drought $\times Energy^e \times$ 2009	-0.136***	-0.153***	-0.077***	-0.030***	0.202***	0.183***	-0.028	-0.052***
	(0.015)	(0.015)	(0.020)	(0.007)	(0.032)	(0.016)	(0.023)	(0.014)
Drought $\times Energy^e \times$ 2010	0.000	-0.169***	-0.099***	-0.095***	0.000	0.101***	-0.067***	-0.117***
	(0.000)	(0.019)	(0.017)	(0.012)	(0.000)	(0.019)	(0.019)	(0.014)
Drought $\times Energy^e \times$ 2011	-0.208***	-0.276***	0.477***	-0.183***	0.067	0.105***	0.300***	-0.206***
	(0.021)	(0.019)	(0.034)	(0.012)	(0.065)	(0.025)	(0.036)	(0.016)
Drought $\times Energy^e \times$ 2012	-0.204***	-0.250***	0.356***	-0.189***	-0.362***	-0.077***	-0.117***	-0.306***
	(0.021)	(0.018)	(0.045)	(0.013)	(0.064)	(0.024)	(0.039)	(0.019)
Drought $\times Energy^e \times$ 2013	-0.312***	-0.297***	0.632***	-0.252***	-0.219***	-0.180***	0.128***	-0.447***
	(0.026)	(0.019)	(0.028)	(0.015)	(0.036)	(0.033)	(0.035)	(0.022)
Firm FE	yes	yes	yes	yes	yes	yes	yes	yes
Year FE	yes	yes	yes	yes	yes	yes	yes	yes
Year-province FE	yes	yes	yes	yes	yes	yes	yes	yes
Year-industry FE	yes	yes	yes	yes	yes	yes	yes	yes
Province-industry FE	yes	yes	yes	yes	yes	yes	yes	yes
Observations	638285	778259	735782	778064	638285	778259	735782	778064
Adjust R^2	0.843	0.884	0.813	0.923	0.843	0.884	0.813	0.923

Note: 2008 is the baseline year. We restrict the sample to observations on common support in this analysis. The dependent variables are logged form of output, revenue, employment, and assets. This table shows the effects of drought on industrial outcomes of power industries over time. The constant term is included but not reported. Standard errors are in parentheses clustered at two-digit industry, and year-province levels. * is p<0.1, ** is p<0.05, and *** is p<0.01.

Table 4.9 Energy-intensive industry classification code

Two-digit industries

10 — Manufacture of raw chemical material and chemical products

25 — Manufacture of non-metallic mineral products

26 — Smelting and pressing of ferrous metals

32 — Smelting and pressing of non-ferrous metals

33 — Processing of petroleum, coking, processing of nucleus fuel

44 — Production and distribution of electric power and heat power

Four-digit electric power industries

- 4411 — Thermal power generation
- 4412 — Hydropower generation
- 4413 — Nuclear power generation
- 4419 — Other power generation

Source: Statistical Bulletin on National Economic and Social Development in 2010.

Chapter 5

Concluding Remarks

This dissertation examines the interaction effects between water governance and socioeconomic activities in China. We investigate how socioeconomic dynamics shape water distribution and water provision systems under rapid urbanization, and whether the current water system is effective enough to achieve better social outcomes in undeveloped areas. Furthermore, we estimate how and to what extent water exploitation and water scarcity affect regional economic activities, and how extreme drought may influence the water–energy nexus and water vulnerability.

In Chapter 2, the association between internal migration and urban water use is estimated. This study finds that floating population increases the total water use in the household sector but decreases the per capita water use in the public service sector. Migrants have no significant impact on the total water use in the public service sector, whereas local residents do, which shows that the restriction of population mobility to central urban areas has affected water allocation. These results are consistent with those of previous studies—that the length of residency has a positive effect on households' water consumption, and urban segregation has distorted Chinese migrants' consumption. Urban development is supposed to have larger positive spillover effects, especially regarding to public service provision.

By contrast, we find in Chapter 3 that private sector participation (PSP) in the water supply sector leads to better health outcomes among children aged under 5 years in rural areas. PSP in water supply is more likely to be implemented in higher risk areas with low piped water access, which leads to a greater improvement effect than corporatization when the water tariff is controlled by the government. In addition, water reform increases piped water access and reduces groundwater use in rural areas, leading to more sustainable management of the water sector and helping to achieve Sustainable Development Goals (SDGs). Capital-driven water infrastructure development can be effective in narrowing the gap of water provision between urban and rural areas with the proper regulation and motivation.

In Chapter 4, we find that highly exploited hydropower regions can be very vulnerable to extreme disasters, causing significant damage to not only agriculture and households, but also the industrial sector. Unstable supply of clean energy could then increase the reliability of fossil fuels. Drought adaptive measures maybe more needed in water-abundant undeveloped regions, along with more efficient water resource management and stringent policies to prevent water pollution transfer. In conclusion, effective water resource management can narrow the public service provision gap, improving both human rights and health. Effective water management is also crucial for green development, balancing energy, and water constraints in China.

China's water policy has evolved rapidly since the 1980s, transforming from a water sector policy to a water resources policy. Resource-oriented water development strategy and water rights were incorporated into the Water Law of 2002. Furthermore, the strictest water resources management strategy has been implemented since 2011 to emphasize the water–human relationship and to cope with the increasing water shortage. These changes reflect the efforts by the Chinese government to modernize the water governance. As the results of this study suggest, for further development of water governance, it is important to recognize the strong relationship of water use to demographic change, market dynamics, and extreme weather events. The sustainable management of common-pool resources, such as water, should be guided by policies that incorporate these interactions and achieve the largest social benefits ultimately.