Vol.7 Issue.4 December 2022

RSEP Review of Socio - Economic Perspectives
ISSN: 2149 - 9276
E-ISSN: 2547-9385

The impact of the south-to-north water diversion project on the usage of water-saving irrigation machinery

Hanfang Xu[1,•] **& Zhen Yao**[2,α]
[1] *Department of Economics, Jinan University, Guangzhou, China*
[2] *Department of Finance, Wenzhou-Kean University, Wenzhou, China*

Article History

Received: 29 June 2022 Revised: 25 November 2022 Accepted: 30 November 2022 Available Online: 5 December 2022

Keywords: South-to-North Diversion Project, water resources, water-saving irrigation machinery
JEL classification: C12; D24; Q15

Citation: Xu, H. & Yao, Z. (2022). The impact of the south-to-north water diversion project on the usage of water-saving irrigation machinery, *Review of Socio-Economic Perspectives,* 7(4), 9-19.

Abstract

Agricultural water-saving irrigation represents an important component of environmental protection with the potential to improve economic development and environmental protection of water-receiving areas, but little is known about the relationship between South-to-North Water Diversion Project and the usage of water-saving irrigation machinery. This paper exploits the 2013–2014 China South-to-North Water Diversion Project reforms which significantly alleviated the water shortage problem in north China. By linking administrative claims data to water-saving irrigation machinery numbers for water-receiving provinces and the control provinces, this paper finds that water-receiving provinces experienced a 19.6 percent post-reform decline in water-saving irrigation machinery usage, and a 7.3 percent drop in water-saving irrigation area relative to other provinces.

---

1. Introduction

As a critical grain-producing area in China, the North China Plain has a large population and a great demand for water. However, the problem of insufficient annual precipitation makes it one of the most water-scarce areas in China, which seriously restricts agricultural and economic development. To alleviate water scarcity, China has implemented a South-to-North Water Diversion Project (SNWDP).

China's South-to-North Water Diversion Project is a mega-engineering scheme with construction and maintenance spanning over six decades (Zhu et al., 2008). The project transfers water from humid Yangtze River basin to dry northern plains of the Yellow, Huai and Hai River basins to improve agriculture and to mitigate drought (Wei et al., 2016). It transfers water through three routes: Eastern Route (ER) is through the Grand Canal, Middle Route (MR) from Danjiangkou reservoir to Beijing, and the Western Route (WR) planned on the Tibet Plateau. Three provinces namely Jiangsu, Shandong and Hebei are located in the eastern route. Four provinces and municipalities namely Beijing, Tianjin, Hebei and Henan are located in the middle route, for which Tianjin and Hebei provinces suffer severe water shortage. Six provinces namely Qinghai, Gansu, Ningxia, Inner Mongolia, Shaanxi and Shanxi are located in the western route. The first phase of the ER was opened to water on November 15, 2013 and the MR was on December 12, 2014. The WR has not yet started.

The completed water transfer line will be over 1152 km long, equipped with 23 pumping stations with a power capacity of 454 megawatt. Due to the natural topography of the Yangtze and North China Plains, pumping stations will raise water from the Yangtze to Yellow River crossing further north, and water will flow downhill through an aqueduct. The amount of water to be diverted in the first, second and third stages are 9.07 billion cubic meters, 10.6 billion cubic meters and 14.8 billion cubic meters, respectively (Wei et al., 2016).

[•] **E-mail:** xuhanfang.iesr19u@hotmail.com & **ORCID:** https://orcid.org/0000-0002-5358-0008
[α] **E-mail:** yaoz@kean.edu & **ORCID:** https://orcid.org/0000-0002-4683-2860

DOI: https://doi.org/10.19275/RSEP137
Article Type: Original Paper

This water transfer scheme has effectively alleviated the shortage of water resources in the Northern areas, i.e., water-receiving areas changed their water supply pattern and supplemented the groundwater (Liu & Zheng, 2002). Besides, SNWDP promoted the sustainable development of the economy and agriculture in the water-receiving areas (Wilson et al., 2017). According to Sheng and Tang (2020), south water has improved the water guarantee rate of more than 40 cities in the water-receiving area, ensuring the safety of the water supply. Sufficient evidence has shown the influence of the SNWDP for water-receiving areas is effective. However, it remains to be seen whether the solution of the water shortage in water-receiving areas will inhibit the development of local water-saving industries and the popularization of water-saving agricultural machinery (such as drip irrigation and sprinkler irrigation technology).

From 1949 to 1990, China's irrigation water consumption continued to rise, and since then, it has begun to fluctuate and decline (Wu, Jin & Zhao, 2010). From 2003 to 2013, agricultural water use increased to a peak, of which irrigation accounted for 95% (Zhang et al., 2013). Nowadays, irrigation water consumption has reached 62.3% of the country's total water consumption (Han et al., 2020). The above arguments show that the water used for agricultural irrigation in China has reached the limit of our country. While the construction of the South-to-North Water Diversion Project has effectively alleviated the shortage of water resources in the northern water-affected areas and replenished groundwater.

This paper aims to analyze whether the water-saving industries and the popularization of water-saving agricultural machinery (drip irrigation and sprinkler irrigation) in water-receiving areas will be affected by the solution to the water shortage in water receiving areas. Since previous research has focused on the impact of the SNWDP on the economy, environment, and water resource utilization rate (water footprint) in a particular region, as well as articles using game theory for pricing analysis, but generally ignored water-saving agricultural irrigation machinery. This paper supplements the shortcomings of the previous literature and conducts an empirical analysis of economics to study whether the SNWDP has an inhibitory effect on water-saving irrigation machinery in the water-receiving area.

The article is organized as follows. Section 2 reviews relevant literature about this topic. Section 3 presents the data I use and describes motivating descriptive statistics. Section 4 is the empirical strategy and section 5 preliminary findings. In section 6, I provide additional results by carrying out robustness test. Section 7 concludes.

2. Literature Review

This section introduces the empirical knowledge regarding the research topic and is related to two streams of literature. First is the impact of SNWDP on economic, environmental and agricultural water use, second is previous works about the development trend of agricultural irrigation machinery.

2.1. The Impact of the SNWDP

Previous studies have proved that the SNWDP positively affects economic development. According to Pholner (2016), SNWDP has different levels of economic stakeholders, including national scale stakeholders, provincial and local scale stakeholders, and basin-scale stakeholders. Fang and other researchers used the WCGE Model to analyze the effect of the SNWDP in 2020. They found that compared with the scenario without SNWDP, the SNWDP could Increase GDP growth by 1% to 2.3%, equivalent to 89 billion yuan, and the chain reaction of SNWDP can increase household income by 2.5% to 4.1%, expand production scale, and provide more than 700,000 jobs. (Fang et al., 2010). By 2020, the SNWDP could create 527 billion yuan of GDP and more than 1 million jobs per year (Fang et al., 2010). Some researchers took Bei Jing as an example to analyze the macroeconomic impact of the increase in the water supply. The results also show the promoting effect of the SNWDP on economy. Miao and Gao (2017) found that from compared 2008 to 2013, the direct economic benefit has increased from 4.39 billion yuan to 53.99 billion yuan, and the estimated full value of economic benefits has increased from 14.07 billion yuan to 231.86 billion yuan. Moreover, the SNWDP could play an essential role in increasing productivity, maintaining water prices, and promoting the development of goods and services (Berrittella et al., 2007).

Even though the SNWDP will have substantial economic benefits, previous researchers have also found that it will have an impact on the environment. According to Pohlner (2016), in the short term, the SNWDP has a negative influence on the society and environment. Zhang (2009) stated that a large amount of water diversion would lead to changes in the hydrological environment in the upper reaches of the Yellow River, the lower reaches of the Han River, and the tributaries of the Yangtze River, and the water supply areas of the central line. Besides, the SNWDP affects both water supply areas and water-receiving areas. Secondary salinization of water-receiving areas of the North China Plain is inevitable, and the reduction of Yangtze River flow will lead to the intrusion of seawater in the Yangtze River Delta (Zhang, 2009). However, in the long run, the SNWDP can contribute to environmental sustainability such as reducing coal energy consumption and mitigating climate change; it can also complete the construction of a sustainable water resources system (Kattel et al., 2019). Moreover, the effective combination of water supply and self-rescuing in water-receiving areas is expected to solve the problem of water shortage fundamentally and ultimately achieve sustainable economic, social and ecological environmental development (Xu et al., 2018).

In agriculture, the SNWDP has made northern cities aware of the importance of energy, irrigation, and sustainability of water use for agriculture (Kattel et al., 2019). Besides, according to Yao and other researchers (2019), the SNWDP will alleviate groundwater shortages in North China by allowing more surface water for agricultural irrigation and reducing the amount of groundwater used for agricultural irrigation. Berkoff (2003) stated that agricultural water use is an essential part, and the implementation of the SNWDP will reduce irrigation use from 115 to 108 km3. Moreover, even though the SNWDP cannot wholly solve the problem of water shortage in the North China Plain, the pressure on water supply can be significantly alleviated, and the output of grain farmers will increase significantly (more than 115 Tcal/year), and the economic benefits will exceed 51 billion yuan/year (Yin et al., 2020).

2.2. The development trend of agricultural irrigation machinery

Water-saving agriculture is the trend of future development (Hu et al., 2010). Due to the lack of water resources, the Chinese government attaches great importance to the development of water-saving agriculture. The scarcity of water will induce the development of water-saving agriculture and thus improving irrigation efficiency; Although more than 5 billion yuan is invested in water-saving agriculture each year, the effect is not significant, and the decline in agricultural water consumption is only 2.9% (Xu et al., 2021). In addition, according to Wu (1998), China has great potential in the field of irrigation water conservation. China's total agricultural water consumption is as high as 73%, but due to the backward irrigation methods, the effective irrigation coefficient is 20%-40% lower than that of developed countries; if effective irrigation equipment is adopted, more than 30 billion cubic meters of water can be saved every year (Wu, 1998). Therefore, agricultural irrigation equipment should be combined with water-saving agriculture to improve irrigation efficiency. Li (1993) stated that a combination of multiple irrigation technologies such as drip irrigation, sprinkler irrigation, low-pressure pipeline water transfer irrigation technology, and surface irrigation technology is used to achieve water-saving effects. Wu (1998) also stated that the application of water-saving measures and technologies in the middle process of farmland irrigation, such as water diversion, water transmission, water distribution, irrigation, etc., can reduce the leakage loss and ineffective evaporation of the water transmission process, and improve the utilization rate of water resources.

3. Conceptual Framework

In this article, micro-data of the water-receiving and water-supply provinces I use comes from the China Rural Statistical Yearbook (CRSY) from 2009 to 2017. This statistical Yearbook, which collects information from rural areas in the provinces in China for the purposes of calculating the number of water-saving irrigation agricultural machinery, is collected and counted by Department of Rural Socio-economic Survey, National Bureau of Statistics. Data on total water supply and other environmental conditions related to province levels are taken from National Data, collected and calculated by National Bureau of Statistics. More detailed data on the dependent variable comes from the China Environmental Statistical Yearbook (CESY), from year 2009 to 2017, including water-saving irrigated area by region, jetting and dropping irrigation area, tinny irrigation area, low-pressure pipe irrigation area, etc.

The CRSY data include information on the basic situation of rural areas and agricultural production conditions, agricultural ecology and environment, rural investment, total output value, intermediate consumption and added value of agriculture, forestry, animal husbandry and fishery, area and output of main agricultural products (cultivation), rural market and prices, cost of agricultural products and income, income and consumption of rural residents, rural culture, education, health and other undertakings, regional rural economy, major rural economic indicators in each region, etc.

The CESY data include information on the natural conditions, water environment, marine environment, atmospheric environment, solid waste, natural ecology, land use, forestry, natural disasters and emergencies, environmental investment, urban environment, rural environment, etc.

Table I presents the descriptive statistics on both outcome variables and control variables.

Table 1. Descriptive statistics of relevant variables

Variable	No. of obs. (1)	Mean (2)	Std. dev. (3)	Min (4)	Max (5)
No. of Water-saving Machinery residence	270	641116	98609	100	527000
Agricultural Water Consumption	270	126	106	5	562
Total Water Supply	270	189	120	22	590
Individual level					
Disposable Income	270	9769	4577	2980	27825
Consumption Level	270	9046	5053	2459	26755
Cultivated Land level					
Effective Irrigation Area	270	7.26	1.02	4.749	8.704
Characteristics on City level					
Hydro Fuel	270	101.56	3.65	91.2	115.4
Agricultural Oil	270	102.14	4.18	93.3	115.6
Semi-mechanized FT	270	101.10	2.22	96	115.7
Mechanized FT	270	101.24	2.23	95.5	114

Notes. This table presents summary statistics for samples used in the analyses. Control variables include characteristics on individual, household level, and characteristics of migrants' inflow cities. Effective irrigation area is calculated in natural log form.

3.1. Data on the Outcome: No. of water-saving irrigation machinery

The outcome variable is the natural log form of the number of water-saving irrigation machinery, mostly referred to drip irrigation machinery, sprinkler irrigation machinery, low-pressure pipeline water delivery irrigation machinery and surface irrigation machinery, including all 30 China provinces, autonomous regions and municipalities (exclude Hong Kong and Macau Special Administrative Regions, Taiwan Province and Tibet Autonomous Region for the lack of data). To further observe whether the SNWDP has an impact on local water-saving industries, I use the total amount of agricultural water used in the year to substitute the above outcome variable. In order to observe the fluctuation range of the dependent variable' log value more intuitively, I show it in the following line chart. See Figure I. The graph on the left shows the average annual ownership of water-saving irrigation machinery in the water-receiving provinces and other control provinces. We can roughly judge that the increase in the number of water-saving irrigation machinery in the water-receiving areas during 2013-2014 and 2014-2015 was slightly smaller than that in the control provinces. The graph on the right shows the net increase in the number of water-efficient irrigation machinery, which is the value of the following year minus the previous year. It's obvious to find that the increase in year 2013-2014 of water-receiving areas is slightly higher than that of control provinces, and in year 2014-2015 quite the opposite. According to this phenomenon, it can be speculated that the average agricultural water consumption in the receiving area may be higher than that in the control provinces.

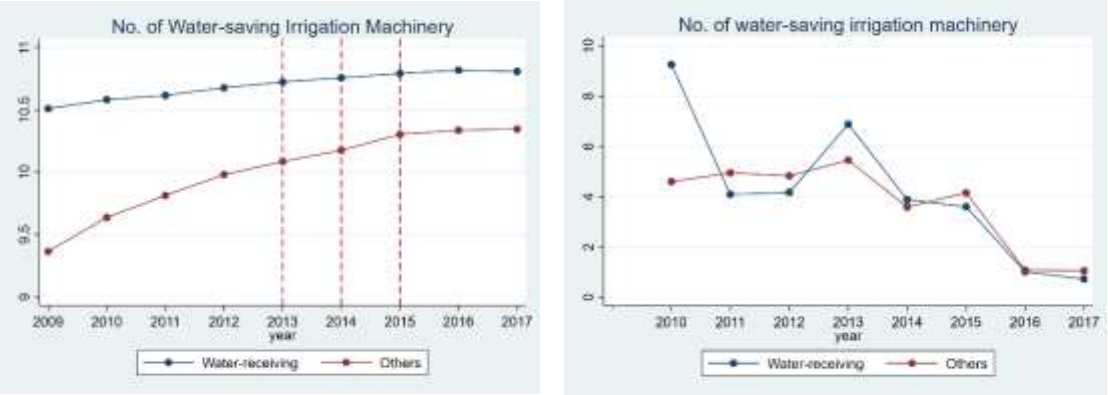

Figure 1. No. of Water-saving Irrigation Machinery

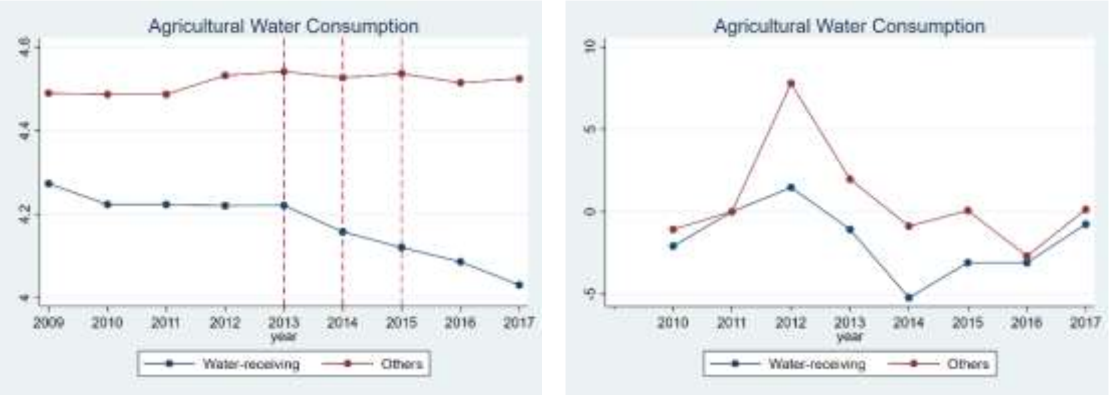

Figure 2. Agricultural water consumption

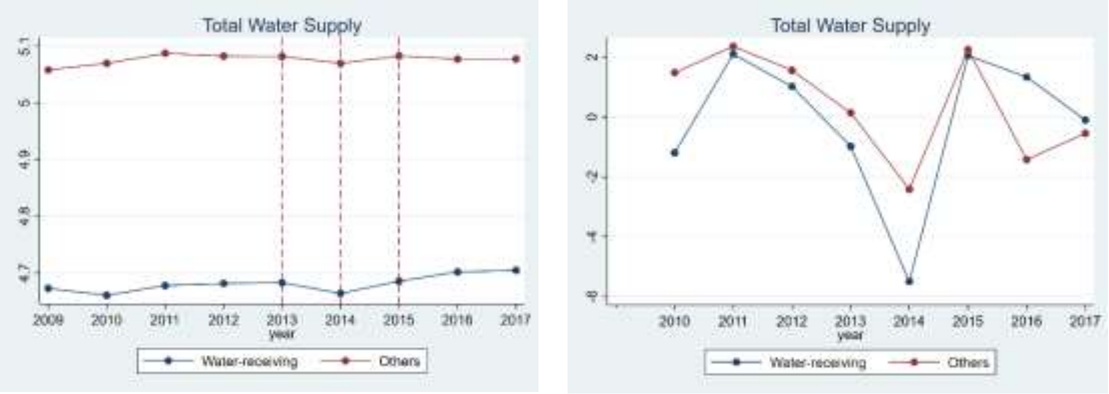

Figure 3. Total water supply

Figure II shows the instrument outcome variable, which is the average agricultural water consumption in both water-receiving areas and control provinces. Similarly, the number is also the log value. Average agricultural water consumption in control provinces is much higher than that of treated provinces. However, different from the above conjecture, there was a significant decrease in agricultural water consumption in the receiving area between 2013 and 2015 than control provinces. This result is quite puzzling for we can’t infer what is causing the significant reduction in agricultural water use in the receiving area. And figure III presents the overall water supply. During 2013 to 2014, i.e., the year which ER of SNWDP is flooded, total water supply for both types of provinces reduced, while in the year which MR of SNWDP is flooded, total water supply for water-receiving areas is significantly increased.

3.2. Data on the Controls

The control variables include 3 different levels: income and consumption level, price index level and cultivated land irrigated area. For the income and consumption level, I controlled per capita disposable income of rural households and the average consumption level of rural residents. For cultivated land irrigated area, effective irrigation area is controlled. For price index level, there includes 4 variables, namely hydroelectric fuel consumer price index, general price index of agricultural means of production, semi-mechanized farm tools price index and mechanized farm tools price index.

4. Identification Strategy

This paper exploits the differential effect of the 2013–2014 SNWDP, which is regarded as a reform on the North Plain for different provinces to implement a difference-in-differences empirical design. The SNWDP reforms reduced the usage and popularization of water-saving agricultural machinery for all water-receiving provinces. But when using the total amount of agricultural water used in the year as outcome variable, the empirical result is surprisingly different from that of the original outcome variable. After the SNWDP, i.e., year 2014, the total amount of agricultural water usage in water-receiving provinces is 9.69% lower than those of other provinces and is statistically significant at 99.9% level. I exclude 2013 for most of our analysis because this is a partially treated year.

Researchers study the differential impact of the SNWDP reform on both the penetration rate of water-saving irrigation machinery and total amount of agricultural water use, implementing a difference-in-differences design. The identifying assumption is that water-receiving provinces, in the absence of the 2013–2014 SNWDP reforms, would have experienced similar outcome changes as other non-treated provinces. This paper will test this assumption by studying pre-reform trends through event study analyses. Following this idea, a set of equations was estimated as:

$$Y_{it} = \beta_0 + \beta_1\, ReceivingArea_i \times ReceivingYear_t + \sum \gamma^k {Z_{it}}^k + \alpha_i + \lambda_t + \varepsilon_{it} \qquad (1)$$

where Y_{it} is a measure of post water-saving irrigation machinery number for province i in year t. The number of water-saving irrigation machinery will be total numbers of drip irrigation, sprinkler irrigation, low-pressure pipeline water transfer irrigation, and surface irrigation machinery. The term $ReceivingYear_t$ is an indicator variable equal to 1 in years 2013 or 2014 and later, and $ReceivingArea_i$ is equal to 1 for those water-receiving provinces (0 otherwise). Here, β is the parameter of interest and represents the differential effect of the reforms for water-receiving provinces. For the other variables, α_i and λ_t stands for province-invariant and time-invariant cluster characteristics, which allows the specification above including fixed effects for each province and year. The year fixed effects account for common time trends in the outcomes and net out effects of the reforms that are common across water transfers, allowing us to isolate the differential impact of the changes in outcome variable. ε_{it} is the error term, which has zero mean and can be serially correlated; Z_{it} is a vector of predetermined characteristics of the province. While this set of control variables is not required in the specification because water-saving machinery variation should be orthogonal to these characteristics conditional on location, its addition is useful to improve the precision of the estimates. Therefore, researchers report results both including and excluding this vector.

This article models the outcomes as a log function because both total agricultural water use and number of water-saving machinery are highly skewed and it is common to assume they change in percentage terms. However, the limitation of a log-linear specification is clear: only under very specific conditions on the error term is the log linear representation of the constant-elasticity model useful as a device to estimate the parameters of interest (Silva and Tenreyro, 2006, p. 644). Despite this, the data do not contain observations where the potential two outcome variables are zero, so a log-linear specification seems appropriate. Furthermore, researchers adjust all standard errors for clustering at the province level.

5.Results

The identifying assumption when using DID model is that the post-reform water-saving irrigation machinery usage outcome in water-receiving provinces would have changed in a manner similar to the outcomes of other non-affected provinces in the absence of the relative change in water transfer and total water supply due to the reforms, i.e., there should be observed a parallel trend before SNWDP. Therefore, researchers test whether the parallel trend assumption is satisfied. See the figure below. The confidence interval for the two periods before the policy implementation includes zero, indicating that the parallel trend assumption is satisfied.

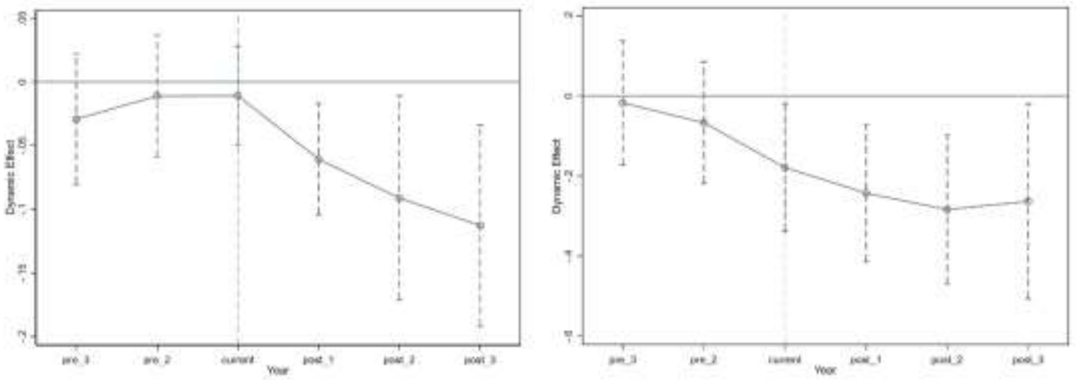

Figure 4. Parallel trend test

Table 2. Preliminary Results

Outcome	(1)	(2)	(3)	(4)	(5)
Panel A. ln(Number of Water-saving Irrigation Machinery)					
DID	-0.339***	-0.231**	-0.284**	-0.327***	-0.196**
	[0.123]	[0.094]	[0.113]	[0.116]	[0.089]
Panel B. ln(Agriculture Water Consumption)					
DID	-0.148**	-0.100**	-0.095**	-0.148**	-0.073**
	[0.069]	[0.051]	[0.036]	[0.070]	[0.033]
Individual Controls	No	Yes	No	No	Yes
Land Controls	No	No	Yes	No	Yes
CPI Controls	No	No	No	Yes	Yes
Province Fixed Effect	Yes	Yes	Yes	Yes	Yes
Year Fixed Effect	Yes	Yes	Yes	Yes	Yes
Obs.	270	270	270	270	270

Notes. DID term is the interaction term of ReceivingArea × ReceivingYear. Standard errors in parentheses adjusted for clustering at province level. Individual level control variables, i.e., the first two are defined as per capita disposable income of rural households (thousand yuan/person) and consumption level of rural residents (thousand yuan/person). Land Control refers to effective irrigation area, which is the area of arable land that has a certain water source, the land is relatively flat, the irrigation projects or equipment have been matched, and normal irrigation can be carried out in the current year under normal years. In general, the effective irrigation area should be equal to the sum of the area of paddy fields and irrigated land that have been equipped with irrigation projects or equipment and can be irrigated normally. The CPI controls include price indexes of hydro fuel, agricultural means of production, semi-mechanized farm tools and mechanized farm tools. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Then researchers provide OLS difference-in-differences estimates in Table II for the log number of water-saving irrigation machinery and the log of agricultural water consumption. Column 1 is the most parsimonious specification, regressing log number of water-saving irrigation machinery or log agricultural water consumption on interactive term for our sample. This column shows the difference-in-difference estimate without any control variables. The coefficient is -0.339 with a standard error of 0.123. This coefficient implies that a 34percentage point lower water-saving machinery usage is associated with water-receiving provinces after SNWDP. From column 2 to column four respectively add control variables on the individual level, land level, and price index level, namely per capita disposable income of rural households and consumption level of rural residents (thousand yuan/person); effective irrigation area; price indexes of hydro fuel, agricultural means of production, semi-mechanized farm tools, and mechanized farm tools. When adding individual controls and land controls the coefficient on interaction term significantly reduces to -0.231 and -0.284. Column 5 represents estimates of all control variables and the coefficient further downs to -0.196. All columns include both years fixed effect and province fixed effect.

As estimated shown in panel A, when controlling nothing, the coefficient of beta is negative 33.9%, which is larger enough than that of when controlling all relevant variables, which is negative 19.6% only. From panel A, we can conclude that water-receiving provinces incurred a relative decrease in the number of water-saving irrigation machinery of 19.6 percent reduction with respect to the control provinces. In panel B, I use the log of agricultural water consumption as the outcome and estimate larger reductions, which estimates a 7.3 percent reduction in water-receiving provinces relative to the control provinces. All estimates are statistically significant at the 5 percent level.

6. Robustness Test

The identifying assumption for DID method is that the post-reform water-saving irrigation machinery usage outcomes in water-receiving provinces would have changed in a manner similar to the outcomes of other non-affected provinces in the absence of the relative change in water transfer and total water supply due to the reforms. Although the result in figure I and figure II may seem like a conflict with parallel assumption, which causes the coefficients estimated in Table II not unbiased, the parallel trend hypothesis test tells us that both outcome variables satisfy the assumption. However, to ensure the robust results, a further difference-in-difference-in-difference (DDD) model or synthetic control method should be used to solve the potential problem. As a result, this section chooses an alternative method, namely DDD to solve the potential problem. Another possible threat to identification is that the reform systematically affected those provinces with lower average water-saving irrigation machinery utilization, which is calculated as effective irrigation area (hectare) divided by quantity of water-saving machinery.

6.1. Difference-in-Difference-in-Difference Estimate

The important assumption of the difference-in-difference method is that the time trend of the control group and the experimental group is the same, and when the time trend of the control group and the experimental group is different, the consistent experimental estimator cannot be obtained, and the estimator needs to be further improved. Another concern is in addition to the SNWDP, there may be other policies that have inconsistent effects on pilot and non-pilot areas, thereby skewing the estimates. It is necessary to use triple difference to overcome this problem, that is, it is necessary to find another pair of "treatment group" and "control group" that are not affected by the SNWDP policy, because inland cities are not affected by the SNWDP policy, at this time the second pair of treatment groups and the difference in the control groups is only derived from the influence of other policies. The difference between the first pair of treatment groups and the control group (including the difference between the SNWDP policy and other policies) is subtracted from the difference between the second pair of treatment groups and the control group. Net effect of SNWDP policy. Based on the above analysis, a triple difference model (DDD) is constructed:

$$
\begin{aligned}
Y_{it} = \; & \beta_0 + \beta_1\, ReceivingArea_i \times ReceivingYear_t \times group \\
& + \beta_2\, ReceivingArea_i \times ReceivingYear_t + \beta_3\, group \times ReceivingYear_t \\
& + \beta_4\, ReceivingArea_i \times group \\
& + \sum \gamma^k Z_{it}{}^k + \alpha_i + \lambda_t + \varepsilon_{it} \qquad (2)
\end{aligned}
$$

Where group is a dummy variable, which equals to 1 when the province is a coastal city, otherwise is 0. When $ReceivingArea_i \times ReceivingYear_t \times group$ is 1, it represents coastal cities in water-receiving areas after implementing SNWDP policy, and the estimated coefficient β_1 is the triple-difference estimator represents the average treatment effect of the SNWDP policy on water-saving irrigation machinery usage. The regression results are as follows:

Table 3. Robust test

Dependent variable	Water-saving machinery usage	Agricultural water consumption
DDD	-0.138***	0.0647**
	[0.640]	[0.085]
Province Fixed Effect	Yes	Yes
Year Fixed Effect	Yes	Yes
Individual Controls	Yes	Yes
Land Controls	Yes	Yes
CPI Controls	Yes	Yes
R-square	0.9616	0.9969
Obs.	270	270

Notes. DDD term is the interaction term of ReceivingArea × ReceivingYear × group. Standard errors in parentheses adjusted for clustering at province level. Outcome variable is the number of water-saving irrigation machinery, taking natural log form. Individual level control variables are defined as per capita disposable income of rural households (thousand yuan/person) and consumption level of rural residents (thousand yuan/person). Effective irrigation area refers to the area of arable land that has a certain water source, the land is relatively flat, the irrigation projects or equipment have been matched, and normal irrigation can be carried out in the current year under normal years. In general, the effective irrigation area should be equal to the sum of the area of paddy fields and irrigated land that have been equipped with irrigation projects or equipment and can be irrigated normally. The CPI controls include price indexes of hydro fuel, agricultural means of production, semi-mechanized farm tools and mechanized farm tools. Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

The coefficient of interactive term DDD is -0.138, with p value of 0.007 and standard error of 0.640. This figure is close to that of in Table II. It verifies that after SNWDP, the water-saving irrigation machinery usage reduces about 13.8% in water-receiving provinces. The estimate is both economically and statistically significant. Surprisingly, the coefficient of agricultural water consumption turns positive, which means water consumption in water receiving provinces is 6.47% higher than that of control provinces.

7. Conclusion

This paper studies how China's South-to-North Water Diversion Project policy that tries to solve the water shortage in North China Plain causally affect water-saving irrigation machinery usage. Using a DID design, this paper finds consistent evidence that the SNWDP reduced water-saving irrigation machinery usage for water-receiving provinces. The results imply that water-saving irrigation machinery usage for water-receiving provinces decreased by 19.6 percent than other provinces. However, this paper also finds that agricultural water consumption associated with water-receiving provinces decreased by 7.3 percent relative to other provinces. This result may seem conflict with each other. Why water-saving irrigation machinery usage in water-receiving provinces decreases but agricultural water consumption also decreases? This may arise from inverse causality, that is decline in agricultural water consumption caused fewer water-saving irrigation machinery usage in water-receiving areas. Yet, this speculation is likely to be wrong. As I use a DDD method to do robust test, the coefficient of interactive term becomes positive, partly proves the incorrectness of the speculation.

References

Berkoff, J. (2003). China: The South–North Water Transfer Project—is it justified? Water Policy, 5(1), 1–28.

Berrittella, M., Rehdanz, K., & Tol, R. S. (2006). The economic impact of the South-North water transfer project in China: a computable general equilibrium analysis.

Chen, Z., Wang, H., & Qi, X. (2013). Pricing and water resource allocation scheme for the south-to-north water diversion project in China. Water Resources Management, 27(5), 1457-1472.

Chen, D., Webber, M., Finlayson, B., Barnett, J., Chen, Z., & Wang, M. (2013). The impact of water transfers from the lower Yangtze River on water security in Shanghai. Applied Geography, 45, 303–310.

Crow-Miller, B., & Webber, M. (2017). Of maps and eating bitterness: The politics of scaling in China's South-North Water Transfer Project. Political Geography, 61, 19–30.

Fang, Q. X., Ma, L., Green, T. R., Yu, Q., Wang, T. D., & Ahuja, L. R. (2010). Water resources and water use efficiency in the North China Plain: Current status and agronomic management options. Agricultural Water Management, 97(8), 1102-1116.

Gao, Y., & Yu, M. (2018). Assessment of the economic impact of South-to-North Water Diversion Project on industrial sectors in Beijing. Journal of Economic Structures, 7(1), 1-17.

Han, S., Tian, F., & Gao, L. (2020). Current status and recent trend of irrigation water use in China. Irrigation and Drainage, 69(S2), 25–35.

He, C., He, X., & Fu, L. (2010). China's South-to-North Water Transfer Project: Is it Needed?. Geography Compass, 4(9), 1312-1323.

Hu, Y., Moiwo, J. P., Yang, Y., Han, S., & Yang, Y. (2010). Agricultural water-saving and sustainable groundwater management in Shijiazhuang Irrigation District, North China Plain. Journal of Hydrology, 393(3-4), 219-232.

Jiang, M., Webber, M., Barnett, J., Rogers, S., Rutherfurd, I., Wang, M., & Finlayson, B. (2020). Beyond contradiction: The state and the market in contemporary Chinese water governance. Geoforum, 108, 246–254.

Kattel, G. R., Shang, W., Wang, Z., & Langford, J. (2019). China's south-to-north water diversion project empowers sustainable water resources system in the north. Sustainability, 11(13), 3735.

Li, Y. (2006). Water saving irrigation in China. Irrigation and Drainage, 55(3), 327–336.

Liu, C., & Zheng, H. (2002). South-to-north water transfer schemes for China. International Journal of Water Resources Development, 18(3), 453-471.

Long, D., Yang, W., Scanlon, B. R., Zhao, J., Liu, D., Burek, P., ... & Wada, Y. (2020). South-to-North Water Diversion stabilizing Beijing's groundwater levels. Nature communications, 11(1), 1-10.

Miao, Z., Sheng, J., Webber, M., Baležentis, T., Geng, Y., & Zhou, W. (2018). Measuring water use performance in the cities along China's South-North Water Transfer Project. Applied Geography, 98, 184–200.

Mo, X., Liu, S., Lin, Z., & Guo, R. (2009). Regional crop yield, water consumption and water use efficiency and their responses to climate change in the North China Plain. Agriculture, Ecosystems & Environment, 134(1-2), 67-78.

Naderi, K., & Babadagli, T. (2014). Large scale applicability of the steam-over-solvent injection in fractured reservoirs (SOS-FR) method: Optimal operating conditions through numerical simulation. Journal of Petroleum Science and Engineering, 122, 497–506.

Pohlner, H. (2016). Institutional change and the political economy of water megaprojects: China's south-north water transfer. Global Environmental Change, 38, 205–216.

Ruisen, Z., Xinguang, D., & Yingjie, M. (2009). Sustainable water saving: new concept of modern agricultural water saving, starting from development of Xinjiang's agricultural irrigation over the last 50 years. Irrigation and Drainage, 58(4), 383–392.

Siebert, S., Burke, J., Faures, J. M., Frenken, K., Hoogeveen, J., Döll, P., & Portmann, F. T. (2010). Groundwater use for irrigation–a global inventory. Hydrology and earth system sciences, 14(10), 1863-1880.

Sheng, J., & Webber, M. (2017). Incentive-compatible payments for watershed services along the Eastern Route of China's South-North Water Transfer Project. Ecosystem Services, 25, 213–226.

Sheng, J., & Tang, W. (2021). Spatiotemporal variation patterns of water pollution drivers: The case of China's south-north water transfer project. Science of the Total Environment, 761, 143190.

Sun, S., Wu, P., Wang, Y., Zhao, X., Liu, J., & Zhang, X. (2013). The impacts of interannual climate variability and agricultural inputs on water footprint of crop production in an irrigation district of China. Science of The Total Environment, 444, 498–507.

Wei, Y., Tang, D., Ding, Y., & Agoramoorthy, G. (2016). Incorporating water consumption into crop water footprint: A case study of China's south–north water diversion project. Science of the Total Environment, 545, 601-608.

Wu, P., Jin, J., & Zhao, X. (2010). Impact of climate change and irrigation technology advancement on agricultural water use in China. Climatic Change, 100(3), 797-805.

Wilson, M., Li, X. Y., Ma, Y. J., Smith, A., & Wu, J. (2017). A Review of the Economic, Social, and Environmental Impacts of China's South–North Water Transfer Project: A Sustainability Perspective. Sustainability, 9(8), 1489.

Xu, X. Z., Song, G. D., Dang, T. M., Liu, J. W., Zhang, H. W., Gao, H., & Liu, Y. K. (2018). Environment and sustainability of the Middle Route, South-to-North Water Transfer Project in China: a close look. Environment, Development and Sustainability, 20(6), 2415-2426.

Yao, Y., Zheng, C., Andrews, C., He, X., Zhang, A., & Liu, J. (2019). Integration of groundwater into China's south-north water transfer strategy. Science of The Total Environment, 658, 550–557.

Yin, Y., Wang, L., Wang, Z., Tang, Q., Piao, S., Chen, D., ... & Zhang, J. (2020). Quantifying water scarcity in northern China within the context of climatic and societal changes and south-to-north water diversion. Earth's Future, 8(8), e2020EF001492.

Yu, M., Wang, C., Liu, Y., Olsson, G., & Wang, C. (2018). Sustainability of mega water diversion projects: Experience and lessons from China. Science of The Total Environment, 619–620, 721–731.

Zhang, L., Heerink, N., Dries, L., & Shi, X. (2013). Water users associations and irrigation water productivity in northern China. Ecological Economics, 95, 128-136.

Zhang, Q. (2009). The South-to-North Water Transfer Project of China: Environmental Implications and Monitoring Strategy 1. JAWRA Journal of the American Water Resources Association, 45(5), 1238-1247.

Zhao, Z. Y., Zuo, J., & Zillante, G. (2017). Transformation of water resource management: a case study of the South-to-North Water Diversion project. Journal of Cleaner Production, 163, 136–145.

Zhao, Y., Zhu, Y., Lin, Z., Wang, J., He, G., Li, H., ... & Wang, Q. (2017). Energy reduction effect of the south-to-north water diversion project in China. Scientific Reports, 7(1), 1-9.