

Economic & Distributional Effects of Dams:

Evidence from Iran

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Abstract — We examine the economic and distributional effects of dams in rural areas. We introduce a novel identification strategy combined with a range of novel measures such as agricultural land rent, revenue, profit and population which are observed at a highly spatially disaggregated level in Iran for about two decades. We demonstrate that downstream areas tend to benefit from dams, whereas other areas do not benefit, or even lose, for example in terms of population. In particular, land owners of downstream areas benefit: the elasticity of agricultural land rent in downstream areas with respect to volume of dams is positive and about 0.03 to 0.05. Overall, the monetary benefits of dams identified by us, in terms of higher rents, wages and profits, cover only 20% of the investment cost of dams. We also demonstrate that using data at a more aggregated level, which is common in the literature, masks important distributional effects.

Keywords — Dams, Iran, Agriculture, Land rent, Infrastructure, Development.

JEL codes —H54, O13, O20, Q15, Q19.

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1 Introduction

This paper contributes to a literature that aims to quantify the economic and distributional effects of agricultural dams. About 30% of irrigated agricultural land worldwide is due to dams ([World Commission on Dams 2000](#)). Nevertheless, we know very little about their effectiveness ([Jeuland 2020](#)).¹ Hence, even a basic question, such as whether it is, in general, economically efficient to construct new irrigation dams to improve productivity in the agriculture sector is basically unanswered, even if one is willing to ignore a number of well-known disadvantages of dam construction, such as increases in malaria, the forced removal of population and environmental degradation ([Mettetal 2019](#)) and exacerbated water scarcity problems in other parts of the economy ([Mesgaran et al. 2017](#)).

We focus on the economic effects of (agricultural) dams for Iran, where there is a heated debate about the effects of dams. We take into account that dams affect local communities through several measures such as agricultural land rent, population movements, agricultural revenue, wages and farmer income.² These measures are key input in many economic studies, but have not been studied in the context of dams.

Agricultural land rent is according to economic theory, one of the first-order key indicators of economic benefits, as the efficiency gains are largely captured by landowners. This approach fits with a long tradition, going back to the 19th century, in using agricultural land rent as a proxy for welfare ([Palmquist 1989](#)). Agricultural land in Iran is typically not owned by absentee landowners who rent out the land to farmers, but owned by local farmers. We also focus on population movements, as a positive effect of dams can be interpreted as a sufficient statistic for the presence of economic benefits of dams ([Redding & Rossi-Hansberg 2017](#)). We supplement these estimates with the effects on farmer's revenues and a range of agricultural productivity measures. Finally, we examine the effect on wages paid, which is likely a second-order indicator of increases in economic benefits, as in competitive labour markets, local productivity improvements do not have effects on wages, but only on local employment.

¹Note that [Jeuland \(2020\)](#) documents an impressive number of *case* studies of the effects of irrigation dams, but these studies are silent on the average effect we are interested in. For the literature on the effects of *hydropower* dams, we refer to [Lipscomb et al. \(2013\)](#).

²We will ignore issues related to health and the impact on local environment ([Lewis et al. 2008](#), [Provencher et al. 2008](#), [Bohlen & Lewis 2009](#), [Lipscomb et al. 2013](#)).

We are the first paper that estimates the effect of the volume of (upstream) dams instead of the number of dams. To address endogeneity issues, we introduce a novel triple-difference method using information on the difference between irrigated and rainfed lands within the same (small) area. Rainfall is the main water resource for rainfed agriculture. Stored water run-off from rivers, dams, lakes and aquifers is the main water source for irrigated agriculture. In Sub-Saharan Africa more than 95% of farmland is rainfed, while the corresponding figure is almost 90% for Latin America, about 60% for South Asia, 65% for East Asia and 75% for the Near East and North Africa (Wani et al. 2009). Our key assumption is that rainfed land is not directly affected by dams, whereas irrigated land, benefits from sources such as rivers and dams. Therefore, we compare changes in outcomes such as land rent between irrigated and rainfed agricultural lands before and after opening of dams. We will discuss about the potential indirect effect of dams on rainfed lands in Section 5, including converting rainfed land into irrigated land and general equilibrium effects which affect rainfed and irrigated land differently.

@@What about indirect effects? Can we test this assumption?@@ Rainfed agriculture, and the difference with irrigated farming, has been widely discussed in the agricultural literature Wani et al. (2009). We employ a panel of highly spatially disaggregated data derived from village-level farmer surveys in Iran from 2000 to 2018 and administrative population data from 1976 to 2016. As emphasised by Strobl & Strobl (2011), finding those data over long periods for developing countries is rare. Our analysis is at a spatially detailed level of areas, which we will call counties, which on average contain only 10,000 households.

Our study relates to a growing, but still small, economic literature that essentially starts with the seminal paper by Duflo & Pande (2007) for India using an IV approach. It shows that in (large) districts located downstream from a dam, agricultural production slightly increases and vulnerability to rainfall shocks declines. Several limitations of this study should be noted. First, the study employs number of dams which is a crude measure of the regulated water rather than the volume of dams. Second, Duflo & Pande (2007) employs information on districts at a rather large geographical level that do not capture the localised effects of smaller dams. Furthermore, in the study, upstream/downstream districts are defined based on administrative borders, which creates substantial measurement error as geographical features such as topographic elevation and river networks delineate the watershed under a dam. Third, the IV approach

is based on (short-run) changes over time of the instrument, and therefore is non-informative about the long-run effects. Some of these shortcomings have been addressed in the ensuing literature. The follow-up literature has partially addressed the first issue by distinguishing between the effects of the number of small and large dams³ (Strobl & Strobl 2011, Blanc & Strobl 2014). For example, Strobl & Strobl (2011) studies the impact of (large) dams on cropland productivity for the whole of Africa.

An important finding of these papers is that the size of dams matters. For example, it appears that small dams increase cropland productivity downstream, but large dams reduce cropland productivity within their close proximity, as shown for South Africa (Blanc & Strobl 2014). Moreover, large dams are more likely to have negative social, health and environmental consequences (Kitchens 2013). For example, Mettetal (2019) shows that a large dams in South Africa increase infant mortality, water pollution and reduce water availability. This suggests that the construction of small dams is more likely to be welfare improving than large ones. These results ignore however that large dams can play a potentially important role in enhancing the positive impact of local small dams because they can provide regulated water to small dams (Blanc & Strobl 2014).

The current paper contributes to this literature in five different ways. First, we introduce a triple-difference method to solve endogeneity issues (but will also employ, and improve, the standard IV approach introduced by Duflo & Pande (2007) and show its limitations in our context). Second, we provide evidence for the effect of dams on a range of measures, notably agricultural land rent which is a common proxy for welfare and information on farmers' income. Third, we take into account the size of dams by considering the volume of dams instead of the number of dams. So, we do not arbitrarily distinguish between small and large dams. Fourth, we distinguish between short run and long run estimates and demonstrate that approaches that use long differences (e.g. 20 years) typically imply much higher estimates than those which are based on short-term differences. This makes it plausible that the long-run effects of dams are much more pronounced than suggested by the current estimates in the literature that employ approaches that assume all the effects of dams are immediate, and which essentially mixes short

³These studies still ignore important variation in the size of dams and also consider the threshold for belonging to the large or small dam category arbitrarily.

and long-run estimates. Finally, we have collected agricultural and population data at village level which enables us to provide evidence on the effect of dams at a more disaggregated level than previous studies, avoiding issues related to the use of large administrative areas.

2 Dam construction and Agriculture in Iran

In Iran, about 18% of workers are employed in the agricultural sector generating 13% of the national income. Iran aims to achieve food self-sufficiency. Its agricultural sector supplies about 90% of domestic food consumed, but at the same time uses about 92% of available freshwater, way above the global average of about 70 % (Mesgaran et al. 2017, Ritchie & Roser 2017). Iran has a semi-arid climate, with many deserts, hence only 9.5% of Iran's land area is cultivated.⁴ The majority of agriculture takes place in the west, northwest, and northern parts of the country where annual precipitation exceeds 250 mm, which is regarded as the minimum threshold for rainfed farming. However, irrigated agriculture is present in regions with precipitations as low as 200 mm per year, or even below 100 mm per year. Consequently, dams have become key for agriculture.

Irrigation is much more common in Iran than in other countries: more than half of its farmland is irrigated (the rest is rainfed), about twice the global average (Portmann et al. 2010).⁵ After the 1979 revolution, promotion of self-sufficiency through cultivation of strategic staple crops such as wheat has led to heavy (energy) subsidies in the agricultural sector, causing an increase in demand for water (Madani et al. 2016). Water is nearly free in Iran, also for the agricultural sector. Therefore, water cost is not a limiting factor for agricultural activities. The only limitation is the unavailability of water.⁶ Before the 1979 revolution, Iran had only 14 large dams. Since then, policies focused on increasing water supply for agricultural production, primarily through building of dams (Yazdandoost 2016),⁷

Iran is now the world's third leading country for dam construction (Madani et al. 2016).⁸

In Figure 1 we show the evolution of the number and volume of dams across Iran during 1976-

⁴Annual precipitation is around 225 mm – far below the global average of 860 mm – and can be as low as 50 mm in deserts but exceeds 1500 mm in the north of Iran (Saemian et al. 2022).

⁵About 5% of agricultural land has pressurized irrigation, while 95% utilizes gravity irrigation.

⁶As a result, the country currently faces serious water challenges, including rising water demand, declining groundwater levels, deteriorating water quality, and increasing threats to the environment and various ecosystems.

⁷For the literature arguing that these policies have little concern for environmental impacts, see (Tahbaz 2016).

⁸Dams are not only built domestically, as it operates projects in 40 countries (Madani et al. 2016).

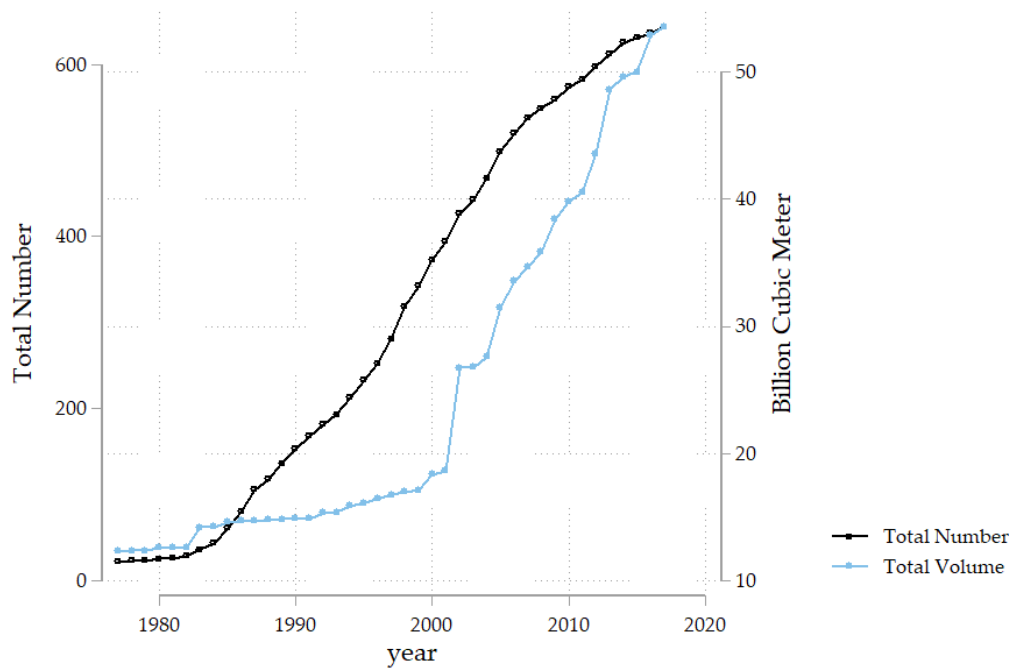


FIGURE 1 – EVOLUTION OF DAMS IN IRAN DURING 1977-2017

2017. The number of dams has increased substantially, by about 660, since the 1980s. Until 2000, newly-constructed dams were rather small, but after 2000, mostly large dams were built tripling dam volume within a rather short period. The large majority, more than 80%, are (almost) entirely for agricultural purposes. Dam construction is far from over: there are still about 125 dams under construction and 500 dams under study. In recent years, however, dam construction has slowed down due to criticism about their impacts on water supply, environmental and degradation.

The Ministries of Energy and of Agricultural Jihad are in charge of building dams: both ministries build about half of all dams. Agriculture is one of the (major or minor) purposes of almost all dams in Iran and just a few dams does not have agricultural improvement as one of their purposes. The Ministry of Agricultural Jihad builds smaller dams for local agricultural use, with an average volume of 2 million m³, while the Ministry of Energy builds larger dams, with an average volume of 140 million m³ for a range of purposes, including hydro-electricity, industry and drinking water, but usually also for agriculture. Both ministries are also responsible for the construction of irrigation canals which might take longer than the construction of the dam itself.

3 Data

This paper combines hydrological and economic data to study the economic impact of dams. In the two following subsections, we discuss the hydrological, geographical and economic data.

3.1 Hydrological and Geographical Data

3.1.1 Dams

We have information on about 644 dams which their height exceeds 3 meters and a capacity of at least 30,000 m³ (out of 660 existing dams).⁹ We have complete information about the purpose, opening year, volume and regulated water volume. Furthermore, we have (incomplete) information about height, irrigated area, lake area and agricultural water volume. We restrict our analysis to 596 dams reporting agriculture as one of their purposes. Almost all (about 94% on average) water is used for agriculture.¹⁰ Figure 2 shows that dams are not evenly distributed across the country: most are in the north-western, western or eastern parts. There are also vast areas without dams, mostly in the central part of Iran, where rivers are non-existent.

Table 1 provides summary statistics. It shows that agriculture is not the only purpose. Flood control and drinking water provision are also common. For example, 24% also aim to improve flood control. Other purposes, such as hydro-electricity generation or supporting industry, do not play much of a role. Dams have an average volume of 84 million m³ and irrigate about 5 thousand hectares of downstream agricultural land. Variation in dam volume is extreme (its standard deviation is about 5 times the mean). The smallest dams have a volume of only 40 thousand m³, whereas the largest have a volume of 7 billion m³. It takes on average 3.2 years to construct a dam. Small dams are obviously constructed much faster.

3.1.2 Basins

We have collected geographical information about Iran's 30 major river basins, and 135 sub-basins¹¹, river kilometers, elevation (for cells of 30m by 30m), overall and river gradients, and flow accumulation using information from several sources (*Guide Lines and Criteria for*

⁹This information is obtained through the Iran Water Resources Management Company within the Ministry of Energy complemented with internet and google maps for missing information.

¹⁰We do not know this percentage for all dams, so the exact percentage may be inaccurate.

¹¹An official local sub-basin definition as in *Guide Lines and Criteria for Classification and Coding Basin in IRAN (2012)* where a sub-basin is defined to have one main river. The average area of sub-basins with this definition is about 12000 km²

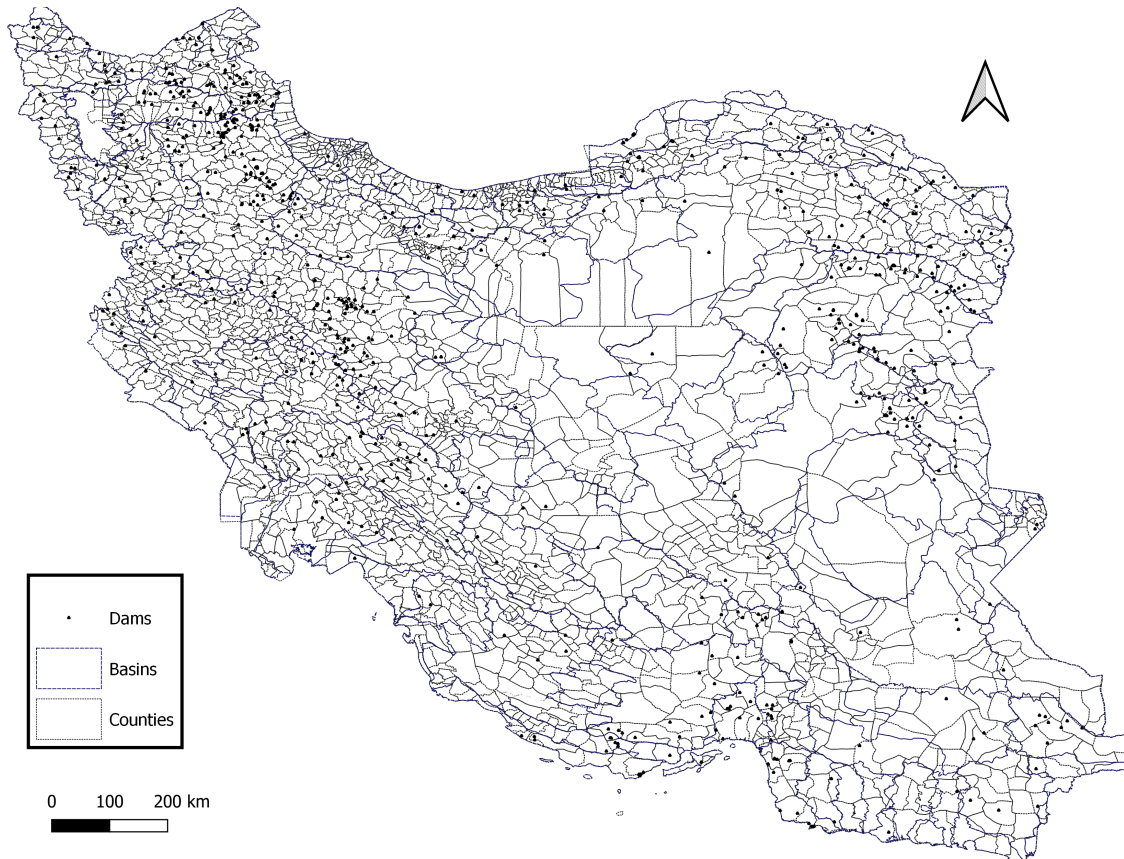


FIGURE 2 – LOCATION OF IRRIGATION DAMS

Notes: This figure shows a map of Iran with dots indicating the location of irrigation dams. Lines depict polygons that delineate the boundary of counties.

Classification and Coding Basin in IRAN 2012, JPL 2020, Andreadis et al. 2013).¹² Our econometric analysis later on will be at the level of counties (as defined for the year 2000). There are 2,194 counties with a median area of about 350 km². This is ten times smaller than the areas defined in Duflo & Pande (2007) and also much smaller than in other studies.¹³ In Panel A of Table 2, we provide descriptive statistics on geography and hydrology characteristics at the level of counties. Counties are an order of magnitude smaller than sub-basins and it should be noted that sub-basins and counties or districts do not overlap since the latter are administrative or political units but the former is hydrological unit. We identify how counties areas are interlinked in terms of water flow, i.e. in terms of their upstream/downstream relationship using hydrological data following Strobl & Strobl (2011).¹⁴

¹²Flow accumulation measures by how much water flows in a geographical river cell of an area, see Appendix A.4

¹³Each district in Iran consist of about 10 counties

¹⁴Duflo & Pande (2007) use administrative areas to define these relationships. This approach is justified when catchment areas are contained within districts and one can classify districts as upstream/downstream to each other.

TABLE 1 – DAMS SUMMARY STATISTICS

Variable	Mean	Std. Dev.	Min	Max
Panel A. Additional Purpose				
Flood control	0.24	0.48	0	1
Drinking water supply	0.17	0.37	0	1
Environment	0.13	0.32	0	1
Industry	0.07	0.25	0	1
Hydro-electrical	0.06	0.24	0	1
Touristic	0.02	0.12	0	1
Panel B. Dates				
Opening Year	1996.8	10.7	1951	2017
Construction period duration (<i>year</i>)	3.2	2.7	0	18
Panel C. Size and Specifications				
Height (<i>m</i>)	27.1	28.4	3.6	205
Total irrigated Area (<i>hectare</i>)	5167.5	25496.7	6	364744
Lake area (<i>hectare</i>)	459.5	1719.2	0.35	21000
Dam Volume (<i>million m³</i>)	90.1	476.9	0.04	7644.3
Regulated Water (<i>million m³</i>)	65.9	335.8	0.04	4260
Agricultural Water (<i>million m³</i>)	58.4	360.1	0.04	4260

Notes: This table shows summary statistics for 596 dams studying in this paper which are used for agricultural purpose. We do not have data on construction duration, total irrigated area and agricultural water for some of the dams in our sample.

Counties within a sub-basin are categorized into upstream/ downstream based on river flow direction. Figure A1 shows an example of a sub-basin that contains several counties with rivers and a dam (shown by the triangle) upstream of counties 4, 9 and 10.¹⁵

As depicted in Figure ??, sub-basins vary greatly in shape and size. Most counties lie completely within a sub-basin which makes it easier to define upstream/ downstream relationships.

Panel B of Table 2 shows the number of own, upstream and downstream dams and volume at the county level by averaging these variables during 2000 until 2017 for each county. In these years, counties had on average 0.2 dams, 6.3 upstream dams and 5.4 downstream dams. In 1976, dams were almost absent and most of the counties (99%) had no dams. By 2017, 20% had at least one dam and 6% at least two dams. Although most counties do not have their own dam, most counties in 2017, 81%, have at least one upstream dam. The median distance of a county with its upstream dam is about 84 km.

This is general not the case.

¹⁵For sensitivity analysis, in Appendix A.3, we define river basins and sub-basins using river flow, as in Lehner & Grill (2013), to determine whether a (sub)basin is upstream, downstream or not related to another (sub)basin. We use global watershed boundaries and level 5 sub-basin delineations at 15 second resolution. This methodology divides Iran into 70 hydrological basins with an average area of 22,900 km² but the results does not change significantly.

TABLE 2 – DATA DESCRIPTION

Variable		Mean	St. Dev	Min	Max
Panel A. Hydrology and Geography					
Elevation (<i>m</i>)		1010.7	654.1	-26.4	2765.6
Slope (percent)		5.8	4.9	1.0	30.1
River Length (<i>km</i>)		117.7	121.6	0.0	895.3
Area (<i>km</i> ²)		730.3	1319.6	11.1	20278.4
Distance to nearest big city (<i>km</i>)		93.3	62.6	2.6	422.7
Flow accumulation (<i>km</i> ²)		2190.8	18728.1	17.1	621447.8
Fraction county with River Gradient:	0-1.5%	0.18	0.15	0	1
	1.5-3%	0.21	0.11	0	0.48
	3-6%	0.24	0.08	0	0.46
	6-9%	0.10	0.05	0	0.25
	9-12%	0.07	0.04	0	0.18
	>12%	0.19	0.19	0	0.84
Panel B. Dams					
Number	Own	0.2	0.5	0	8.1
	Upstream	6.3	11.1	0	66.1
	Downstream	5.4	11.3	0	87.8
Volume (<i>million m</i> ³)	Own	16.1	182.1	0	6219.4
	Upstream	298.2	1045.2	0	16054.4
	Downstream	562.5	1724.1	0	13860.8
Panel C. Agriculture and Population					
Share of irrigated land (Percent)		0.51	0.41	0	1
Irrigated	Rent	1.31	0.77	0.10	8.74
	Revenue	18.91	19.12	0.29	176.1
	Profit	7.87	9.05	-7.24	101.8
Rainfed (<i>m</i> ³)	Rent	0.39	0.43	0.01	5.14
	Revenue	12.21	18.91	0	520
	Profit	4.53	9.12	-58.6	209.7
Population		9404.6	6917.4	187	81292
Rain (<i>mm/year</i>)		380.3	206.6	55.9	1183.3

Notes: This table shows Data description for 2,194 counties. Panel A shows hydrological and geographical characteristics. In Panel B Average of Number and volume of own, upstream and downstream dams in each county during 2000 until 2018 are reported. Panel C shows agricultural variables, population and rain data for counties which is averaged during the period for each county. Agricultural rent, revenue, and profit are reported in million Toman per Hectare. For averaging, we adjust agricultural variables to 2018 prices. Agriculture data source is a survey at village level which is aggregated at county level resulting in an unbalanced panel sample between 2000 and 2017 for 2059 counties. Population data is from the Decennial Census from 1976 until 2016 which is available for about 30 thousand villages and is aggregated at county level. For rain we use [GSFC \(2019\)](#).

3.2 *Economic Data*

We use 2 different datasets related to farmer's expenditures and revenues, agricultural production and cultivated area obtained from Ministry of Agricultural Jihad. The first dataset, summarized in Panel C of Table 2, is a survey covering crop product costs and revenues in about 30 thousand villages across the country over 2000 to 2017.¹⁶ We aggregate this to 2,194 counties across 250 districts (defined for the year 2000) because we do not have the exact location of the villages. This rich dataset provides information on farmer costs and revenues for each product, land rent, labor wage, total labor cost, water cost, fertilizer cost, and farmer's revenues for rainfed and irrigated products separately. In 145 counties, so about 7% of counties, there is no information about their agricultural costs and revenues during our study period which probably means that there is no agricultural activity there. In Panel C of Table 2, we show the descriptive statistics that play a major role in our analysis: land rent, farmer profit and revenue, and population. Irrigated land rent is about 1.3 million Tomans (about 104\$) and rainfed land rent is about 390 thousand Tomans (about 32\$).

The second dataset provides information on the cultivated area and crop production across 225 districts from 1991 to 2015 (defined for the year 1991 with an average area of about 7000 km²). Combined with information on crop price (that is district and year specific), we calculate the production value for 19 main crops (separately for rainfed and irrigated products). This allows us to calculate for each year at the district level, the total cultivated area (in thousand hectares), value of production (in million Rials) and yield (in million Rials per hectare). Summary statistics are reported in Table A10 of Section A.5 in the Appendix.

We also use census information on county level population for the years 1976, 1986, 1996, 2006, 2011, and 2016. On average about 8 thousand people live in a counties. Rain data at county level is derived from NASA (GSFC (2019)).

4 **Empirical Framework**

4.1 *Difference-in-differences estimation*

Our analysis exploit county panel data using variation over time in dam placement. For identification of the causal effect of dam construction on own and downstream counties we rely on a

¹⁶We do not have data on orchard products which cover 25 percent of cultivated area.

triple difference strategy. First, we use a ‘naive’ difference-in-differences strategy, so we compare differences in outcomes between counties in which larger dams are constructed than others.

$$\ln y_{r dt}^I = \beta_1^I + \beta_2^I \text{asinh}(D_{r dt}) + \beta_3^I \text{asinh}(D_{r dt}^U) + \beta_4^I \text{asinh}(D_{r dt}^D) + \beta_5^I Z_{r dt} + \beta_6^I Z_{r dt}^U + \beta_7^I Z_{r dt}^D + \delta_r + \alpha_{dt} + \epsilon_{r dt}^I, \quad (1)$$

where $y_{r dt}^I$ is one of the outcome variables including agricultural land rent, farmer’s revenue and profit for irrigated products, labor wage, and population in county r in district d and year t . $\text{asinh}(D_{r dt})$ is arcsinh (or inverse hyperbolic sine)¹⁷ of dam volume in county r in year t . $\text{asinh}(D_{r dt}^U)$ and $\text{asinh}(D_{r dt}^D)$ show the same variables for dams located upstream and downstream of county r , respectively. β_2^I , β_3^I , and β_4^I are parameters to be estimated. $Z_{r dt}$, $Z_{r dt}^U$, $Z_{r dt}^D$ are a set of time-varying control variables for the county, its upstream and downstream counties including rain and differential linear time trends for share of different levels of elevation in the county, overall gradient, county area, and river length. We sum river length and county area across all upstream counties and average the other variables (which are proportions).¹⁸

δ_r is a county fixed effect which control for time-invariant characteristics that affect the likelihood of dam construction and outcome variables in the county. α_{dt} is a district-by-year interaction fixed effect that controls for annual shocks that are common across counties in a district. $\epsilon_{r dt}^I$ is a county-year specific error term. In other specifications, we also include sub-basin-by-year fixed effects to control for annual shocks that occur at the sub-basin level. We only exploit dam construction variation between counties within a district or sub-basin for identification.

Because this identification strategy relies on between-county differences in dam construction, it

¹⁷Inverse hyperbolic sine transformation can be applied in econometric studies to transform right-skewed variables that include zero or negative values. It approximates the natural logarithm of the variable and allows retaining zero-valued observations. Since we have lots of zeros in dam volume of counties, we use inverse hyperbolic sine as an approximation for logarithm which is almost the same as natural logarithm in large positive values and can have zero values too. We are (predominantly) interested in the effect of upstream dam volume. For this variable, at the beginning of the observation period, there are quite some zeros, but less so at the end (About 20 Percent of counties). This makes asinh for upstream volume attractive. In Table A4, we estimate some robustness checks to this functional form. First, we use a dummy which equals one if the county has an upstream dam and the interaction of this dummy and the logarithm of upstream dam volume (Which is subtracted by logarithm of average upstream dam volume for better interpretation), but for the other controls we keep asinh. Furthermore, we use the log volume of the upstream dam, and no dummy, but we substitute the volume of zero with the volume of the 50% of the smallest dam in our dataset. Finally, we estimate the model only using the log of the volume upstream, but we exclude observations without any upstream dam

¹⁸We use information on surface elevation at each of the cells within a county to compute the fraction of county area in four different elevation categories: 0-250 meters, 250-500 meters, 500-1,000 meters, and above 1,000 meters. County overall gradient is the average of the steepness of the ground surface of all the cells in the county and is measured as the tangent of the surface.

might still suffer from endogeneity in dam placement within districts. For example, counties that anticipate larger increases in agricultural productivity and population may be more likely to receive dam investments, implying a spurious positive relationship between population increase, agricultural growth and dam building. Therefore, we consider a triple differences strategy (DDD) as our main identification strategy, where the additional difference comes from comparing irrigated and rainfed agricultural land. Irrigated agriculture is the main direct beneficiary of dam construction, whereas rainfed agriculture does not receive any direct benefits.

We improve upon the literature which either used the number of dams (Duflo & Pande 2007, Strobl & Strobl 2011, Mettetal 2019) or the difference between small and large dams (Blanc & Strobl 2014), using the volume of regulated water by dams as our main explanatory variable. This is a more accurate measure because the dam effect depends on the amount water regulated. Since the distance between the upstream dam and the county is also important, as a robustness check we use a weighted measure of upstream dam volume with weights equal to the inverse of distance from the downstream county.

For the above specification to be consistent, the annual variation in dam construction across counties within a district must be uncorrelated with other county-specific shocks. In other words, dams should be randomly allocated across counties within a district. This assumption may be violated if, for instance, counties on increasing trends receive more (or less) dam construction. Thus, unless the set of controls Z captures all time-varying factors that affect dam construction and the outcome variable (e.g. agricultural revenue and land rent), a naive difference-in-differences regression as equation (1) may produce inconsistent estimates of the parameters of interest. Moreover, these biases may be upward or downward depending on the political or economic motivation behind dam placement. We emphasize that we use a finer geographical unit (county), so we likely overcome most biases as most political factors are usually present at the district level, but we cannot completely rule out such biases.¹⁹

In the next sub-section we propose a novel approach to address the endogeneity problem. We develop a triple difference strategy that uses the difference between irrigated and rainfed products. The identifying assumption underlying our analysis is that in the absence of dam

¹⁹Previous studies used the instrumental variable approach to overcome this problem (Duflo & Pande 2007, Strobl & Strobl 2011, Lipscomb et al. 2013, Blanc & Strobl 2014, Mettetal 2019). We also apply such an IV and improved instrumental variable method which is discussed in Appendix A.2.

construction, the evolution of economic outcomes of irrigated products and rainfed products within a county would have parallel trends.

4.2 Triple differences approach

Rainfed agriculture relies on rainfall for water, so we will assume that dams do not have an effect on rainfed production. Therefore, if we run regression 1 for rainfed products as follows:

$$\ln y_{r dt}^R = \beta_1^R + \beta_2^R \text{asinh}(D_{r dt}) + \beta_3^R \text{asinh}(D_{r dt}^U) + \beta_4^R \text{asinh}(D_{r dt}^D) + \beta_5^R Z_{r dt} + \beta_6^R Z_{r dt}^U + \beta_7^R Z_{r dt}^D + \delta_r + \alpha_{dt} + \epsilon_{r dt}^R, \quad (2)$$

we expect β_2^R , β_3^R , and β_4^R to be zero. We exploit this to employ a triple difference strategy to find the causal effect of dams. We consider the following regression specification which is subtraction of equation 2 from 1:

$$\ln y_{r dt}^I - \ln y_{r dt}^R = \tilde{\beta}_1 + \beta_2 D_{r dt} + \beta_3 D_{r dt}^U + \beta_4 D_{r dt}^D + \tilde{\beta}_5 Z_{r dt} + \tilde{\beta}_6 Z_{r dt}^U + \tilde{\beta}_7 Z_{r dt}^D + \tilde{\delta}_r + \tilde{\alpha}_{dt} + \tilde{\epsilon}_{r dt}, \quad (3)$$

where $y_{r dt}^I$ is agricultural land rent, farmer's revenue or farmer's profit for *irrigated* products in county r in district d and year t , and $y_{r dt}^R$ is the same variable for *rainfed* products in the same county. Taking the difference between the performance of irrigated and rainfed outcomes removes all unobserved characteristics that might change over time (at the county level) but affect irrigated and rainfed products similarly. By assumption, dam construction has a time-varying heterogeneous effect on irrigated and rainfed products. The identification assumption is that in the absence of changes in the volume of water regulated by dams, the change over time in the difference in outcomes between rainfed and irrigated land within the same county would have been the same. We believe that this assumption is hardly restrictive and therefore the triple difference results could be interpreted causally. However, we elaborate on several potential threats to identification and estimate additional specifications to make sure they are not driven by unobserved omitted factors.

First, we control for basin-by-year fixed effects because of different hydrological and geographical characteristics of basins which may affect how dams affect agriculture. Basins are hydrological units and not administrative units so they do not overlap district borders. This specification is further improved by adding district-by-year fixed effects allowing different districts to have different flexible trends. This would take care of violations that occur at the district-level. For example, the allocated budget from the central government might vary over

time. Once a district receives a higher budget it may invest at the same time in dams and other agricultural inputs (such as subsidized fertilizer). These additional fixed effects are particularly important when we analyse the effect of dams on land rent, since this variable may have different trends in different districts because of reasons correlated with dam construction. For example because of dam construction, people will move to districts where big dams are built because of better access to drinking water and buy villas there which will increase land price in those districts without any relationship with agricultural improvement.

Second, even with basin-by-year fixed effects and using a triple-differences approach, one might expect a differential time trend for irrigated and rainfed production because of differences over time in rainfall and other geographical characteristics at the county level. We, therefore, control for average rainfall of each county in each year and also for some other geographical trends of own, upstream and downstream counties including differential linear trends for different elevation, overall gradient, county area, and river length.

Third, it takes some time for the effect of the dams to materialize in the downstream because after construction of dams, some complementary infrastructures like canal networks must be constructed before the water can be effectively used. We take this into account by using lag of dam variables. In addition, we use long differencing, i.e. we keep the first and last year of our data, to look at the long-run effect.

Fourth, the effect of dams changes according to the distance from the county and the effect is smaller in farther downstream counties. We weight volume of upstream/downstream dams by their distance to the county. This allows closer dams to be more important than farther dams. We also consider a threshold for the effect of dams in another strategy and only use the volume of dams closer than 50km.

Fifth, dams may increase the attractiveness of downstream villages for recreational activities, such as villas. The nearby population may flow to the region due to increased water availability for converting agricultural land for building villas. This increased in demand could drive up land rents in downstream areas not because of an improvement in agriculture. This effect is expected to be higher in villages closer to big cities. To control for this confounding factor, we add the interaction of year by the distance of the county to the nearest big city.

Sixth, after dam construction, because of availability of adjusted water, supply of irrigated land will increase. This effect which can also be seen in Table 7, leads to a supply effect of these lands and make them more available. This fact would result in downward bias in our estimates because it would decrease the land rent of irrigated land because of supply effect.

Seventh, we emphasize that the general equilibrium effects for both types of agricultural activities may be the same. If there exist some general equilibrium effects which increases outputs in rainfed land more, our results would be biased. But it seems that both of these lands are equally affected by general-equilibrium. We may not identify the effect well if the rainfed lands become irrigated after dam construction, which is unlikely due to the characteristics of rainfed crops and the type of rainfed lands and unavailability of rivers and water close to them, and secondly, Table 7 shows that after the dams does not have any statistically significant effect on the rainfed area of their own or downstream districts.

Finally, we argue that an instrumental variables (IV) strategy along the lines used in the dams literature is only suitable for very large countries with significant elevation differences and the instrument, which is based on the interaction of geography and time, does not provide enough statistical variation in the first stage. Nonetheless, we provide estimates from such, an IV strategy as well as an improved strategy in Appendix A.2. The results here are broadly consistent with the DDD strategy, but are mostly statistically insignificant.

5 Results

5.1 Main results

Panel A of Table 3 shows basic estimation results for agricultural land rent and profit. Columns (1) and (2) report DiD estimation results based on specification (1) and without basin-by-year fixed effects and rain and geographical trends control. Column (1) shows that 1% increase in the volume of upstream dams leads to 0.023% increase in irrigated land rent, which is statistically significant at the 1 percent level. Column (2) shows that agricultural profit also increases by 0.04% upon a 1% increase in the volume of upstream dams. The results also show that an increase in the volume of the regulated water in the county or downstream dams does not significantly affect outcome variables. This is consistent with the idea that dams just affect their downstream areas positively.

The next two columns report triple-difference estimation results based on specification (3).²⁰ The results change only slightly. Column (3) shows that 1% increase in the volume of upstream dams leads to 0.03% increase in irrigated land rent compared to rainfed. Column (4) shows that the effect of volume on profit is also 0.03%.²¹

TABLE 3 – MAIN RESULTS: EFFECT OF DAMS ON AGRICULTURAL RENT AND PROFIT

Dep. Variable:	Irrigated (Diff-in-Diff)		Triple Differences	
	Rent	Profit	Rent	Profit
	(1)	(2)	(3)	(4)
Panel A. Annual differences				
Own	0.005 (0.013)	0.017 (0.020)	0.027 (0.023)	0.001 (0.022)
Upstream	0.023*** (0.006)	0.047*** (0.010)	0.031*** (0.010)	0.030** (0.013)
Downstream	-0.001 (0.007)	0.001 (0.0131)	0.014 (0.010)	0.009 (0.013)
Observations	24,583	22,200	12,877	9,827
$\bar{R}^2$	0.807	0.617	0.652	0.570
Panel B: Long differences				
Own	0.016 (0.019)	-0.030 (0.050)	0.027 (0.042)	-0.107 (0.089)
Upstream	0.034** (0.014)	0.065** (0.030)	0.055** (0.026)	0.140** (0.060)
Downstream	-0.007 (0.009)	0.024 (0.025)	0.018 (0.023)	0.016 (0.048)
Observations	2,230	1,934	944	518
$\bar{R}^2$	0.879	0.748	0.712	0.580
Time FE	Y	Y	Y	Y
County FE	Y	Y	Y	Y
Basin-Year FE	N	N	N	N
Control	N	N	N	N
Cluster	Y	Y	Y	Y

Notes: Table shows coefficient estimates from regressions of rent and profit on measures of dam volume. Columns (1) and (2) show the effect of volume of own, upstream, and downstream dams on agricultural land rent and agricultural profit in irrigated cultivations. We include year and county fixed effects in all specifications but not basin by year fixed effects and rainfall and geographical trends. Columns (3) and (4) show triple difference results based on the comparison between irrigated and rainfed cultivations. Panel B uses the same specifications as in Panel A but keeps observations from the first and last year of the data to find the long differencing effect. Standard errors are clustered at the county level and reported in parentheses. *, **, *** represent significance at 10%, 5%, and 1% level respectively.

²⁰The number of observations for DDD regressions is about half of DD regressions because a county has to have both irrigated and rainfed agriculture in the sample to be included in DDD.

²¹In Table A5 in Appendix A.3, we use an alternative definition for upstream and downstream but the results are similar.

In Panel B of Table 3 we use the same specification as for Panel A but now we estimate long-difference method using only first and last year observations. We find that the effects become somewhat larger: Irrigated land rent and profit increase by 0.034 and 0.065% respectively. Given the triple difference strategy, we find also larger effects of about 0.055 and 0.140 percent for land rent and profit, respectively. Since it takes time for the effect of dams to materialize in downstream areas, this effect is larger than Panel A. It is worth noting that own and downstream effects remain absent in all long-difference specifications.²² For robustness check, we estimate the same specification in Table A3 for rainfed agricultural land as placebo and it can be seen that upstream dams doesn't have any effect on rainfed land which was expected.

5.2 Sensitivity Analysis

To gain confidence about the results, we perform a range of robustness checks. First, we control additionally for rainfall and linear trend in geographical controls including river length, county elevation, slope, and area, and also basin-by-year fixed effects in Table 4. The effect of upstream dams is still positive, very similar in magnitude, and statistically significant, but typically at lower levels. In the triple-difference specification, land rent increases by 0.03% (significant at 1%) and profit increases by 0.02% (significant at 10%), but the increase in profit is not statistically significant at conventional significant levels. It is worth noting that in line with our assumption, the effect of rain when applying the triple difference is negative. Higher rain helps rainfed crops more because they are solely reliant on rain while it does not help irrigated crops. Therefore, the difference between irrigated and rainfed agriculture decreases. In Tables A7 and A9 in Appendix A.3, we report how the effect changes by adding district and sub-basin fixed effects or rainfall and geographical controls which shows that our results are robust to these alternative specifications.

The second concern applies to the measurement of volume of upstream dams. Farther dams are likely to have a smaller effect than closer dams. To account for this we use the distance-weighted volume. Columns (1) and (2) in Table 5 show the estimation results for the triple-differences specification using these new explanatory variables. The result for land rent is larger than our main results and for profit it is the same.

²²We cannot use event study in our context since our explanatory variables are continuous and increasing overtime.

TABLE 4 – ROBUSTNESS REGRESSIONS: INCLUSION OF
BASIN BY YEAR AND GEOGRAPHICAL TRENDS

Dep. Variable:	Irrigated (Diff-in-Diff)		Triple Differences	
	Rent	Profit	Rent	Profit
	(1)	(2)	(3)	(4)
Panel A: Annual differences				
Own	-0.005 (0.008)	0.007 (0.018)	0.026 (0.023)	-0.014 (0.025)
Upstream	0.013* (0.007)	0.034** (0.015)	0.033*** (0.010)	0.023 (0.017)
Downstream	-0.003 (0.008)	0.014 (0.015)	0.0142 (0.0108)	0.001 (0.018)
Rain/100	-0.02 (0.04)	-0.01 (0.10)	-0.0432** (0.0195)	-0.1*** (0.03)
Observations	24,127	21,680	12,873	9,827
$\bar{R}^2$	0.886	0.676	0.656	0.552
Panel B: Long differences				
Own	-0.001 (0.021)	0.013 (0.071)	0.022 (0.042)	-0.107 (0.089)
Upstream	0.037* (0.020)	0.109* (0.060)	0.054** (0.026)	0.137** (0.061)
Downstream	0.007 (0.019)	0.021 (0.061)	0.0215 (0.024)	0.018 (0.050)
Rain/100	0.172 (0.305)	0.555 (0.423)	0.0919 (0.101)	0.0829 (0.208)
Observations	2,152	1,868	944	518
$\bar{R}^2$	0.906	0.668	0.712	0.575
Time FE	Y	Y	Y	Y
County FE	Y	Y	Y	Y
Basin-Year FE	Y	Y	Y	Y
District-Year FE	Y	Y	Y	Y
Control	Y	Y	Y	Y
Cluster	Y	Y	Y	Y

Notes: Please see note under Table 3. Here we add rain, basin by year fixed effects, and linear geographical trends as controls. Standard errors are clustered at the counties and reported in parentheses. *, **, *** represent significance at 10%, 5%, and 1% level respectively.

A final concern is that the increase in land rents may be due to higher demand for recreation and villa construction. The increase in farm profits is not consistent with this story because implicit or explicit land rent is counted as a cost. Nonetheless, to see the importance of this and other potential explanations, we add the interaction of distance to the nearest big city and the year of observation as an additional control variable in columns (3) and (4) of Table 5. This does not change the results and, therefore, we conclude that proximity to urban centers is unlikely to drive our results.

TABLE 5 – ROBUSTNESS REGRESSIONS: DAM DISTANCE AND PROXIMITY TO CITIES

Dep. Variable:	Dam volume weighted by distance		Control for distance to city	
	Rent	Profit	Rent	Profit
	(1)	(2)	(3)	(4)
Panel A: Annual differences				
Own	0.027 (0.024)	-0.004 (0.023)	0.026 (0.024)	-0.020 (0.026)
Upstream	0.041** (0.016)	0.044** (0.019)	0.039*** (0.015)	0.049** (0.022)
Downstream	0.012 (0.013)	-0.001 (0.016)	0.019 (0.013)	-0.009 (0.022)
Observations	12,197	9,342	12,197	9,342
$\bar{R}^2$	0.653	0.568	0.655	0.555
Panel B. Long differences				
Own	0.0367 (0.0424)	-0.0805 (0.0696)	0.0345 (0.0415)	-0.119 (0.0969)
Upstream	0.103*** (0.0343)	0.0637 (0.0754)	0.0940*** (0.0345)	0.138* (0.0808)
Downstream	0.0313 (0.0321)	0.00840 (0.0563)	0.0507 (0.0309)	-0.0217 (0.0710)
Observations	908	502	908	502
$\bar{R}^2$	0.720	0.601	0.732	0.589
Time FE	Y	Y	Y	Y
County FE	Y	Y	Y	Y
Basin-Year FE	N	N	N	N
Distance to City Trend	N	N	Y	Y
Cluster	Y	Y	Y	Y

Notes: In columns (1) and (2) we divide volume of each upstream/downstream dam by its distance with the county and then add them up to find the weighted average effect of upstream/downstream dams. In columns (3) and (4), we control for distance with nearest big city trend as a robustness check. Panel B is the same as Panel A but just keep observations in the first and last year to find the long-difference effect. Standard errors are clustered at the counties and reported in parentheses. *, **, *** represent significance at 10%, 5%, and 1% level respectively.

5.3 Other Dependent Variables

Up to now, our main focus was on the effect of dams on agricultural land rent and profit, but dam construction may impact other outcomes. We look at population, agricultural revenues, and agricultural wages in Table 6.²³ We can only use the DD strategy for population and labor wage as we cannot make a distinction along the water source dimension for these variables. Panel A show the short-run results while Panel B show the long-run results. In all columns, we use basin-by-year fixed effects and geographical trends in addition to time and county fixed effects. The results show that dams do not have any robust and significant effect on agricultural wages. This could be due to excess labor supply in the labor market in Iran. Iran has had double digit unemployment rates in the past decades, implying an excess labor supply. This is particularly important for the unskilled agricultural labor market. Therefore, any increase in labor demand is simply met by the available excess supply and would not result in any changes in wages. Furthermore, labor may migrate from nearby counties and erode any local increases in the labor demand. The results are more interesting for population. Dam construction in the downstream of a county negatively affects population and in the long-run 1% increase in the volume of regulated water downstream reduces population by 0.044% (significant at 1%). On the other hand, dam construction in the upstream of a county increases population. The long-run elasticity here is 0.032 and significant. We do not have a direct measure of migration, but the results show that migration is likely from villages upstream dams to those in the downstream. Columns (3) and (4) show that upstream dams lead to increase in agricultural revenue of downstream which is consistent with increase in agricultural profit of downstream.

5.4 District-level Results

Finally, we use another dataset which is at district level to find the effect of number of large dams on total irrigated and rainfed area and production values. We use number of large dams in Table 7 to closely mimic the approach in [Duflo & Pande \(2007\)](#). Columns (1) and (2) of Table 7 shows that dams lead to 10 and 11% increase in irrigated and production value of their own district but not downstream districts which is different from our disaggregate level results and could be because of the sheer size of districts. In columns (3) and (4) we can see that dams

²³We have all of the farmer's costs in our data including the amount of money paid to workers and the hours worked so we calculate labor wage for each farmer and aggregate it to county level.

TABLE 6 – EFFECT OF DAMS ON POPULATION, WAGE AND REVENUE

Dep. Variable:	Diff-in-Diff			DDD
	Wage	Population	Irrigated Revenue	Revenue
	(1)	(2)	(3)	(4)
Panel A. Annual differences				
Own	-0.002 (0.002)	-0.006 (0.008)	0.008 (0.016)	-0.001 (0.016)
Upstream	0.0001 (0.001)	-0.002 (0.004)	0.032*** (0.008)	0.023* (0.012)
Downstream	-0.002 (0.002)	-0.015*** (0.004)	0.001 (0.009)	0.020 (0.013)
Observations	24,131	10,918	24,495	10,618
$\bar{R}^2$	0.988	0.804	0.768	0.622
Panel B. Long differences				
Own	0.001 (0.005)	0.002 (0.011)	-0.020 (0.036)	-0.038 (0.082)
Upstream	0.002 (0.009)	0.032** (0.014)	0.051** (0.020)	0.162*** (0.049)
Downstream	-0.001 (0.008)	-0.044*** (0.015)	0.017 (0.018)	-0.019 (0.036)
Observations	2,122	4,362	2,190	598
$\bar{R}^2$	0.995	0.600	0.835	0.695
Time FE	Y	Y	Y	Y
County FE	Y	Y	Y	Y
Basin-Year FE	Y	Y	Y	Y
Control	Y	Y	Y	Y
Cluster	Y	Y	Y	Y

Notes: This table shows the effect of own, upstream and downstream volume of dams on labor wage, population and agricultural revenue. In columns (1) to (3), we see the difference in difference method and in column (4), we report triple difference results for agricultural revenue. Panel B is the same as Panel A but just keep observations in the first and last year to find the long-difference effect. Standard errors are clustered at the counties and reported in parentheses. *, **, *** represent significance at 10%, 5%, and 1% level respectively.

do not have any effect on area and production of rainfed agriculture productions. This means that there is not any statistically significant transmission between rainfed and irrigated lands after constructing a dam. By using triple difference method in columns (5) to (8), we show that irrigated area increase about 10% more than rainfed area and its production value increases 12% more than rainfed production value.

TABLE 7 – EFFECT OF OWN AND UPSTREAM NUMBER OF DAMS ON IRRIGATED AND RAINFED AREA AND PRODUCTION OF THE DISTRICT

Dep. Variable:	Irrigated		Rainfed		Triple-Difference			
	Area	Production	Area	Production	Area	Production		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Own	0.099** (0.044)	0.109** (0.052)	0.009 (0.042)	-0.008 (0.043)	0.099* (0.057)	0.045 (0.054)	0.118* (0.059)	0.078 (0.059)
Upstream	-0.018 (0.023)	0.0001 (0.028)	0.038 (0.030)	0.017 (0.027)	0.002 (0.073)	-0.007 (0.094)	-0.066 (0.070)	-0.097 (0.086)
Rain (log)	0.145*** (0.047)	0.208*** (0.056)	0.751*** (0.163)	1.056*** (0.176)	-0.678*** (0.173)	-0.574*** (0.163)	-1.014*** (0.178)	-0.851*** (0.168)
Observations	3,461	3,458	2,612	2,586	2,894	2,894	2,865	2,865
Adjusted R-squared	0.821	0.812	0.856	0.859	0.793	0.827	0.803	0.837
Time FE	Y	Y	Y	Y	Y	Y	Y	Y
District FE	Y	Y	Y	Y	Y	Y	Y	Y
Basin-Year FE	Y	Y	Y	Y	Y	Y	Y	Y
Rain	Y	Y	Y	Y	Y	Y	Y	Y
Geo. Control	Y	Y	Y	Y	N	Y	N	Y
cluster	Y	Y	Y	Y	Y	Y	Y	Y

Notes: Column (1) and (2) show the effect of own and upstream dams on Irrigated area and Irrigated production value of the district. Column (3) and (4) shows the same results for rainfed productions. In column (5) to (8) we use triple difference approach to find different effect of dams on irrigated and rainfed area and production value. In column (5) and (7) we don't control for Geographical variable trends while in other columns we control for that. Standard errors are clustered at the counties and reported in parentheses. *, **, *** represent significance at 10%, 5%, and 1% level respectively.

5.5 *Alternative approaches*

Our approach may be compared to an IV approach with location fixed effects that has been used previously in the literature (Duflo & Pande 2007, Strobl & Strobl 2011). This approach essentially uses the interaction of river suitability for dam construction at a county level with the predicted share of dams in the basin (which is time varying) as a time-varying instrument for the presence of dams. We also apply this approach and improve on the literature by using more detailed information about river suitability, which increases the strength of the instrument in Section A.2. However, similar to previous works, as, for example in the seminal work by Duflo & Pande (2007), the instrument is only strong enough to predict the number of dams but not the volume of dams. Unfortunately, in the second stage, standard errors are so large that they are essentially non-informative. Consequently, despite the large number of dams constructed in Iran, this approach is only applicable in the largest countries in the world or whole continents (see for example also Blanc & Strobl (2014), which focuses on South Africa, and which uses the policy of the apartheid regime as an instrument for dam location). The results of our instrument variable strategy using both Duflo & Pande (2007) instrument and improved instrument can be seen in Tables A1 and A2 in Appendix A.2.

5.6 *Cost-Benefit Analysis*

In this section, we conduct a back-of-envelope calculation of the costs and benefits of dam construction in downstream counties. As mentioned above, constructing a dam in upstream which increases upstream dam volume by 1%, will lead to 0.05% increase in downstream land rent and agricultural profit. Each dam has on average 26 county in downstream according to our data and the average size of a county is about 700 km². Since 30% of Iran land is agricultural land,²⁴ a new typical dam will affect about 546 thousand hectare agricultural land, on average. According to our data, the average land rent is 9.5 million per Hhctare in 2017 which means that a new typical dam will lead to on average about 260 billion Rials increase in downstream agricultural land rent. Assuming once more a 50 years of lifespan for the dam, the present value of land rent increase would be estimated. Dividing this benefit by the cost of a typical dam which is about 60 thousand billion Rials²⁵, this imply an 8 percent cost-benefit ratio. If

²⁴<https://data.worldbank.org/>

²⁵www.tahririeh.com/news/11566/

we also take into account the increase in agricultural profit of downstream areas as another benefit, this ratio will increase to about 24 percent. To estimate benefit of the dam resulting from increase in agricultural profit, we use the fact that counties' population is on average about 36 thousand which means about 4 thousand farmers.²⁶ Their average profit is about 100 million Rials annually. Since each dam has 26 counties in downstream, about 100 thousand farmers will be affected by a typical new dam. This new dam will lead to 0.05% increase in farmer's profit which means a total increase of about 500 billion Rials in agricultural profits downstream of a typical new dam. Calculating the present value of this benefit, assuming once more a 50 years lifespan for a new dam, and adding this number to the benefit resulting from increase in land rent, will lead to 24 percent cost-benefit ratio. This means that if the only purpose of the dam is for agricultural purpose, dam construction would not be beneficial but it should be noted that dams usually have other purposes such as drinking water supply, controlling flood and hydro-electricity and the benefits of them should also be taken into account.

6 Conclusions

In this paper we look at the distributional effect of dams. Our preferred specification shows that 1 percent increase in the volume of regulated water increase farm land rents, profits, and revenues for downstream county significantly by X, XX, XXX, respectively. The effect is insignificant for the county hosting the dam because counties could be both upstream and downstream of dams and the effects are mixed which was mentioned in [Duflo & Pande \(2007\)](#). Long differences and annual difference-in-differences or triple-differences estimation strategies yield fairly similar results. However, the long differences estimates are larger. Interpreting this as the long-run effect of dam construction, this pattern is consistent with the idea that building irrigation channels take time and hence the long-run effect of dams is larger.

The triple-differences strategy is a novel addition to the literature and relies on the comparison between irrigated and rainfed land. The robustness of results and the range of falsification test confirm that the identifying assumptions are valid. This strategy does not suffer from the weak first-stage that geographical IVs suffer from, when applying in small countries. It also needs a different set of assumptions that may be more easily satisfied.

²⁶Assuming 4.5 members in each household and 50 percent of population of counties to be farmers: $36000 \times 0.5 / 4.5$.

The set of outcome variables used in this paper are new as well. We concentrate on agricultural land rent, agricultural wages, and population. Land rent is probably the most relevant variable, because in efficient capital markets it reflects the maximum value that could be extracted from land. The fact that rents increase after dam construction shows that regulation of water resulted from dam construction, increase water security for farmers. We do not find any impact on wages, which may reflect the excess labor supply in Iran. Population also increases in the counties downstream the dam. This suggest local migration in order to benefit from the agricultural opportunities created by the dam.

We can also conduct a back-of-envelope calculation of the costs and benefits of dam construction in own and downstream counties. Cost-benefit analysis of constructing a typical dam in upstream would be between 20 to 30% which results from increase in agricultural land rent and profit of downstream counties.

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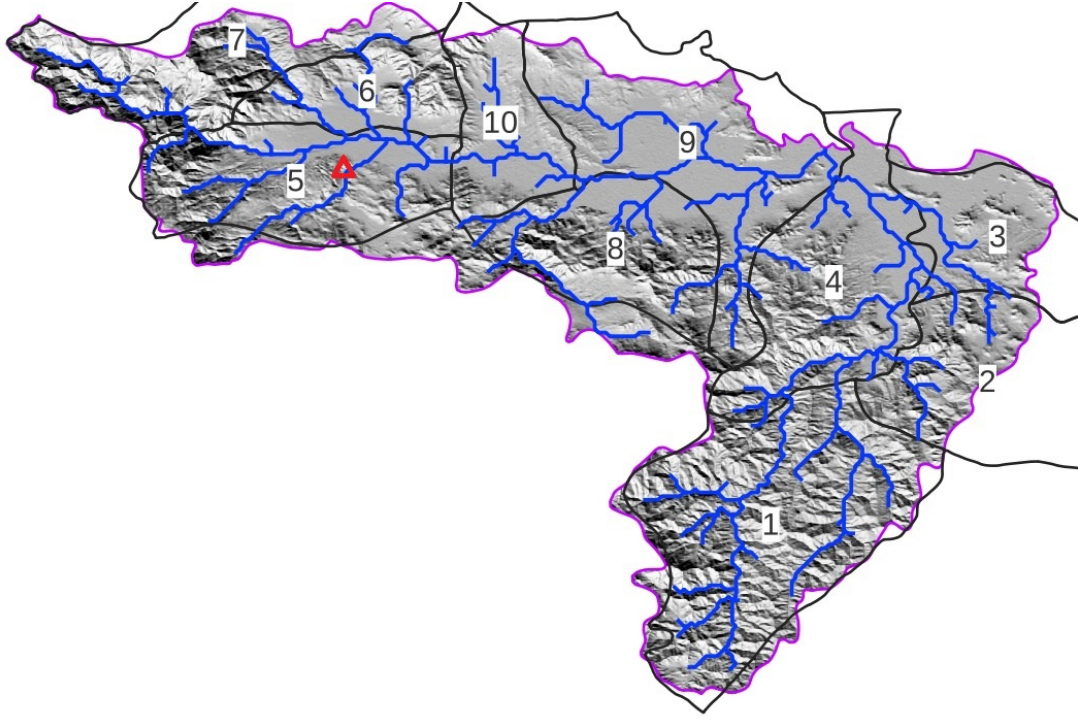


FIGURE A1 – A SAMPLE SUB-BASIN BORDER, COUNTIES WITHIN IT, RIVER NETWORK AND A SAMPLE DAM

Notes: Border of a sample sub-basin can be seen in purple and 10 counties are located completely or partially within this sub-basin with black borders. The triangle is a dam which is upstream of counties 4, 9 and 10. county 4 is also downstream of counties 1, 2 and 3 because of river flow direction which is caused by elevation difference.

Appendix

A.1 Upstream and Downstream definition Example

A.2 IV approach

A.2.1 Duflo & Pande (2007) approach

In their seminal article on the impact of large dams in India, [Duflo & Pande \(2007\)](#) suggest an innovative IV strategy to address the endogeneity problems intrinsic in [1](#). More specifically, they calculate the share of dams located in a state (which is at a more aggregate level than their unit of analysis of districts) prior to their sample period and multiply this share by the total number of dams in India. They then regress the district level of dams on this state-level variable interacted with district-level river gradient indicators to predict arguably exogenous district-level dam construction proxies, which they use as instruments. They use the river gradient proxies on the grounds that certain river gradients are more appropriate for dam construction than others. In contrast, the use of the state share of dams implicitly assumes a

state-level variation in the policy of dam allocation and assumes that this can be proxied by the ex ante state share interacted with time dummies. Follow-up studies (Strobl & Strobl (2011), Blanc & Strobl (2014), Mettetal (2019)) also used a similar method to predict number of dams in each geographical area. In A1, we report the results of the instrument strategy using the same method and instrument as Duflo & Pande (2007). Here, we use both number and volume of dams as our dependent variable and it seems that River Gradient between 6 and 9 percent is more suitable for dam construction and also bigger dams in Iran. Using this method to predict volume of dams lead to statistically insignificant result in second stage and F-test of predicting volume of dams is less than 5 which is not good. Hence, we provide a different instrument to predict volume of dams.

TABLE A1 – DUFLO & PANDE (2007) INSTRUMENT 1ST STAGE RESULTS

Dep. Var:	Number of Dams		Volume of Dams	
	Cross Section (2017)	Interacted with Predicted number of Dams in Basin	Cross Section (2017)	Interacted with Predicted Volume of Dams in Basin
	(1)	(2)	(3)	(4)
Fraction river Gradient 3-6%	-0.0621** (0.0271)	-0.146 (0.120)	-0.112** (0.0483)	-0.225 (0.326)
Fraction river Gradient 6-9%	0.189*** (0.0450)	0.860*** (0.259)	0.357*** (0.0974)	2.045*** (0.744)
Fraction river Gradient above 9%	-0.181*** (0.0468)	-0.572*** (0.180)	-0.217** (0.101)	-1.206 (0.870)
F-Test	7.57	5.28	4.68	3.21
p-value	[0.000]	[0.001]	[0.003]	[0.02]
Observations	2,173	39,114	2,173	39,114
Adjusted R-squared	0.124	0.954	0.052	0.838
Fixed effects	Sub-basin	county	Sub-basin	county
Basin-Year FE	N	Y	N	Y
Geography Controls	Y	Y	Y	Y
cluster	Y	Y	Y	Y

A.2.2 Improved Instrument Variable Approach

Here we adopt the instrumental variables strategy altered to fit our context on two fronts. Firstly, in terms of using a higher geographical classification to capture ex-ante variations in the policy of dam allocation we use a more aggregate (than our counties) delineation of river basins. Second, we use flow accumulation instead of river gradient to predict volume of dams

which is a better predictor for volume of dams than river gradient.

To implement this strategy, we construct measures of county flow accumulation for multiple cells in each Iranian county with use of engineering definition method described in [Andreadis et al. \(2013\)](#). To compute average flow accumulation in rivers of each county, we restrict attention to cells in a county through which a river flows and compute the average of flow accumulation in these cells. The logic is that larger dams can be built in counties which their river has more flow accumulation. So, we estimate this specification:

$$\ln D_{rbt} = \beta_1 + \beta_2 FA * \ln \bar{D}_{bt} + \beta_3 Z_{rbt} * \ln \bar{D}_{bt} + \delta_r + \alpha_{bt} + \epsilon_{rbt} \quad (\text{A.1})$$

which D_{rbt} is IHS of dam volume in the county r and basin b in year t . $\bar{D}_{bt}$ is predicted volume of dam incidence in the basin. This is constructed by multiplying total volume of dam construction in Iran with the fraction of volume of dams in the state in 2000. Use of predicted, rather than actual, dam volume incidence ensures that the measure is exogenous with respect to the volume of dams in the county.

To generate instruments for D_{rbt} , D^U_{rbt} , and D^D_{rbt} , we use the same method as [Duflo & Pande \(2007\)](#). We use parameters from [A.1](#) to predict the volume of dams per county $\hat{D}_{rbt}$. For upstream counties, the predicted volume of dams, $\hat{D}^U_{rbt}$, is the sum of predicted values from [A.1](#) for all upstream counties (it equals zero if the county has no upstream county). We do the same for downstream counties. Then, We estimate [1](#) using $\hat{D}_{rbt}$, $\hat{D}^U_{rbt}$, $\hat{D}^D_{rbt}$, $\hat{Z}_{rbt}$, $\hat{Z}^U_{rbt}$, and $\hat{Z}^D_{rbt}$ as instruments.

A.3 Other robustness checks and Placebo

TABLE A2 – IMPROVED INSTRUMENT VARIABLE RESULTS

Dep. Variable:	Volume of Dams		Irrigated Rent		
	Cross Section (2017)	Interacted with Predicted Vol- ume of Dams in Basin	Baseline	+Geog. Controls	+Basin- Year FE
	(1)	(2)	(3)	(4)	(5)
Flow Accumulation	0.0121*** (0.0034)	0.0409*** (0.0108)			
Own			0.288 (0.222)	0.305 (0.221)	0.393 (0.294)
Upstream			0.250* (0.140)	0.230 (0.148)	0.150 (0.129)
Downstream			-0.053 (0.044)	-0.058 (0.045)	-0.078 (0.060)
F-test	12.66	14.3			
p-value	[0.000]	[0.000]			
Observations	2,173	39,240	24,560	24,505	24,505
Time FE	N	Y	Y	Y	Y
Fixed effects	Basin	county		county	
Basin-Year FE	Y	Y	N	N	Y
Geography controls	Y	Y	N	Y	Y
cluster	Y	Y	Y	Y	Y

Notes: The first column in this table shows the first stage by using Flow Accumulation interacted by predicted volume of dams in the basin as an instrument for predicting volume of dams in each county in each year. Columns (2) to (4) shows the second stage. In column (2) we don't control for geographical trend variables and basin by year fixed effect. In column (3) we control for geographical trends and in column (4) we control for both geographical trends and basin by year fixed effects. Standard errors are clustered at the counties and reported in parentheses. *, **, *** represent significance at 10%, 5%, and 1% level respectively.

TABLE A3 – PLACEBO: EFFECT OF DAMS ON RAINFED AGRICULTURAL LANDS

Dep. Variable:	Annual Differences			Long Differences		
	Rent	Profit	Revenue	Rent	Profit	Revenue
	(1)	(2)	(3)	(4)	(5)	(6)
Own	-0.006 (0.006)	-0.026* (0.015)	-0.006 (0.009)	-0.018 (0.017)	0.059 (0.107)	-0.042** (0.020)
Upstream	0.001 (0.006)	-0.013 (0.013)	-0.009 (0.006)	-0.026 (0.016)	-0.042 (0.071)	-0.041 (0.028)
Downstream	-0.002 (0.005)	-0.015 (0.010)	-0.006 (0.006)	0.003 (0.013)	-0.015 (0.059)	-0.001 (0.019)
Observations	19,999	15,661	19,546	1,684	1,148	1,584
Adjusted R-squared	0.916	0.599	0.820	0.949	0.626	0.895

Notes: Table shows coefficient estimates from regressions of rainfed land rent, profit, and revenue on measures of dam volume. Columns (1) to (3) show the effect of volume of own, upstream, and downstream dams on agricultural land rent, profit, and revenue annually. We include year, county, and basin by year fixed effects in all specifications as well as rainfall and geographical trends. Columns (4) to (6) uses the same specifications as in Columns (1) to (3) but keeps observations from the first and last year of the data to find the long differencing effect. Standard errors are clustered at the county level and reported in parentheses. *, **, *** represent significance at 10%, 5%, and 1% level respectively.

TABLE A4 – ROBUSTNESS CHECK ON FUNCTIONAL FORM OF EXPLANATORY VARIABLE

Dep. Variable:	Interaction of Volume and Dummy		Upstream=0.2 if no upstream dam		Exclude counties with no upstream dam	
	Irrigated	DDD	Irrigated	DDD	Irrigated	DDD
	(1)	(2)	(3)	(4)	(5)	(6)
Upstream(Dummy)	0.060 (0.044)	0.302*** (0.057)				
Upstream(Dummy)*	0.017* (0.008)	0.047*** (0.011)				
Log(Volume of Upstream)			0.014*** (0.004)	0.029*** (0.005)	0.006 (0.011)	0.031* (0.017)
Own	-0.008 (0.008)	0.0118 (0.016)	0.005 (0.013)	0.009 (0.016)	-0.022 (0.015)	0.000 (0.021)
Downstream	0.001 (0.007)	0.012 (0.009)	-0.001 (0.007)	0.010 (0.009)	-0.014 (0.011)	-0.023* (0.014)
Observations	24,303	13,258	24,583	13,258	18,494	9,737
Adjusted R-squared	0.885	0.450	0.807	0.450	0.834	0.444

Notes: Columns (1) and (2) show the effect of upstream dam dummy and its interaction with logarithm of upstream dam volume on agricultural land rent using difference in difference method(irrigated land) in column (1) and triple difference approach in column (2) using the difference between irrigated and rainfed land rent. We subtracted logarithm of average volume of upstream for better interpretation of results. In columns (3) and (4), we replace upstream dam volume of those counties which does not have any upstream dam by 0.2 which is half of the volume of the smallest dam to avoid logarithm of zero problem. To tackle this issue on another way, we drop those counties which does not have any upstream dam and use logarithm of upstream dam volume as explanatory variable in columns (5) and (6). We include year, county, and basin by year fixed effects in all specifications as well as rainfall and geographical trends. Standard errors are clustered at the counties and reported in parentheses. *, **, *** represent significance at 10%, 5%, and 1% level respectively.

TABLE A5 – EFFECT OF DAMS BY USING DIFFERENT DEFINITION FOR UP/DOWNSTREAM

Dep. Variable:	Rent	Profit	Revenue	Population
	(1)	(2)	(3)	(4)
Own	0.001 (0.013)	0.011 (0.021)	0.004 (0.016)	-0.006 (0.008)
Upstream	0.028*** (0.008)	0.030** (0.013)	0.020** (0.009)	0.018*** (0.005)
Downstream	0.001 (0.006)	0.007 (0.013)	0.004 (0.00879)	-0.014*** (0.003)
Observations	24,583	22,200	24,495	10,948
Adjusted R-squared	0.807	0.616	0.768	0.753
Time FE	Y	Y	Y	Y
county FE	Y	Y	Y	Y
Basin-Year FE	N	N	N	N
Control	N	N	N	N
cluster	Y	Y	Y	Y

Notes: This table shows the effect of volume of own, upstream and downstream dams on logarithm of land rent, farmer's profit and revenue, and population by using the second definition of upstream and downstream which is based on 6-digit HYDRO1K sub-basins. Standard errors are clustered at the counties and reported in parentheses. *, **, *** represent significance at 10%, 5%, and 1% level respectively.

TABLE A6 – EFFECT OF DAMS ON AGRICULTURAL LAND RENT
Irrigated (Diff-in-Diff)

Dep. Variable:	Irrigated (Diff-in-Diff)				Triple Difference			
	Rent							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. Short Difference								
Own	0.00584 (0.0136)	0.00635 (0.0135)	-0.0113 (0.0119)	-0.0115 (0.0118)	0.0270 (0.0235)	0.0273 (0.0234)	0.0261 (0.0234)	0.0257 (0.0232)
Upstream	0.0235*** (0.00643)	0.0229*** (0.00645)	0.0132* (0.00690)	0.0130* (0.00690)	0.0309*** (0.0105)	0.0294*** (0.0106)	0.0336*** (0.0105)	0.0327*** (0.0105)
Downstream	-0.00155 (0.00707)	-0.00259 (0.00708)	-0.00828 (0.00817)	-0.00875 (0.00814)	0.0145 (0.0106)	0.0131 (0.0106)	0.0153 (0.0107)	0.0142 (0.0108)
Rain		-0.000302*** (0.000102)		-0.000473* (0.000250)		-0.000381** (0.000172)		-0.000432** (0.000195)
Observations	24,583	24,583	24,467	24,467	12,877	12,877	12,877	12,877
Adjusted R-squared	0.807	0.807	0.828	0.828	0.652	0.652	0.653	0.653
Panel B. Long Difference								
Own	0.0161 (0.0199)	0.0183 (0.0198)	-0.0185 (0.0175)	-0.0192 (0.0173)	0.0279 (0.0425)	0.0240 (0.0422)	0.0221 (0.0422)	0.0220 (0.0420)
Upstream	0.0339** (0.0145)	0.0328** (0.0144)	0.0168 (0.0148)	0.0147 (0.0147)	0.0552** (0.0262)	0.0524** (0.0265)	0.0566** (0.0263)	0.0540** (0.0263)
Downstream	-0.00771 (0.00976)	-0.00868 (0.00967)	-0.0467*** (0.0142)	-0.0510*** (0.0144)	0.0181 (0.0233)	0.0214 (0.0238)	0.0200 (0.0244)	0.0215 (0.0241)
Rain		-0.000457* (0.000250)		0.000921 (0.000889)		0.00129 (0.000830)		0.000919 (0.00101)
Observations	2,230	2,230	2,212	2,212	944	944	944	944
Adjusted R-squared	0.879	0.880	0.901	0.901	0.712	0.713	0.712	0.712
Time FE	Y	Y	Y	Y	Y	Y	Y	Y
county FE	Y	Y	Y	Y	Y	Y	Y	Y
Basin-Year FE	N	N	Y	Y	N	N	Y	Y
Control	N	Y	N	Y	N	Y	N	Y
cluster	Y	Y	Y	Y	Y	Y	Y	Y

Notes: In columns (1) to (4) of this table, we show the effect of volume of own, upstream, and downstream dams on agricultural land rent in Irrigated productions using difference-in-difference method. In columns (5) to (8) we show triple difference results by using difference between irrigated and rainfed production. Columns (1) and (5) controls for county and year fixed-effects but not geographical trend and rainfall control and without basin by year fixed effects. In columns (2) and (6), we control for rain and geographical trends. In columns (3) and (7), we added basin by year fixed effects but not control for rainfall and geographical trend. In columns (4) and (8), we include both basin by year fixed effects and rainfall ad geographical trend controls. Panel B is the same as Panel A but just keep observations in the first and last year to find the long-difference effect. Standard errors are clustered at the county and reported in parentheses. *, ** *** represent significance at 10%, 5%, and 1% level respectively.

TABLE A7 – EFFECT OF DAMS ON AGRICULTURAL LAND RENT

Dep. Variable:	Irrigated (Diff-in-Diff)				Triple Difference			
	Rent							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. Short Difference								
Own	0.00584 (0.0136)	0.00635 (0.0135)	-0.0113 (0.0119)	-0.0115 (0.0118)	0.0270 (0.0235)	0.0273 (0.0234)	0.0261 (0.0234)	0.0257 (0.0232)
Upstream	0.0235*** (0.00643)	0.0229*** (0.00645)	0.0132* (0.00690)	0.0130* (0.00690)	0.0309*** (0.0105)	0.0294*** (0.0106)	0.0336*** (0.0105)	0.0327*** (0.0105)
Downstream	-0.00155 (0.00707)	-0.00259 (0.00708)	-0.00828 (0.00817)	-0.00875 (0.00814)	0.0145 (0.0106)	0.0131 (0.0106)	0.0153 (0.0107)	0.0142 (0.0108)
Rain		-0.000302*** (0.000102)		-0.000473* (0.000250)		-0.000381** (0.000172)		-0.000432** (0.000195)
Observations	24,583	24,583	24,467	24,467	12,877	12,877	12,877	12,877
Adjusted R-squared	0.807	0.807	0.828	0.828	0.652	0.652	0.653	0.653
Panel B. Long Difference								
Own	0.0161 (0.0199)	0.0183 (0.0198)	-0.0185 (0.0175)	-0.0192 (0.0173)	0.0279 (0.0425)	0.0240 (0.0422)	0.0221 (0.0422)	0.0220 (0.0420)
Upstream	0.0339** (0.0145)	0.0328** (0.0144)	0.0168 (0.0148)	0.0147 (0.0147)	0.0552** (0.0262)	0.0524** (0.0265)	0.0566** (0.0263)	0.0540** (0.0263)
Downstream	-0.00771 (0.00976)	-0.00868 (0.00967)	-0.0467*** (0.0142)	-0.0510*** (0.0144)	0.0181 (0.0233)	0.0214 (0.0238)	0.0200 (0.0244)	0.0215 (0.0241)
Rain		-0.000457* (0.000250)		0.000921 (0.000889)		0.00129 (0.000830)		0.000919 (0.00101)
Observations	2,230	2,230	2,212	2,212	944	944	944	944
Adjusted R-squared	0.879	0.880	0.901	0.901	0.712	0.713	0.712	0.712
Time FE	Y	Y	Y	Y	Y	Y	Y	Y
county FE	Y	Y	Y	Y	Y	Y	Y	Y
Basin-Year FE	N	N	Y	Y	N	N	Y	Y
Control	N	Y	N	Y	N	Y	N	Y
cluster	Y	Y	Y	Y	Y	Y	Y	Y

Notes: In columns (1) to (4) of this table, we show the effect of volume of own, upstream, and downstream dams on agricultural land rent in Irrigated productions using difference-in-difference method. In columns (5) to (8) we show triple difference results by using difference between irrigated and rainfed production. Columns (1) and (5) controls for county and year fixed-effects but not geographical trend and rainfall control and without basin by year fixed effects. In columns (2) and (6), we control for rain and geographical trends. In columns (3) and (7), we added basin by year fixed effects but not control for rainfall and geographical trend. In columns (4) and (8), we include both basin by year fixed effects and rainfall and geographical trend controls. Panel B is the same as Panel A but just keep observations in the first and last year to find the long-difference effect. Standard errors are clustered at the counties and reported in parentheses. *, **, *** represent significance at 10%, 5%, and 1% level respectively.

TABLE A8 – EFFECT OF DAMS ON AGRICULTURAL PROFIT

Dep. Variable:	Irrigated (Diff-in-Diff)				Triple Difference			
	Profit							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. Short Difference								
Own	0.0176 (0.0207)	0.0181 (0.0207)	0.0126 (0.0186)	0.007 (0.018)	0.001 (0.022)	-0.0133 (0.0253)	-0.0134 (0.0255)	-0.0142 (0.0254)
Upstream	0.0469*** (0.0109)	0.0463*** (0.0109)	0.0283** (0.0116)	0.034** (0.015)	0.030** (0.013)	0.0252 (0.0171)	0.0248 (0.0178)	0.0229 (0.0177)
Downstream	0.000751 (0.0131)	-0.000330 (0.0130)	0.0117 (0.0137)	0.014 (0.015)	0.009 (0.013)	0.00316 (0.0178)	0.00388 (0.0180)	0.00121 (0.0180)
Rain		-0.000312* (0.000188)		-0.0001 (0.0010)		-0.000913*** (0.000296)		-0.00108*** (0.000342)
Observations	22,200	22,200	22,075	21,680	9,827	9,827	9,827	9,827
Adjusted R-squared	0.617	0.617	0.636	0.676	0.552	0.553	0.552	0.552
Panel B. Long Difference								
Own	-0.0308 (0.0500)	-0.0263 (0.0495)	-0.00906 (0.0504)	0.0134 (0.0716)	-0.107 (0.0896)	-0.108 (0.0900)	-0.107 (0.0899)	-0.107 (0.0894)
Upstream	0.0655** (0.0308)	0.0632** (0.0303)	0.0773* (0.0398)	0.109* (0.0600)	0.140** (0.0605)	0.139** (0.0611)	0.141** (0.0601)	0.137** (0.0614)
Downstream	0.0239 (0.0254)	0.0221 (0.0248)	0.0674** (0.0338)	0.0215 (0.0609)	0.0161 (0.0483)	0.0178 (0.0500)	0.0163 (0.0492)	0.0179 (0.0499)
Rain		-0.00112*** (0.000412)		0.00555 (0.00423)		0.000625 (0.00166)		0.000829 (0.00208)
Observations	1,934	1,934	1,918	1,868	518	518	518	518
Adjusted R-squared	0.748	0.750	0.749	0.668	0.580	0.578	0.576	0.575
Time FE	Y	Y	Y	Y	Y	Y	Y	Y
county FE	Y	Y	Y	Y	Y	Y	Y	Y
Basin-Year FE	N	N	Y	Y	N	N	Y	Y
Control	N	Y	N	Y	N	Y	N	Y
cluster	Y	Y	Y	Y	Y	Y	Y	Y

Notes: In columns (1) to (4) of this table, we show the effect of volume of own, upstream, and downstream dams on agricultural profit in Irrigated productions using difference-in-difference method. In columns (5) to (8) we show triple difference results by using difference between irrigated and rainfed production. Columns (1) and (5) controls for county and year fixed-effects but not geographical trend and rainfall control and without basin by year fixed effects. In columns (2) and (6), we control for rain and geographical trends. In columns (3) and (7), we added basin by year fixed effects but not control for rainfall and geographical trend. In columns (4) and (8), we include both basin by year fixed effects and rainfall and geographical trend controls. Panel B is the same as Panel A but just keep observations in the first and last year to find the

TABLE A9 – EFFECT OF DAMS ON AGRICULTURAL PROFIT

Dep. Variable:	Irrigated (Diff-in-Diff)				Triple Difference			
					Profit			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. Short Difference								
Own	0.0176 (0.0207)	0.0181 (0.0207)	0.0126 (0.0186)	0.007 (0.018)	0.001 (0.022)	-0.0133 (0.0253)	-0.0134 (0.0255)	-0.0142 (0.0254)
Upstream	0.0469*** (0.0109)	0.0463*** (0.0109)	0.0283** (0.0116)	0.034** (0.015)	0.030** (0.013)	0.0252 (0.0171)	0.0248 (0.0178)	0.0229 (0.0177)
Downstream	0.000751 (0.0131)	-0.000330 (0.0130)	0.0117 (0.0137)	0.014 (0.015)	0.009 (0.013)	0.00316 (0.0178)	0.00388 (0.0180)	0.00121 (0.0180)
Rain		-0.000312* (0.000188)		-0.0001 (0.0010)		-0.000913*** (0.000296)		-0.00108*** (0.000342)
Observations	22,200	22,200	22,075	21,680	9,827	9,827	9,827	9,827
Adjusted R-squared	0.617	0.617	0.636	0.676	0.552	0.553	0.552	0.552
Panel B. Long Difference								
Own	-0.0308 (0.0500)	-0.0263 (0.0495)	-0.00906 (0.0504)	0.0134 (0.0716)	-0.107 (0.0896)	-0.108 (0.0900)	-0.107 (0.0899)	-0.107 (0.0894)
Upstream	0.0655** (0.0308)	0.0632** (0.0303)	0.0773* (0.0398)	0.109* (0.0600)	0.140** (0.0605)	0.139** (0.0611)	0.141** (0.0601)	0.137** (0.0614)
Downstream	0.0239 (0.0254)	0.0221 (0.0248)	0.0674** (0.0338)	0.0215 (0.0609)	0.0161 (0.0483)	0.0178 (0.0500)	0.0163 (0.0492)	0.0179 (0.0499)
Rain		-0.00112*** (0.000412)		0.00555 (0.00423)		0.000625 (0.00166)		0.000829 (0.00208)
Observations	1,934	1,934	1,918	1,868	518	518	518	518
Adjusted R-squared	0.748	0.750	0.749	0.668	0.580	0.578	0.576	0.575
Time FE	Y	Y	Y	Y	Y	Y	Y	Y
county FE	Y	Y	Y	Y	Y	Y	Y	Y
Basin-Year FE	N	N	Y	Y	N	N	Y	Y
Control	N	Y	N	Y	N	Y	N	Y
cluster	Y	Y	Y	Y	Y	Y	Y	Y

Notes: In columns (1) to (4) of this table, we show the effect of volume of own, upstream, and downstream dams on agricultural profit in Irrigated productions using difference-in-difference method. In columns (5) to (8) we show triple difference results by using difference between irrigated and rainfed production. Columns (1) and (5) controls for county and year fixed-effects but not geographical trend and rainfall control and without basin by year fixed effects. In columns (2) and (6), we control for rain and geographical trends. In columns (3) and (7), we added basin by year fixed effects but not control for rainfall and geographical trend. In columns (4) and (8), we include both basin by year fixed effects and rainfall and geographical trend controls. Panel B is the same as Panel A but just keep observations in the first and last year to find the long-difference effect. Standard errors are clustered at the counties and reported in parentheses. *, **, *** represent significance at 10%, 5%, and 1% level respectively.

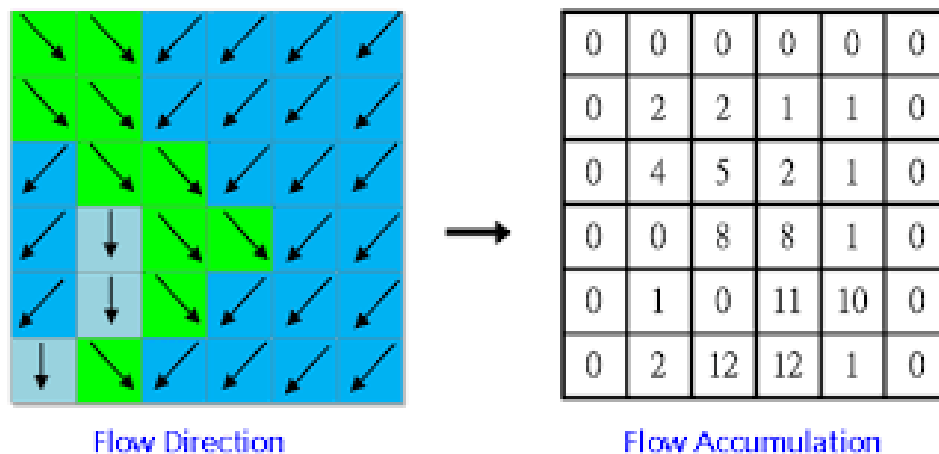


FIGURE A2 – FLOW ACCUMULATION DEFINITION

Notes: This figure shows how flow accumulation can be calculated in each cell in a simple model. The left figure shows water direction between adjacent cells and by using these directions, the right figure shows number of cells that their water will flow to each cell.

A.4 Flow accumulation

Figure A2 shows a simple model to calculate flow accumulation of each cell in a hypothetical 6*6 grid.

A.5 Other data

A.6 To Do List!!

- Tasks Done:

1. Deflating Table ?? and combining Tables ??, ??, and ?? so that number of observations would be 2194 for all of the rows (take average for different years) and change text according to this change (Comments 11 to 14 of Jos) ✓
2. Trend of irrigated and rainfed land shares and the average, min, and max in districts. (Comment 15 of Jos) ✓
3. Use $\ln(\text{rev}) - \ln(\text{cost})$ instead of $\text{ISH}(\text{rev} - \text{cost})$ as an approximate for $\ln(\text{profit})$ and play around the best variable to choose. Another option is to use deflated linear profit instead of logarithm. (Comment 16 of Jos) ✓
 - Profit: 9 Percent Negative Irrigated/ 17 Percent Negative Rainfed
 - rent diff: 3 Percent Negative

TABLE A10 – AGRICULTURAL DATA AT DISTRICT LEVEL

Variable	Number of Observations (end- beginning)	Average (Standard Deviation)			Min	Max
		Total	Beginning	End		
Area Under Cultivation (Thousand Hectares)						
Total	229-229	41959 -50136	32247 -51533	43907 -52160	0	357301
Irrigated	229-229	19303 -22461	13919 -21144	19658 -22631	0	149262
Rainfed	229-229	22656 -38889	18328 -39604	24249 -40507	0	281885
Value of Production (Million Rials, Real)						
Total	229-229	5276356 -7158854	4242352 -6831440	6757302 -8233091	0	8.19*107
Irrigated	229-137	4469903 -6534909	5998252 -7463598	5626409 -7320456	0	7.48*107
Rainfed	229-229	878311 -1813207	653892 -1500061	1131195 -1988047	0	1.92*107
Yield (Million Rials per Hectare)						
Total	227-138	189.49 -177.65	219.93 -210.62	217.57 -193.81	0	2244.22
Irrigated	223-137	254.92 -214.72	275.09 -189.92	308.32 -234.05	0	6446.64
Rainfed	184-100	50.1 -62.59	35.74 -18.52	68.38 -88.08	0	1166.9

Notes: Beginning Period is 1991 and End period 2015. Data source is at district and crop level which is aggregated all crops in each district.

- Profit diff: 26 Percent Negative
 - Rev diff: 19 Percent Negative
 - Irrigated/Rainfed Profit (Y FE)
 - * $ISH(\text{rev}-\text{cost})$: 0.17 (t=2.35)
 - * $\ln(\text{rev})-\ln(\text{cost})$: 0.01 (t=2.8)
 - * $\ln(\text{rev}-\text{cost})$: 0.04 (t=4.31)
 - * $\text{rev}-\text{cost}$: 281 (t=4.35)
 - * $\text{deflated}(\text{rev}-\text{cost})$: 506 (t=3.57)
 - Triple Difference (Y FE)
 - * $ISH(\text{rentw}-\text{rentr})$: 0.10 (t=2.52)
 - * $\ln(\text{rentw}-\text{rentr})$: 0.03 (t=2.94)
 - * $\ln(\text{rentw})-\ln(\text{rentr})$: 0.04 (t=5.56)
 - * $\text{rentw}-\text{rentr}$: 23 (t=4.55)
 - * $\text{deflated}(\text{rentw}-\text{rentr})$: 42 (t=4.27)
4. use dummy for having own, upstream, and downstream dam and its interaction with logarithm of volume instead of $ISH(\text{volume})$. (Comment 30 of Jos) ✓ Figure ??
 5. Selection bias in DDD: focus on those counties that have both irrigated and rainfed in DD strategy as a robustness check. ✓ (Still DDD effect is larger than DD but less than before)
 6. Check what percent of villages have both irrigated and rainfed and decide whether to disaggregate our data into village data and get new results. We can assume location of each village at centroid of its county or try to find the locations: ✓ 18 Percent of village-year pairs have both irrigated and rainfed in a specific year / 29 percent of vilages have both irrigated and rainfed during the period
- Writing or Editing Tasks:

1. Discuss about differences between irrigated and rainfed land. Are they different products? Are some products more suitable in rainfed? What are the differences between type of land? (Comment 17 of Hans):
 - Type of land: Mountain areas and steep lands are more suitable for rainfed
 - Some products like wheat and barley are more suitable for rainfed
 - Some regions which do not have good access to rivers or underground water are more suitable for rainfed
 2. Improving Intro and Conclusion.
 3. Some concrete violation scenarios for five potential robustness check at the end of Empirical strategy section.
 4. General equilibrium effects for rainfed and irrigated agricultural activities may be different. Discuss the possibilities and consequences at the end of Empirical strategy or Results Section. (Comment 33 of Jos and Comment 2 of Hans)
 - Discuss indirect effect of dams on rainfed agriculture
 - Potential decrease in rainfed land and transformation to irrigated.
 5. Advantages of DDD over IV and its disadvantages and their differences at the end of DDD section
 6. Complete IV in the appendix.
- Time consuming and harder Tasks:
 1. District level data:
 - It might be interesting to collapse the data to district-level for comparison with previous studies. We could claim that previous studies have aggregation bias;
 - Volume of All Dams instead of Number large of Dams in Table 7;
 - Adding downstream dams in Table 7;
 - Total land (irrigated+rainfed) as dependent variable in Table 7.

2. Improve Cost-benefit Part:

- Find cost-benefit for all(some) dams separately and average their effect;
- Find the cost benefit for a sample large and a sample small dam (For example p25 and p75);
- Make numbers in the cost-benefit excel sheet more accurate according to real data for example percent of agricultural land in county;
- Find Predicted cost of all dams with available cost data
- Write all of the calculation details in just one footnote instead of several short footnotes.

3. Dependent Variable at county level but explanatory variable, volume of upstream dams of the district and volume of dams in the same district and also volume of upstream dams of the county. Cluster at district level.

4. Find the results for 50% larger dams and 50 percent smaller dams separately or other heterogeneity of results including geographical, size, goal, and etc.

5. Heterogeneity of results, for example different type of crops, different size of dams: Show a table summarizing type of crops and percent of counties that have that crops (irrigated and rainfed separately)- Crop Selection: Show the results for just wheat or barley which have both rainfed and irrigated

• Remaining not so important Tasks:

1. Adding Temperature as another control variable to avoid OVB.
2. Comparing the results with previous studies especially Duflo by relating Profit and Yield or etc.