A Multi Sector Empirical Analysis of Economic Growth Effects on Water Use in the U.S. Over the Period 1960-2015

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Abstract

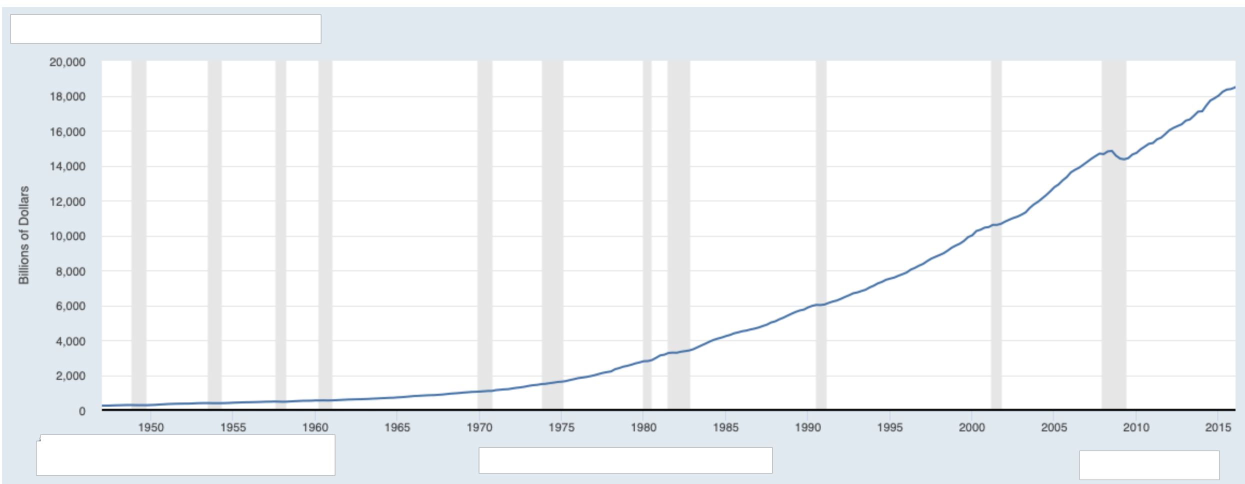
This study investigates economic growth effects on water withdrawals by four major water-intensive sectors of the United States economy namely: municipal, industrial, irrigation and thermoelectric. A two-step system generalised method of moments (GMM) estimator which allows the dynamic aspects and persistence in water withdrawals to be modeled is employed to estimate four sector-specific dynamic panel data models. The estimations account for the endogenous nature of several explanatory variables using internally generated instruments according to the GMM method, and instrument for GDP using international tourist receipts. The data entails information on all 50 States of the United States covering the period 1960-2015. My results show that economic growth had statistically significant effects on water withdrawals by the municipal and industrial sectors. The relationships between economic growth and water withdrawals by the municipal and industrial sectors follow and inverted-U shape. My results however show no statistically significant effects of economic growth on irrigation and thermoelectric water withdrawals.

Keywords: Water withdrawals, municipal, self-supplied industrial, irrigation, thermoelectric, dynamic panel, economic development

1 Introduction

As an economy grows in both population and income level, water demand can grow as well (Rock, 1998). Expansion in population and income levels can cause output demand to go up leading to more input (water) demand for production or consumption. The United States population, GDP and GDP per capita have all steadily grown since the 50s (Debaere and Kurzendoerfer, 2017), (see Figure 1 below). Population more than doubled, GDP expanded more than eightfold, and GDP per capita grew nearly sixfold between 1950 and 2015. During the same period, water withdrawals in the United States experienced steady declines according to reports by the United States Geological Survey (USGS) department. Specifically, water withdrawals (in millions of gallons a day) by the top four water-intensive sectors of the economy namely: municipal, industrial, irrigation and thermometric, leveled off and began to slowly decline (see Figure 2 below).[1] The observed opposite trends between growth of the U.S. economy (measured by per capita income growth), and falling water withdrawals contradict expectations that growth and rising standards of living be accompanied by increased resource use (Debaere and Kurzendoerfer, 2017).

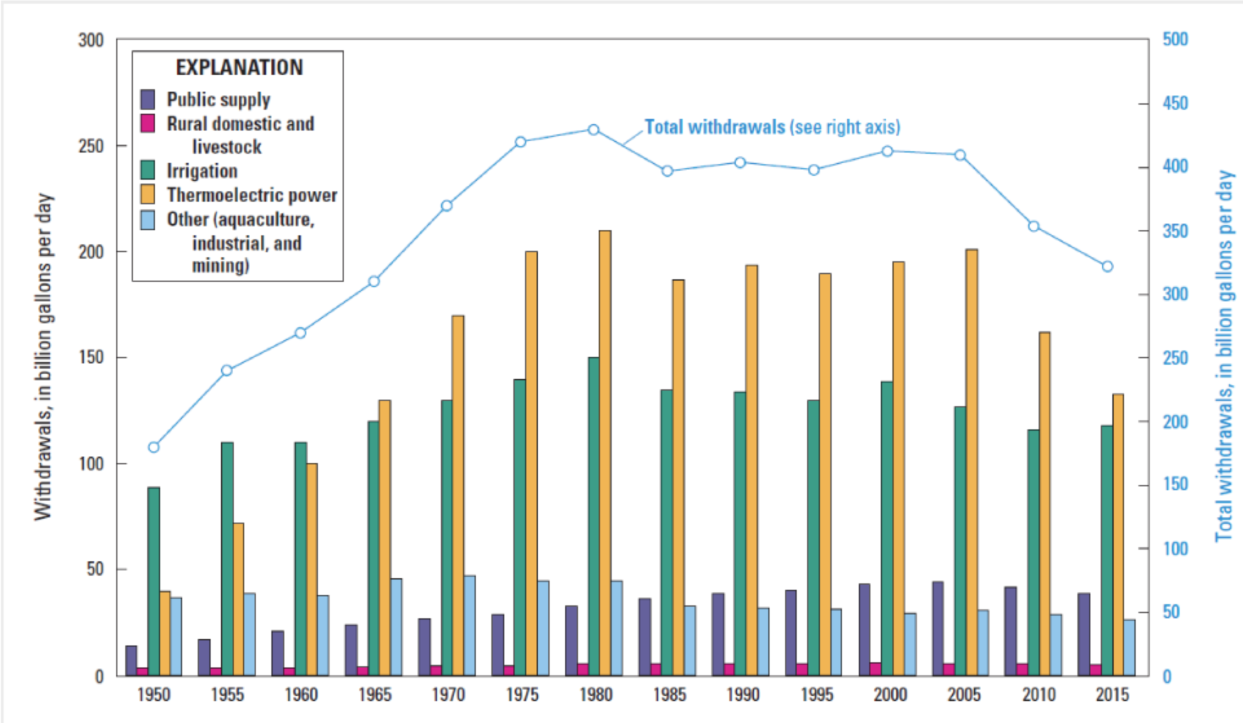
Figure 1: U.S. Gross Domestic Product, 1950-2015



Source: U.S. Bureau of Economic Analysis (2020)

[1]Estimated water withdrawals for irrigation and thermometric uses began to fall in the year 1980; roughly a decade after withdrawals by the industrial sector had began to reduce. However, declines in water withdrawals by the municipal sector did not start until 2005.

Figure 2: Trends in total water withdrawal by water-use category, 1950- 2015



Source: Dieter et al. (2018)

The goal of this research is to estimate the relationships between growth of the U.S. economy and water withdrawals by the municipal, industrial, irrigation and thermometric sectors.[2] I employ a two-step system generalised method of moments (GMM) estimator which allows the dynamic aspects and persistence in water withdrawals to be modeled, to estimate four sector-specific dynamic panel data models. The estimations account for the endogenous nature of several explanatory variables using internally generated instruments according to the GMM method, and also instrument for GDP using international tourist receipts. The data entails information on all 50 States of the United States covering the period 1960-2015. My results show statistically significant effects of economic growth on water withdrawals by the municipal and industrial sectors. Both municipal and industrial water withdrawals exhibit Inverted U-shape relationships, also called environmental Kutznets curve(EKC) with economic growth. My results however show no statistically significant effects of economic

[2]The terms economic growth and income are used interchangeably in this study.

growth on irrigation and thermoelectric water withdrawals. This lack of direct significant economic growth effect on water withdrawals by the irrigation and thermoelectric sectors suggest that technological improvements in the sectors could have been entirely responsible for the observed declines in water withdrawals by the two sectors.

Early research, example (Kane, 2017; Dieter et al., 2018; Walton, 2019; Nastu, 2019) favor efficiency improvements and behavioral changes as the key factors responsible for the declining water withdrawals in the U.S. These earlier reports are however mostly based on expert discussions and opinions rather than formal statistical testing or empirical analysis. Debaere and Kurzendoerfer (2017) presents one of the only few studies on U.S. water that conducts formal statistical analysis of data on this subject. He argues that the evolution of the U.S. economy towards a service economy, with noticeable declines in manufacturing, and temporal slow down in agriculture have all played a major part in slowing down water use. No studies have however yet empirically investigated the direct correlation between growth of the U.S. economy and the observed declines in water withdrawals by the various sectors. A good understanding of these relationships could facilitate useful predictions about the direction future water withdrawals as U.S. economy continues to grow.

General previous water use and economic growth relationship studies include: Rock (1998); Goklany (2002); Gleick (2003); Dalhuisen et al. (2003); Bhattarai (2004); Barbier (2004); Cole (2004); Jia et al. (2006); Hemati et al. (2011); Duarte et al. (2013); Katz (2015); Sebri (2016). Nearly all these studies focused on testing for an inverted-U (Environmental Kuznets Curve-type) relationship between water use and income. These studies obtain mixed results regarding water - income relationship. Rock (1998); Cole (2004); Barbier (2004); Duarte et al. (2013); Katz (2015) find evidence in support of an inverted -"U" relationship between income and water use, while Sebri (2016) find evidence in support of an "N"- shape relationship. Gleick (2003) finds no relationship between water use and income. This lack of consistency in results is attributable to methodological and data differences in the different studies (Katz, 2015).

This study contributes to the existing literature on water use — income relationship in two ways. First, by estimating system GMM models proposed by Arellano and Bover (1995); Blundell and Bond (1998), I account for persistence in water use/withdrawals thus potentially heightening the accuracy of my results in terms consistency in the estimator. Previous research estimate OLS (Rock, 1998), Weighted Least Squares (WLS) regressions (Rock, 1998; Katz, 2015) and fixed effects models (Bhattarai, 2004; Jia et al., 2006; Katz, 2015). Both OLS and WLS yield inconsistent estimators when there is persistence in data (Kiviet, 1995). The system GMM approach employed in this paper also allows for one account for any potential endogeneity biases through the use of internally generated instruments. Lastly, the system GMM method allows estimates to be obtained for time–invariant controls, which is infeasible in a fixed effects estimation. Since system GMM estimators may suffer from issues of invalid exclusion restrictions, instrument proliferation, underidentification and weak instrumentation, I conduct various diagnostic tests to check the appropriateness of my results.

Second, the data set analyzed in this study is of reasonably good quality in terms of less incidence of missing data, and length of the period covered, 1960 — 2015. Katz (2015) notes that one of the biggest shortcomings in water use - income studies is the use of poor quality data sets, which is possibly the reason why regression results have been inconsistent in previous work.

The rest of the paper is organized as follows. The next section contains distinctions between water use, withdrawals and consumption, a brief theoretical discussion of the connections between economic growth and water use, and brief summaries of previous research on water withdrawals by the municipal, industrial, irrigation and thermoelectric sectors. In section 3, I present the empirical model and Identification strategy. Data description is given in section 4. The empirical results and discussion are presented in section 5. Section 6 concludes the study. The Appendix contains variable definitions, summary statistics and correlations, and relevant plots on water use and income.

2 Water use, withdrawal, and consumption distinctions

Before examining the water use and income relationship, it is important that I clarify the distinctions between water use, withdrawal, and consumption. The term *water use* is broad and refers to all instream and offstream uses of water by humans (Council et al., 2002; Badr et al., 2012). Instream use refers to water use that occurs at a source (ground or surface), whereas offstream use describes water use that occurs are a point away from the source. *Water withdrawal* is the physical act of conveying or diverting water away from its source for use elsewhere. It is a measurable metric (Badr et al., 2012). Withdrawn water that is lost in transit is referred to as *conveyance loss*, which then becomes *return flows* when the conveyance loss water flows back to its source, or other water bodies. *Water consumption* is losing water to evaporation, transpiration, addition to manufactured products, consumption by humans and live stock. In this case, water is completely lost from its source. Water consumption occurs between withdrawal and return flows.

Water use is typically measured using either withdrawals or consumption. The decision to use withdrawals or consumption depends on the research question, and data availability. Keller (1992); Keller et al. (1995); Rock (1998) for instance, use water consumption arguing that this is a better measure for water use because it excludes return flows, thus captures the actual amount of water leaving the system. However, Debaere and Kurzendoerfer (2017) argues withdrawals are an economically meaningful measure since one pays for how much water they withdraw (if only withdrawal costs), and withdrawals represents the water available for production or consumption, regardless of how much of it returns to the environment. Therefore, unlike water consumption, withdrawals reflect both economic and physical scarcities. Water withdrawals rather than consumption are analyzed in this study. I also use terms *water use* and *water withdrawals* interchangeably to mean the same thing.

3 Water use and income

Several reasons exist why economic growth may be expected to affect water withdrawals. First, higher incomes may allow access to additional sources of water that may not have been attainable at low income levels, examples include, pumping of deep aquifers, treating brackish water, etc (Katz, 2015). Second, higher incomes imply better standards of living, and a potential rise in demand for water-intensive luxuries such swimming pools, lawns and parks. On the flip side, a rise in incomes may result less water use particularly where the higher incomes allow for affordability and use of more efficient water use technologies such as drip-irrigation, dry-cooling technologies in thermometric power plants, water-conserving toilets and shower heads in residential and commercial buildings.

Economic growth may impact water withdrawals in different sectors differently. Impacts may be direct or indirect. Direct impacts involve where growth leads to more or less water withdrawals in a sector. For example, economic growth may afford more people the means to invest in water-saving equipment which may result in water residential water withdrawal decreases. Indirect impacts by contrast, involve where growth causes a sector's output to go up or down, resulting an increase or decrease in water withdrawals by the sector for production. For Example, economic growth can lead energy demand increases, and more water withdrawals for power production as a result. Highlighting the distinction between indirect and indirect impacts of growth on water withdrawals is important because, unlike direct impacts, indirect impacts can be hard to measure. Indeed, one of the biggest challenges in correctly estimating growth effects on water withdrawals is clearly specifying the role that other factors, other than population play (Katz, 2015). These other factors such as efficiency improvements in water use vary from sector-to-sector and need to be carefully accounted for in an estimation. In the next four subsections, I present brief discussions of previous sector-level water-income studies and outline key factors that have been identified to impact water withdrawals by the different sectors in addition to income.

It is important to add that economic growth can also be affected by water use (Howe, 1976). Water is a key ingredient in many production processes in an economy, such agriculture and electricity production. Thus, more or less water use can affect production and growth of an economy. In particular, investments in water storage and transportation infrastructure can have big consequences for local economic growth by changing the time and place of water availability.

3.1 Municipal water withdrawals

Municipal water withdrawals describe water withdrawn by private and municipal suppliers that have at least have 15 connections, or deliver water to a minimum of 25 people (Dieter et al., 2018). Deliveries are typically made to domestic, commercial and industrial users. Some of this water is also used for municipal services, such as firefighting, parks, public pools, and wastewater treatment, while a portion of it is lost in transit (conveyance losses). Deliveries to domestic users make up the biggest share of municipal withdrawals (Dieter et al., 2018). In 2015, nearly 87 percent of the U.S. population received portable water deliveries from municipal supply, 1 percent greater than the number of people served in 2010.

According to Stout (1999), population size poses the greatest impact on municipal withdrawals. Other variables identified to directly affect municipal withdrawals include rainfall, atmospheric temperature (which affects evaporation rates), socio-economic factors such income, and water prices.

The most widely studied factor known to affect domestic/residential water use or demand is water price, see for example Cuthbert and Lemoine (1996); Association (2000); Worthington and Hoffman (2008). By contrast, very few papers including (Headley, 1963; Grafton et al., 2011) have studied income effects on domestic/residential water use. Specifically, Headley (1963) studied the relationship between family income and residential water use across different communities in San-Francisco Oakland metropolitan area. He finds that higher income communities used more water on average than lower income ones. Headley provides two reasons for this: first, the more affluent communities had bigger landscaped residential lots that required more water use. Second, higher income households were less sensitive to the cost of water, since that accounted for only a small portion of their disposal income.

3.2 Self-supplied industrial water withdrawals

Industrial water withdrawals refer to self-supplied water withdrawals for industrial uses. Common sources of self-supplied industrial water include withdrawals from the ground (renewable or fossil), freshwater from rivers, lakes and other water bodies, direct use of agricultural drainage water or treated wastewater, and desalinated water (Ritchie and Roser, 2020). Self-supplied industries are typically not connected to any municipal distribution network, and often hold their own water right instead of relying on municipal/utility water rights. The USGS department estimates that self-supplied industrial withdrawals dropped approximately 43% between 1985 and 2015.

Katz (2015) presented one of the very few studies that looks at economic growth relationship with self-supplied industrial water withdrawals in the U.S. His study focused on testing for an Environmental Kutznet curve-type relationship between industrial water withdrawals and income.[3] Katz estimates a reduced-form fixed effects regression model introducing only income as an explanatory variable for industrial water withdrawals.

Other factors identified to affect self-supplied industrial water withdrawals include: water prices, industrial output prices, weather and seasonal factors, and technology (Worthington, 2010). Different studies have researched the impacts of some of these factors on industrial water use.[4]

[3] Gu et al. (2017) estimates inverted-U relationships between economic growth and industrial water use by different regions in China.

[4] Williams and Suh (1986) estimate price elasticities for industrial, residential and commercial water demands. They find a higher price elasticity (-0.74) for industrial water demand than residential and commercial demands, corroborating the earlier result of Babin et al. (1982), who estimated a price an upper limit water price elasticity of -0.81 for selected US industries. The Williams and Suh (1986) study added variables like total rainfall during summer, average temperature during summer in their regression estimation, being one of only a few studies on this subject to do that.

3.3 Irrigation water withdrawals

Irrigation water withdrawals are among the largest withdrawals in the US accounting for nearly 43 percent of all total freshwater withdrawals in 1975, 48 percent in 2000, and down to 37 percent in 2015. The factors that derive irrigation water withdrawals are less obscure compared to the factors deriving withdrawals in other sectors (Stout, 1999). Major among these factors include: 1) the type of irrigation technology; 2) climatic factors, such as temperature and precipitation; 3) economic factors, such as water prices, energy prices, general economic conditions; and 4) the type of crop irrigated (Green et al., 1996).

Rock (1998) presents one of the first studies that investigates economic growth effects on irrigation water withdrawals. Using a cross-country data set of selected countries (mostly developed), Rock estimated a Weighted Least Squares regression model that included income, a measure for agriculture water use efficiency, population, dummy variables for geographic regions, and dummy variables for trade openness as explanatory variables. He however left out other key variables like temperature, precipitation, crop and energy prices, which are known to impact irrigation water withdrawals. Rock also did not explicitly indicate whether his model was to estimate an overall correlation or find proximate causal effects of growth on irrigation water withdrawals. Other studies that looked at irrigation water withdrawals and income relationship include Goklany (2002) and Bhattarai (2004). Both of these papers are cross-country studies focused mainly on testing for an EKC-type relationship for agricultural water withdrawals. Unlike these previous studies, this study attempts to estimate the direct contribution of economic growth on irrigation water demand.

Renzetti (1988) analyzed industrial water demand responsiveness to output demand for different subsectors within the industrial sector. He finds water demand to be output elastic for users in the petrochemical, forestry and light subsectors. Meaning, water demand rises more than proportionately with output demand increases in these sectors

3.4 Thermometric water withdrawals

Thermoelectric water withdrawals account for the largest fraction of water withdrawals in the US (Dziegielewski et al., 2006). However, roughly 90 percent of all water withdrawn for thermoelectric use is discharged back into the environment after use (Dziegielewski et al., 2006). At the same time, thermoelectric facilities often require specific amounts of water to be available in a plant at all times, which makes such water unavailable for other uses. The type of cooling system used in a thermoelectric facility dictates how much water the facility withdraws, consumes and discharges back into the environment (Dziegielewski et al., 2006). In closed-loop cooling systems for example, withdrawn water is used and reused multiple times, and most of it gets consumed in the process, hence not discharged back into the environment. By contrast, in open-loop cooling systems water is used once and discharged back into the environment potentially making it available for other uses such as irrigation, municipal, and use by aquatic animals.

A limited number economics studies exist on factors that affect thermoelectric water withdrawals. Thompson and Young (1973) published one of the few studies on this subject. The authors present three classes of factors that affect thermoelectric water use. The first class comprise factors that directly affect water use, such as water prices and production technology. The second class consist of factors that affect electricity demand, example, electricity prices and the price of substitutes for electricity (such as gas), population, and the level of general economic activity. And the third class consist of factors that affect waste and heat discharge to water, such as facility standards.

No known previous studies considered the relationship between economic growth and thermolectric water use in the US. The fact that economic growth may lead to more or less energy demand and possibly more or less water use in energy production is one reason studying the direct contribution of growth on thermolectric water withdrawals may be useful. Such information may provide better insight into how future energy demand issues may influence water demand for power production.

4 Empirical Estimation

4.1 Dynamic panel data estimation: Identification assumptions

One critical methodological shortcoming of past water - income regressions is the failure to take into account persistence in withdrawals. Period-to-period water distribution, storage infrastructure and water rights issues can be expected generate persistence in water withdrawals. To capture intertemporal dynamics that can result from persistence in water rights, water infrastructure, and related dimensions of water use, I estimate dynamic non-linear panel data (DPD) models for water withdrawals by each of the four sectors considered in this study. The models are non-linear in the sense that I introduce the square of GDP per capita in each model to capture possible quadratic relationships between water withdrawals and income, as suggested in the literature. The empirical model is:

$$w_{ij,t} = \beta_0 + \beta_1 w_{ij,t-1} + \beta_2 \boldsymbol{X}_{ij,t} + \beta_3 \boldsymbol{Z}_{ij} + v_{ij} + \gamma_t + \varepsilon_{ij,t} \quad (1)$$

where $w_{ij,t}$ is the natural log of water withdrawals per capita per day by sector i in state j at time t; $w_{ij,t-1}$ is the value of $w_{ij,t}$ in the previous period; $\boldsymbol{X}_{ij,t}$ is the set of time varying variables including GDP per capita and GDP per capita squared; $\boldsymbol{Z}_{ij}$ is the set of time-invariant variables; v_{ij} is the state-specific effect; γ_t is a time dummy and ε_{it} is the idiosyncratic error term.

In estimating Equation (1), a number of issues arise that must be addressed. Endogeneity is the first issue that needs be addressed. The lagged dependent variable, GDP per capita, GDP per capita squared and potentially other control variables in $\boldsymbol{X}$ might be correlate with the error term due to measurement error, omitted variables, and/or reverse causality (Nickell, 1981; Sevestre and Trognon, 1985; Kiviet, 1995). A typical way to deal with endogeneity is to use instrumental variable estimation methods. Finding suitable instruments is no easy task. Moreover, determining whether or not a particular instrument is good enough is even more challenging. In estimations such as the one in Equation (1) where finding good external instruments can be greatly difficult, the alternative is to use internal instruments such as higher order lags of the endogenous variables, which is precisely the approach use in generalized method of moment (GMM) estimation.

4.2 GMM estimation of a dynamic panel data model

Under the GMM method, the first difference approach is the most common way to estimate a dynamic panel data model like Equation 1. With this approach Equation (1) implies estimating the following difference equation:

$$w_{ij,t} - w_{ij,t-1} = \beta_1(w_{ij,t-1} - w_{ij,t-2}) + \beta_2(\boldsymbol{X}_{ij,t} - \boldsymbol{X}_{ij,t-1}) + \tilde{\gamma}_t + (\varepsilon_{ij,t} - \varepsilon_{ij,t-1}). \quad (2)$$

The problem with estimating Equation (2) is that the endogeneity issue is still propagated through the lagged dependent variable since $E[(w_{ij,t-1} - w_{ij,t-2})(\varepsilon_{ij,t} - \varepsilon_{ij,t-1})] \neq 0$. Holtz-Eakin et al. (1988) and Arellano and Bond (1991) proposed a way to address this endogeneity problem; by using two period or more lags of the dependent variable as instruments for the differenced lagged dependent variable since

$$E[w_{ij,t-s}(\varepsilon_{ij,t} - \varepsilon_{ij,t-1})] = 0, \quad \text{for} \;\; t = 3, 4, ...T \;\; \text{and} \;\; s \geq 2. \quad (3)$$

This estimator is known as the Arellano–Bond or difference GMM estimator.

Alonso-Borrego and Arellano (1999) notes that the Arellano–Bond estimator may potentially suffer from large small-sample biases where the number of time periods is small and the dependent variable shows a high level of persistence. In response to this weakness of the Arellano–Bond estimator, Arellano and Bover (1995) and Blundell and Bond (1998) propose the system GMM estimator. The system GMM estimator circumvents the finite sample bias problem present in the Arellano–Bond estimator by making the additional assumption that the initial conditions of the underlying data generating process is mildly stationary. This assumption allows for the introduction of the following additional moment conditions besides those specified in Equation 3 (the difference model):

$$E[(w_{ij,t-1} - w_{ij,t-2})(v_{ij} + \varepsilon_{ij,t})] = 0 \quad \text{for} \quad t = 3, ..., T. \tag{4}$$

That is, the lagged first-differences of the dependent variable are used to construct orthogonality conditions for the error term in Equation 1 in levels [5].

The additional orthogonality conditions of the system GMM produce asymptotic efficiency gains by the estimator, which comes at a cost, in that, the number of instruments tends to increase exponentially with the number of time periods. This is known as instrument proliferation. Instrument proliferation create finite sample biases due to overfitting of the endogenous variables, and also increases the chances of false positive results often characterized by high specification test values (i.e. values close to 1) of the Hansen (1982) J-test, a standard test statistic used to check the validity of a dynamic panel model (see Roodman (2009)).[6] To avoid the issue of instrument proliferation, I follow Roodman (2009) and collapse the instrument matrix of my system GMM estimator.[7]

Another fundamental issue that can arise in both difference and system GMM estimations is the presence of second or higher order serial serial correlation in the error terms. This causes estimates to be biased (Arellano and Bond, 1991). I employ the Arellano-Bond (2) test to check for the absence of second-order serial correlation in the differenced errors. P-value greater than 0.05 imply an absence of a moving average (MA) error component of order greater than one.

An additional and more crucial issue to address is reverse causal effects of water use itself

[5]The extra orthogonality conditions in both difference and system GMM estimators come from the fact that suitable lags of the lagged explanatory variables in levels can be treated as either endogenous, predetermined or strictly exogenous.

[6]The Hansen $J-test$ tests for the validity of exclusion restrictions. The null hypothesis of this test is that the GMM instruments are jointly valid instruments, meaning, uncorrelated with the error term, and that the excluded instruments are correctly excluded from the estimated model. A Hansen's J-test value greater than 0.1 and not more than 0.9 suggests that the instruments are valid, see (Roodman, 2009)

[7]The collapse option in the xtbaond2 command in stata does this.

on GDP, which can result in an upward bias in Equation 1 if water use is positively related related to GDP. To overcome these issues and appropriately estimate GDP effects on water use, I employ an instrument I_{ijt} that is correlated strongly with GDP (i.e. the condition of relevance) and is excluded from the second stage (exclusion restriction). Following (Shafik and Bandyopadhyay, 1992), I use international tourist receipts as an instrument for GDP. Shaikh and Gandjour (2019) notes that international tourist receipts reflect expenditures by international inbound visitors. The World Tourism Organization, explain these receipts to include spending on lodging, food and drinks, fuel, transport, entertainment, shopping, etc in a destination country.

Intuitively, the connection between tourism and the economy is straightforward (Shaikh and Gandjour, 2019). Tourism generates an increase in economic activity directly or indirectly, and results in an increase in the wealth of the residents through the services they provide and employment, for instance. Thus, it should be positively related to the GDP of a country (Shaikh and Gandjour, 2019). An extensive set of literature that looks at tourism-growth relationship include: (Brida and Pulina, 2010; Brida et al., 2010; Gunduz and Hatemi-J, 2005; Lean and Tang, 2010; Brida and Risso, 2009) cited in (Shaikh and Gandjour, 2019).

The instrument easily satisfies the relevance criteria (with positive correlation coefficient between international tourist receipts of about 0.956, also see Figure 3 below). I argue that exclusion retriction $Cov(I_{it}, \varepsilon_{ijt}|Z_{ijt}, v_{ij}, \gamma_t) = 0$ is also satisfied, but may be weakly satisfied since tourist in the U.S. consume water even though this amount is relatively insignificant.

In summary, I report coefficient estimates from two-step Difference and system IV-GMM estimations, robust standard errors corrected for finite sample bias (Windmeijer, 2005) and clustered by state, Hansan J-tests statistics (to check for the joint validity of instruments used) and Arellano-Bond (2) tests (to check for second order serial correlation in the errors).

5 Data

Four panel data sets are analyzed in this study, one for each sector. Each panel data set contains 5-year interval information on all 50 states of the US for the period 1960 - 2015. Water withdrawals by the *municipal*, *industrial*, *irrigation*, and *thermoelectric* sectors are obtained from a series of five-year interval reports published by the USGS department (USGS, 2018). The reports also contain information on *Water losses* by the municipal sector, *irrigated land* and *population*.

GDP data, *Ag-value added*, *Industry value added*, and *Industry production tax* data, all (in current US $), are obtained from published data of the U.S. Bureau of Economic Analysis (US BEA, 2019). State level GDP data for the year 1960 is unavailable, and therefore approximated for with 1963 data. Data on *international tourist receipts* are collected from the National Travel and Tourism Office website (NTTO, 2020). State level data for international tourist receipts are not available, and are therefore obtained through prediction. First, a regression model is build using the national values for international tourist receipts regressed no national level GDP. The estimated regression fit showed an $R-squared$ value of 0.97, and is used to predict state level tourist receipts from state GDP values. This prediction assumes that the distribution of state level international tourist receipts mimic national receipts. Figure 3 shows scatter plots of state GDP against the predicted state values for international tourist receipts. All dollar values in the data are converted to constant 2005 US dollars using the 2005 average price index of 195.3 (base period 1982-84=100).

Energy production, *Energy consumption* and *Electricity price* data are collected from data publications of the United States Energy Information Administration (US EIA, 2019). *Temperature* and *Precipitation* data are collected from historical weather publications by the National Climatic Data Center (NCDC, 2019). *Corn price* data are from the United States Department of Agriculture data site (USDA, 2019). And *Inflation rate* data are collected from the official data site of the United States Bureau of Labor Statistics (BLS, 2019).[8]

Table 1 presents the list of all the variables used in this research and their descriptions as well as data sources. While Table 2 reports summary descriptive statistics. In addition, Figures 4, 5, 6 and 7. in the appendix respectively show summary distribution plots for GDP per capita against water withdrawals by the municipal, industrial, irrigation and thermoelectric sectors.

Table 1: Variable descriptions and data sources

Variable	Description	Data Source
GDP	Gross Demostic Production (in mils. of 2005 US $)	(US BEA, 2019)
Tourist receipts	International tourist receipts (in mils. of 2005 US $)	(NTTO, 2020)
Population	Total population (in 000s)	(USGS, 2018)
Temperature	Average annual temperature (in degrees Fahrenheit)	(NCDC, 2019)
Precipitation	Average annual precipitation (in Inches)	(NCDC, 2019)
Electricity price	Average annual electricity price (in cents/kwhr)	(US EIA, 2019)
Water rights	The type of water rights doctrine applicable in a State	
Irrigation withdrawals	Irrigation water withdrawals (in mil. gallons/day)	(USGS, 2018)
Irrigated land	Number of irrigated acres (in 000s)	(USGS, 2018)
Ag-value added	Agriculture value added to GDP (in mils. of 2005 US $)	(US BEA, 2019)
Corn price	Average corn price (in US $/bushel)	(USDA, 2019)
Municipal withdrawals	Municipal water withdrawals (in mil. gallons/day)	(USGS, 2018)
Water use/losses	Water use/losses by the municipal sector (in mil. gallons/day)	(USGS, 2018)
Residential energy use	Average residential energy use (in US $ /mil. Btu)	(US EIA, 2019)
Industrial withdrawals	Self-supplied industrial water withdrawals (in mil. of gallons/day)	(USGS, 2018)
Industry value added	Private industry value added (in mil. gallons/day)	(US BEA, 2019)
Industry production tax	Private industry production tax (in mils. of 2005 US $)	(US BEA, 2019)
Inflation rate	Average annaul inflation rate (%)	(BLS, 2019)
Thermoelectric withdrawals	Thermolecetric water withdrawals (in mil. gallons/day)	(USGS, 2018)
Gasoline price	Average annual gasoline price (in US $/ mil. Btu)	(US EIA, 2019)
Energy production	Total annual energy production (in mil. Btu)	(US EIA, 2019)
Energy consumption	Total annaul energy consumption (in mil. Btu)	(US EIA, 2019)

Note: Water use doctrine categories: 1 = riparian doctrine, 2 = prior appropriation doctrine, 3 = mix doctrine.

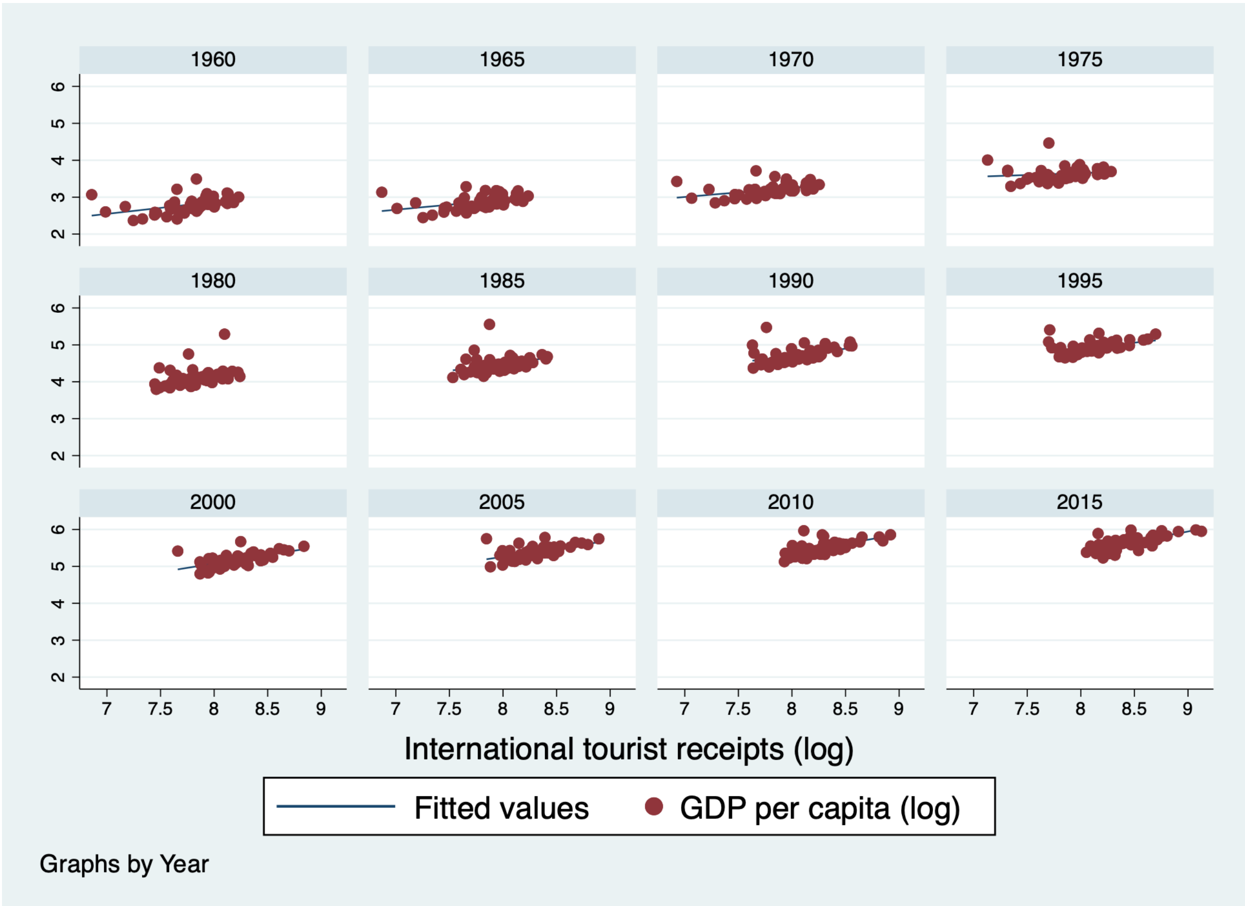
[8] Inflation rate data are national level averages, since state level data unavailable

Table 2: Descriptive Statistics

Variable	Mean	Std	Min	Max	N
Variables common in all models					
GDP	695,766	275,429	5,228.4	1.34e+07	600
Tourist receipts	171,998	59,601	95,423	256,145	600
Population	4,949	5,513	229	38,918	600
Temperature	52	10	23	86	600
Precipitation	36	14	9	75	600
Electricity price	6	4	0.1	26	600
Water rights	NA	NA	NA	NA	NA
Irrigation withdrawals model					
Irrigation withdrawal	2,512	5,017	0	5,017	600
Irrigated land	1,103	1,953	0	10,400	600
Ag-value added	7,132	11,403	5	142,565	600
Corn price	3	1	0.9	6	600
Municipal withdrawals model					
Municipal withdrawal	686	885	23	6,300	600
Water use/losses	285	416	0.02	3,300	600
Residential energy use	201,366	202,124	1,854	897,823	600
Industrial withdrawals model					
Industrial withdrawal	543	801	0.2	5,400	600
Industry value added	2	2	0.1	14	600
Industry production tax	50,881	92,063	315	886,549	600
Inflation rate	4	4	0.1	14	600
Thermoelectric withdrawals model					
Thermoelectric withdrawal	2,753	3,389	0	17,100	600
Gasoline price	10	7	0.3	28	600
Energy production	1,224,435	2,177,014	292	1.80e+07	600
Energy consumption	1,600,196	1,780,843	61,433	1.29e+07	600

N consists of data no n=50 groups/states over T=12 periods

Figure 3: Gross domestic product (GDP) and international tourist receipt relationships



6 Results

Table 3 reports IV-GMM regression results for Equation 1. The dependent variables in the regressions under the columns headed "municipal", "industrial", "irrigation" and "thermoelectric" are respectively: the natural logs of water withdrawals per capita per day by the municipal, industrial, irrigation and thermoelectric sectors. The Difference GMM (Diff GMM) regressions are meant to provide checks against the system GMM (Sys GMM) regressions. The strong persistence exhibited in water withdrawals make the system GMM more appropriate to interpret (Alonso-Borrego and Arellano, 1999). The system GMM regression for municipal water use shows an autoregressive coefficient estimate value of 0.558, which is statically significant at the 1% level. This suggests the presence of moderately high level of persistence in municipal water withdrawals. In the municipal model also, the coefficient estimates 0.989 and -0.0485 for Ln (GDP per $cap.$) and Ln (Ln (GDP per $cap.$ $squared$) respectively are both statistically significant at the 1% level. Meaning, the relationship between municipal withdrawals and GDP per capita exhibits an initial constant elasticity value of 0.989% which then decreases by 0.0485% on average for every 1% increase in GDP per capita, *ceteris paribus.* In addition, the negative co-efficient value of Ln (Ln (GDP per $cap.$ $squared$) in the municipal model suggests that municipal water withdrawals and GDP per capita exhibit a inverted-U relationship. I estimate the turning point of this inverted-U relationship at \$26,793, which is lower than the \$27,584 estimated by (Katz, 2015). Katz estimated a reduced form fixed effects model with only income as an explanatory variable for water use.

Table 3: Two-step IV-GMM regressions for water withdrawals by various sectors

	Municipal		Industrial		Irrigation		Thermoelectric	
	Diff GMM	Sys GMM	Diff GMM	Sys GMM	Diff GMM	Sys GMM	Diff GMM	Sys GMM
Ln (water use)$_{t-1}$	0.612***	0.558***	0.309***	0.281**	0.855***	0.820**	0.342***	0.311**
	(0.148)	(0.101)	(0.096)	(0.088)	(0.034)	(0.032)	(0.141)	(0.125)
Ln (GDP per cap.)	0.633**	0.989*	1.072*	1.182*	5.151	4.322	-0.172	-0.199
	(0.479)	(0.712)	(0.998)	(0.919)	(3.210)	(5.920)	(0.363)	(0.630)
Ln (GDP percap. squr)	-0.047**	-0.0485**	-0.089*	-0.101*	-0.004	-0.098	(0.042)	(0.014)
	(0.022)	(0.031)	(0.071)	(0.056)	(0.009)	(0.109)		
Precipitation	-0.003*	-0.0011			-0.0052*	-0.0029		
	(0.001)	(0.0009)			(0.0014)	(0.004)		
Temperature	0.009***	0.006***			0.0128**	0.015**	0.032	0.012
	(0.001)	(0.001)			(0.005)	(0.006)	(0.047)	(0.037)
Ln (population)	0.061**	0.018*	0.067	0.049			0.347*	0.297*
	(0.033)	(0.010)	(0.193)	(0.131)			(0.243)	(0.153)
Ln (Irrigated land)					0.304***	0.209***		
					(0.001)	(0.0048)		
Ln (production tax)			-1.644***	-1.414***				
			(0.695)	(0.566)				
Ln (energy prod.)							0.304***	0.302***
							(0.074)	(0.058)
Ln (energy price)					-0.033**	0.031*	0.233	0.089
					(0.016)	(0.022)	(0.523)	(0.195)
Time trend	-0.02**	-0.014**	-0.098**	-0.076*	-0.081**	-0.062*	-0.007**	-0.002**
	(0.001)	(0.006)	(0.052)	(0.042)	(0.0471)	(0.029)	(0.001)	(0.0003)
Water rights :								
Prior appropriation		0.220**		-0.599		0.561**		-2.213***
		(0.056)		(0.409)		(0.298)		(0.231)
Mixed doctrine		0.110*		-0.339		0.280*		-1.477*
		(0.029)		(0.275)		(0.116)		(0.499)
Instruments	23	45	21	47	26	47	25	46
Hansen J-test	[0.105]	[0.276]	[0.260]	[0.168]	[0.246]	[0.241]	[0.309]	[0.612]
Diff-in-Hansen test	[0.421]	[0.232]	[0.156]	[0.363]	[0.491]	[0.302]	[0.244]	[0.165]
AR(1)	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.002]	[0.002]
AR(2)	[0.068]	[0.275]	[0.548]	[0.435]	[0.502]	[0.402]	[0.343]	[0.343]
Wald χ^2	483.13 ***	7478.15***	7549***	5683***	5820.46***	4001.02***	38678.35***	44178.51***
Observations	482	550	490	550	481	494	483	530
States	49	50	49	50	50	50	49	50

Notes: Diff GMM is Difference GMM and Sys GMM is system GMM. Robust standard errors are in parentheses. Standard errors corrected for finite sample bias (Windmeijer, 2005) and are clustered by State. *tourist receipts* is introduced as an instrument for GDP per capita in each regression. *, ** and *** denote significance at the 10%-, 5%- and 1%-level, respectively. The reference category of *water rights* is the *riparian doctrine*.

Furthermore, using the coefficient estimates on Table 3, I generate results for the short and longrun effects of growth on municipal water withdrawals presented on Table 4. The results on Table 4 suggest that the short-run effect growth on municipal water withdrawals is approximately 0.892% (statistically significant at the 1% level), with a standard error of about 0.251%. Long-run effects are estimated at about 2.018% (statistically significant at the 1% level), with a standard error of 0.973%.[9]

Table 4: Estimated short and long-run effects of economic growth on municipal and industrial water withdrawals

	Coef.	Std. Err.	P-value	95% Conf. Interval	
Municipal					
Short-run effect	0.892	0.251	0.000	0.116	1.820
Long-run effect	2.018	0.973	0.000	1.212	5.293
Industrial					
Short-run effect	0.980	0.724	0.041	0.015	7.113
Long-run effect	1.363	1.086	0.033	0.895	11.328

Note: All values except the p-values are in percent.

The system GMM regression for Industrial water use in Table 3 shows an autoregressive coefficient estimate of 0.281 which is statistically significant at the 1% level, suggesting a somewhat low persistence level in industrial water withdrawals. The coefficient estimates 1.182 and -0.101 for *Ln* (*GDP per cap.*) and *Ln* (*GDP per cap.squr*) respectively, (both statically significant at the 10% level), suggests that the relationship between industrial water withdrawals and per capita exhibit an initial constant elasticity value of 1.182%, which then decreases by about 0.101% on average for every 1% increase in GDP per capita, *ceteris paribus*. The statistically significant negative co-efficient estimate of *Ln* (*GDP per cap.squr*) in the industrial model suggests that industrial water withdrawals and per capita GDP exhibit an inverted-U (ECK-type) relationship with an estimated turning point at $120,922, which is well above the $106,248 estimate of (Katz, 2015).

Also, the short/long-run estimates on Table 4 suggests that the short-run effect of growth on industrial water withdrawals is approximately 0.980% (statistically significant at the 5% level), with a standard error of 0.724%, whilst the total long-run effect is about 1.363% (statistically significant at the 5% level), with a standard error of 1.086%.

The system GMM regression results for the irrigation and thermoelectric models in Table

[9] Longrun effects are computed as $\frac{\alpha_1}{1-\rho} + 2\frac{\alpha_2}{1-\rho}$.

3 show statically significant autoregressive coefficient estimates for both regressions. Thus, suggesting the presence of some persistence in water withdrawals by both sectors. However, the coefficient estimates for Ln ($GDP\ per\ cap.$) and Ln ($GDP\ per\ cap.squr$) in either model are not statistically significant. Meaning, there is not enough evidence to suggest a direct effect of economic growth on water withdrawals by the irrigation and thermometric sectors in the U.S. This lack of evidence supporting growth as a relevant contributor to irrigation, and thermoelectric water withdrawals in the U.S does suggest that other factors such as efficiency improvements may have been entirely responsible for the slowing down of water use in the sectors. In fact, the statistically significant trend system GMM coefficient estimates of -0.062 and -0.007 for irrigation and thermoelectric water withdrawals reported in Table 3 suggest that per capita irrigation withdrawals decreased by approximately 6.2% on average every 5 years over the period 1960–2015, while per capita thermoelectric withdrawals decreased by approximately 0.7% every 5 years over the period 1960–2015. These results agree with the conclusions of Schaible and Aillery (2012), Donnelly and Cooley (2015), and Stubbs (2016) that technology improvements in irrigation have been the main contributor in achieving dramatic reductions in agricultural water use in the U.S, particularly in the Western part of the country.

The system GMM results in Table 3 also show that water withdrawals by the municipal, irrigation and thermometric are significantly affected by the type of water use rights applicable in state. Specifically, relative to a state that applies the riparian water use doctrine, municipal water use is approximately 0.220% higher for a state that applies the prior appropriation doctrine, and about 0.110% higher for a state that applies mixed water use law. For irrigation water use, prior appropriation states and mixed doctrine states respectively used about 0.561% and 0.280% more water relative to the riparian doctrine states. However, for theormoelectric water use prior appropriation states and mixed doctrine states respectively used 2.213% and 1.477% less water relative to the riparian doctrine states. The results suggest no significant effects of water rights on self-supplied industrial water withdrawals.

On the specification tests provided in Table 3, the Hansen J-test give a p-values greater 0.05, implying that the null hypothesis of valid overidentification restrictions in the GMM specifications are not rejected. The p-values for the the Diff-in-Hansen test are also greater 0.05. Meaning, the null hypothesis that having additional moment conditions in system GMM specification in Equation (3) is valid, cannot be rejected. The test for second order auto-correlated disturbances in the first-differenced equation, AR(2) give p-values greater 0.05, suggesting there is no evidence of significant second order autocorrelated disturbances in the first-differenced equation. The GMM specifications pass all the specification tests, thus hint at proper specifications.

7 Discussion

The inverted-U relationship between economic growth and municipal water withdrawals found in this study falls in line with a report by (Walton, 2019) that affordability of water-saving devices is important to water conservation. A rise income levels afford more people the ability to acquire and use water-saving devices, or buy new homes which tend to come with water and energy-conserving installments. The significant inverse effects of time on municipal water withdrawals found in my results suggests that technology adoption had substantive effects on municipal water withdrawal declines. Examples of a growing list of water-conserving devices inverted and sold over the years include: 1) the low flow high-efficiency faucet aerators, found to save more than 500 gallons of water a year; 2) low flow water efficient showerheads, these save more than 2000 gallons of water a year, 3) automatic shut-off nozzles, 4) shower timers, 5) dual flush toilet converters that use 0.5 gallons per liquid waste flush and 1.5 gallons for solid waste 6) tank bags, 7) grey water diverters, used to recycle water from showering or rinsing laundry into a storage vessel, 8) Soaker hoses for lawn and garden: these work like drip irrigation pumping water directly into plant roots, 9) rainwater tanks to collect rain water, and 10) rainfall shutoff devices that connects to a sprinkler system and shuts it off when there is moisture on the soil from a recent or current rain shower. The market for these devices have grown in the U.S. over the years (Walton, 2019). Greater use of these water-conservation devices could potentially offset a sizable portion of population growth effects in water demand.

The self-supplied industrial sector has perhaps achieved more success in reducing its water use than any of the other sectors since the 1950s (Larsen, 2015). Efforts around recycling and reuse of wastewater have helped sector reduce its water use significantly over the years. Some factors that may have triggered efforts to recycle and reuse wastewater include: increasing cost of freshwater, regulatory requirements around water discharge by the EPA, discharge costs, sense of corporate social responsibility to reduce water use on the part of companies, and efforts to contribute to sustainability. The benefits of recycling and reusing wastewater become especially greater for bigger organizations, since this helps reduce spending on freshwater and increase operational efficiency see (Fraquelli and Giandrone, 2003).

Unlike other sectors, the factors that drive agricultural water use are quite well known. Evapotranspiration is a major one, which is mainly influenced of solar radiation. Different crops have different evapotranspiration requirements, thus makes agricultural water use greatly dependent on crop type. The level of evapotranspiration is also affected by climatic factors such as temperature, humidity, and wind speed. One crop can have different evapotranspiration needs in different climatic regions.

Technology improvements in irrigation have significantly lowered water use by the sector (Trapolino, 2019; FT Avelino and Dall'erba, 2020), as also found in this study. Some advances in irrigation technology include: Pivot control panels/telematics that wirelessly communicate with and control center pivots; Soil-moisture sensors that monitor soil-moisture content; sprinkler systems with improved water-application patterns through the use of multiple streams, sizes and angles; Yield-modeling tools such as computer-based crop-growth-simulation models used to predict potential crop outcomes based on historic climate data, local weather patterns and management practices; variable frequency drives that control the speed and pressure of water pumps, and Smartphones that allow farmers to review their fields' soil-moisture content from afar and schedule irrigation as needed (Stubbs, 2016; Board, 2020). There is also evidence available to show that adaptation of some of these irrigation technologies has increased over the years.

An important point to add is that, reductions in farm level use may not always lead to reductions in aggregate water use (Stout, 1999). Often, irrigation technology or management regime changes lead to reductions in deep infiltration and runoff. In most instances, irrigated water that deep percolates becomes ground-water recharge, and runoff water from one irrigated field ends up as supply other fields elsewhere. Such farm level water saving outcomes do not necessarily reduce withdrawals at source, see "The paradox of irrigation efficiency" by (Grafton et al., 2018).

Water withdrawals for thermometric use is mainly influenced by the type of cooling technology, as explained in earlier part of this study, freshwater prices, used water discharge costs and efficiency regulations. It remains unclear which of these factors is the biggest contributor to the declines in withdrawals trends. Even though the role of recent developments and use of dry (air) cooling technologies in power generation could be a key factor see (Torcellini et al., 2003; Badr et al., 2012; Donnelly and Cooley, 2015). In a study, the USGS found that the number of power plants built or converted since the 1970s that use more efficient cooling-system technologies has increased significantly, estimating about 1,290 power plants across the U.S (Muskal, 2014).

8 Summary and conclusion

Water is a critical ingredient for the production of goods and services in many sectors of the United States economy, directly and indirectly affecting production. Current economics literature provides insights into various factors that affect water use in different sectors, including agriculture, manufacturing, domestic/residential and energy production, but this information has so far not included the effects of economic growth on water use, especially as it relates to the United states. It is not far fetched to expect economic growth to lead to more or less water use in different sectors.

This study estimates economic growth effects water on withdrawals by four sectors of the U.S economy namely: municipal, industrial, irrigation and thermoelectric. GDP per capita in the United States grew nearly six fold between 1950 and 2015, but water withdrawals plateaued and steadily decreased during the same period. While some scholars have attributed the falling trends in water withdrawals to improvements in technology and behavioral changes, the possible effect of other factors such economic growth cannot be ignored. Previous water use — economic growth relationship studies on the U.S. include (Rock, 1998; Katz, 2015). This study re-examines the subject by employing a different estimation approach applied to an extended data set.

A two-step system generalised method of moments (GMM) estimator due to Arellano and Bover (1995) and Blundell and Bond (1998) is employed. This allows the dynamic aspects and persistence in water withdrawals to be modeled. Potential endogeneity in the explanatory variables is accounted for using a set internally generated instruments according to the GMM method, and GDP is instrumented for using international tourist receipts following (Shaikh and Gandjour, 2019). I estimate four dynamic panel data models using data on all 50 states of the United States covering the period 1960-2015.

My results show that economic growth had statistically significant effects on water withdrawals by the municipal and industrial sectors. And the relationships between economic growth and water withdrawals by these sectors are consistent with an inverted-U relationship. Meaning, water use by each sector initially increases with economic growth, reaches a maximum, and then begins to decline. I however find no statistically significant economic growth effects on irrigation and thermoelectric water withdrawals. This suggests that the observed declines in water use by these latter two sectors may entirely attributable to the technological advancements in each sector, specifically irrigation technology, and efficiency improvements such as dry cooling technologies in energy production.

Ultimately, the actions of the largest water using states including California, Texas, Idaho, Florida, Illinois, North Carolina, Arkansas, Colorado, Michigan, New York, Alabama and Ohio, which collectively account of more than 50% total water withdrawals Muskal (2014) will play a critical part in determining the direction of water use in the U.S going into the future. It is also important to add that despite current declines in total water withdrawals, and possibly going into the future, reliance on ground water to meet everyday water needs and buffer variability in surface water supply as increased considerably since 1949 (Russo et al., 2014). Sustaining the present declines may therefore require actions that jointly reduce withdrawals from both surface and groundwater sources.

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Appendices

Figure 4: Plots of log municipal water withdrawals per capita per day and log GDP per capita

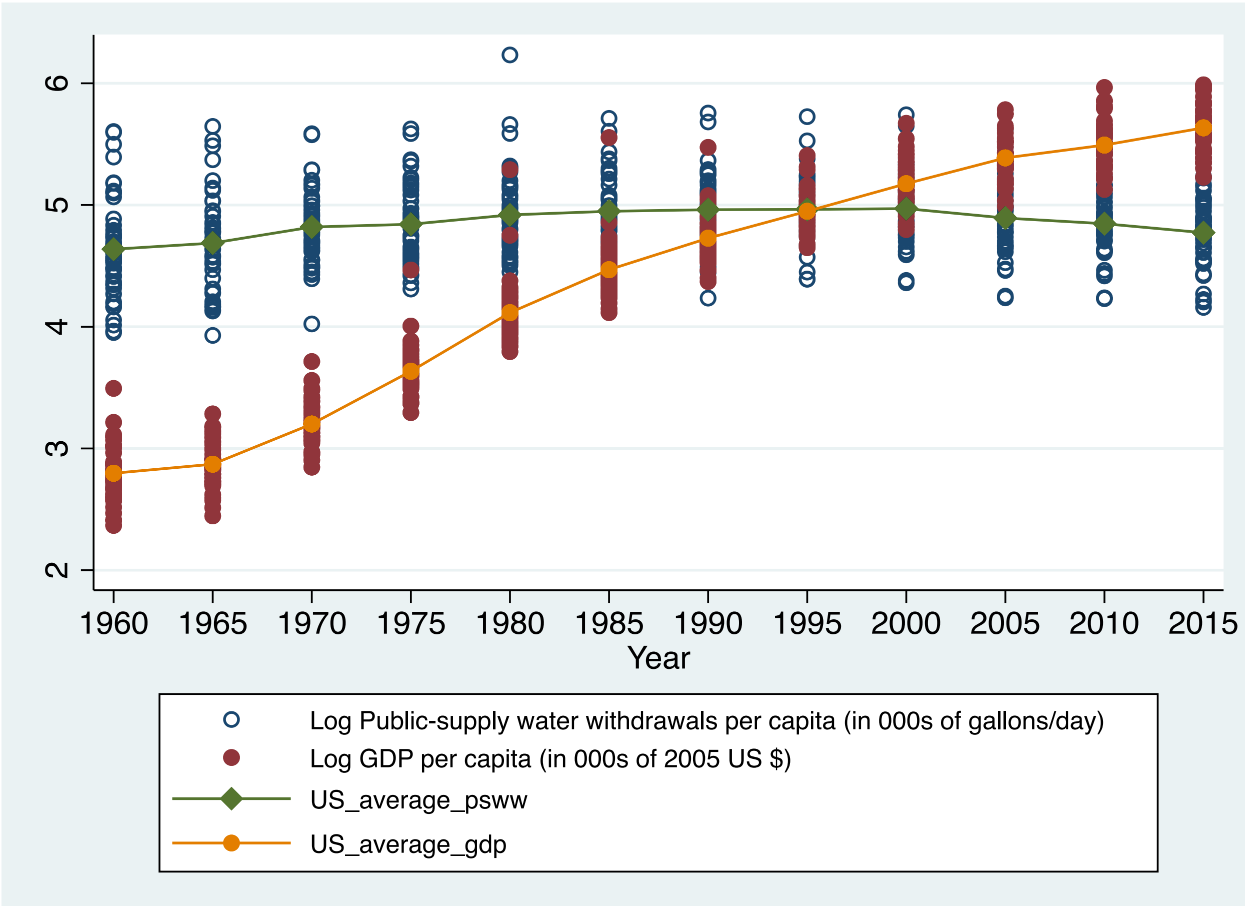

Figure 5: Plots of log self-supplied industrial water withdrawals per capita per today and log GDP per capita

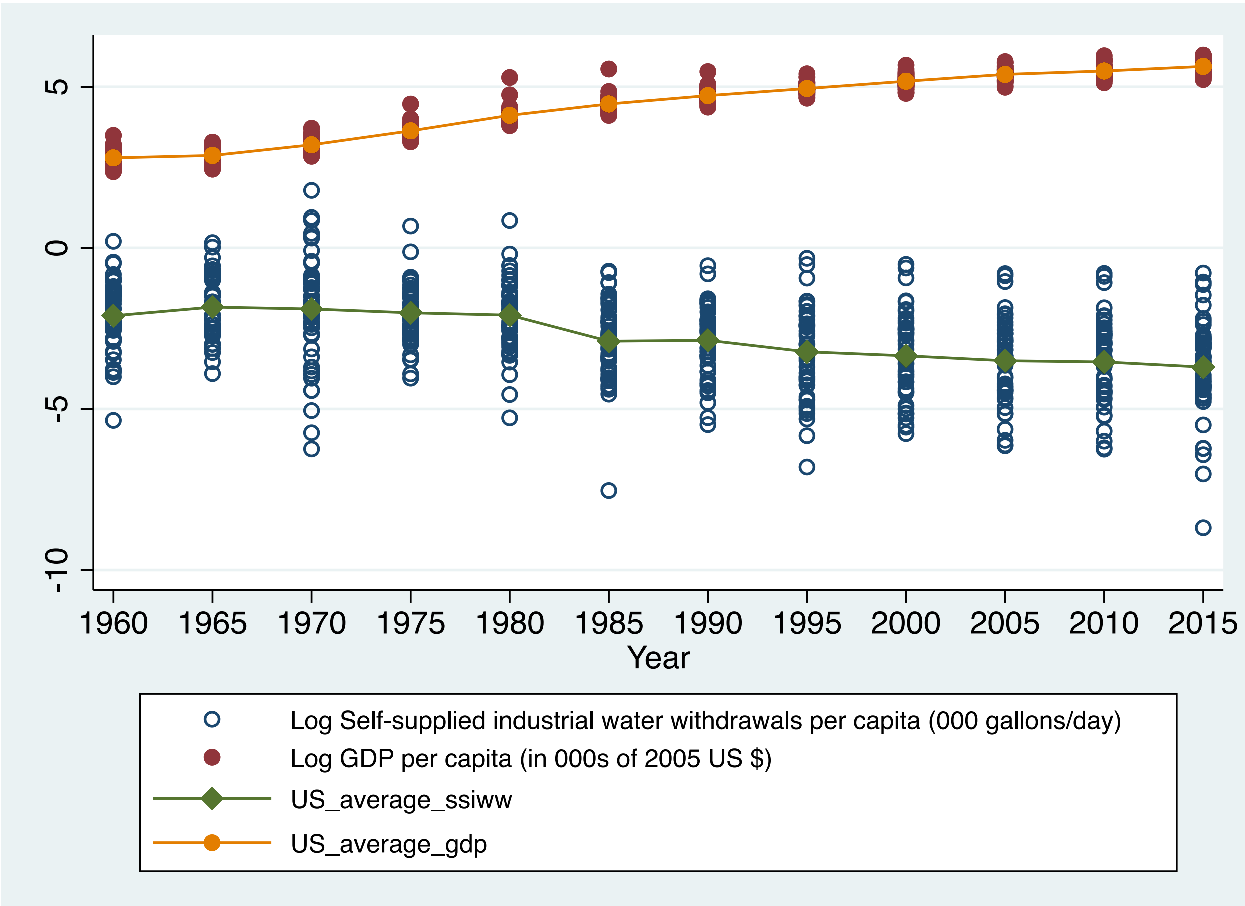

Figure 6: Plots of log irrigation water withdrawals per capita per day and log GDP per capita

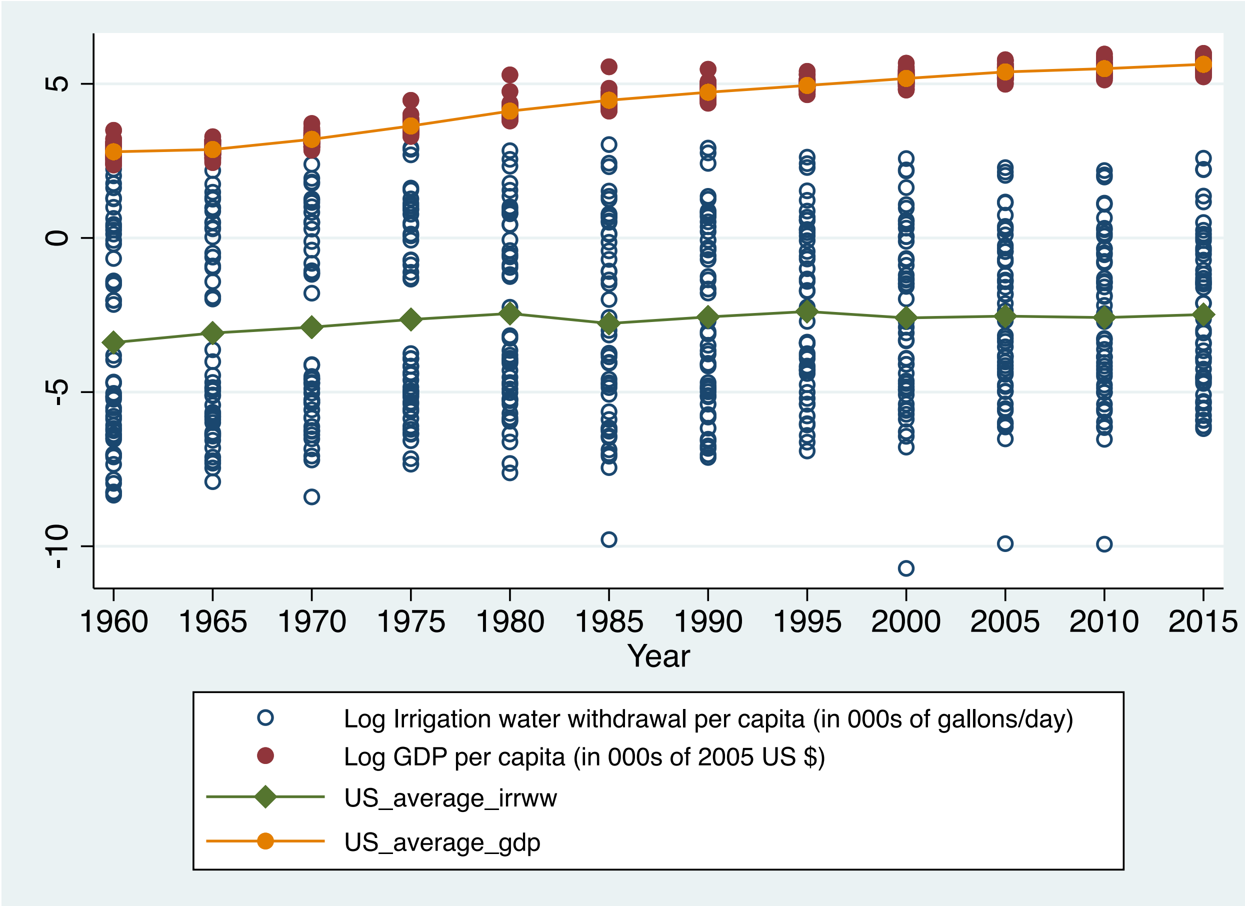

Figure 7: Plots of log thermoelectric water withdrawals per capita per day and log GDP per capita