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# **An Econometric Analysis of the Impact of Forest Restoration on Agriculture in the Verde River Watershed, Arizona**

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# An Econometric Analysis of the Impact of Forest Restoration on Agriculture in the Verde River Watershed, Arizona

## 1. Introduction

An important function of forested watersheds is to provide ecosystem services for water quantity and quality (Groffman et al. 2004, Karimzadegan et al. 2007, Guo et al. 2008, Karahalil et al. 2009). It has been estimated that the forested watersheds of Arizona contribute nearly 90% of the total streamflow in the state (Ffolliot 1975). Furthermore, forests of the Southwestern U.S. serve as some of the most important recharge areas for large regional aquifers (Pool et al. 2011). These aquifers are connected to springs and baseflow-dependent streams and wet meadows, supporting some of the rarest and most diverse ecosystems in the semiarid landscapes of the Southwest and providing water supplies to rural communities (Haney et al. 2008). Changes to land and watershed management may change the timing and rates of recharge to these aquifers (National Research Council 2008). Such watershed management changes are vitally important to protect the springs and baseflow dependent streams connected to these aquifers, especially in light of potential warmer and drier conditions predicted by climate change models.

Viewed as a watershed management strategy, forest treatments or forest restoration treatments (including thinning and burning) influence the hydrology of watersheds and result in measureable and significant increases in surface water yield<sup>1</sup> (Baker 2003). This is largely because the reduced canopy cover that results from thinning (also called selective harvesting) allows greater volumes of precipitation to reach the forest floor (Rogerson 1968). In addition, thinning reduces evapotranspiration by the forest. In the absence of natural fire, prescribed fire or burning may be necessary to maintain treated plots and would consume understory vegetation and accumulated pine needles and branches thereby reducing evapotranspiration (Zimmerman 2003)<sup>2,3</sup>.

Known as the Four Forest Restoration Initiative (4FRI), the US Forest Service is planning to embark on a large-scale restoration of four national ponderosa pine (*Pinus ponderosa*) forests in Arizona including the Kaibab, Coconino, Apache-Sitgreaves, and Tonto. The first phase includes forest thinning and/or burning projects on about 600,000 (actually, 593,211) acres over a ten-year period, with eventual treatment of 2.5 million acres total (U.S. Department of Agriculture 2011)<sup>4</sup>. Out of 593,211 acres, about

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<sup>1</sup> Maintaining water quality is also a consideration of forest treatments. The ability of watersheds to moderate runoff and purify water supplies is directly related to the forest cover. For example, treating drinking water from watersheds with 60% forest cover costs half as much relative to watersheds with only 30% forest cover (Postel and Thompson, 2005). Our study focuses on water quantity not water quality.

<sup>2</sup> Burning also minimizes the opportunities where small trees oftentimes out-compete the large ones for moisture, and the large trees may die.

<sup>3</sup> Another benefit of forest treatments is to reduce fire risk since trees are not too close together and there is more vegetative ground cover.

<sup>4</sup> In September 2013, the Forest Service approved the transfer of the first phase stewardship contract from Pioneer Forest Products to Good Earth Power AZ LLC to treat 300,000 acres over ten years.

276,715 acres reside in the Verde River watershed where agricultural lands are being irrigated. Based on responses to experimental forest treatments conducted from the 1950s to 1980s, a reduction in tree basal area of > 30% produces a water yield of 5 to 15% over pretreatment yield by the end of the ten-year period (Baker 1986). A simulation with a regional groundwater flow model showed an increase in groundwater recharge of 2.8 % to aquifers of the Verde River watershed over a ten-year period from planned forest restoration treatment (Wyatt et al. 2014).

The objective of this study is to investigate the impact of water yield increase from forest restoration on agricultural production in the Verde River watershed in central Arizona. Its importance is manifested in a well-developed contingent valuation survey in the same watershed that reveals irrigators' willingness to pay for the 4FRI projects, including initial treatments, follow-up treatments, and monitoring that help ensure quality and quantity of irrigation water (Mueller et al. 2013). In addition, as the Intergovernmental Panel on Climate Change (2007) points out, the impacts of global warming in Arizona are likely to include less available irrigation water (due to higher mean annual temperatures, increased evapotranspiration, changing weather patterns and more fuel for wildfires during hotter drier summers), a decline in farmed acres, and other adverse effects on Arizona's agricultural economy. Recently, as Gregg Garfin at University of Arizona pointed out, climate change is really water change in the Southwest. The latest National Climate Assessment shows that future water supply in Arizona could be worse than previous predictions. Water reduction in major rivers in Arizona could reach 15 percent by the second half of this century (Loomis 2014). As forest restoration treatments increase downstream runoff and groundwater recharge, it will, in principle, greatly benefit Arizona in water uses such as agriculture use.

Specifically, this study uses a reduced-form econometric regression model with 1969-2010 time-series data to estimate the economic benefits of the increased water yield due to forest restoration in the Verde River watershed. Most irrigated farmlands of Yavapai County lie within the Verde River Watershed, making it easy to use county data collected by the U.S. Department of Agriculture (USDA). We have not found other studies of this kind that quantify the impact of increased water yield from forest restoration on agricultural production. In the literature, for example, Smith et al. (2010) and West et al. (2009) created a survey instrument, interviewed individuals who are knowledgeable about the Verde River watershed, and identified an extensive list of the values that stakeholders place on the watershed. This list includes the value of water for irrigation although it is not quantified. Their research does not include how forest restoration affects irrigation water. Numerous studies in hydrology and hydrogeology utilize experiments and stimulations to examine the relationship of forest management and water yield, but do not relate to how it affects agriculture (for example, Rogerson 1968, Baker 1986, Zimmerman 2003, Wyatt et al. 2014).

## 2. Study Area

Our study area is the Verde River watershed in Arizona. Figure 1 shows the location of the watershed, important USGS stream gages, towns, and planned forest restoration area within the watershed.

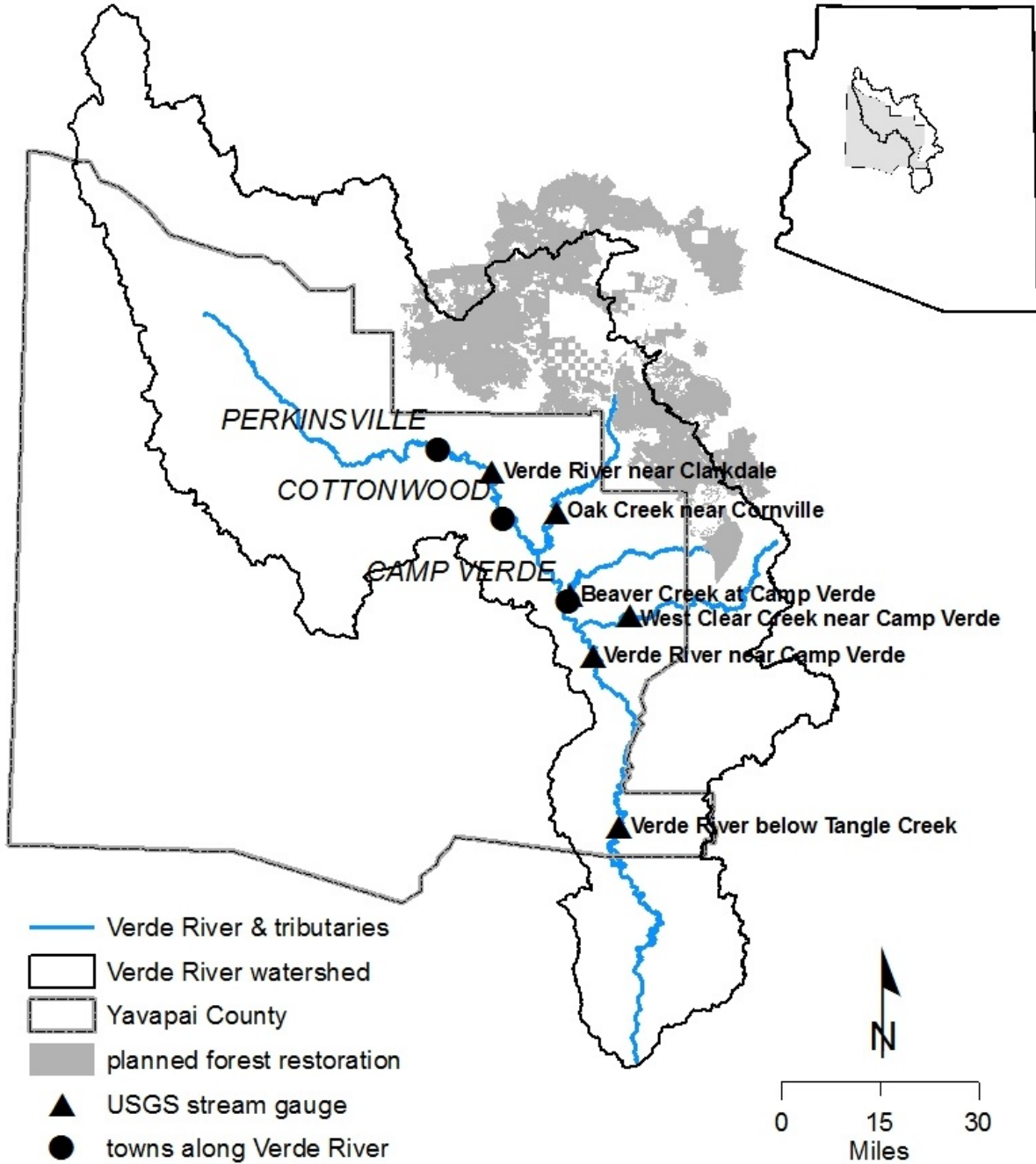


Fig. 1. Verde River Watershed, Arizona, USA

In semi-arid Arizona, approximately 75% of cultural water use is by agriculture each year<sup>5</sup>. Major sources of water supply are surface water and groundwater<sup>6</sup>. Besides the Colorado River, main surface water resources are the Gila and Little Colorado River and their tributaries. The reach of the Verde River within our study area is the longest remaining, perennial, free-flowing reach of river in the State of Arizona. There are no water storage dams and reservoirs on this reach, only small irrigation diversion structures. The perennial reach of the Verde River starts near Sullivan Lake and meanders southeast 195 miles before reaching its confluence with the Salt River near Phoenix. It shows It is home to some “thriving native fish species and bald eagles and is the only Arizona river to receive Wild and Scenic designation by the National Wild and Scenic Rivers System” (McKinnon 2006, West et al. 2009, Water Education Foundation and the University of Arizona 2007). The Verde River watershed drains 6,646 square miles or 4,253,440 acres<sup>7</sup>. Slightly more than 50% of the watershed is in Yavapai County and another 40% of the watershed that lies in the adjacent Coconino County drains into the Verde River within Yavapai County<sup>8</sup>. It also covers parts of two other counties: Gila, and Maricopa (Arizona NEMO 2005). 276,715 out of 593,211 acres of ponderosa pine trees treated by the first phase of the 4FRI projects are located in this watershed, and approximately 50,000 acres of related forest restoration treatments in the Verde Watershed will occur beyond the 4FRI project. Because forest restoration is expected to increase surface water yield in the Verde River, it will ultimately benefit the agricultural activities in the watershed. The entire watershed is divided into the upper (from Sullivan Lake to Perkinsville along the Verde River), middle (from Perkinsville to Camp Verde and bounded to the north by the Mogollon Rim and the San Francisco Volcanic field and to the south by the Black Hills), and lower (below Camp Verde) subwatersheds (West et al. 2009). The Middle subwatershed is commonly known as the Verde Valley.

Major agricultural products are forage, corn for grain, field and grass seed crops, pecans, and vegetables<sup>9</sup>. Substantial agricultural activities take place in the middle Verde subwatershed which has been an active farming region for about 800 years including the pre-European-settlement period (Alam 1997). Irrigation ditches serve to provide water to agricultural lands and have sustained the agriculture. Most of the ditches currently in use were built more than 100 years ago (Alam 1997, The Verde Independent 2010). Farmers have to purchase property with claimed water rights to draw water from a

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<sup>5</sup> Cultural water use is defined relative to instream water use that is for support of fish, riparian ecosystems, recreation activities, etc. within a stream channel.

<sup>6</sup> Reclaimed wastewater contributes 3% of water use in the state of Arizona.

<sup>7</sup> 1 square mile = 640 acres.

<sup>8</sup> According to the GIS layers we have from the USGS, the Verde Watershed is 4,239,210 acres. The Yavapai portion is 2,153,296 or 50.8%. Only 407,585 acres (or 10.4 %) of the Verde watershed does not drain to the Verde River in Yavapai County and this portion does not have ponderosa pine forest. In other words, all of the forest slated for treatment in the Verde Watershed drains to the Verde River in Yavapai County.

<sup>9</sup> Agricultural products also include live stock (cattle, horses, layers, ducks, and sheep), poultry, and their products.

ditch. Surface water allocation is determined based on the doctrine of prior appropriation (the “first in time, first in right” principle) meaning the farmland where water was put to beneficial use first, has the more senior water right (Water Education Foundation and the University of Arizona 2007).

Competing water rights, rapid population growth, and regional droughts have contributed to decreases in baseflow in the Verde River since the early 1990s (The Nature Conservancy 2011, Springer and Haney 2008; Pawlowski 2013). The resiliency of the flows in the river has drawn increasing attention from environmental groups and other stakeholders in recent years. Declines in baseflow can negatively affect human communities and ecosystems in the watershed. In 2006, a non-profit advocacy environmental group American Rivers named the Verde River as the 10<sup>th</sup> most endangered river in the United States (McKinnon 2006). The 4FRI forest treatments have significant implications for the Verde River watershed in regard to how much the projects could increase water supply to ease the emerging challenges that the watershed is facing.

### 3. Empirical Model

Our empirical model is developed based on the commonly used Cobb-Douglas production function which originally shows the relationship of an output to two inputs in the field of microeconomics. Research into production function has a long history. First introduced in 1928 (Cobb and Douglas 1928), the standard form of this function includes labor and capital as inputs:

$$Y = AL^\alpha K^\beta \quad (1)$$

where Y is production of a good, A is total factor productivity, L is labor input, K represents capital input, and  $\alpha$  and  $\beta$  are output elasticities of labor and capital respectively.  $\alpha$  and  $\beta$  reflect how sensitive or responsive the output is to a change in labor or capital. As constants, two elasticities are determined by available technology (Douglas 1976). This is insightful and also the major reason why later research in the literature regards technology as an independent input.<sup>10</sup> Over time, an aggregate economy-wide Cobb-Douglas production function is also developed and adopted by macroeconomists. The economy-wide function suggests that output/income depends on technology and factors of production or inputs (e.g., Hildebrand 1960, Lewis 1972, Ng and Zhao 2010). Motivated by this insight, this paper proposes the use of a modified aggregate Cobb-Douglas production function to formulate the relationship of agricultural output and inputs with the emphasis on the link between agricultural output and water use input. That is,

$$Y_t = A_t L_t^\alpha K_t^\beta W_t^\gamma N_t^\delta e^{\varepsilon_t} \quad (2)$$

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<sup>10</sup> A critique of the Cobb–Douglas production function in the literature is that it lacks microeconomic foundations because it is not derived based on the production process. It is developed in a form with attractive mathematical characteristics, such as diminishing marginal returns to either labor or capital.

where  $Y_t$  is agricultural income/output,  $A_t$  is technology,  $L_t$  is labor input,  $K_t$  is capital input,  $W_t$  is water use,  $N_t$  is land;  $\varepsilon_t$  is a random disturbance term and it captures all other factors which influence the dependent variable  $Y_t$  other than regressors  $A_t, L_t, K_t, W_t$ , and  $N_t$ ; and  $t$  is the time in years.

Essentially, we augment the common Cobb-Douglas production function by including water use and land use. This is motivated by the production characteristics of agriculture.

Taking log on both sides, we have

$$\log(Y_t) = \log(A_t) + \alpha \log(L_t) + \beta \log(K_t) + \gamma \log(W_t) + \delta \log(N_t) + \varepsilon_t \quad (3)$$

There are two advantages to focus on the logarithmic version of the model. First, it has more econometrics, meaning as the estimated coefficient of each input can be accurately and simply interpreted—each coefficient of an input measures the percentage change in output caused by a one percent change in that input. Second, it is easier to estimate such a linear model.

Agricultural income is represented by total farm labor and proprietors' income. Labor is measured by hired farm labor. Capital is represented by estimated market value of all machinery and equipment in operation per farm (i.e., the average market value). Land is represented as the land in farms. We do not have data on technology. Therefore, we consider two approaches to take into account technology. One is to assume that technology is a function of capital. Intuitively, technological improvement will result in more sophisticated machinery and equipment. Therefore, market value of machinery and equipment on operation per farm may increase. In this case, we have

$$\log(A_t) = \chi \log(K_t) + \mu_t \quad (4)$$

Combining Eqs (3) and (4), we have

$$\log(Y_t) = \alpha \log(L_t) + \phi \log(K_t) + \gamma \log(W_t) + \delta \log(N_t) + \nu_t \quad (5)$$

where  $\phi = \chi + \beta$ , and  $\nu_t = \varepsilon_t + \mu_t$ . Empirically, we include a constant term to obtain unbiased estimates,

$$\log(Y_t) = a + \alpha \log(L_t) + \phi \log(K_t) + \gamma \log(W_t) + \delta \log(N_t) + \nu_t \quad (6)$$

Our second approach is to include a time trend, since previous research has used time trend as a proxy for technology (e.g. Huang 2010). Therefore, our second empirical model is

$$\log(Y_t) = a + bt + \alpha \log(L_t) + \phi \log(K_t) + \gamma \log(W_t) + \delta \log(N_t) + \nu_t \quad (7)$$

Our models are reduced-form time-series regression models. Such a reduced-form analysis is objective and comprehensive since it takes into account all direct and indirect effects of forest treatments on agriculture. This approach is widely used in environmental economics—one prominent example is the work of Horowitz (2009), who uses a reduced-form approach to estimate the economic impact of global

warming. The main advantage is its simplicity by ignoring complicated ecological and physical processes but including a few parameters. As the literature points out, successful modeling and forecasting does not necessarily require a structural model (Campbell and Diebold 2005, Zhao and Fletcher 2011).

#### **4. Data**

Agricultural water use data in the study area—the Verde River watershed—are calculated based on historic stream gauging data. We average the June daily baseflow in cubic feet per second (cfs) at three upstream gauges (Figure 1) (Verde River near Clarkdale, Oak Creek near Cornville, West Clear Creek near Camp Verde), add estimated baseflow for Beaver Creek at Camp Verde (from a one-time measurement), subtract one downstream gauge (Verde River near Camp Verde), and then minus 21% for riparian evapotranspiration (Blasch et al 2006). The results are daily irrigation water drawn by all ditches or daily agricultural water use provided by all ditches in the watershed. Note that, Verde River below Tangle Creek gauging data are used to interpolate missing data from 1969 to 1987 for the Verde River near Camp Verde gauge. However, because both the Camp Verde and Tangle Creek gauges were not functioning in June of 1982, Verde River near Camp Verde flow was estimated based on interpolation using proportionate amount of Verde River near Camp Verde flow relative to the other gages in other years.

Based on the fact that the Verde Valley has a 194-day growing season, we multiply the daily water use values by 194 days to derive annual water use data (in acre-feet). Annual agricultural water use data cover the 1969-2010 period.

Obtaining data on other variables for the watershed is also a challenge. The Verde River watershed spans four counties but the majority of the irrigated portions of the watershed are in Yavapai County. Figure 1 shows that about half of the Verde River watershed overlaps half of Yavapai County. For two reasons, (1) the only irrigated agriculture in Yavapai County outside of the Verde River watershed is one small field in the Agua Fria drainage, and (2) the other three counties in the watershed do not have significant agricultural production by being away from the Verde River, we hence could use Yavapai County agricultural data to approximate the Verde River watershed agricultural data.

Annual data on total farm labor and proprietors' income (in thousands of dollars) from 1969 to 2010 in Yavapai County are from Bureau of Economic Analysis. Five-year interval data on all other variables in Yavapai County—land in farms (in acres), hired farm labor, and estimated market value of all machinery and equipment on operation per farm (in dollars),—are obtained from the USDA Census of Agriculture (i.e., Historical Census Publications), for the period of 1954-2011. Since all survey data from USDA Census of Agriculture are based on a 5-year cycle, we had to interpolate missing values by assuming that the growth rate of each variable was constant between two survey years. This approach



may distort time-series properties of our data. However, in the robustness check tests, we show that our results are qualitatively similar even if we drop these survey variables. Our merged data cover the sample period from 1969 to 2010.

## 5. Empirical Results

### 5.1. Unit Root Tests

To avoid model misspecification, we did unit root tests. We tested whether the major variables of interest (e.g., agricultural income  $Y_t$  and agricultural water use  $W_t$ ) have unit roots or not (unit roots against deterministic time trends). If the variables have unit roots, Eqs. (6) and (7) may be misspecified, and an error-correction or a first-difference representation may be required

More specifically, we utilized the popular Akaike information criterion (AIC) to determine the lag length (Burnham and Anderson 2002). AIC is chosen because it is “superior than the other criteria under study in the case of small sample (60 observations and below)” (Liew 2004). The results show that the lag lengths in  $\log(Y_t)$  and  $\log(W_t)$  are 0 and 0, respectively. We ran the widely used Dickey-Fuller tests to test whether unit roots are present (Dickey and Fuller 1979). The unit root null hypothesis is rejected at the 1% level of statistical significance for  $\log(Y_t)$  and at the 1% level of statistical significance for  $\log(W_t)$  (Table 1). The evidence supports the specifications we have in Eqs. (6) and (7).

### 5.2. Results

We report whole sample results (i.e., coefficient estimate and t-value for each independent variable and adjusted  $R^2$ ) in Table 2. The autocorrelation problem found in time series data means that the error terms are correlated over time. The methodology to compute what are often called heteroskedasticity- and autocorrelation- consistent (HAC) standard errors was developed by Newey and West (Newey and West 1987). The t-ratios in Table 2 are based on Newey-West HAC standard errors with the lag parameter set equal to 1.

We report four sets of results. In Panel A (Tables 2, 3, and 4), we report the results based on Eqs. (6) and (7), which use the survey data on labor, capital and land. In Panel B (Tables 2, 3, and 4), we report the results for the regression models that do not use the survey data. As we have pointed out, such survey data may result in distortion, since we have to interpolate missing values. Again, Eq. (6) assumes that technology is a function of capital, while Eq. (7) uses time trend to proxy technology as in Huang (2010). All the models include water use, which is our focus. Our emphasis is to estimate the relationship between agricultural output/income and water use. In all cases except one, water use ( $\log(W_t)$ ) is

**Table 1: Unit Roots Tests**

	Y	W
Lags (AIC)	0	0
t-Statistic	(-5.08) <sup>***</sup>	(-5.92) <sup>***</sup>

Note:

\* means that the level of statistical significance is 10%.

\*\* means that the level of statistical significance is 5%.

\*\*\* means that the level of statistical significance is 1%.

**Table 2: Whole Sample Regressions 1969-2010**

	Panel A With survey data			
	<u>Without time trend</u>		<u>With time trend</u>	
	Estimate	t-value	Estimate	t-value
Constant	1.80	0.42	4.19	0.58
t			-0.03	-0.82
Log(L <sub>t</sub> )	1.69 <sup>***</sup>	3.97	1.54 <sup>***</sup>	4.11
Log(K <sub>t</sub> )	0.15	0.95	0.45 <sup>***</sup>	4.55
Log(W <sub>t</sub> )	0.20	0.93	0.24	1.00
Log(N <sub>t</sub> )	-0.57 <sup>***</sup>	-2.74	-0.86	-1.45
R <sup>2</sup>	0.42		0.41	
	Panel B: without survey data			
	<u>Without time trend</u>		<u>With time trend</u>	
	Estimate	t-value	Estimate	t-value
Constant	-0.34	-0.08	4.17	1.33
t			0.03 <sup>***</sup>	4.39
Log(W <sub>t</sub> )	0.95 <sup>**</sup>	2.14	0.39	1.18
R <sup>2</sup>	0.13		0.27	

Note:

\* means that the level of statistical significance is 10%.

\*\* means that the level of statistical significance is 5%.

\*\*\* means that the level of statistical significance is 1%.

**Table 3:** Sub-Sample Regressions 1969-1989

Panel A With survey data				
	<u>Without time trend</u>		<u>With time trend</u>	
	Estimate	t-value	Estimate	t-value
Constant	-124.71***	-3.92	-1526.90	-0.49
t			2.58	0.45
Log(L <sub>t</sub> )	4.87	0.00	232.07	0.46
Log(K <sub>t</sub> )	0.19	0.00	0.56	0.00
Log(W <sub>t</sub> )	0.21	0.63	0.24	0.66
Log(N <sub>t</sub> )	6.55***	2.79	-4.27	-0.20
R <sup>2</sup>	-0.05		-0.11	

Panel B: without survey data				
	<u>Without time trend</u>		<u>With time trend</u>	
	Estimate	t-value	Estimate	t-value
Constant	8.47***	4.28	8.47***	3.74
t			-0.03	-1.32
Log(W <sub>t</sub> )	-0.05	-0.25	-0.01	-0.05
R <sup>2</sup>	-0.05		-0.04	

Note:

\* means that the level of statistical significance is 10%.

\*\* means that the level of statistical significance is 5%.

\*\*\* means that the level of statistical significance is 1%.

**Table 4:** Sub-Sample Regressions 1990-2010

Panel A With survey data				
	<u>Without time trend</u>		<u>With time trend</u>	
	Estimate	t-value	Estimate	t-value
Constant	10.20	0.43	-20.00	-0.80
t			-0.06	-0.97
Log(L <sub>t</sub> )	0.80	1.59	1.53**	2.03
Log(K <sub>t</sub> )	-0.82	-0.83	1.19	0.62
Log(W <sub>t</sub> )	1.33**	2.09	1.29**	1.97
Log(N <sub>t</sub> )	-0.77	-1.17	-0.30	-0.49
R <sup>2</sup>	0.62		0.60	

Panel B: without survey data				
	<u>Without time trend</u>		<u>With time trend</u>	
	Estimate	t-value	Estimate	t-value
Constant	-12.78	-1.61	-11.66	-1.47
t			0.02	1.22
Log(W <sub>t</sub> )	2.29**	2.75	2.12**	2.52
R <sup>2</sup>	0.35		0.35	

Note:

\* means that the level of statistical significance is 10%.

\*\* means that the level of statistical significance is 5%.

\*\*\* means that the level of statistical significance is 1%.

statistically insignificant at the conventional 5% level. For instance, if we use the survey data and do not include the time trend, the coefficient on  $\log(W_t)$  is 0.20 with a t-ratio of 0.93. This suggests that water use is not statistically significant.<sup>11</sup>

However, the results based on the whole sample from 1969 to 2010 may be biased, because the coefficients of the relevant variables can change dramatically over the 42 years (Table 2). Consider the coefficient of water use. In early years, water use may not be a significant factor holding constant other variables, because water supply was not binding. However, in recent decades, persistent drought has made water supply a binding factor. The coefficient of water supply can change dramatically. Our whole-sample estimation clearly does not allow for such time variation in the coefficients. Therefore, we split our sample into two equal-length sub-samples, i.e., 1969-1989 and 1990-2010. The fact of having persistent drought since 1991 or 1992 in the Verde River watershed actually supports this division.

We report the results for 1969-1989 in Table 3 in the same fashion as Table 2. In all cases, water use was not statistically significant, which is consistent with our hypothesis.

We present the results for 1990-2010 in Table 4 in the same fashion as Table 2. Consistent with our hypothesis, water use is a statistically significant determinant of agricultural income in recent decades. In all cases,  $\log(W_t)$  has a statistically significant coefficient. For instance, water use has a coefficient of 1.33 with a t-ratio of 2.09, which is significant at the 5% level for a two-sided test. Our estimation suggests that if water use increases by 1%, the farm income will increase by 1.33%. Therefore, water use is not only statistically but also economically significant. This is the central finding of our paper.

### *5.3. Implications*

Because forest restoration projects may increase water supply, the water use associated with any increase in supply has significant economic benefit to farmers in the Verde River watershed. With the estimated coefficient for water use (1.33%) and the expected increase in water yield caused by the 4FRI, we are able to estimate the economic benefits of forest restoration on agriculture.

How do we forecast the increase in water yield? Paired watershed studies in Arizona during the 1950s to 1980s compared untreated watersheds with treated watersheds. Ffolliot (1975) reported that in the Beaver Creek Experimental Watershed study area, which lies within the 4FRI area, forest thinning using strip cuts and patch cuts resulted in water yield increases of about 1 inch per year. Since average annual water yield in the Beaver Creek Watershed is less than 10 inches per year, a 1-inch or 10%

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<sup>11</sup> If we drop the survey variables and do not include the time trend,  $\log(W_t)$  is statistically significant (its coefficient is 0.95 with a t-ratio of 2.14). However, this may be due to missing-variable biases, because as soon as we include the time trend which proxies technology,  $\log(W_t)$  loses its statistical significance (its coefficient decreases to 0.39 with a t-ratio of 1.18).

increase carries some importance. Unfortunately, the Beaver Creek and other studies showed that increased water yields diminished over time so that increases were negligible after 6 to 10 years post treatment (Baker 1986; 2003). This gradual decrease was due to greater evapotranspiration as new vegetation replaced the trees which were thinned. The forest treatments proposed by 4FRI include not only the initial mechanical thinning of the forest, but the maintenance of the new reduced forest density with the reintroduction of a more frequent, low intensity, fire regime.

Based on the size of the treatment area and the predicted response based on historic studies (Baker 2003), water yield is expected to increase by 5-10% by the end of the ten-year period. Since 1% increase in water yield increases income to farmers by 1.33%, 5-10% increase in water yield will cause agricultural income to rise by  $1.33 \times 5 = 6.65\%$  to  $1.33 \times 10 = 13.3\%$  annually in the Verde River watershed. This estimate includes the assumption that 100 percent of the increase in water yield is utilized by agriculture.

## **6. Conclusion**

The Four Forests Restoration Initiative is an innovative, stakeholder driven initiative to develop healthy and more resilient forests, which improve not only forest health, but other ecosystems services, such as watershed services and water yield. By adopting a reduced-form time-series regression model, we split the data sample for the Verde River watershed in Arizona into 1969-1989 and 1990-2010, and conclude that during the second time period, water use is statistically and economically significant, due to a prolonged drought.

Our central finding is, if water use increases by 1%, the farm income will increase by 1.33%. If a 5-10% increase in water yield caused by the first phase of the 4FRI is all used by agriculture, agricultural income will increase by 6.65-13.3% annually. This also assumes that the planned forest restoration treatments maintain water yield increases through application of frequent prescribed burns to thin encroaching vegetation.

The significance of this study is that, irrigators in the Verde Valley would benefit from greater resiliency in the forested watershed which provides their supplies. There are no future climate predictions which show greater availability of water. All models show warmer temperatures, which would result in greater evapotranspiration rates in the watershed, further diminishing the supply of water. Because the rights to water in the river are currently overallocated, any diminishments in the quantity of water from the current full allocation will lead to water shortages and choices of partitioning a limited supply. So, this forest treatment project will help water users guarantee their existing water supplies better.

There are some limitations in the approach of this study. As mentioned in Section 2, about 75 % of cultural water use is by agriculture each year in Arizona. There is also instream water use. Assuming

that 100 percent of the increase of water yield from forest restoration is utilized by agriculture is not realistic. A percentage smaller than 75% should be utilized in further research, consistent with the current distribution of water use in the region. The estimated agricultural benefit from forest restoration in this paper is thus an upper limit. In terms of the regression model, we ignore direct precipitation to the agricultural lands and underestimate agricultural water use in the watershed. More research is also needed to be done to compare the agricultural benefit with the cost of forest restoration, and to take into account all benefits resulted from forest restoration.

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## References

- Alam, J. 1997. Irrigation in the Verde Valley: A Report of the Irrigation Diversion Improvement Project: Verde Natural Resource Conservation District.
- Baker, M.B., Jr. 1986. Effects of Ponderosa Pine Treatments on Water Yield in Arizona. *Water Resources Research* 22, 67–73.
- Baker, M.B., Jr. 2003. Hydrology in Ecological Restoration of Southwestern Ponderosa Pine Forests. Edited by Peter Friederici. Island Press, Washington, D.C., 161–174.
- Blasch, K.W., J.P. Hoffmann, L.F. Graser, J.R. Bryson, and A.L. Flint. 2006. Hydrogeology of the Upper and Middle Verde River Watersheds, central Arizona. U.S. Geological Survey Scientific Investigations Report 2005-5198, 102 p.
- Burnham, K. P., D. R. Anderson. 2002. Model Selection and Multimodel Inference: a Practical Information-Theoretic Approach. Springer, New York.
- Campbell, S.D., F.X. Diebold, 2005. Weather Forecasting for Weather Derivatives. *Journal of the American Statistical Association* 100, 6–16.
- Cobb, C. W., P. H. Douglas. 1928. A Theory of Production. *American Economic Review* 18 (Supplement), 139–165.
- Dickey, D.A., W.A. Fuller. 1979. Distribution of the Estimators for Autoregressive Time Series with a Unit Root. *Journal of the American Statistical Association* 74, 427–431.
- Douglas, Paul H. 1976. The Cobb-Douglas Production Function Once Again: Its History, Its Testing, and Some New Empirical Values. *Journal of Political Economy* 84 (5), 903–916, October.
- Ffolliott, P.F. 1975. Water Yield Improvement by Vegetation Management: Focus on Arizona. Produced by University of Arizona for Rocky Mountain Forest and Range Experiment Station, Pap. PB-246 055, U.S. Dep. Of Comm., Nat. Tech. Information Serv., Washington D.C. Groffman, P.M., C.T. Driscoll, G.E. Likens, T.J. Fahey, R.T. Holmes, C. Eager, J.D. Aber, 2004. Nor gloom of night: a new conceptual model for the Hubbard Brook ecosystem study. *BioScience* 54 (2), 139–148.
- Guo H., B. Wang, X.Q. Ma, G.D. Zhao, S.N. Li. 2008. Evaluation of Ecosystem Services of Chinese Pine Forests in China. *Science in China Series C – Life Sciences* 51 (7), 662–670.
- Haney, J.A., D.S. Turner, A.E. Springer, J.C. Stromberg, L.E. Stevens, P.A. Pearthree, V. Supplee. 2008. Ecological Implications of Verde River Flows. A report by the Arizona Water Institute, The Nature Conservancy, and the Verde River Basin Partnership, 114 p.

- Hildebrand, John R. 1960. Some Difficulties with Empirical Results from Whole-Farm Cobb-Douglas-Type Production Functions. *Journal of Farm Economics* 42 (4) (Nov., 1960), 897–904.
- Horowitz, J. 2009. The Income–Temperature Relationship in a Cross-Section of Countries and Its Implications for Predicting the Effects of Global Warming. *Environmental and Resource Economics* 44, 475–493.
- Huang, H., Madhu K. 2010. An Econometric Analysis of U.S. Crop Yield and Cropland Acreage: Implications for the Impact of Climate Change. Selected paper prepared for presentation at the Agricultural and Applied Economics Association 2010 AAEA, CAEA, and WAEA Joint Annual Meeting, Denver, Colorado, July 25–27.
- Intergovernmental Panel on Climate Change. 2007. The IPCC Fourth Assessment Report. <http://www.ipcc.ch/2007>.
- Karahalil U., S. Keles, E.Z. Baskent, S. Köse. 2009. Integrating Soil Conservation, Water Production and Timber Production Values in Forest Management Planning Using Linear Programming. *African Journal of Agricultural Research* 4 (11), 1241–1250.
- Karimzadegan H., M. Rahmatian, M. Dehghani Salmasi, R. Jalali, A. Shahkarami, 2007. Valuing Forests and Rangelands—Ecosystem Services. *International Journal of Environmental Research* 1 (4), 368–377.
- Lewis, C. 1974. Simultaneous Equation Production Functions (Cobb-Douglas Type) for Decisions Pertaining to Sea-Based Tactical Air Resources. *Naval Research Logistics Quarterly* 21 (3), 491–503, September.
- Liew, Venus Khim-Sen. 2004. Which Lag Length Selection Criteria Should We Employ?, *Economics Bulletin, AccessEcon*, 3(33), 1–9.
- Loomis, Brandon. 2014. New Climate Report Holds Dire Predictions for the Southwest. *The Arizona Republic*. May 7.
- McKinnon, S. 2006. Thirsty Cities Threaten Verde River: Growth Plans Put River on List of 10 Most Endangered. *The Arizona Republic*. April 19.  
<http://www.azcentral.com/arizonarepublic/news/articles/0419verderiver0419.html?&wired>
- Mueller, J. M. W. Swaffar, E. A. Nielsen, A. E. Springer, and S. M. Lopez. 2013. Estimating the Value of Watershed Services Following Forest Restoration. *Water Resources Research* 49, 1773–1781, doi:10.1002/wrcr.20163.



- National Research Council. 2008. *Hydrologic Effects of a Changing Forest Landscape*. National Academies Press, Washington D.C. 168 p.
- Newey, Whitney K., Kenneth D. West. 1987. A Simple, Positive Semi-Definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix. *Econometrica* 55 (3), 703–708.
- Ng, P. & Zhao, X. 2011. No matter how it is measured, income declines with global warming. *Ecological Economics* 70, 963–970.
- Pawlowski, S. 2013. *Going with the Flow: A Summary of Five Years of Water Sentinels Flow Data Collection on the Upper Verde River*, Grand Canyon Chapter of the Sierra Club, Phoenix, AZ.
- Pitzer, Gary, Susanna Eden, Joe Gelt. 2007. *Layperson’s Guide to Arizona Water*. A report by the Water Education Foundation and the University of Arizona Water Resources Research Center.
- Pool, D.R., K. W. Blasch, J. B. Callegary, S. A. Leake, and L. F. Graser. 2011. *Regional Groundwater-Flow Model of the Redwall-Muav, Coconino, and alluvial basin aquifer systems of northern and central Arizona*: U.S. Geological Survey Scientific Investigations Report 2010-5180, v. 1.1, 101 p.
- Postel, Sandra L., Barton H. Thompson, Jr. 2005. Watershed Protection: Capturing the Benefits of Nature’s Water Supply Services. *Natural Resources Forum*, 29, 98–108.
- Rogerson, T.L. 1968. Thinning Increases Throughfall in Loblolly Pine Plantations. *Journal of Soil and Water Conservation* 23, 141–142.
- Smith, D.H., Sarah Viglucci, and Patricia West. 2010. *A Further Analysis of the Verde River Watershed Ecovalues*. Working Paper Series—10-04, The W. A. Franke College of Business Working Paper Series, Northern Arizona University, March.
- Springer, A.E., J.A. Haney. 2008. Chapter 2. Background: Hydrology of the Upper and Middle Verde River, 5-14. From Haney, J.A., D.S. Turner, A.E. Springer, J.C. Stromberg, L.E. Stevens, P.A. Pearthree, V. Supplee. 2008. *Ecological Implications of Verde River Flows*. A report by the Arizona Water Institute, The Nature Conservancy, and the Verde River Basin Partnership.
- The Verde Independent. 2010. *Irrigation Ditches*. June 24. Retrieved on August 6, 2012. <http://verdenews.com/main.asp?SectionID=292&SubSectionID=1508&ArticleID=37058>.
- U. S. Department of Agriculture, Forest Service. 2011. *Proposed Action for Four Forest Restoration Initiative* (unpublished). 95 p.

- West, Patricia, Dean Howard Smith, William Auberle. 2009. Valuing the Verde River watershed: an assessment. Working Paper Series—09-03, The W. A. Franke College of Business Working Paper Series, Northern Arizona University, March.
- Wyatt, C. J.W., O'Donnell, F. C. and Springer, A. E. 2014. Semi-Arid Aquifer Responses to Forest Restoration Treatments and Climate Change. *Groundwater*. doi: 10.1111/gwat.12184.
- Zhao, X., J.J. Fletcher. 2011. A Spatial-Temporal Optimization Approach to Watershed Management: AMD treatment in the Cheat River watershed, WV, USA. *Ecological Modelling*, 222(9), 1580–1591.
- Zimmerman, G.T. 2003. Fuels and Fire Behavior. In *Ecological Restoration of Southwestern Ponderosa Pine Forests*. Edited by Peter Friederici. Island Press, Washington, D.C., 126–143.