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Influence of Climate Variability on the Market Price of Water in the Gila-San Francisco Basin

Jennifer L. Pullen and Bonnie G. Colby

Emerging water markets in the western United States have slowly developed as usage patterns have changed over time. This article develops an econometric model for the Gila-San Francisco Basin. Results indicate the market price of water has risen in response to drought and market conditions. Analysis shows a statistically significant relationship between the price and quantity of water transferred, year the transaction occurred, location where the transaction occurred, new use of the water right, and whether the transaction occurred during a drought year. Using the Standard Precipitation Index, we find negotiated prices are higher during dry years.

Key words: drought, econometric, hedonic, market price, Palmer Hydrological Drought Index, Standard Precipitation Index, water, western United States

Introduction

Water markets have slowly evolved in response to pressures to change the historic distribution of water rights and usage patterns in the western United States. Water markets have flourished in regions where water resources are fully allocated and new water development is costly. Well-functioning water markets encourage the transfer of water rights to satisfy demand for additional supplies. Laws and policies that allow water rights to be traded help to create a market price for water that can reflect its economic value, and encourage water to be allocated based on its value.

This article develops an econometric model of derived demand for water prices in the Gila and San Francisco Basins in New Mexico, located in the southwestern United States. The Gila-San Francisco Basin has changing water use patterns that are representative of many areas in the western United States. Water rights are purchased for a variety of reasons in the Gila-San Francisco Basin: for domestic use, as a production input in mining, and as an input in agricultural crop production and livestock watering.

The derived demand model is motivated by Palmquist (1989). The model analyzes water price data from 1977–1996 to better understand the characteristics that determine water prices in this region. Water rights possess a number of characteristics that vary among each right. These characteristics include traits that cannot be changed by the owner of the water right and traits that can be changed in response to market information. The price for which each water right sells depends on the characteristics

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associated with that particular water right, along with regional factors related to derived demand for water.

In an active market, an individual who purchases a water right is unable to influence the equilibrium price, but the price paid depends on the characteristics of the water right the buyer selects, as well as on regional water demand factors. Similarly, a single seller cannot influence the equilibrium price. The equilibrium price for a specific bundle of characteristics is determined by the interaction of all buyers and sellers of water rights in a particular market.

On the demand side are the individuals who wish to obtain water rights for use as an input for agricultural crop production, mining, or domestic uses. Individuals using water rights as an input in production seek to maximize profits and their offer price for a particular water right will depend on its characteristics, prices of outputs and other inputs, the desired profit level, and the producers' skill level (as in the case of farmers and miners).

The market equilibrium price will adjust to eliminate excess demand or supply for water rights. In the Gila-San Francisco water market, the amount of water that can be consumptively used in a given year is fixed by the 1964 court decree in *Arizona v. California*.[1] Water market regions are very specialized in the western United States due to hydrological, legal, and financial restrictions on water transfers. The models presented here estimate the relative importance of various factors on the market price of water rights in this area. This study particularly focuses on the effect drought has had on the market price for water.

Previous Modeling of Water Prices

Water markets exist in various regions worldwide, and numerous publications examine the operation of these markets. An abundance of literature is available on laws and policies as they affect the structure and functioning of water markets. However, very little empirical analysis has been conducted and published on the performance of these water markets. This section highlights prior econometric analyses of water market prices.

Loomis et al. (2003) examined the market transactions for environmental purposes in the western United States, using the hedonic price method as the basis of their model. A linear and additive model was proposed, due to the public good aspect of instream uses of water, though the final model evaluated consisted of a nonlinear logarithmic functional form. Loomis et al. model the price per acre-foot of water right as a function of several different independent variables. The independent variables in this model include the new environmental purpose for the water transaction (such as recreation, endangered species, and wetland restoration), the average precipitation at the location of the transaction, the type of purchaser and seller, and whether the transaction was a lease or purchase. The model was found to have reasonable explanatory power ($R^2 = 0.61$), and the following independent variables were statistically significant: purchaser or seller is a government agency, average rainfall at the location of the transaction, water is purchased for recreational use, water purchased is used to protect threatened and

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[1] See *Arizona v. California*, 376 U.S. 340, 348 (1964).

endangered species, and water is used to benefit a wetland area. The study's results indicate that water transactions for environmental purposes are occurring more frequently and involve large monetary values.

Brookshire et al. (2004) examined water market prices in the semi-arid West for three areas—Arizona's Central Arizona Project, Colorado's Colorado Big Thompson Project, and New Mexico's Middle Rio Grande Conservancy District. Their study explains water rights price variation by exploring many characteristics of the markets, including both supply and demand factors. Using a (double-log) reduced-form model, Brookshire et al. included data on the type of seller and buyer, new use of the water, the Palmer Drought Index in each region, temperature, and population of each area. Their results suggest water prices are lower in wetter periods, and the type of buyer has a significant influence on the price of the water transaction.

Michelsen, Booker, and Person (2000) developed a two-equation rational expectations model to explain price variation in the Colorado Big Thompson water market. Variables in their model include: regional economic activity, housing starts, the farm debt-asset ratio, the inflation rate, and nominal interest rate. According to their findings, economic activity is a significant determinant for water-right prices, and an increase in the regional water supply can significantly affect the value of existing water rights.

Hedonic price analysis has been used in a few studies to estimate the value of different attributes incorporated in land and water. Crouter (1987) addressed the question of separability and competitiveness in water markets by estimating the hedonic price function for farm real estate in the portion of Weld County served by the Northern Colorado Water Conservancy District (NCWCD). This function relates a parcel's selling price to its attributes: quantities of land and water, value of improvements, and location. The model examines the price of a parcel of farm real estate as a function of the distance from the nearest town with a population greater than 1,000, the actual value of improvements, water, land, and an index soil quality. Crouter's results indicate that the water rights market of the sample area in 1970 was not efficient in the sense of being separate from the land market and competitive. The nonseparability of the function suggests the water market functioning in the NCWCD area had not developed to the point where it was distinct from the land market.

Faux and Perry (1999) employed the hedonic price function in a manner similar to Crouter. They applied the hedonic price method to agricultural land sales in Treasure Valley, Oregon, to reveal the implicit market price of irrigation water. They estimated the value of water in irrigation as well as the value of other attributes connected to the land. In the Treasure Valley area, water use is primarily for irrigation, but pressures have been mounting to allocate more of the water supply to aid salmon migration and survival. The marginal value of irrigation water in Treasure Valley was found to be $9 per acre-foot. Faux and Perry conclude that the value of irrigation supply in Treasure Valley was shown to be consistent, irrespective of the differing water rights and water storage facilities of the district providing water. Observed differences in sales prices between the districts were instead attributed to differences in quality of soils found in the districts.

Although water markets first emerged in Australia during the mid-1980s, little market activity occurred during this time. It was not until the last half of the 1990s that water market activity increased and water transfers became a normal occurrence in the agriculture sector. Bjornlund and Rossini (2005) explore the prices paid for water rights in order to examine evidence of rational behavior in water markets. They argue that in an efficient and competitive market, the price of allocations and entitlements should reflect the general level of interest in the economy given a similar level of risk. The prices in the two markets should therefore follow each other, with prices of allocations driving the price of entitlements. The authors evaluate prices paid in the Goulburn Murray Irrigation District in Northern Victoria over the 10-year period 1993–2002 to look more closely at this connection. The relationship is considered in three different ways: (*a*) calculation and comparison of the earnings-to-investment ratio at the time of buying water; (*b*) comparing and analyzing the cycle factors for the price of allocations and entitlements produced by the ratio to moving average method; and (*c*) by estimating the internal rate of return which could have been obtained by investing in water, selling the allocations yielded by the entitlement over a holding period, and the selling of the entitlement again at the end of the holding period.

The earnings-to-investment ratio was computed by dividing the mean monthly prices paid for allocations, less the cost of water supply, by the mean monthly prices paid for entitlements. Bjornlund and Rossini contend this ratio should indicate the kind of return that investors in entitlements could expect to receive if they reacted to short-term price signals. The authors observe that the earnings-to-investment ratio for water fluctuates widely due to the variation in the price of seasonal water, and toward the end of the irrigation season the price of allocations becomes low. Using a classical decomposition technique, cycle factors were computed for both the price of allocations and entitlements. These cycle factors should show the price variation not explained by trend or seasonality. The authors found that the two cycles move together, which suggests a close relationship between the movement in allocation and entitlement prices and that irrigators make financially sound decisions in the two markets. Finally, Bjornlund and Rossini treated water as an investment opportunity. Their findings reveal that returns on investments in water entitlements during the first 10 years of market operations were in excess of the return that could have been obtained by investing in other assets.

Bjornlund and Rossini conclude that when comparing the relationship between prices paid for allocations and entitlements, the price of entitlements clearly reflects the price of allocations, as rational market behavior would suggest. Based on their findings, the price of allocations fluctuates at about twice the rate of the price of entitlements, suggesting that the price of allocations reacts to short-term changes such as allocation level, evaporation, and rainfall, while the price of entitlements reacts to longer-term trends.

Although water transactions occur throughout the world, little empirical analysis has been conducted on prices and transactions in these markets. The limited available econometric analysis research is discussed in the preceding paragraphs. Only Brookshire et al. (2004) and Bjornlund and Rossini (2005), to this point, have explored the relationship between precipitation, drought, and water market prices. Loomis et al. (2003) use precipitation in lieu of a drought index, while Michelsen, Booker, and Person (2000) do not choose to explore the relationship between water market prices and precipitation. Faux and Perry (1999), as well as Crouter (1987), take an entirely different approach in their analysis of water markets. Faux and Perry employ the hedonic price function to examine the implicit market price of irrigation water, while Crouter assesses separability and competitiveness in water markets.

Exploring a different study area—the Gila-San Francisco Basin—our study expands on Brookshire et al.'s (2004) previous work examining how drought, population growth, and other derived demand factors have influenced water market prices.

Study Area

The Gila-San Francisco Basin is located in southwestern New Mexico's Grant County, which has a population of 29,842 (Sonoran Institute, 2007). The Basin is a diverse region in which water is used for mining, agricultural, municipal, environmental, and recreational purposes. This Basin is experiencing a growing demand for municipal water supplies, exerting economic pressure for water to be transferred out of other uses. Much of the Gila-San Francisco Basin lies within the Gila National Forest and Gila Wilderness Area, and is divided into two sub-basins—the Gila and the San Francisco.

The major population center in the area is Silver City. Towns located within the Gila-San Francisco Basin are small and widely scattered. Historically, mining and ranching were the dominant land and water uses in the Basin. Over the years, both industries have declined and their water rights have been sold for other uses. Water used in the Gila-San Francisco Basin comes primarily from surface water sources, but groundwater pumping is also widespread. Surface water rights on the Gila and the San Francisco are typically supplied by small private ditch companies. Silver City and other small towns in the area operate water treatment and distribution systems that depend on groundwater. Most other residential and commercial water users have their own private groundwater wells (Saliba-Colby and Bush, 1987).

Both groundwater and surface water rights are subject to the doctrine of prior appropriation in New Mexico. The "first-in-time, first-in-right" prior appropriation doctrine governs water rights in most western states and gives senior water rights priority over junior right holders in times of low streamflows (Colby, Crandall, and Bush, 1993). The New Mexico Office of the State Engineer (OSE) administers water rights and exerts regulatory control over groundwater by designating hydrologic regions as groundwater basins when there are no further water supplies available for appropriation. Once a basin has been closed, the only way to obtain water rights is by acquiring them from an existing water rights holder. The water rights must then be transferred to the new owner for their place and purpose of use, in transfer procedures administered by the OSE. The Gila-San Francisco Basin was closed to additional groundwater appropriations during the mid-1960s.

Water rights may not be transferred out of the Gila-San Francisco Basin and are not transferable between the Gila and the San Francisco sub-basins. Water rights must always remain within their sub-basin of origin, but the consumptive use portion of that water right may be transferred out of the sub-basin. Silver City is located just outside of the Gila-San Francisco Basin but has purchased water rights that originate in the Gila-San Francisco Basin. Because Silver City had been purchasing water rights from the Gila-San Francisco Basin prior to adjudication in 1968, the OSE still allows the consumptive use portion of the water right to be transferred out of the basin. All other water right transactions involving the transfer of water between basins are decided on a case-by-case basis by the OSE (Jackson, 2005).

Water market activity began in the Gila-San Francisco Basin when the Basin was closed to additional appropriation in the 1960s. Water rights were primarily held by ranchers and farmers, but in the 1960s, mining interests purchased large quantities of water rights from irrigators. Water rights are now held by a variety of interests: individual homeowners, irrigators, small water service organizations, Silver City, mining corporations, and others. Water transactions that occur now typically involve much smaller quantities of water rights than those purchased by mining interests from farmers decades ago.

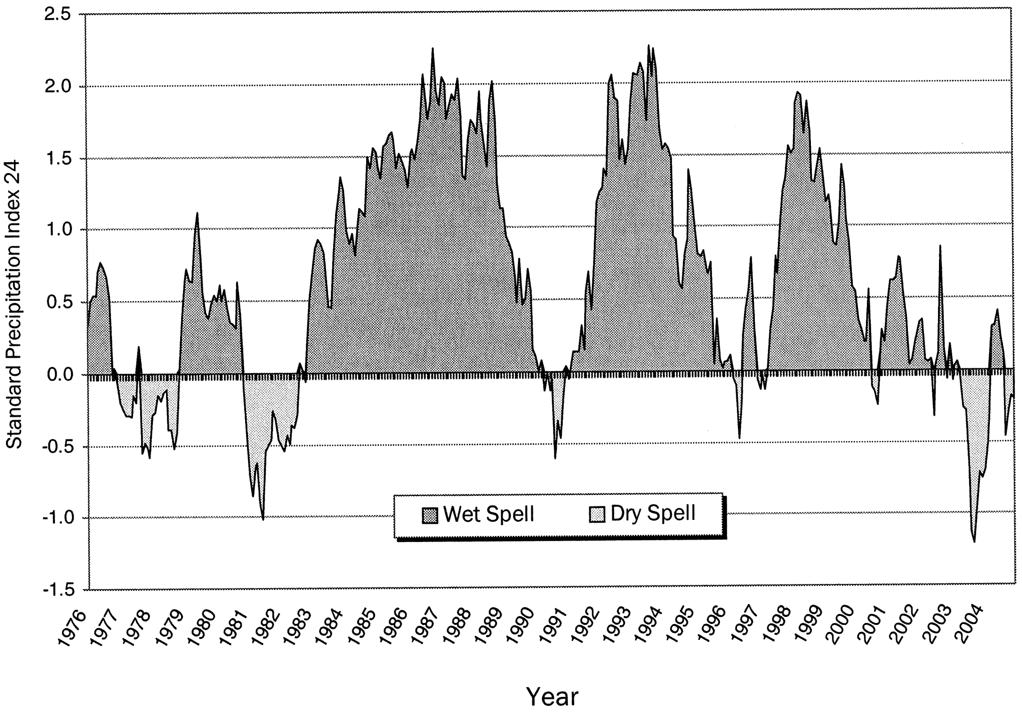

Figure 1. New Mexico Climate Division 4: 24-Month Standard Precipitation Index

Drought

Drought has been a persistent issue in New Mexico, causing the emergence of many problems with an already over-allocated water supply. During periods of drought, water resources are often depleted by water users, resulting in dry stream beds and falling reservoir levels. The current drought has affected water levels throughout the western United States. Southwestern New Mexico has been experiencing mild drought conditions since 1996, with the 1998–1999 winter being the driest of the century (New Mexico OSE). Several other periods of dry conditions occurred during the study period. Figure 1 illustrates the 24-month Standard Precipitation Index (SPI) for New Mexico's Climate Division 4 (National Climatic Data Center), which highlights several dry periods during the study period. The Gila-San Francisco Basin is located in Climate Division 4.

The major climate variable used in determining drought is precipitation (rain and snowfall). There are several drought indices that measure how precipitation over time has deviated from normal. In this study two different time scales of the SPI are compared to each other. These time scales reflect long-term drought conditions. The SPI calculation is based on the precipitation record for a specific location and time period (National Drought Mitigation Center). These time scales reflect the impact of drought on the availability of the different water resources. For example, soil moisture conditions respond to a relatively short-term scale, while groundwater, streamflow, and reservoir storage reflect longer-term precipitation patterns (Hayes, 2006). The SPI is fitted to a probability distribution, which is then transformed into a normal distribution whereby the mean SPI for the location and desired period is zero (Edwards and McKee, 1997). The SPI is measured from –4.0 to +4.0, with +4.0 indicating heavy precipitation. The 12-month and 24-month SPI time scales reflect long-term precipitation patterns tied to streamflows, reservoir levels, and even groundwater levels.

In analyzing water transaction data reported on a monthly or quarterly basis, it is important to consider that transactions are not typically reported during the month in which they occur. Negotiations of water transactions may start several months prior to the completion of the transaction. Ideally, one would include in a model the drought indicators that transactors were able to observe at the time they were negotiating a transaction. However, data identifying the time period of negotiations do not exist. Consequently, we compare the performance of longer-term drought indices to explore the role of drought information on negotiated prices.

Nearly all western states require a change-of-ownership application to be filed with a state agency for water right transfers. The application period can vary considerably by state. The time period from when the application is submitted to the time when the water right actually changes hands may vary from a few months to over a year (Colby, 1995). To account for the time delay involved in the water transfer application process in New Mexico, a six-month lag of the drought index is examined. The six-month lag is compared to the model with a non-lagged drought index and the results are reported for the Gila-San Francisco region.

Econometric Analysis

All econometric models were estimated using a derived demand price method as a two-stage least squares (2SLS) equation (Palmquist, 1989). The estimated model is a hedonic regression which takes the form:

$$p = f(q, \mathbf{s}), \tag{1}$$

where p is the price per acre-foot of water, q is the quantity of water transferred in the transaction, and $\mathbf{s}$ is a vector of other variables expected to affect the transaction price. The vector of variables includes the drought index, year the transaction occurred, the location of the transaction, the change in population during the study period, the price of copper, and the annual average sale price of calves during the study period. Each variable is discussed in detail in subsequent paragraphs.

Analysis is based on 65 water market transactions reported during the period 1977–1996 in the Gila-San Francisco Basin. The sources of data for water transactions used in this analysis are public agency publications, *The Water Strategist* and *Water Market Update*, and interviews with transactors and administrative officials. The water transaction data analyzed in this study area are the most comprehensive available for the region.

We test for endogeneity using the Hausman-Wu test. The Hausman-Wu test compares the ordinary least squares (OLS) estimates with the 2SLS estimates to determine whether the differences are statistically significant (Wooldridge, 2003). Price and quantity are found to be endogenous in all Gila-San Francisco models explored; this means the explanatory variable *quantity* is determined simultaneously with the dependent variable *price*, causing a correlation between the quantity and the error terms of the model. The instrumental variables included in the quantity equation attempt to explain as much variation as possible. One independent variable included in the price equation is also included in the instrumental variation equation, the drought index. The instrumental variable equation also examines supply-side variables, such as agricultural output prices, average per capita income, and the type of supplier, to explain variation in quantity. In addition to the supply-side variables that explain the instrumental variable equation, temperature is also included. It is thought that temperature may play an important role in the quantity of water available. Several of the instrumental variables are statistically significant at the 1% to 10% levels. The instrumental variable equations are reported in tables 1–4 after the regression results.

In the models developed here, the drought indices are hypothesized to be negatively related to the price of water. This implies that as drought intensifies, the price of water increases. The price of water is also expected to be negatively correlated with the size of the water transaction, indicating economies of scale. Water purchased in the Gila sub-basin is hypothesized to be higher priced relative to the adjacent San Francisco sub-basin, due to increased economic activity in the Silver City area adjacent to the Gila sub-basin. Population is expected to have a positive influence on price per acre-foot. Several demand variables are included, such as annual average calf prices and the average annual copper price—both of which are expected to be positively correlated to the price of water.

Each of the independent variables that represent the characteristics of water markets in the Gila-San Francisco area are identified and discussed below.

- *Size of the Transaction.* Water rights in the Gila-San Francisco Basin are defined in acre-feet per year. In the econometric analysis, the independent variable *qhat* (natural log of quantity per acre-feet) measures the predicted values for quantity from the instrumental variable equation of water transferred to the buyer on a logarithmic scale. This variable was included in the model to test the hypothesis that larger quantities of water rights sell for lower prices per acre-foot, reflecting economies of scale in water acquisitions.

- *Drought Indices.* Two drought indices were examined in separate models. All other independent variables were treated identically across these models, in order to focus on differences attributed to different drought indices. The different time scales of the *SPI* measure how drought has influenced the price of water transactions per acre-foot. The hypothesized value for the different time scales of the *SPI* is a negative impact on price; as drought intensifies, the price of water increases.

- *Trend.* This explanatory variable looks at the year the transaction occurred. It is a time trend that numbers each year 0 through 17. The price of each water right is adjusted to 2004 dollars using the Consumer Price Index. The time trend variable explains the price variation in water rights for each given year after accounting for inflation. This variable is hypothesized to be positively related to price. In other words, the price of water is expected to increase over time.

- *Location of the Transaction.* This independent variable looks at the sub-basin where the water rights transaction took place. The dummy variable *Gila* takes on a value of 1 if the transaction involves a water transaction occurring in the Gila sub-basin, and a value of 0 if the transaction occurred in the San Francisco sub-basin. *Gila* measures the price per acre-foot of a transaction taking place in the Gila sub-basin when compared to a transaction occurring in the San Francisco sub-basin.

- *Change in Population.* The Gila-San Francisco Basin has experienced both growth and decline in annual county population over the study period. The variable ln(*population*) examines how the change in population on a logarithmic scale has influenced the price of a water right per acre-foot over time. The change in population for Grant County, where the Gila-San Francisco Basin is located, is analyzed on a yearly basis.

- *Price of Copper.* Mining was once a prominent economic activity in the Gila-San Francisco Basin. The mining industry purchased several water rights during the 1977–1996 study period. The variable ln(*copper*) is examined to explore the impact of the natural log of average annual price of copper on a water right per acre-foot. The average annual price of copper is analyzed based on the New York Commodity Price Index. This price is measured as cents/pound and is converted to 2004 dollars using the Consumer Price Index (CPI).

- *Calf Prices.* Along with irrigated hay and pasture, ranching has been a widespread economic activity in our study area. The variable ln(*calf*) examines the average annual selling price of calves in the state of New Mexico on a logarithmic scale. Calf prices are measured in dollars/cwt and are converted to 2004 dollars using the CPI. Livestock production makes up a large portion of the agricultural sector in the Gila-San Francisco Basin.

Results

Results of the econometric analysis are reported in tables 1–4. Almost all the independent variables are statistically significant at the 5% level. All significant variables have the hypothesized sign for their coefficient value with the exception of *qhat*. The R^2 for all four models is reasonably high, with at least 72% of the variation in price being explained by the independent variables included in all models. All four models also have relatively high F-statistics, indicating a high level of significance.

All models were tested for heteroskedasticity using White's General Test and the Breusch-Pagan Lagrange Multiplier Test. Both tests indicate heteroskedasticity of an unknown nature. Heteroskedasticity was corrected for using the White estimator (corrected covariance-variance matrix) to estimate the asymptotic variance of the least squares estimator. The corrected variance follows a chi-squared distribution because it is asymptotic rather than exact. The functional form of the models examined was based on the results found by performing a Box-Cox transformation, which is a device used to generalize a linear model. The transformation

$$\mathbf{X}^{(\lambda)} = (\mathbf{X}^{(\lambda)} - 1) / \lambda \tag{2}$$

is defined for all values of λ, and $\mathbf{X}$ must be strictly positive (Box and Cox, 1964). Several functional forms were examined, including linear, log-linear, linear-log, and double-log

Table 1A. Results for Gila-San Francisco Model with SPI 12 (dependent variable = *Natural Log of Adjusted Price per Acre-Foot*)

Variable	Parameter Estimate	Elasticity Marginal Effect	Robust Standard Error	χ^2	Significance Level
Intercept	15.23443		2.12613	51.34	< 0.0001
qhat	0.30472	0.30472	0.08333	13.37	0.0003
SPI_12 [a]	−0.04063		0.06553	0.38	0.5352
Trend	0.05591	0.40513	0.02208	6.41	0.0114
Gila	0.83673	0.84936	0.11996	48.65	< 0.0001
ln(*population*)	0.22183	0.15766	0.03837	33.42	< 0.0001
ln(*copper*)	−3.63975	−3.63975	0.45583	63.76	< 0.0001
ln(*calf*)	1.64738	1.64738	0.34281	23.09	< 0.0001

No. of Observations = 65
$R^2 = 0.7366$

[a] Insignificant at the 10% level.

Table 1B. Instrumental Variable Results for Gila-San Francisco Model with SPI 12 (dependent variable = *Natural Log of Quantity Purchased*)

Variable	Parameter Estimate	Standard Error	*t*-Value	Pr > *t*-Statistic
Intercept	−82.66044	46.92047	−1.76	0.0833
ag_seller	0.84823	1.48447	0.57	0.5699
ln(*avg_per_cap*)	8.02451	4.69389	1.71	0.0926
ln(*alfalfa*)	1.23580	1.52422	0.81	0.4208
SPI_12	−0.11819	0.26119	−0.45	0.6526
Temp	−0.02794	0.01382	−2.02	0.0477

No. of Observations = 65
$R^2 = 0.1785$

specifications. The results of the Box-Cox transformation using Stata and SAS's TRANSREG procedure indicate a double-log model with a best lambda value of 0.25; this is consistent with the econometric results found when comparing functional forms and with the model specifications used in previous studies. A limitation of using the Box-Cox transformation to determine our functional form is that several independent variables were omitted in order to perform the transformation because they contained negative values or were dummy variables.

The double-log form was used to estimate all models. For the independent variables that were not transformed with the natural log operator, the regression coefficients have the same interpretation as they would in a semi-log specification. That is, the coefficients are partial or semi-elasticities, which is the natural form for models with dummy variables:

$$\beta_1 = \partial \ln(y)/\delta X_1. \tag{3}$$

For the independent variables that have been transformed with the natural log operator, the coefficients can be interpreted as elasticities. Elasticity measures the percentage

Table 2A. Results for Gila-San Francisco Model with SPI 12 Six-Month Lag (dependent variable = *Natural Log of Adjusted Price per Acre-Foot*)

Variable	Parameter Estimate	Elasticity Marginal Effect	Robust Standard Error	χ^2	Significance Level
Intercept	14.67826		1.79529	66.85	< 0.0001
qhat	0.17491	0.17491	0.06376	7.53	0.0061
SPI_12 Six-Month Lag	−0.25176	−0.18579	0.09552	6.95	0.0084
Trend	0.06797	0.49252	0.01772	14.72	0.0001
Gila	0.86275	0.87175	0.11438	56.89	< 0.0001
ln(*population*)	0.17919	0.12736	0.04025	19.82	< 0.0001
ln(*copper*)	−3.60490	−3.60490	0.43469	68.77	< 0.0001
ln(*calf*)	1.82561	1.82561	0.29740	37.68	< 0.0001

No. of Observations = 65
$R^2 = 0.7392$

Table 2B. Instrumental Variable Results for Gila-San Francisco Model with SPI 12 Six-Month Lag (dependent variable = *Natural Log of Quantity Purchased*)

Variable	Parameter Estimate	Standard Error	*t*-Value	Pr > *t*-Statistic
Intercept	−121.44749	45.91647	−2.64	0.0105
ag_seller	0.93963	1.43640	0.65	0.5156
ln(*avg_per_cap*)	11.21361	4.60111	2.44	0.0178
ln(*alfalfa*)	2.53557	1.50375	1.69	0.0970
SPI_12 Six-Month Lag	0.38377	0.25423	1.51	0.1365
Temp	−0.02177	0.01381	−1.58	0.1204

No. of Observations = 65
$R^2 = 0.2063$

change in the dependent variable for a 1% change in one of the "logged" variables (Greene, 2003), i.e.:

$$(\partial Y/\partial X_k)(X_k/Y) = \partial \ln(Y)/\partial \ln(X_k) = \beta_k. \tag{4}$$

The independent variables that were not transformed by the natural log operator are the dummy variables and the variables that are not strictly positive. The marginal effect calculation for the non-dummy variables is written as:

$$E_k = \beta_k X_k \tag{5}$$

(Franklin and Waddell, 2003), where X_k = the average value of the independent variable. The elasticity calculation for the dummy variable is denoted by (Kennedy, 1998):

$$E = (100 * (\text{EXP(parameter estimate)} - 1)) / 100. \tag{6}$$

Tables 1–4 include the marginal effect and elasticity for the appropriate variables. The results for each independent variable are discussed below.

Table 3A. Results for Gila-San Francisco Model with SPI 24 (dependent variable = *Natural Log of Adjusted Price per Acre-Foot*)

Variable	Parameter Estimate	Elasticity Marginal Effect	Robust Standard Error	χ^2	Significance Level
Intercept	15.29982		1.85438	68.07	< 0.0001
qhat	0.23196	0.23196	0.06033	14.78	0.0001
SPI_24 [a]	–0.18970		0.12377	2.35	0.1254
Trend	0.06879	0.49846	0.02308	8.89	0.0029
Gila	0.88750	0.89360	0.12338	51.75	< 0.0001
ln(*population*)	0.21365	0.15186	0.04995	18.29	< 0.0001
ln(*copper*)	–3.68474	–3.68474	0.45989	64.19	< 0.0001
ln(*calf*)	1.71503	1.71503	0.30700	31.21	< 0.0001

No. of Observations = 65
$R^2 = 0.7274$

[a] Insignificant at the 10% level.

Table 3B. Instrumental Variable Results for Gila-San Francisco Model with SPI 24 (dependent variable = *Natural Log of Quantity Purchased*)

Variable	Parameter Estimate	Standard Error	*t*-Value	Pr > *t*-Statistic
Intercept	–117.70472	42.08347	–2.80	0.0070
ag_seller	1.16137	1.40501	0.83	0.4118
ln(*avg_per_cap*)	10.24301	4.25628	2.41	0.0193
ln(*alfalfa*)	3.51937	1.57606	2.23	0.0294
SPI_24	0.55797	0.24301	2.30	0.0252
Temp	–0.01394	0.01424	–0.98	0.3318

No. of Observations = 65
$R^2 = 0.2433$

- *Size of the Transaction.* An unexpected result is that the variable *qhat* has a positive parameter estimate. This finding shows that larger quantities of water rights do not sell for a significantly lower price per acre-foot than smaller quantities of water rights, suggesting economies of scale are not evident in the Gila-San Francisco Basin's water market.

- *Drought Indices.* The longer-term 12- and 24-month *SPI*s with a six-month lag were found to be statistically significant at the 1% and 10% level, respectively. The 12- and 24-month *SPI* without a lag are both statistically insignificant. The marginal effects of the 12-month *SPI* and 24-month *SPI* with a six-month lag are –0.18 and –0.14, respectively. The significance of these two values may indicate that the six-month lag on the *SPI*s, which illustrates the time associated with the change of ownership of water rights in the Gila-San Francisco Basin, better reflects changes in water prices than the 12- and 24-month *SPI*s without a lag. The marginal effects for the longer-term drought models with a six-month lag are consistent with the hypothesis that as drought intensifies, the price for water increases. The

Table 4A. Results for Gila-San Francisco Model with SPI 24 Six-Month Lag (dependent variable = *Natural Log of Adjusted Price per Acre-Foot*)

Variable	Parameter Estimate	Elasticity Marginal Effect	Robust Standard Error	χ^2	Significance Level
Intercept	14.68243		1.86514	61.97	< 0.0001
qhat	0.26777	0.26777	0.06435	17.32	< 0.0001
SPI_24 Six-Month Lag	−0.19409	−0.14362	0.11365	2.92	0.0877
Trend	0.06949	0.50354	0.02315	9.01	0.0027
Gila	0.86020	0.86953	0.11461	56.33	< 0.0001
ln(*population*)	0.20364	0.14474	0.04671	19.01	< 0.0001
ln(*copper*)	−3.58444	−3.58444	0.42119	72.42	< 0.0001
ln(*calf*)	1.74424	1.74424	0.33006	27.93	< 0.0001

No. of Observations = 65
$R^2 = 0.7359$

Table 4B. Instrumental Variable Results for Gila-San Francisco Model with SPI 24 Six-Month Lag (dependent variable = *Natural Log of Quantity Purchased*)

Variable	Parameter Estimate	Standard Error	*t*-Value	Pr > *t*-Statistic
Intercept	−102.62027	41.97871	−2.44	0.0175
ag_seller	1.05569	1.43413	0.74	0.4646
ln(*avg_per_cap*)	9.14341	4.30623	2.12	0.0379
ln(*alfalfa*)	2.79560	1.56054	1.79	0.0784
SPI_24 Six-Month Lag	0.37587	0.23508	1.60	0.1152
Temp	−0.01976	0.01408	−1.40	0.1659

No. of Observations = 65
$R^2 = 0.2099$

marginal effect of the 12-month and 24-month *SPI* with a lag indicates that for a one-unit increase in the SPI, the price of water decreases by 18% and 14%, respectively. Thus, our results reveal that buyers and sellers of water rights react to long-term hydrological conditions.

- *Trend.* The year the transaction occurred is statistically significant at the 1% level in all models. This confirms that over time, the price of water increases—as one would expect.

- *Location of the Transaction.* The binary variable *Gila* is statistically significant at the 1% level in all four models. This variable measures the difference between water purchased in the Gila sub-basin and water transactions that occurred in the San Francisco sub-basin. The significant coefficient of the *Gila* variable is approximately 0.85 for all models, and the marginal effect is roughly 0.86 for all four models. This result can be interpreted to mean that if the water rights transaction occurred in the Gila sub-basin when compared to the San Francisco sub-basin, the price is approximately 86% higher. This finding is consistent with the more rapid and extensive development in the Gila sub-basin compared to the San Francisco sub-basin.

- *Change in Population.* The change in population over the years is a statistically significant variable in determining the price of a water right. The variable ln(*population*) was found to be statistically significant at the 1% level in all four models. The positive parameter estimate on the ln(*population*) explanatory variable indicates that as the percentage change in population of an area increases, the price of water rights increases.

- *Price of Copper.* The natural log of the annual average price of copper is a significant variable in determining the selling price of a water right. The variable ln(*copper*) has a large test statistic and is statistically significant at the 1% level in all four models. The elasticity of the ln(*copper*) variable ranges from –3.5 to –3.6 in the models analyzed. As illustrated by this result, for a 1% increase in the average annual price of copper, the price of a water right decreases by approximately 3.5%. As the price of copper becomes more expensive, the price of water rights declines. This finding is counterintuitive given the prominence of copper mining as a water use in this region. However, we note that the mining industry in Grant County, New Mexico (Sonoran Institute, 2007), has declined significantly over the study period, and this decline appears unrelated to copper prices.

- *Calf Prices.* The natural log of the annual average calf pricing variable, ln(*calf*), was found to be statistically significant at the 1% level in all four models. An elasticity measure, the ln(*calf*) values range from 1.64 to 1.82, indicating that for a 1% increase in the annual average calf price, the price of a water right will sell for nearly 2% more.

Conclusion

The results of this study reveal that regional water markets are strongly influenced by characteristics of water rights, by regional demand factors, and by drought. The Gila-San Francisco Basin models are not without their limitations. While we know endogeneity exists, we were unable to find a strong predictor for *qhat*. An additional limitation of our research is the inability to clearly identify the time delay associated with the change in ownerships of water rights. We address other potential limitations of our explanatory variables in their respective narrative discussions. However, given the limitations of the model, econometric analysis has shown a statistically significant relationship between the price of a water right and the location where the transaction occurred, the change in population, and whether the transaction occurred during a drought year.

Both long-term SPIs with a six-month lag yielded similar results. The 12-month and 24-month SPIs with a six-month lag results have a high test statistic, which suggests they better represent the influence of drought on water prices in the Gila-San Francisco region than do the 12- and 24-month SPIs without a lag. The significance of the drought indices emphasizes the importance of climate variability on the market price of water. The results indicate that the longer-term drought indices without a lag have little influence on the market price of water. This illustrates the time delay associated with the change of ownership in water rights in New Mexico's Gila-San Francisco Basin.

Drought has been a persistent issue in this region during many different time periods. As long-term drought conditions occur or intensify in this region, one can expect the price of water to increase. From the results reported, we can anticipate increased water market prices with prolonged drought conditions.

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