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The Development of Water Rights in Colorado

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Abstract

Property rights will be more carefully defined and enforced when the value of a resource rises or the probability of losing the resource increases. A simple model is estimated on litigation data for Colorado to test this hypothesis. According to the model, the number of water rights cases will rise when the demand for water increases or the supply of water decreases. Several versions of such a model with a deterministic and, alternatively, a stochastic trend component are estimated. The estimates are robust across model type and confirm the theoretical conclusions on the determinants of water rights cases.easy.

Key words: Water Rights, Property Rights, Western U.S. History, Structural Time Series.

JEL category: Q25, N41, N51

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1 Introduction

An important insight offered by the property rights economics literature is that institutions, or the rules of the game, affect how well markets function (Pejovich 1990). Properly functioning markets require well-defined and enforceable property rights. When property rights are poorly defined or weakly enforced, market incentives that encourage entrepreneurial activity, innovation and invention, creative activity, and hard work will diminish in effectiveness (Demsetz 1967).

Property rights do not spring up from the ground well defined and enforceable. Rather, they change over time due, in part, to changing economic circumstances (Demsetz 1967; Anderson 1982; Pejovich 1990). People not only pursue their self-interest within the rules, they also allocate resources to changing the rules of the game to their own benefit (Anderson 1982, p. 761). In fact, establishing and protecting property rights can be considered a productive activity toward which resources will be devoted.

The manner in which certain property rights emerge and change over time is the focus of this study. The origins and evolution of Western water law offer an important example of how property rights change in response to changing economic incentives. The paper focuses on the Colorado experience largely due to the fact that Colorado was one of the first states to establish a system of water rights based exclusively on the system of prior appropriation. Many of the developments in water rights in the rest of the Western United States derive in one way or another from the Colorado system.

Our study offers the first quantitative evidence that links economic incentives with water rights defining and enforcing activity. Our model suggests that water claimants will more carefully define their rights to water when either the demand for water increases or the supply of water decreases. The approach is strictly positive; it is demonstrated how water rights evolve as incentives change over time. No judgment is offered on the economic efficiency of these changes.

The manner in which water rights evolve and adapt to increasing demand for water and frequent periods of scarcity is at least as relevant today as it was in the late 19th century. Rapidly rising demand coupled with periodic severe droughts exert great pressure on today's water allocation institutions, in the U.S. as in other countries. Competition for water has multiplied for a number of reasons including rapid urban population growth, protection of instream water rights, competition for water between states, and the recognition of Native American water rights.

The remainder of the paper is organized as follows. The next section provides a brief account of water rights development in Colorado, offering qualitative evidence of how the rules of the game evolve with changing economic circumstances. This is followed by an outline of a simple model for water rights development. The data are presented next, followed with a presentation of empirical model estimates. The paper ends with a brief summary and some conclusions.

2 Historical and Legal Background

Western water law evolved in no small part due to changing economic circumstances. During the California gold rush current mining technology required the diversion of water for use on lands not adjacent to the stream, a practice in direct conflict with the riparian doctrine of water rights prevalent in the Eastern United States. The California miners set down their own rules and regulations governing the use of water, rules that recognized the priority of first arrival and the right to divert water for beneficial use. Priority of right and the diversion of water for beneficial use were to become cornerstones of the Western doctrine of prior appropriation.

Dunbar (1983) offers a readable account of early history of Colorado water rights. When gold and silver were discovered in Colorado in the 1850s, miners organized districts and adopted rules that outlined rights to water and minerals in the ground. The right of diversion and priority of water rights were established in the rules set down by the miners as early as 1859.

The fast-growing mining camps created demand for locally-produced food. Early irrigation diversion works in central Colorado produced vegetables for the miners; these ditches were small, narrow structures that irrigated just a few acres. Lands nearest the streams were cultivated first; as these lands became fully claimed, additional irrigation development required larger and more elaborate irrigation works that could carry water to lands farther from the streambed. The diversion of water for use on lands not adjacent to the watercourse arose from the necessities presented by the dry and arid environment.

Recognizing the need to protect capital investments by miners and early irrigators, the new Colorado territorial legislature permitted diversion of water to non-riparian lands and allowed irrigators the right to build ditch works on the land of others. The territorial legislature also provided a method for distributing water during periods of scarcity. Later legislation in 1864 and 1868 explicitly provided for priority of water rights.

Early laws, customs adopted by the miners, and irrigation practice provided a framework for the system of prior appropriation in Colorado. However, old habits die hard and, hence, the new system received repeated court challenges from riparian water users. The courts eventually succeeded in fending off challenges to prior appropriation but other issues arose as increasing demand for water created new challenges for the system of prior appropriation.

Three overlapping but distinct periods of water rights litigation can be identified for Colorado. In the earliest period, from about 1872 to the early 1890s, the majority of court cases had to do with upholding and refining the doctrine of prior appropriation. Early irrigators defended the rule of diversion and priority of right in order to protect their investments in the farm enterprise. Increased demand for food fostered private investments in ditches and canals, resulting in the emergence of canal corporations and creating more property rights defining and enforcing activity. Cases involving canal corporations were prominent in the second period. Litigation of this type first appeared in 1892 and continued through the early 1900s. Increases in water storage, dryland farming, and changes in the point of diversion characterize the third and final period of water rights litigation. The storage of water in reservoirs, water rights transfers, and changes in the point of diversion were important issues litigated in this third period.

3 Theoretical Background

Anderson (1982) offers testable propositions regarding property rights defining and enforcing activity. First, higher market values or greater scarcity will cause individuals to strengthen their claims to resources. Second, an increase in the probability of losing an asset will increase property rights enforcing activity. In this section we outline a simple model that examines these propositions in the context of Colorado water rights litigation.

In the present model, water rights defining and enforcing activity depends on the value of water and the scarcity of water: the higher the value, the greater the benefits from additional defining and enforcing activity. The value of water depends on four factors, (a) prices of farm crops, (b) farm production per acre, (c) the number of acres per farm, and (d) the quantity of water available in the stream. The demand for water will increase due to an increase in farm productivity, measured by higher output per acre. The demand for water will also increase if the price of crops increases. The demand for water will rise if the size of the farm increases, as measured by the average number of acres per farm, since more acres under irrigation require more water.

As for water supply, the flow of water in rivers and streams in Colorado varies considerably from season to season and year to year. In periods of low flow, the value of water increases.

We assume nondecreasing costs of water rights defining and enforcing activity over the time horizon. The costs of litigation increased greatly during the early years of the twentieth century. Mead (1902) notes that costs incurred over water rights litigation had accumulated to more than $2 million in Colorado by 1902.

An important implication of this model is that irrigators will increase their efforts to protect and define their rights to water when their demand for water increases or when the supply of water decreases.

4 Data

The paper's model suggests that water rights enforcing activity depends on the value of crops, average farm size, and the level of streamflow. Table 1 presents a summary of crop values per acre in the early history of Colorado. Values declined from the 1880s to the 1890s, probably due to the depression and deflationary pressures during the mid 1890s. During the period 1900-09, however, crop values soared, probably reflecting the impact of the Reclamation Act. Crop values in Colorado jumped 27 percent from their level of 1882-89. The general trend of increasing crop values per acre from 1882 to 1919 implies an increasing value of water.

By far, the largest proportion of these crops was grown on irrigated farms. Table 2 shows that 95 percent of Colorado's wheat output in 1899 was irrigated, as was 99.4 percent of the alfalfa hay crop. In value terms, according to the 1890 census, irrigated crops accounted for 89 percent of all crops grown in Colorado.[1]

The number of court cases dealing with water rights is chosen as a measure of water rights defining and enforcing activity. Specifically, court cases dealing with water rights at the Supreme Court and appellate levels are collected from several editions of the *American Digest*, a publication that lists headnotes of court cases by legal category. Cases are selected from the category "Water and Water Courses" from four editions of the *Digest*. Case headnotes are scanned to ensure that the case is related, in general, to the protection or definition of the right to water. Some cases and categories of cases are excluded. Cases involving damages to land due to water seepage from canals, for example, do not involve the value of water and so are excluded. Subcategories such as "Bed and Banks" are also excluded. The types of cases included range from issues such as rights of way to damages due to loss of flow, and from appurtenance to the validity of the system of prior rights.[2]

Data are also collected for streamflow and crop value. Streamflow data are taken from U.S. Geological Survey (1954, 1958) publications. Criteria for selection of rivers and recording stations include the completeness of early records and the location of the river. Based on these criteria, two rivers are selected: the Cache la Poudre, recorded at Ft. Collins, and the Arkansas River, recorded at Canyon City. Much of the farmland irrigated in Colorado depends on the flow of these two rivers.

An index of streamflow is used since it reflects variations of flow around a base level without regard to the nominal quantities. The flow index is constructed from the mean of the nominal flows of the Cache la Poudre and Arkansas Rivers, with the base set at the mean level of the combined flows.

Crop value and crop value per acre data are collected for six crops.[3] As discussed above, most of the crops grown during this period were irrigated. Of course, the typical farmer must be concerned not only with the value of crops or revenue but also with the cost of production. Unfortunately, cost data do not exist. Instead, we assume that costs for the average farmer follow the same time path as the general level of prices. An estimated consumer price index from the *Historical Statistics of the United States* is used to deflate crop values per acre as a means of getting at the value of crops to the farmer net of production costs.

The number of farms per year in Colorado is estimated using decennial census figures.[4] Annual data are interpolated from the decennial figures.

The number of water rights cases may increase over time simply due to an increase in the population of farmers. To eliminate this possibility we use the number of cases per farm as the dependent variable. For explanatory variables, we use the index of streamflow (*FLOW*), inflation-adjusted value of crops per acre (*RVAL*), and the number of acres per farm (*ACRE*). Acres per farm is important as a means of capturing the effect of increasing farm size on litigation. The final variable definitions used in the empirical model along with some basic statistics are provided in Table 3.

5 Estimation Method and Results

The time series properties of the data are checked with standard tests for stationarity and unit root (Table 4). The evidence suggests that the variable *FLOW* is stationary. The variable

ACRE, by contrast, appears to follow a unit root. The variable *RVAL* and the dependent variable *CASE* are unlikely to be unit root processes.

The time series properties of the variables, including that of the dependent variable *CASE,* exclude the application of cointegration methods for estimating how *CASE* depends on the variables *FLOW*, *ACRE*, and *RVAL*. As discussed by Harvey (1989) and Koopman et al. (1995), if one wants to allow for the possibility of a trend in the data series, two methods are available: (a) least squares with a deterministic trend, or (b) structural time series with a stochastic trend component. Both options will be examined. Since the variable *ACRE* appears to follow a unit root, it enters the model in first difference form.

Estimating a least squares model subject to a deterministic trend component generates an equation of the form

$$y_t = \mu + \sum_i \delta_i t^i + \sum_i \sum_j \alpha_{ij} x_{i,t-j} + \varepsilon_t \qquad \text{for } t = 1,\ldots,T \tag{1}$$

where y_t is the dependent variable, μ a constant term, t^i a deterministic time trend of order i and δ_i the coefficient associated with the trend term t^i. Furthermore, $x_{i,t-j}$ is regressor variable i subject to time lag j, α_{ij} a coefficient associated with variable $x_{i,t-j}$, and ε_t a zero mean constant variance error term.

By contrast, the structural time series model can be expressed in its most general form as

$$y_t = \mu_t + \sum_i \sum_j \alpha_{ij} x_{i,t-j} + \varepsilon_t \qquad \text{for } t = 1,\ldots,T \tag{2}$$

where μ_t a time-dependent intercept term, which is specified to follow the process

$$\mu_t = \mu_{t-1} + \beta_{t-1} + \eta_t \qquad \eta \sim \text{NID}(0,\sigma_\eta^2) \tag{3}$$

$$\beta_t = \beta_{t-1} + \xi_t \qquad \xi \sim \text{NID}(0,\sigma_\xi^2) \tag{4}$$

In the context of equations (3) and (4), μ_t can be interpreted as the "level" of a stochastic trend and the drift parameter β_t as its "slope." Both "level" and "slope" are assumed to be following random walks, with their respective white-noise disturbances η_t and ζ_t independent of each other and of ε_t. This general trend model can be tested down to simpler form, such as a "level" only model, which would be written as

$$\mu_t = \mu_{t-1} + \eta_t \qquad \eta \sim \text{NID}(0, \sigma_\eta^2) \tag{5}$$

After estimation of the model parameters, a Kalman filter is applied to determine the state vectors μ_t and β_t.[5]

The estimation results for equation (1) are summarized in Table 5. Since theory suggests a long response lag, the lag polynomials are assumed to be of order four initially. Similarly, a polynomial of order four is initially assumed for the time trend. From left to right, the models are simplified through exclusion restrictions relative to the initial fourth-order model. As is evident from the probability values in the line "Restrictions" in Table 5, the data do not support a model with less than a third-order time trend at the 5 percent level. To document model fit, probability values for a number of statistical specification tests are provided. Some statistical problems are evident for each one of the models at the 5 percent level. Model 2 is the one with the fewest statistical problems. This model also has the lowest value for the Schwarz information criterion. As a consequence, it will be selected as the base model with which the stochastic trend models are compared in Table 6.

Table 6 presents three stochastic trend models along with deterministic trend model 2 of Table 5. Stochastic trend model 1 contains both a stochastic "level" and a stochastic "slope," while models 2 and 3 do not have a stochastic "slope." A likelihood ratio test of the restrictions implied by model 2 relative to model 1 suggests that no "slope" is needed. The same message is obtained from the Akaike information criterion. One can also observe that the estimated parameters are hardly affected by the exclusion of the "slope" component. Hence, the evidence is in favor of the simple stochastic trend model incorporated in model 2. However, the result of dropping the "slope" component suggests a problem with the normality of the model residuals. An inspection of the residuals indicates that this is caused by one observation, the year 1895. The addition of an observation-specific dummy variable for this year removes the normality problem. As a consequence, the estimated parameter of *RVAL* drops slightly.

The deterministic trend model 1 in Table 6 replicates model 2 of Table 5. The second deterministic model in Table 6 includes the same observation-specific dummy variable that is present in the third stochastic trend model. Similar to the stochastic trend model, adding the dummy variable improves the statistical fit and lowers the estimated parameter of *RVAL*. Compared to the stochastic trend models, the two deterministic models have a better in-sample fit by most of the reported statistical criteria. However, as is rather typical for higher-order deterministic trend models, they perform rather poorly out of sample. This is evident from the out-of-sample forecasting tests in Table 6. The problems get worse the longer the time horizon of the out-of-sample forecast. This is very evident from Figures 1 and 2, which compare the forecasting performance of deterministic trend model 2 of Table 6 with stochastic trend model 3, respectively. The poor out-of-sample performance of the deterministic trend models suggests that it is safer to use the stochastic trend model for economic analysis. Fortunately, this choice has no significant impact on the economic conclusions that can be drawn. This is because not only are there no differences in the signs of the three variables *RVAL*, *ACRE*, and *FLOW* across the different models and model classes, but there is also very little variation in the estimated coefficients of these variables.

If the rudimentary theory of this paper is correct, then streamflow as measured by variable *FLOW* should have a negative coefficient while real crop value per acre (*RVAL*) and the number of acres per farm (*ACRE*) should both have positive coefficients. The estimation results largely confirm the theory. An increase in the size of the average farm, or more specifically, an increase in its rate of change, causes a rise in litigation. This effect is highly significant statistically. Streamflow also has the expected sign and is similarly significant. The real value of crops per acre, by contrast, has the expected sign, but the level of statistical significance is less convincing than that for the other two variables.

If one picks stochastic trend model 3 of Table 6 as the preferred model, it is illuminating to look at a decomposition of the model as presented in Figure 3. The upper-left diagram confirms the relatively good fit of the model with three explanatory variables and a stochastic trend in level form. This impression is confirmed by the fact that the behavior of ε_t, the irregular component of the model, does not suggest a particular pattern. The graph in the lower-left corner, however, provides the most interesting piece of information, the behavior over time of the stochastic trend component (μ_t). This trend suggests some underlying force, apart from the included variables, that has a significant impact on the long-run behavior of water rights litigation.

Conflicting demands for water amplified by population growth generated the rapid rise of litigation in the 1880s and 1890s. During this period, many of the lingering issues regarding riparian rights versus rights by prior appropriation were largely resolved by the courts. Then, at about the turn of the century, the trend turned down due to two factors: (1) fewer and fewer unresolved water rights issues emerged as the number of settled property right issues increased, and (2) the construction of reservoirs prompted by the Reclamation Act helped to smooth out highly variable periods of rainfall, and (3) an increase in dryland farming. As noted by Tarlock

(2001), dams reduced the need to enforce water rights in the courts, thus lowering the number of lawsuits undertaken.

6 Summary and Conclusions

A model of the development of water rights in Colorado is developed using annual data for crop value, streamflow, farm size, and the number of court cases covering the years 1884 to 1920. Two alternative empirical models are estimated, one that relies on a deterministic trend, and one that incorporates a stochastic trend. The stochastic trend model is preferred due to significantly better out-of-sample performance.

According to the theoretical model, greater water rights defining and enforcing activity is expected when (a) the demand for water increases, or (b) the supply of water decreases. The empirical model confirms that proxies for the demand and supply of water can explain a good part of the level of water rights litigation over time: litigation increases when the potential benefits of additional property rights defining and enforcing activity rise. This result confirms a basic hypothesis in the economics literature on property rights. Future work could examine the costs of defining and enforcing activity as well as the benefits.

Enforcing and protecting property rights to water is clearly no less of an issue today than it was in 19th century Colorado. In fact, there is significant potential for serious future conflict not only in the arid parts of the Western U.S. but also in many parts of the world outside the U.S., including the Middle East. Many of the property rights issues for water outside the U.S. are likely to require international litigation and the development of a set of new international rules and regulations.

Notes

[1] U.S. Department of the Interior, Census Office (1894), p. 90. Wheat cultivation dominated early irrigation in Colorado until the early 1880s. Falling relative wheat prices encouraged diversification into corn, oats, and alfalfa. But alfalfa required three to four times more water per acre than did wheat, thereby exacerbating water shortages in the late 1880s (Fox 1916, pp. 133-34).

[2] See American Digest 1658 to 1896 (1904), American Digest 1897 to 1906 (1910), American Digest 1907 to 1916 (1922), American Digest 1916 to 1926 (1929).

[3] The data are collected from U.S. Department of Agriculture, Bureau of Statistics (1907a, 1907b, 1908a, 1908b) and the Yearbook of Agriculture, volumes 1907 to 1920.

[4] Census figures on the number of farms are obtained from the "Historical Statistics of the United States," Colonial Times to 1970, Part 1, 1976.

[5] The filter places more weight on the most recent observations and discounts past observations accordingly the faster the "level" and "slope" change.

References

American Digest 1658 to 1896, 1904. Vendor and Purchaser to Willful Injuries. West Publishing Co.: St. Paul.

American Digest 1897 to 1906, 1910. Vendor and Purchaser to Zinc. West Publishing Co.: St. Paul.

American Digest 1907 to 1916, 1922. War to Zoological Societies. West Publishing Co.: St. Paul.

American Digest 1916 to 1926, 1929. Trover and Conversion to Wharves. West Publishing Co.: St. Paul.

Anderson, T.L., 1982. Institutional Underpinnings of the Water Crisis. Cato Journal 2(3), 759-792.

Anderson, T.L., 1983. Water Crisis: Ending the Policy Drought. Johns Hopkins University Press: Baltimore.

Bowman, K.O., Shenton, L.R., 1975. Omnibus Test Contours for Departures from Normality Based on $\sqrt{b_1}$ and b_2. Biometrika 62, 243–250.

Brown, R.L., Durbin, J., Evans, J.M., 1975. Techniques for Testing the Constancy of Regression Relationships over Time. Journal of the Royal Statistical Society, Series B 37, 149–192.

Demsetz, H. 1967. Toward a Theory of Property Rights, American Economic Review, Papers and Proceedings 57(2), 347-359.

Dunbar, R. 1983. Forging New Rights in Western Waters. University of Nebraska Press: Lincoln and London.

Engle, R.F., 1982. Autoregressive Conditional Heteroscedasticity with Estimates of the Variance of United Kingdom Inflation. Econometrica 50, 987–1007.

Fox, L.P. 1918. State Regulation of the Canal Corporation in Colorado. Michigan Law Review 16(3).

Fox, L.P., 1916. Origins and Early Development of Populism in Colorado. Ph.D. dissertation, University of Pennsylvania.

Harvey, A.C., 1989. Forecasting, Structural Time Series Models and the Kalman Filter. Cambridge University Press: Cambridge and New York.

Jarque, C.M., Bera, A.K., 1987. A Test for Normality of Observations and Regression Residuals. International Statistical Review 55, 163–172.

Koopman, S.J., Harvey, A.C., Doornik, J.A., Shephard, N., 1995. Stamp 5.0: Structural Time Series Analyzer, Modeller and Predictor. Chapman and Hall:London.

Kwiatkowski, D., Phillips, P.C.B., Schmidt, P., Shin, Y., 1992. Testing the Null Hypothesis of Stationarity Against the Alternative of a Unit Root: How Sure Are We That Economic Time Series Have a Unit Root? Journal of Econometrics 54, 159–178.

Ljung, G.M., G.E.P. Box, 1978. On a Measure of Lack of Fit in Time Series Models. Biometrika 65, 297–303.

Mead, E. 1902. The Growth of Property Rights in Water. The International Quarterly. Sept.-Dec., pp. 1-12.

Pejovich, S., 1990. The Economics of Property Rights: Toward a Theory of Comparative Systems. Online version. Kluwer Academic Publishers: Boston.

Phillips, P.C.B., Perron, P., 1988. Testing for a Unit Root in Time Series Regression. Biometrika 75, 335–346.

Ramsey, J.B., 1969. Tests for Specification Errors in Classical Linear Least-Squares Regression Analysis. Journal of the Royal Statistical Society, Series B 31, 350–371.

Tarlock, A.D., 2001. The Future of Prior Appropriation in the New West, Natural Resources Journal 41, 769–793.

White, H., 1980. A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity. Econometrica 48, 817–838.

Williams, W.D., 1938. Irrigation Law in Colorado: Part II. Rocky Mountain Law Review, 10(2), pp. 87-104.

U.S. Department of Agriculture, Bureau of Statistics, 1907a. Corn Crops of the United States, 1866-1906. Bulletin No. 56. General Printing Office: Washington, D.C.

U.S. Department of Agriculture, Bureau of Statistics, 1907b. Wheat Crops of the United States, 1866-1906. Bulletin No. 57. Government Printing Office: Washington, D.C.

U.S. Department of Agriculture, Bureau of Statistics, 1908a. Hay Crops of the United States, 1866-1906. Bulletin No. 63. Government Printing Office: Washington, D.C.

U.S. Department of Agriculture, Bureau of Statistics, 1908b. Potato Crops of the United States, 1866-1906. Bulletin No. 58. Government Printing Office: Washington, D.C.

U.S. Department of Agriculture, Division of Publications, 1907-1920. Yearbook of the United States Department of Agriculture. Government Printing Office: Washington, D.C.

U.S. Department of Commerce, Bureau of the Census, 1913. Thirteenth Census of the United States, Volume V, Agriculture, 1909 and 1910. Government Printing Office: Washington, D.C.

U.S. Department of Commerce, Bureau of the Census, 1976. Historical Statistics of the United States, Colonial Times to 1970, Part 1. Government Printing Office: Washington, D.C.

U.S. Department of the Interior, Census Office, 1894. Eleventh Census of the United States, 1890: Report on Agriculture by Irrigation in the Western United States, by F.H. Newell.

U.S. Geological Survey, 1954. Compilation of Records of Surface Waters of the United States through September 1950, Part 9: Colorado River Basin, Water Supply Paper No. 1313. Government Printing Office: Washington, D.C.

U.S. Geological Survey, 1958. Compilation of Records of Surface Waters of the United States through September 1950, Parts 6-8: Missouri River Basin below Sioux City, Iowa, Water Supply Paper No. 1310. Government Printing Office: Washington, D.C.

TABLE 1
Value of Crops per Acre

Period	Dollar Value per Acre
1882-1889	16.20
1890-1899	13.51
1900-1909	20.52
1910-1919	25.42

TABLE 2
Acreage and Production of Irrigated Crops, 1889

Crop	Acreage		Production	
	Total ('000s)	% Irrigated	Total ('000s)	% Irrigated
Corn	85	48	1276	68
Wheat	295	84	5588	95
Oats	121	83	3080	96
Barley	22	92	531	96
Hay	455	99	1107	99
Potatoes	44	82	4466	92

Note: Production is in bushels, except for hay, which is in tons.

TABLE 3
Definition of Variables and Basic Statistics, 1884-1920

Variable	Definition	Mean	Minimum	Maximum
CASE	annual water rights cases heard by the supreme and appellate courts per hundred thousand farms	28.570	8.621	64.171
RVAL	inflation-adjusted value of irrigated crops per acre, annual data for Colorado	64.024	35.333	92.536
FLOW	an annual combined index of streamflow for two rivers in Colorado	104.405	49.000	218.000
ACRE	annual acres of farms divided by the number of farms for Colorado	46.504	28.383	69.130

TABLE 4
Tests for Stationarity and Unit Roots in the Data Series

Variable	KPSS [H0 = I(0)]		Phillips-Perron [H0 = I(1)]	
	Trend	No-Trend	Trend	No-Trend
CASE	0.176	0.223	-3.607**	-3.518**
ACRE	0.118	0.111	-2.161	-2.242
RVAL	0.108	0.522**	-3.465*	-2.704*
FLOW	0.095	0.132	-6.606****	-7.078****

Notes: Rejections of H0 at * = 10%, ** = 5%, *** = 2.5%, **** = 1%. KPSS stands for the Kwiatkowski et al. (1992) test. It has stationarity as the null. The other is due to Phillips and Perron (1988). It has a unit root as the null.

TABLE 5
Estimation Results for Deterministic Trend Models of *CASE,* 1884-1920

	Model 1			Model 2			Model 3			Model 4		
	coeff	t-val	p-val	coeff	t-val	p-val	coeff	t-val	p-val	coeff	t-val	p-val
constant	-70.982	-1.34	0.192	-11.690	-0.44	0.663	33.739	2.68	0.013	13.087	0.57	0.577
Time	24.208	1.98	0.059	9.163	2.52	0.018	2.440	2.36	0.026	6.762	1.94	0.063
$Time^2$	-1.703	-1.70	0.102	-0.436	-2.30	0.030	-0.073	-3.23	0.003	-0.290	-1.64	0.112
$Time^3$	0.048	1.46	0.158	0.006	1.92	0.066				0.003	1.22	0.234
$Time^4$	0.000	-1.29	0.210									
RVAL(-4)	0.334	1.84	0.078	0.317	1.73	0.095	0.154	0.90	0.374			
ΔACRE(-4)	0.937	2.09	0.047	1.265	3.39	0.002	1.288	3.29	0.003	1.193	3.10	0.005
FLOW(-4)	-0.234	-3.70	0.001	-0.244	-3.83	0.001	-0.258	-3.88	0.001	-0.208	-3.33	0.003
R^2	0.7314			0.7128			0.6703			0.6783		
Adjusted R^2	0.6530			0.6439			0.6069			0.6165		
Schwarz BIC.	123.05			122.39			122.87			122.47		
P-values for:												
Restrictions	0.140			0.109			0.044*			0.056		
Durbin-Wat.	0.188			0.148			0.099			0.231		
LM het	0.121			0.263			0.463			0.221		
White het				0.631			0.499			0.486		
ARCH(1)	0.015*			0.064			0.248			0.056		
CuSum	0.204			0.083			0.224			0.990		
CuSum^2	0.099			0.040*			0.238			0.028*		
Chow	0.139			0.147			0.036*			0.042*		
Jarque-Bera	0.787			0.518			0.049*			0.423		
Reset-2	0.020*			0.100			0.123			0.070		

Notes: Parameter restrictions are tested against an unrestricted fourth-order distributed lag model with a fourth-order deterministic time trend. The Durbin-Watson statistic tests for first-order autocorrelation. Heteroskedasticity is checked with a simple LM test that regresses the squared residuals on a constant and the squared fitted values and White's (1980) test. The test for ARCH(1) effects (Engle 1982) regresses the squared residuals on the lagged squared residuals. Structural stability is tested with the Cusum, Cusum^2 (Brown et al. 1975), and Chow test statistics. Normality is checked with the Jarque-Bera (1987) test and correct structural form with Ramsey's (1969) Reset test of order two. An * identifies significance at the 5% level of a statistical adequacy test.

TABLE 6
Stochastic Versus Deterministic Trend Models of *CASE*, 1884-1920

Variables	Stochastic Trend Models			Deterministic Trend Models	
	Model 1	Model 2	Model 3	Model 1	Model 2
constant				-11.690	2.682
				(0.662)	(0.908)
Time				9.163	6.961
				(0.017)	(0.036)
$Time^2$				-0.436	-0.317
				(0.029)	(0.066)
$Time^3$				0.006	0.004
				(0.064)	(0.145)
μ (for last year)	16.204	18.062	22.222		
	(0.246)	(0.203)	(0.075)		
β (for last year)	-1.4782				
	(0.386)				
RVAL(-4)	0.321	0.315	0.283	0.317	0.273
	(0.118)	(0.128)	(0.116)	(0.093)	(0.092)
ΔACRE(-4)	1.171	1.165	1.123	1.265	1.128
	(0.007)	(0.008)	(0.004)	(0.002)	(0.001)
FLOW(-4)	-0.260	-0.261	-0.278	-0.244	-0.263
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)
D_1895			24.910		25.138
			(0.003)		(0.003)
R^2	0.5936	0.5530	0.6746	0.7110	0.7970
Akaike Inform. Crit.	4.965	4.808	4.553	4.497	4.207
Normality $\chi^2(2)$	3.618	**22.16	2.218	3.146	0.866
Heterosk. F(10,10)	0.191	0.270	0.569	0.188	0.343
DW	2.107	2.085	2.011	2.045	2.072
Box-Ljung $\chi^2(6)$	12.70	9.476	8.547	9.653	10.11
Forecast $\chi^2(6)$	2.586	2.457	2.920	8.888	4.324
Forecast $\chi^2(10)$	4.913	4.988	9.378	**165.516	**80.380

Notes: p-values are provided in parentheses. Normality is checked with the Bowman-Shenton (1975) test (5% critical value = 5.99); Heterosk stands for a heteroskedasticity test (5% critical value = 2.98); DW indicates the Durbin Watson test for first-order autocorrelation. Box-Ljung is the Ljung and Box (1978) for higher-order autocorrelation. Forecast χ^2(h) are out-of-sample one-step-ahead predictive tests *h* observations into the future. For statistical adequacy tests, * and ** indicate rejection of the null hypothesis at the 5 and 1% levels, respectively.

FIGURE 1
Out-of-Sample Performance of Deterministic Trend Model 2 of Table 6

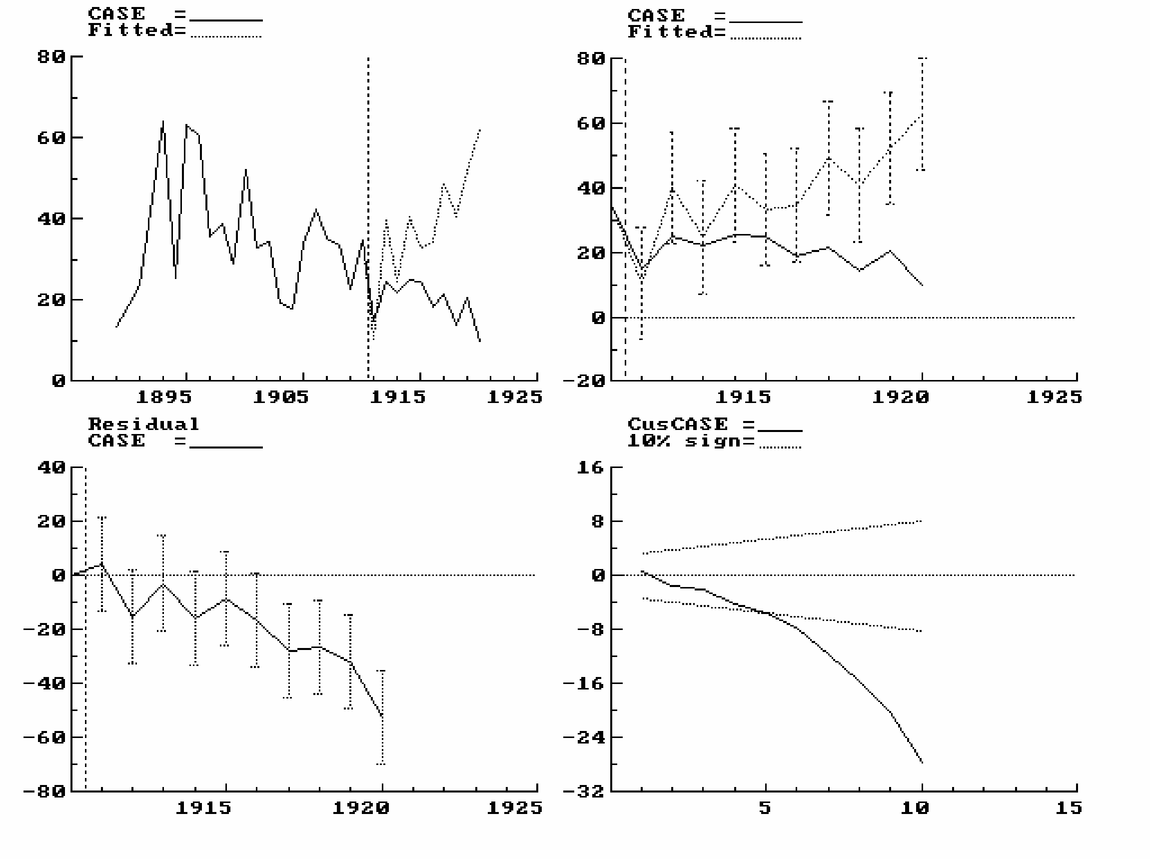

FIGURE 2
Out-of-Sample Performance of Stochastic Trend Model 3 of Table 6

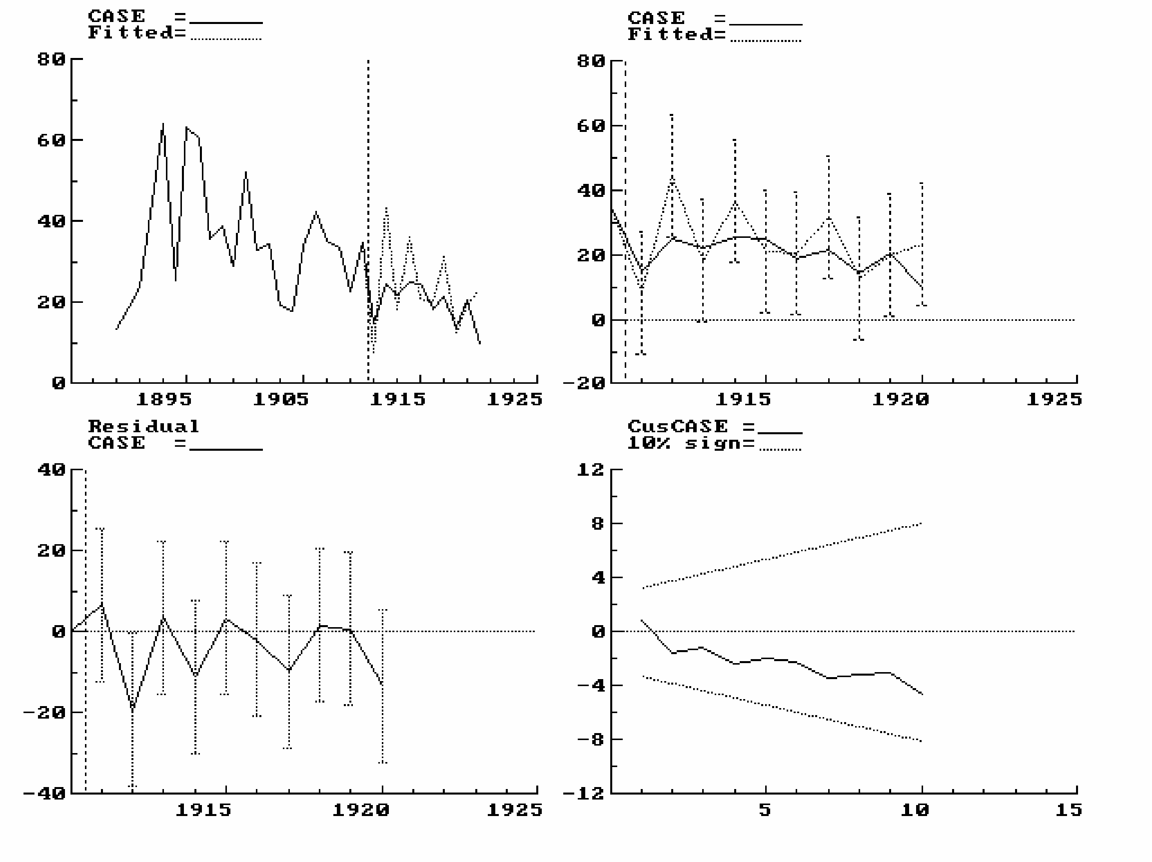

FIGURE 3
Components of Stochastic Trend Model 3 of Table 6