2001

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Published in *Journal of Real Estate Finance and Economics* 22:1 (2001), pp. 99–116.

Empirical Tests of the Fundamental-Value Hypothesis in Land Markets

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Abstract
The land-price boom of the 1970s followed by the bust of the 1980s generated considerable interest in the determination of land prices and the study of whether those prices reflect fundamental value. In this article, three techniques are used to examine the fundamental-value hypothesis in Iowa and Nebraska agricultural land markets. Duration dependence tests indicate that land markets are not affected by rational expectations bubbles. Conversely, Markov chain and time-reversibility tests suggest that land prices depart from fundamental value due to the existence of nonrandom price changes and asymmetric land price patterns. The results of this research should be viewed as a complement to the existing body of knowledge in our quest to enhance our understanding of agricultural land-price movements.

Keywords: agricultural land, price patterns, rational bubbles, fundamental-value hypothesis

1. Introduction

Despite the myriad of tests that have been conducted using both land and stock-market data, a consensus in the literature with regard to the existence of departures from fundamental value has not been reached. Fundamental value is usually defined to be the present value of the future cash flows associated with a particular asset. However, actual market prices may depart from fundamental value due to overreactions or rational expectations bubbles.[1] The existence of overreactions suggests nonrandom or asymmetric [2] patterns in returns. Rational-expectations bubbles suggest a tendency for price to deviate from fundamental value for an extended period of time as a result of the self-fulfilling beliefs of market participants. Tests can be conducted to examine returns for empirical attributes of overreactions and bubbles, such as autocorrelation and skewness, that result from extended runs of price increases followed by crashes. If nonrandom patterns, asymmetric patterns, or rational-expectations bubbles are detected in returns, it suggests that departures from fundamental value are likely.

The existence of price overreactions, rational-expectations bubbles, and nonrandom price-change patterns in financial and real estate markets is an empirical question with important practical and policy implications. The purpose of this research is to further study the question of whether land prices reflect fundamental

value. If it can be empirically verified that asymmetries or nonrandom patterns occur in a particular financial market, it is more probable that prices do not reflect fundamental value. A finding that prices depart significantly from fundamental value raises several interesting questions including the following: are prices driven by speculative excesses instead of fundamental forces, and can one identify when departures from fundamental value occur?

The three techniques used in this article test for different types of departures. One technique tests for negative duration dependence, an attribute unique to rational-expectations bubbles, while the other two test for more general asymmetric or nonrandom-return patterns. This article provides additional insights into the behavior of land prices by testing for rational bubbles, asymmetries, and nonrandom patterns in agricultural land time series without specifying a precise model of land prices. These techniques avoid the problems associated with testing a joint null hypothesis of a well-specified model and no departures from fundamental value. Taken together, the evidence provided by these three techniques will further our understanding of agricultural land price movements and should be viewed as a complement to the existing body of knowledge.

Markov chain analysis is used to determine whether land-price changes follow a random walk, and the time reversibility technique is used to test for asymmetric or nonlinear patterns in land-price changes. Both of these techniques reject the null hypothesis of symmetry or random walk behavior. This evidence is consistent with the existence of departures from fundamental value. The statistical theory of duration dependence is used to determine whether agricultural land values exhibit negative duration dependence, an empirical attribute unique to rational-expectations bubbles. The null hypothesis of no duration dependence could not be rejected, and, therefore, we do not find evidence of rational-expectations bubbles in Iowa and Nebraska land markets. However, departures from fundamental value may still occur in the Iowa and Nebraska land markets due to the nonrandom and asymmetric return patterns detected by the Markov chain and time-reversibility techniques.

This article is organized as follows: Section 2 gives a brief review of the literature, Section 3 describes the data, Sections 4, 5, and 6 present the results of the duration dependence, Markov chain, and time-reversibility tests, Section 7 concludes the article.

2. Literature review

The agricultural land boom of the 1970s followed by the bust of the 1980s generated considerable interest in the determination of land prices and the study of whether those prices reflect fundamental value. One category of tests compares the time-series properties of actual prices to the time-series properties of the fundamentals that are believed to determine prices. Falk (1991) found that Iowa farmland price movements are much more volatile than rent movements using unit root and cointegration tests. Hallam *et al.* (1992) used pairwise cointegration analysis to study relationships between real U.K. land prices and several fundamental variables; they found little evidence of cointegration. Lloyd and Rayner (1990) also used cointegration analysis and found that cash rents alone do not de-

termine real land prices in the United Kingdom. All of these tests assume linearity relating observations in a series to the value of prior observations using one set of parameters. However, boom-bust price cycles or departures from fundamental value suggest nonlinear patterns in price changes.

Another group of studies examines the linkage between land prices and fundamentals such as cash rents, returns to assets, interest rates, and inflation. Featherstone and Baker (1987) found that U.S. land values overreact to changes in asset values, returns to assets, and interest rates. Lloyd (1994) found that U.K. land values overreact to changes in rents and underreact to changes in inflation. Schmitz and Moss (1996) found that farmland values in the United States overreact to changes in market fundamentals in the short run. This evidence of overreaction suggests that land prices may depart from fundamental value; however, these studies rely on a correctly specified model of land values and test a joint null hypothesis of a well-specified model and no bubbles.

The three empirical tests used in this research do not require the development of a well-specified model of land values; rather, they test for patterns in price changes through time. McQueen and Thorley (1994) applied a statistical runs test-based methodology known as duration dependence to test for rational-expectations bubbles in New York Stock Exchange stocks. Using data from 1927 to 1991, they found evidence of decreasing hazard rates (negative duration dependence) in monthly real stock returns. This finding is consistent with the existence of rational-expectations bubbles in the stock market.

While duration-dependence tests are used to test specifically for rational-expectations bubbles, other techniques that detect nonlinearities or asymmetries in data can be used to test for more general patterns in price changes that are consistent with the existence of bubbles and departures from fundamental value. Markov chains were initially used by Neftçi (1984) to test for asymmetry in the business cycle. McQueen and Thorley (1991) were the first to apply the Markov chain technique to test for predictability in stock-market returns. McQueen and Thorley's results indicated that annual real stock returns exhibit significant nonrandom walk behavior and negative serial autocorrelation in the sense that low (high) returns tend to follow runs of high (low) returns in the postwar (1947–1987) period. The existence of negative serial autocorrelation suggests that stock prices follow mean reverting behavior that limits departures from fundamental value.

The time-reversibility test was developed by Ramsey and Rothman (1988) to investigate the proposition that the business cycle is asymmetric in the sense that upturns in the cycle are longer but less steep than downturns. Ramsey and Rothman also applied the test to weekly stock return data from the Center for Research in Security Prices (CRSP) and found strong evidence of time reversibility in stock returns with the effect concentrated in the first 30 weeks (lags).

3. Data

The empirical tests in this article are implemented using a time series of the average annual value per acre of agricultural land and buildings[3] for Iowa and Nebraska from 1910 to 1995. The data were obtained from the U.S. Depart-

ment of Agriculture's (USDA) farm real estate value, by state, series. Nebraska and Iowa were chosen as the states to include in this study for several reasons. Farmland in the Midwest, especially in Iowa, is more homogenous than farmland in other areas of the country. Also, land in these states is not typically valued for its potential nonagricultural uses as is land in more urban states. The agricultural land-value series was used to compute continuously compounded annual real percentage price changes using the January PPI with a base year of 1982.

4. Duration dependence

Rational-expectations bubbles are a specific type of bubble that occurs when investors realize that prices exceed fundamental value but the probability of a high return exactly compensates investors for the probability of a crash. As the bubble continues, its innovation is positive and small relative to an infrequent but large negative innovation if the bubble bursts. In other words, price changes exhibit negative duration dependence (an inverse relation between the probability of a run ending and the length of the run) in the presence of rational-expectations bubbles. As the bubble persists, price continues to increase causing autocorrelation and longer runs of price increases than expected from an independent series.

4.1. Methodology

According to Kiefer (1988), duration analysis is a convenient means of interpreting data that is best represented as a sequence of conditional probabilities. The theory of duration dependence is operationalized and tested using a hazard-function specification that measures the probability of an unexpected price decrease ($\varepsilon_t < 0$) given a sequence of prior price increases ($\varepsilon_{t-i} > 0$). In the presence of negative duration dependence, the hazard rate,

$$h_t = \Pr\,(\varepsilon_t < 0, \varepsilon_{t-1} > 0, \varepsilon_{t-2} > 0, \ldots, \varepsilon_{t-i} > 0, \varepsilon_{t-i-1} < 0) \qquad (1)$$

decreases with i, the number of prior positive innovations. In other words, negative duration dependence implies that the probability that a run of price increases will end should decline as the length of the run increases. To test for duration dependence, annual percentage land-price changes are transformed into series of positive and negative run lengths. As indicated by McQueen and Thorley (1994), the data then consist of a set (S_I) of I observations on random run length, T. The hazard rate, which represents the probability that a run ends at t given that it lasts no more than t years, is defined as $h_t \equiv \Pr(T = t \mid T \geq t)$. If rational bubbles are present, $h_{t+1} < h_t$ for all T (McQueen and Thorley, 1994). A similar inequality does not hold for runs of price decreases because rational expectations bubbles can not be negative.

The density of a duration of length t can be written as $f\,(t, \Theta)$. If a sample of n runs is available, and each individual run is independent of the others, the log

likelihood function is

$$L(\Theta S_l) = \sum_{i-1}^{n} Ln\, f\,(t_i, \Theta) \tag{2}$$

where Θ is a vector of parameters.[4]

The density function version of the log likelihood is commonly parameterized with an exponential or Weibull distribution. The exponential distribution has a constant hazard function that reflects no duration dependence and can be used for durations that do not exhibit much variation. The Weibull distribution is generalization of the exponential distribution that allows for positive and negative monotonic duration dependence (Kiefer, 1988). The Weibull distribution was chosen as the functional form for the hazard function.[5] The density and hazard functions for the Weibull distribution are given in (3) and (4)

$$f_t = \gamma \alpha t^{\alpha-1} e^{(-\gamma t^{\alpha})} \tag{3}$$

$$h_t = \gamma \alpha t^{\alpha-1} \tag{4}$$

Substituting (3) into (2) yields the log likelihood function for the Weibull distribution,

$$L(\gamma,\, \alpha) = \ln \gamma + \ln \alpha + (\alpha - 1) \sum_{i=1}^{n} \ln t_i - \gamma \sum_{i=1}^{n} t_i^{\alpha} \tag{5}$$

The duration-dependence test is performed by maximizing the log-likelihood function with respect to α and γ. The independent variable is the current run length, and the dependent variable is 1 (0) if the run ended (did not end) in the next period. The null hypothesis of no rational-expectations bubbles (no duration dependence or a constant hazard function) implies that α = 1. The bubble alternative suggests that the probability of a positive run ending should decrease with run length (α < 0). Duration dependence does not depend on the value of γ (Kiefer, 1988).

4.2. Results

Table 1 shows summary statistics for Iowa and Nebraska agricultural land price changes. Consistent with the presence of bubbles in general, both series have significant negative skewness coefficients and significant excess kurtosis coefficients. The positive first- and second-order autocorrelation coefficients suggest positive serial correlation in annual price changes, a pattern consistent with the existence of bubbles. In the presence of positive serial correlation, increases or decreases in land prices tend to be followed by further changes in the same direction, and there is no mechanism that works to bring prices back toward fun-

Table 1. Summary statistics of annual real price changes[a] in Iowa and Nebraska land, 1910 to 1995.

	Iowa	Nebraska
n[b]	85	85
Mean	0.0039	0.0027
Skewness[c]	–0.5823	–0.4098
	(0.0313)	(0.1297)
Excess Kurtosis	2.2276	0.8514
	(0.0001)	(0.1243)
ρ_1[d]	0.4571	0.3768
ρ_2	0.0663	0.0298
ρ_3	–0.1010	–0.0152
ρ_4	–0.1006	–0.1422
ρ_5	–0.0221	–0.0433
ρ_6	–0.0677	0.0195
ρ_{12}	–0.0681	–0.0081
$Q(6)$[e]	21.1001*	14.6576*
	(p = 0.002)	(p = 0.023)
$Q(12)$	23.6827*	18.2262
	(p = 0.022)	(p = 0.109)
Number of price increases	52	45
Number of price decreases	33	40
Total number of runs of any length	31	31

Notes. [a] All price changes are continuously compounded.
[b] n is the number of annual observations.
[c] Numbers in parentheses below the skewness and excess kurtosis coefficients are asymptotic standard errors. $(6/n)^{1/2}$ and $(24/n)^{1/2}$.
[d] ρ_t is the sample autocorrelation at lag t.
[e] $Q(6)$ and $Q(12)$ are the Ljung-Box portmanteau test statistics for 6 and 12 autocorrelations.
* Indicates significance at the 5 percent level.

damental value as there is when returns exhibit negative serial autocorrelation or mean reversion. The Ljung-Box (1978) portmanteau is a formal test designed to detect departures from zero autocorrelations in either direction. For both Iowa and Nebraska land, the null hypothesis of no serial autocorrelation is rejected for returns at lag six, but when the number of lags is increased to 12, the null hypothesis could not be rejected for Nebraska. These linear-based tests of skewness, kurtosis, and autocorrelation provide evidence consistent with the presence of bubbles in general, but they do not constitute a conclusive test of the fundamental value or rational bubbles hypotheses.

Table 1 reports the number of positive and negative price changes for each series. For Iowa, there were 52 years of price increases (61.18 percent) and 33 years of price decreases (38.82 percent). The Nebraska price changes were almost equally divided between positive and negative, with 45 years (52.94 percent) of price increases and 40 years (47.06 percent) of price decreases. As stated by McQueen and Thorley (1994), the null hypotheses of no duration dependence, symmetry, and random price-change patterns all imply that price changes should be

Table 2. Run counts, hazard rates, and tests of duration dependence for runs of price increases in Iowa and Nebraska land values, 1910 to 1995.

	Iowa		Nebraska	
Run Length (t)	Run Frequency[a]	Sample Hazard Rates[b]	Run Frequency	Sample Hazard Rates
1	16	0.30769	16	0.35556
2	14	0.38889	12	0.41379
3	7	0.31818	6	0.35294
4	6	0.40000	3	0.27273
5	4	0.44444	1	0.12500
6	3	0.60000	1	0.14286
7	1	0.50000	1	0.16667
8	1	1.00000	1	0.20000
9			1	0.25000
10			1	0.33333
11			1	0.50000
12			1	1.00000
Weibull model (maximum likelihood estimation):				
α		1.7198		1.5174
Standard error		0.1827		0.1787
Asymptotic t-ratio		9.413*		8.49*

Notes. [a] Run frequency denotes total number of runs with length not less than t.

[b] The sample hazard rates are calculated as follows: $h_t = \dfrac{\text{number of runs of length } t}{\sum_{j=i}^{n} \text{number of runs of length } j}$ for $t = 1$ to n.

Example: In Iowa, the probability of a run of length 1 ending is calculated as 16/52 while the probability of a run of length 2 ending is 14/36.

* Indicates significance at the 5 percent level.

serially independent. Therefore, under the null, runs based on the sign of the price changes are geometrically distributed with $p = 0.6118$ for Iowa and $p = 0.5294$ for Nebraska. Under the null hypothesis, the probability of a price increase or decrease next period is the same in each period, regardless of the prior sequence. In contrast, the rational-expectations bubble alternative implies that the probability of a price increase or decrease in the future depends on the sequence of prior price changes.

Table 2 reports run frequency and hazard rates for all run lengths[6] for Iowa and Nebraska land. For Iowa, the longest positive run lasted eight years; for Nebraska the longest positive run lasted 12 years. Hazard rates estimate the probability that a run ends (price decreases in the next year) at t given that it lasts no more than t years. Given a particular number of price increases observed in a row, the hazard rates estimate the probability that the price change next period will be negative (the “bubble” will burst). For example, given a run of three price increases, the hazard rates for Iowa indicate a 31.82 percent chance that the next price change will be negative, causing the bubble to burst.

Table 2 also reports the results of the duration dependence test for rational expectations bubbles. Under the null hypothesis of no duration dependence (no rational expectations bubbles), the hazard rates are constant ($\alpha = 1$). Under the rational bubbles are alternative, the hazard rates decrease (probability of a run ending decreases) with the length of the run. However, for runs of price increases in Iowa, there is a fairly consistent pattern or increasing hazard rates. For runs of price increases in Nebraska, hazard rates decline for run lengths of two to five but increase steadily for runs that last five years or longer. Thus, both Iowa and Nebraska appear to exhibit increasing hazard rates instead of decreasing hazard rates.

Table 2 also reports the results of the maximum likelihood estimation using the Weibull distribution. For both Iowa and Nebraska, the null hypothesis of no duration dependence ($\alpha = 1$) can be rejected at the 5 percent level. However, the values of the α coefficients are not consistent with the rational bubbles model, which suggests that the probability of a run ending should decline with the length of the run (decreasing hazard rates, negative duration dependence, or $\alpha < 1$). Thus, we can conclude that there is duration dependence in Iowa and Nebraska land values, but it is likely to be positive duration dependence instead of negative duration dependence. According to Kiefer (1988), positive duration dependence suggests that the probability that a run will end increases as the length of the run increases. This finding of positive duration dependence is not consistent with the rational-expectation bubbles model, but it does suggest that the probability of a run ending is dependent on the length of the run. This evidence of positive duration dependence and the evidence of positive serial correlation, negative skewness, and excess kurtosis found in Nebraska and Iowa land-price changes are consistent with a more general bubbles model and suggests that departures from fundamental value may still occur. The Markov chain and time-reversibility techniques are used to further test the land data for the existence of nonlinear or asymmetric price-change patterns.

5. Markov chains

Using the Markov chain technique, the random walk hypothesis is reduced to restrictions on transition probabilities[7] from one state to another. The restrictions are tested using the likelihood function. The random walk (symmetry) hypothesis implies that the transition probabilities are equal regardless of the prior return sequence. To test the random walk hypothesis using agricultural land values, a two-state Markov chain is defined by letting one state represent price increases and the other price decreases. A two-state third-order Markov chain is used to estimate the probability of a price decrease given three prior years of price changes. If the probability of a price decrease following three years of price decreases is the same as the probability of a price decrease following three years of price increases, the null hypothesis of random walk behavior (symmetry) in price changes cannot be rejected. Rejection of the null hypothesis suggests that patterns or trends exist in land-price changes.

5.1. Methodology

In this study, the Markov chain methodology is applied to annual agricultural land values for Iowa and Nebraska. Increases or decreases in land values are measured as continuously compounded annual percentage changes $\{R_t\}$. To test the random walk hypothesis, the finite state Markov process $\{I_t\}$ is defined as follows:

$$I_t = \begin{cases} 1 \text{ if } R_t > 0 \\ 0 \text{ if } R_t \leq 0 \end{cases} \tag{6}$$

The derived series $\{I_t\}$ is a two-state Markov chain[9] that represents price increases as a l and price decreases as a 0. If price changes are random, the probability of observing a price decrease (increase) should not depend on the prior sequence of price changes. To test this hypothesis, the transition counts (N_{ijk} and M_{ijk}) and transition probabilities (λ_{ijk}) are formed from the information contained in $\{I_t\}$. In a third-order Markov chain, N_{ijk}, M_{ijk}, and λ_{ijk} are formed by conditioning the analysis on the price changes from three prior years.[10] Following the notation used by McQueen and Thorley (1991), the transition counts and transition probabilities form the following matrices:

Transition Count Matrix
Previous States — Current State

$$\begin{array}{ccc c}
 & & & \begin{array}{cc} 0 \quad & \quad 1 \end{array} \\
\begin{array}{c} 0 \\ 0 \\ 0 \\ 0 \\ 1 \\ 1 \\ 1 \\ 1 \end{array} & \begin{array}{c} 0 \\ 0 \\ 1 \\ 1 \\ 0 \\ 0 \\ 1 \\ 1 \end{array} & \begin{array}{c} 0 \\ 1 \\ 0 \\ 1 \\ 0 \\ 1 \\ 0 \\ 1 \end{array} & \left[\begin{array}{cc} N_{000} & M_{000} \\ N_{001} & M_{001} \\ N_{010} & M_{010} \\ N_{011} & M_{011} \\ N_{100} & M_{100} \\ N_{101} & M_{110} \\ N_{110} & M_{111} \\ N_{111} & M_{000} \end{array}\right]
\end{array}$$

Transition Probabilities Matrix
Previous States — Current State

$$\begin{array}{ccc c}
 & & & \begin{array}{cc} 0 \quad & \quad 1 \end{array} \\
\begin{array}{c} 0 \\ 0 \\ 0 \\ 0 \\ 1 \\ 1 \\ 1 \\ 1 \end{array} & \begin{array}{c} 0 \\ 0 \\ 1 \\ 1 \\ 0 \\ 0 \\ 1 \\ 1 \end{array} & \begin{array}{c} 0 \\ 1 \\ 0 \\ 1 \\ 0 \\ 1 \\ 0 \\ 1 \end{array} & \left[\begin{array}{cc} \lambda_{000} & 1-\lambda_{000} \\ \lambda_{001} & 1-\lambda_{001} \\ \lambda_{010} & 1-\lambda_{010} \\ \lambda_{011} & 1-\lambda_{011} \\ \lambda_{100} & 1-\lambda_{100} \\ \lambda_{101} & 1-\lambda_{101} \\ \lambda_{110} & 1-\lambda_{110} \\ \lambda_{111} & 1-\lambda_{111} \end{array}\right]
\end{array}$$

For example, N_{000} denotes the number of observations of state sequence 0 0 0 0 in the series of annual price changes, while M_{000} is the number of observations of state sequence 0 0 0 1.

The transition probability (λ_{000}) for a two-state third-order Markov chain is

$$\lambda_{000} = \mathrm{P}[I_t = 0 \mid I_{t-3} = 0, I_{t-2} = 0, I_{t-1} = 0] \tag{7}$$

where λ_{000} is an estimate of the probability that a sequence of three years of price decreases will be followed by a fourth price decrease and $(1 - \lambda_{000})$ describes the probability that such a downswing will be followed by a price increase in the fourth year. Restrictions are imposed on the transition probabilities to investigate the random walk hypothesis. If price changes are random (symmetric), the probability of a particular future state should be the same, regardless of the past

sequence of price changes. The null (random walk) hypothesis is $\lambda_{000} = \lambda_{111}$. The general alternative hypothesis is that price changes exhibit nonrandom or asymmetric behavior in the sense that the probability of a price decrease (increase) differs depending on the prior observed sequence of price changes, $\lambda_{000} \neq \lambda_{111}$.

The maximum likelihood estimate of λ_{ijk} is

$$\hat{\lambda}_{ijk} = \frac{N_{ijk} \,/}{(N_{ijk} + M_{ijk})} \tag{8}$$

and the asymptotic variance is

$$\sigma^2(\hat{\lambda}_{ijk}) = \frac{\hat{\lambda}_{ijk}\,(1 - \hat{\lambda}_{ijk})}{(N_{ijk} + M_{ijk})} \tag{9}$$ [11]

After the transition probabilities are estimated, a likelihood ratio test (LRT) is used to formally test the null hypothesis, $\lambda_{000} = \lambda_{111}$. The LRT is

$$\text{LRT} = 2\,[L_U - L_R] \tag{10}$$

where L_U is the unrestricted likelihood function, and L_R is the restricted likelihood function. The LRT is asymptotically distributed chi-square with n degrees of freedom.

5.2. Results

The transition counts and MLE of the transition probabilities, $\hat{\lambda}_{ijk}$, for the third-order process are reported in Table 3. The unconstrained point estimates of $\hat{\lambda}_{000}$ and $\hat{\lambda}_{111}$ for Iowa and Nebraska are consistent with the earlier findings of positive serial dependence in annual price changes. Runs of price decreases and runs of price increases tend to persist in both Iowa and Nebraska, $\hat{\lambda}_{000} > (1 - \hat{\lambda}_{000})$ and $(1 - \hat{\lambda}_{111}) > \hat{\lambda}_{111}$.

Under the null hypothesis, the probability of a price decrease is the same regardless of whether it follows three price decreases (λ_{000}) or three price increases (λ_{111}). Iowa prices decreased six out of 10 times following three years of price decreases but decreased only six out of 21 times when the preceding three years showed price increases. In Iowa during the years between 1910 and 1995, the probability of observing a price decrease after a sequence of three years of price decreases was over twice as high ($\hat{\lambda}_{000}$ = 60%) as the probability of observing a price decrease following three years of price increases ($\hat{\lambda}_{111}$ = 28.6%). The results for Nebraska show an even larger difference between the transition probabilities. Nebraska land prices decreased 13 out of 17 times ($\hat{\lambda}_{000}$ = 76.5%) following three prior years of price decreases. After three years of price increases, Nebraska prices decreased only six out of 17 times ($\hat{\lambda}_{111}$ = 35.3%). For both Iowa and Nebraska, the data suggest that a price decline is more likely following three years of price decreases than three years of price increases.

Table 3. Maximum likelihood estimates and likelihood ratio tests for annual land price changes, 1910 to 1995, third-order Markov chains.

Iowa Transition Count Matrix			Nebraska Transition Count Matrix		
Previous States	Current State		Previous States	Current State	
	0	1		0	1
0 0 0	6	4	0 0 0	13	4
0 0 1	2	6	0 0 1	2	6
0 1 0	1	1	0 1 0	2	2
0 1 1	6	7	0 1 1	4	6
1 0 0	4	4	1 0 0	4	4
1 0 1	0	7	1 0 1	2	5
1 1 0	7	6	1 1 0	6	5
1 1 1	6	15	1 1 1	6	11

MLE estimates:	Iowa	Nebraska
$\hat{\lambda}_{000}$	0.600	0.7647
	(0.155)[a]	(0.103)
$\hat{\lambda}_{111}$	0.286	0.3529
	(0.099)	(0.116)
Likelihood ratio hypothesis test:		
H_0 $\lambda_{000} = \lambda_{111}$ [b]		
LRT	2.783**	6.391*

Notes. [a] The numbers in parentheses below the MLE estimates of the transition probabilities $\hat{\lambda}_{ijk}$ are the associated asymptotic standard errors, $\hat{\sigma}(\lambda_{ijk})$.
[b] The critical value for $H_0 : \lambda_{000} = \lambda_{111}$ is $\chi^2(1) = 3.8415$ at the 5 percent level and $\chi^2(1) = 2.706$ at the 10 percent level.
* Indicates significance at the 5 percent level.
** Indicates significance at the 10 percent level.

The LRT (10) is used to formally test the random walk (symmetry) hypothesis by reestimating $\hat{\lambda}_{000}$ and $\hat{\lambda}_{111}$ with the restriction under the null, $\lambda_{000} = \lambda_{111}$. This restriction implies that the probability of a price decrease should be the same regardless of the prior sequence of price changes. During the period under investigation, 32 out of 82[12] price changes in Iowa were decreases while in Nebraska 39 out of 82 price changes were decreases. These counts indicate the following restrictions under the null hypothesis for Iowa ($\lambda_{000} = \lambda_{111} = 0.3902$) and Nebraska ($\lambda_{000} = \lambda_{111} = 0.4756$). Implementing the likelihood ratio test (10) results in a LRT of 2.783 for Iowa and 6.391 for Nebraska. The critical values, given in Table 3, indicate that the null hypothesis of random price changes can be rejected for Nebraska at the 5 percent level and for Iowa at the 10 percent level.

The fact that $\lambda_{000} = \lambda_{111}$ is rejected in favor of $\lambda_{000} \neq \lambda_{111}$ for both Iowa and Nebraska land markets indicates that the probability of a price decrease differs depending on the prior sequence of price changes. In other words, price changes exhibit nonrandom walk behavior and are not symmetric. This finding suggests

that patterns exist in land-price changes and may be indicative of a market where prices depart from fundamental value due to a lack of market efficiency.

6. Time reversibility

The time-reversibility test is used to determine whether the covariance relationship in a time series is the same expressed both forward and backward in time. If the relationships are the same, then the series is symmetric and is labeled as a "time-reversible" series, providing support for the null hypothesis of symmetry. If the relationships differ, the series is said to be "time irreversible," a finding consistent with asymmetric or nonlinear price change patterns. Ramsey and Rothman (1988) developed the test to investigate the proposition that the business cycle is asymmetric in the sense that upturns in the cycle are longer but less steep than downturns. The technique is applied here to test for asymmetry or bubbles in agricultural land markets. The typical asymmetric "bubbles" pattern suggests the existence of long, gradual periods of price increases followed by sharp, quick drops when the bubbles "burst."

6.1. Methodology

A stationary time series $\{X_t\}$ is time reversible (symmetric) if for every positive integer n, and every $t_1, t_2, \ldots, t_n \in z$, the vectors $(X_{t_1}, X_{t_2}, \ldots, X_{t_n})$ and $(X_{-t_1}, X_{-t_2}, \ldots, X_{-t_n})$ have the same joint probability distributions.[13] By the stationarity of $\{X_t\}$, $(X_{-t_1}, X_{-t_2}, \ldots, X_{-t_n})$ and $(X_{-t_{1+m}}, X_{-t_{2+m}}, \ldots, X_{-t_{n+m}})$ have the same joint distributions for any integer m. Ramsey and Rothman explain that if $m = t_1 + t_n$, then time reversibility implies that the vectors $(X_{t_1}, X_{t_2}, \ldots, X_{t_n})$ and $(X_{t_n}, X_{t_{n-1}}, \ldots, X_{t_1})$ have the same joint-probability distributions for a stationary time series $\{X_t\}$. This is the sense in which the probabilistic structure going forward in time is identical to that going backward in time.

The time-reversibility test is conducted by testing for equality between individual moments from the joint-probability distribution of a stationary time series $\{X_t\}$. If the moments are equal, the series is time reversible. If $\{X_t\}$ is time reversible, then

$$E\,[X^i_t \cdot X^j_{t-k}] = E\,[X^j_t \cdot X^i_{t-k}] \tag{11}$$

for all $i, j, k \in N^*$, where the expectation is taken with respect to each joint distribution.

For $i = j = 1$, (11) is the tautology that the autocovariance of a stationary time series at lag k is equal to itself. When at least one of i, j is greater than one, $i, j, \in N^*$, the two terms in the statement are called generalized autocovariances. If there exists a lag k at which the two moments in (11) do not equal each other, the series is time irreversible. While (11) represents a sufficient condition for time irreversibility, it is not a necessary one since only a subset of the moments from the joint distributions are considered. Specifically, only the pairs (X_t, X_{t-k}) and (X_{t-k}, X_t)

are considered, which renders the autocovariance function unable to distinguish forward from reverse time. Therefore, Ramsey and Rothman developed symmetric-bicovariance functions

$$\gamma_{2,1}(k) = \{E[X_t^2 \cdot X_{t-k}] - E[X_t \cdot X_{t-k}^2]\} \tag{12}$$

$$\gamma_{1,2}(k) = \{E[X_t \cdot X_{t-k}^2] - E[X_t^2 \cdot X_{t-k}]\} \tag{13}$$

to examine the differences in population moments for all integer values of k.[14] If $\{X_t\}$ is time reversible, then $\gamma_{2,1}(k) = \gamma_{1,2}(k) = 0 \; \forall \, k \in N^*$.

In practice, Ramsey and Rothman's test statistic, $\hat{\gamma}_{2,1}(k)$, is the difference between the sample estimates, $\hat{\beta}_{2,1}(k)$ and $\hat{\beta}_{1,2}(k)$ of the bicovariances[15] for a stationary series $\{X_t\}$ with T observations,

$$\beta_{2,1} = (T-k)^{-1} \sum_{t=k+1}^{t=T} X_t^2 \cdot X_{t-k} \tag{14}$$

$$\beta_{1,2} = (T-k)^{-1} \sum_{t=k+1}^{t=T} X_t \cdot X_{t-k}^2 \tag{15}$$

$$\gamma_{2,1}(k) = \beta_{2,1}(k) - \beta_{1,2}(k) \tag{16}$$

for various integer values of k. Under the null hypothesis that $\{X_t\}$ is time reversible, the expected value of $\gamma_{2,1}(k)$ is zero for all k. The test statistic, $\hat{\gamma}_{2,1}(k)$, is a linear function of $\hat{\beta}_{2,1}(k)$ and $\hat{\beta}_{1,2}(k)$, and it is unbiased, consistent, and converges in quadratic mean to $\gamma_{2,1}(k)$.

No exact small-sample expression for $\mathrm{Var}(\hat{\gamma}_{2,1}(k))$ in the general case exists because the exact expression for the sample autocorrelation function is not generally known. Therefore, the approximate variances of the sample autocorrelation function that are used to test the significance of the estimated autocorrelation function at any particular lag must be generated using Monte Carlo simulation. Ramsey and Rothman suggest the following estimation procedure. First, identify and estimate an ARMA model for the given time series. Second, run a Monte Carlo simulation to obtain the estimated standard deviations for $\hat{\gamma}_{2,1}(k)$ for the particular ARMA model. The significance of $\hat{\gamma}_{2,1}(k)$ is judged by comparing the value of the statistic to plus or minus two times the estimated standard deviation.

6.2. Estimation

The time-reversibility tests are conducted after the stationarity of the Iowa and Nebraska land-value series is confirmed via the Augmented Dickey-Fuller and Phillips-Perron unit root tests. The stationary series of price changes is used to estimate the symmetric bicovariance statistic (16) for lags one to 25. The null hypothesis of time reversibility (symmetry) is stated as $\hat{\gamma}_{2,1}(k) = 0$ for all k.

The ARIMA identification procedure in Shazam indicated that the autocorrelation at the first lag was the only one significantly different from zero. Therefore, an AR(1) was chosen as appropriate for the data. Investigation of the residuals that result from applying the AR(1) to each times series show that the resulting Q-statistics for all lags are low, an indication that the residuals for both data series are white noise. The coefficients and variance of the estimated AR(1) equations are given in (17) for the Iowa series and (18) for the Nebraska series:

$$X_t = 0.00279557 + 0.46427\ X_{t-1} + \varepsilon_t, \text{ where } \sigma^2(\varepsilon_t) = 0.0072846 \tag{17}$$

$$X_t = 0.0022155 + 0.38133\ X_{t-1} + \varepsilon_t, \text{ where } \sigma^2(\varepsilon_t) = 0.0075543 \tag{18}$$

Equations (17) and (18) in conjunction with the respective $\sigma^2(\varepsilon_t)$ are used in a Monte Carlo simulation to generate 500 groups of 85 data points. Each set of 85 data points is used to estimate (16), the symmetric bicovariance test statistic ($\hat{\gamma}_{2,1}(k)$) for k = 1 to 25. The distributional properties for each $\hat{\gamma}_{2,1}(k)$ are estimated based on the 500 simulated data sets. The significance criterion for $\hat{\gamma}_{2,1}(k)$ is two standard-error bounds.

6.3. Results

The estimated symmetric bicovariance functions for the Iowa series of price changes are shown in Figure 1.[16] For k = 3, 4, 8, and 9, $\hat{\gamma}_{2,1}(k)$ takes on values significantly different from zero, indicating time irreversibility concentrated at years 3, 4, 8, and 9 in Iowa land values. Therefore, the null hypothesis of time reversibility ($\hat{\gamma}_{2,1}(k) = 0$) in Iowa price changes can be rejected, indicating that agricultural land price changes in Iowa follow an asymmetric or nonlinear pattern. This finding suggests that the pattern of ascent may differ from the pattern of descent in the Iowa land market. This finding is consistent with the typical "bubbles" pattern that suggests longer, more gradual periods of price increases followed by sharp, quick drops when the bubbles "burst."

Figure 2 is a graph of the symmetric bicovariance functions for the Nebraska series. Like Iowa price changes, Nebraska price changes are modeled as an AR(1). Only $\hat{\gamma}_{2,1}(4)$ is significantly different from zero for Nebraska returns, indicating evidence of time irreversibility or asymmetry concentrated at year 4. This finding is consistent with the evidence of asymmetry provided by the Markov chain model.

7. Summary and conclusion

The boom-bust price cycle in U.S. agricultural land values in the 1970s and 1980s generated considerable interest in the study of whether land prices depart from fundamental value. Many empirical tests rely on the assumption of linearity and test a joint hypothesis of correct model specification and no departures from

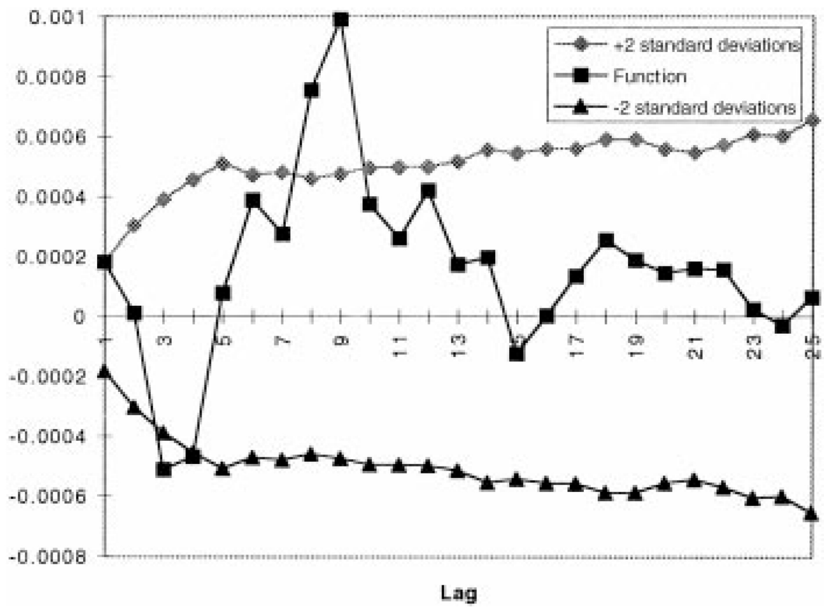

Figure 1. Symmetric bicovariance function and standard error estimates for Iowa.

fundamental value. This article provides additional insights into the behavior of land prices by testing for rational bubbles, asymmetries, and nonrandom patterns in agricultural-land time series without specifying a precise model of land prices. These techniques avoid the problems associated with testing a joint null hypothesis of a well-specified model and no departures from fundamental value. This research should be viewed as another step toward understanding agricultural land-price movements.

A rational-expectations bubble suggests a tendency for price to deviate from fundamental value for an extended period of time as a result of the self-fulfilling beliefs of market participants. Using the duration dependence technique, the null hypothesis of no duration dependence could be rejected for Iowa or Nebraska land values. However, the maximum-likelihood estimation results suggest that land-price changes in both states exhibit positive, not negative, duration dependence, meaning that the probability that a run will end actually increases with the length of the run. This finding suggests that Iowa and Nebraska land price changes do not exhibit the specific pattern associated with rational expectations bubbles. However, it does not mean that departures from fundamental value may not occur as the result of nonrandom or asymmetric price-change patterns. The Markov chain analysis rejects the null hypothesis of random price-change patterns (symmetry) in Iowa and Nebraska land markets, and the time-reversibility tests reject time reversibility (symmetry) in Iowa and Nebraska land-price changes. Furthermore, agricultural land-price changes in Iowa and Nebraska are characterized by positive serial dependence, which implies an absence of corrective forces to curtail departures from fundamental value. The time-reversibility

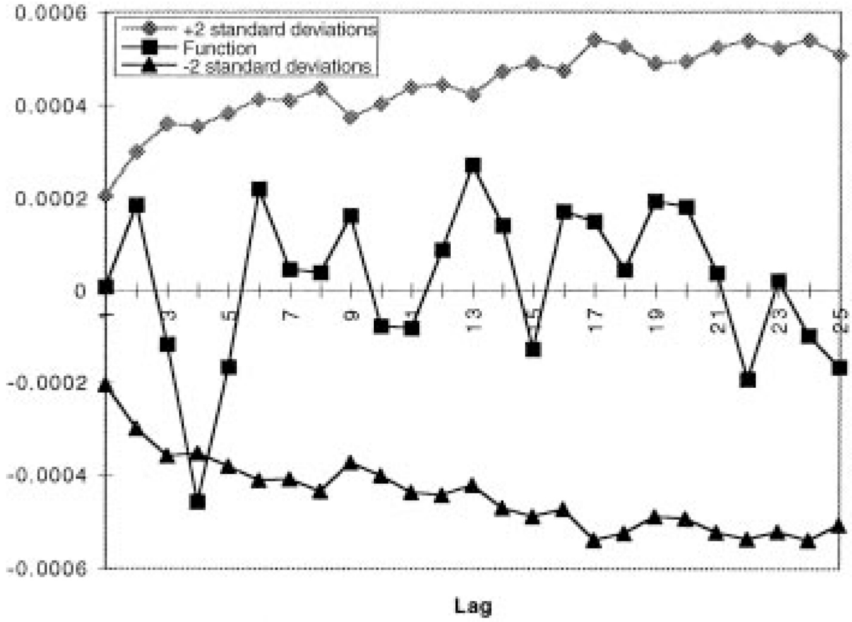

Figure 2. Symmetric bicovariance function and standard-error estimates for Nebraska

technique is especially useful for determining the timing of potential nonlinearities. Specifically, nonlinear effects seem to exhibit strong influence on the behavior of the Iowa time series at years 3, 4, 8, and 9. For Nebraska, the nonlinear effect is concentrated at year 4. This evidence of asymmetric price change patterns is consistent with the existence of a general "bubbles" pattern in agricultural land prices—long periods of gradual price increases followed by sharp, quick drops.

The results of the duration dependence test suggest that rational-expectations bubbles do not exist in Iowa and Nebraska land values. We do, however, find evidence of more general asymmetric and nonlinear price patterns that may cause departures from fundamental value in the agricultural land market. Although these results may appear contradictory, they are not. Duration dependence tests for a specific type of pattern, while the Markov chain and time-reversibility techniques test for asymmetries and nonlinearities in general. These indications of nonrandom and asymmetric patterns in agricultural land values are consistent with other recent studies (Featherstone and Baker, 1987; Lloyd, 1994; and Schmitz and Moss, 1996) that find evidence of departures from fundamental value in the agricultural land market. The evidence of positive serial correlation suggests that systematic profit opportunities may exist in the Iowa and Nebraska agricultural land markets as prices depart from fundamental value.

Acknowledgment

We wish to thank John Geppert, Bruce Johnson, Gordon Karels, Richard Perrin, and James Schmidt as well as UNL finance and UNL agricultural economics seminar participants for their comments.

Notes

1. Rational-expectations bubbles occur when investors realize that prices exceed fundamental value but the probability of a high return exactly compensates investors for the probability of a crash. For a review of the theoretical literature on rational expectations bubbles, see Camerer (1989).
2. Asymmetry occurs when the correlation properties of a time series differ through time.
3. Annual price changes are used because they are most likely to show asymmetry. The value per acre of land and buildings is used because the value per acre of land alone is available only from 1950 to the present.
4. This log-likelihood function includes the density term for completed runs only. According to McQueen and Thorley (1994), partial runs can be ignored in large samples.
5. A Lagrange multiplier test of the exponential model against the Weibull model indicated that the null hypothesis (the exponential model was the correct model) could be rejected for both Iowa and Nebraska. However, a Lagrange multiplier test of the Weibull model against a more generalized gamma distribution indicated that the null hypothesis (the Weibull model was the correct model) could not be rejected for either Iowa or Nebraska. Therefore, the Weibull model was selected for both Iowa and Nebraska.
6. For the purposes of duration dependence tests, a run of 4 is also considered to be a run of 3, 2, and 1. This convention is used so that the hazard rates give the expected probability of a price decrease given the prior sequence of x price increases or decreases.
7. A transition probability is the probability that the change in the series is negative (positive) given that the change was negative (positive) in the previous three periods.
8. Note that I_t is invariant to monotonic transformations of R_t.
9. $\{I_t\}$ is a stationary series because it was created from the first differences of Iowa and Nebraska land values, which were found to be stationary by virtue of unit root tests.
10. Using a two-state second-order Markov chain model, the null hypothesis could not be rejected for Iowa, but it could be rejected for Nebraska. The findings of the second-order model were consistent with McQueen and Thorley's (1991) results using a second-order model to study pre-World War II stock-market returns. They conjectured that the second-order model was not appropriate for the prewar period that was characterized by relatively long runs of "good" and "bad" years and suggested using a third- or fourth-order model. For each state in this analysis, there are a total of 31 runs during the years spanning 1910 to 1995 (Table 1). For Iowa, 64.52 percent of the runs last two years or less; for Nebraska, 67.74 percent of the runs last two years or less. Given that nearly one-third of the runs in each state last three years or more, a third-order Markov chain was ultimately chosen for this analysis.
11. Ignoring the initial states, the maximum likelihood (8) and (9) are related to the mean and variance of the binomial distribution.
12. The number of price changes is 82 instead of 85 because price changes from three years were dropped from the sample in order to create a third-order chain.
13. A nonstationary time series is time irreversible by definition.

14. It is possible to test for time reversibility in higher moments, but according to Ramsey and Rothman, the estimates for higher moments have high standard errors.
15. Bicovariances are third moments of a time series.
16. The standard-error bounds widen as the number of lags grows; this is a general feature of the estimated standard deviations for pure autoregressive models.

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