Spring 1998

Timber price trends

Jack Lutz
University of New Hampshire, Durham

TIMBER PRICE TRENDS

BY

Jack Lutz
BSF, University of New Hampshire, 1976
BS, University of New Hampshire, 1976
MM, Northwestern University, 1980

DISSERTATION

Submitted to the University of New Hampshire
in Partial Fulfillment of
the Requirements for the Degree of

Doctor of Philosophy

in

Natural Resources

May, 1998

UMI Number: 9831956

This dissertation has been examined and approved.

Dissertation Director, Dr. Theodore E. Howard, Associate Professor of Forestry Economics

Dr. John M. Halstead, Associate Professor of Resource Economics

Dr. Lawrence C. Hamilton, Professor of Sociology

Dr. Harold W. Hocker, Professor Emeritus of Forestry

Dr. Bruce E. Lindsay, Professor of Resource Economics

1/15/98

Date

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ABSTRACT

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Jack Lutz
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Timber price forecasts are important components of timberland investment analysis. Econometric models used in forecasting timber prices can be complex because demand for timber is derived through demand for other products such as paper and housing. In contrast to econometric methods, time series analysis or *autoregressive* techniques allow price forecasts to be made from the timber price series themselves.

A necessary condition for using time series techniques is that the timber price series be *stationary* or *mean-reverting*. The primary hypothesis in this study was that timber prices *would not* be stationary and time series techniques *could not* be applied to their analysis. A secondary hypothesis was that shocks to timber prices occur so frequently that prices would not have a chance to revert to a mean and so statistical tests would not show that timber prices are stationary.

Four commonly used tests for stationarity were applied to eleven timber price series to test the primary hypothesis and a list of timber shocks was developed to test the secondary hypothesis. The stationarity tests indicated that all of the price series were either first or second difference stationary. However, the stationarity tests tested only for a constant *mean*, and not for a constant variance. Charts of all the price series indicate that the variability of each series has changed over time. Since a constant variance is a

required condition of stationarity, this result suggests the primary hypothesis should not be rejected.

Operations control chart techniques were used to analyze the changing variances and to determine if recent subsets with fixed mean and variance existed. All eleven price series were first difference stationary over some recent subset of years. The primary hypothesis *can* be rejected for the most recent subsets of all the price series tested.

The subsets of the price series suggest the existence of breakpoints in the series. It was then hypothesized that breakpoints common to several price series might indicate timber price shocks. Breakpoints were selected on an *a priori* basis by studying the behavior of the level price series. Sharp changes in direction or volatility were chosen for testing with Chow's breakpoint test.

Common breakpoints were compared to the list of possible shocks developed to test the original secondary hypothesis. The breakpoints did *not* correspond well to any shocks. This points to a limitation in using time series analysis: changes in the underlying process producing the price series can be identified as having occurred, but it is not possible to determine the cause of that change. Econometric techniques might be useful in identifying the causes.

INTRODUCTION

Timber price forecasts are an important component in timberland investment decisions. Examples of the decisions depending in part on timber prices are:

1. Acquisitions—what price should be paid for this property?
2. Hold/Sell Decisions—is this property providing adequate returns (hold) or are the returns too low (sell)?
3. Strategic Dispositions—when dispositions are due to an imbalance in a portfolio or the cash needs of a client, which property or properties should be sold and what price should be received for this property?
4. Forest Management Planning—how can operating plans and budgets be fine-tuned to maximize returns in anticipation of fluctuations in timber prices?

Most timberland investment decisions are based on a projected rate of return—usually an internal rate of return (IRR)—for the property. The projected IRR is calculated from the actual or hypothetical investment in the property and projected cash flows. The cash flows consist of two pieces: annual revenues and a "residual" value. The annual revenues are primarily generated by timber sales. The "residual" value is the value of the property at the end of the investment period, and represents the cash received from the actual or hypothetical sale of the property. A substantial portion of this "residual" value is the value of the standing timber on the property at that time.

Both of these cash flow components depend heavily on timber price projections. In summary, accurate prediction of revenues and standing timber values requires accurate prediction of timber prices.

The purpose of this research is not to actually forecast timber prices, but to determine if time series analysis techniques can provide useful information for forecasting timber prices. Four steps are involved in this process:

1. Determine if the price series are *stationary* (or *mean-reverting*)—that the series have fixed means and variances over time. This is a necessary condition for using time series techniques.
2. Determine if there are any significant changes in the process generating that price series—any *breakpoints*—over the life of the series. Understanding the long-term behavior of the price series is important in long-term forecasts. However, if there have been recent changes in the behavior of the price series, this difference in behavior can be important in making near-term price forecasts.
3. Determine if the most recent process generating the timber price series is stationary. If the most recent trend is stationary, time series techniques can be used in developing the near-term forecast for the timber price series.

4. Identify breakpoints common to a number of price series. Any breakpoints common to several different price series may indicate significant *timber price shocks*. An understanding of past shocks and the impacts they have had on prices may allow the price forecaster to identify or anticipate similar shocks as they occur in the future, and incorporate those impacts into timber price forecasts.

CHAPTER I

METHODOLOGY

Two widely accepted modeling techniques are available for analyzing timber price trends: econometric models and time series (*autoregressive*) models. The type of model used depends on the objective of the analysis and, to some extent, the data available. The rationale for using time series models in this research is to evaluate the potential for using time series techniques to forecast timber prices.

Econometric models use economic theory and judgment to select one or more independent variables (e.g., Gross Domestic Product (GDP), lumber production or lumber prices) that help to explain the behavior of a dependent variable (e.g., timber prices). The research and thinking required in developing the model—before data are ever entered into a computer—can be as useful as any coefficients calculated for any equation. Time series models rely entirely on the past behavior of the dependent variable itself. There is no need to understand why the variable behaves the way it does.

A danger in the use of either type of model is to assume that once it is created or "solved" it can be used forever. However, the model is "good" only as long as the fundamental relationships among the variables do not change. Econometric models may provide better information on the state of these fundamental relationships. Monitoring such statistics as correlation coefficients and covariance can alert the modeler to structural changes in the relationships. With a time series model, there are no other data to watch, no indicators that the structure behind the dependent variable has changed. In this sense, an econometric model might be superior to a time series model in anticipating changes in timber price behavior.

However, there are some difficulties in using econometric models to forecast timber prices. Their strength in using other variables to explain the behavior of the dependent variable is of less use here than in other models—econometric models attempting to explain timber price behavior can be very complex.

The volumes of timber demanded and supplied are usually represented as a function of price and other factors:

$$Q^D_{timber} = f(P_{timber}, X_1, X_2, \ldots X_n)$$

$$Q^S_{timber} = f(P_{timber}, Y_1, Y_2, \ldots Y_n)$$

Where $Q^D{}_{timber}$ is the quantity demanded, $Q^S{}_{timber}$ is the quantity supplied, P_{timber} is the price offered/asked, and the X's and Y's are other factors.

By rearranging these equations, given a quantity, we can solve for price. For example, the demand equation above would become:

$$P_{timber} = f^{-1}(Q^D_{timber}, X_1, X_2, \ldots X_n)$$

Forecasting timber prices would depend on the forecast for the quantity demanded and the forecasts for all the other factors in the equation. Each forecasted variable would have some range of uncertainty around its forecast, and would contribute to the range of uncertainty around the forecast around the timber price. An equation would have to be developed for each species and product (i.e., pulpwood or sawlog) to be forecast.

The complexity depends in part on the requirements of the forecaster. It may be possible to create aggregates such as "softwood lumber" or "Douglas-fir logs" and reduce the number of equations needed in forecasting. On the other hand, Resource Information Systems, Inc. (RISI) of Bedford, Massachusetts, a major commercial forecasting service specializing in the forest products industry, uses over 50,000 equations in developing its forecasts for pulp and paper, lumber, panels and timber (Young 1997).

Sohngen and Haynes (1994) used an econometric approach in studying Douglas-fir stumpage prices. The demand for timber is a derived demand, and the price for timber should be a function of prices of products for which timber is used. For example, the demand for Douglas-fir sawlogs is derived from the demand for Douglas-fir lumber, plywood and log exports. They suggested the following model for Douglas-fir stumpage prices:

$$P_{stump} = f(P_{lum}, P_{ply}, P_{\log ex}, \text{cos}ts)$$

where P_{stump} is the price of stumpage, P_{lum} is the price of lumber, P_{ply} is the price of plywood, P_{logex} is the price of log exports, and costs are the manufacturing costs for converting stumpage into lumber or plywood. They were looking at past behavior and not explicitly forecasting future prices.

Using a model like this, forecasts of stumpage prices would be a function of the forecasts for lumber, plywood and log export prices (and conversion costs). But how would *those* forecasts be developed?

The demand for Douglas-fir lumber and plywood is derived largely from the demand for housing starts and repair and remodeling of existing housing. However, since the pulp and paper industry in the Pacific Northwest is dependent upon sawmill chips for its wood fiber supply, the demand for Douglas-fir sawlogs is also derived to some extent from the demand for chips, which in turn is derived from the demand for pulp and paper. In turn, the demand for paper in the United States is highly correlated with GDP.

The demand for Douglas-fir export logs is derived from the demand for fiber in Pacific Rim countries, primarily Japan, with Korea and Taiwan being other principal destinations. The relative strength of the economies (and monetary policies) in these countries can affect exchange rates and prices, which can affect prices for imported wood products.

If at any time the volume of Douglas-fir supplied is less(/more) than the demand, the price will rise(/fall). However, if the price for Douglas-fir rises enough, lumber made from other species (e.g., western hemlock, southern pine, red spruce, radiata pine) will be substituted for Douglas-fir lumber. Douglas-fir plywood may also be replaced by other products such as southern pine plywood and oriented-strand board (OSB).

Further discussion of the complexities of timber price forecasting using econometric models may be found in Appendix A.

In summary, to forecast timber prices using econometric models, several other variables must be forecast, either explicitly or implicitly. The forecast for each variable would have some uncertainty around it that would add to the uncertainty around the forecast for the timber price variable. Each timber species and product combination to be forecast must have its own model. Perhaps the most complex relationship would be forecasting the substitution among species. The result is that a large number of models and variables are necessary for forecasting timber prices.

One of the strengths of a time series or autoregressive model is that it does not depend on forecasts of other variables. Therefore, while econometric models are useful in understanding the behavior of timber prices, the complexities involved in forecasting a number of different timber prices suggest it may be worthwhile to consider time series models as an alternative means of forecasting timber prices.

Time Series Models

Time series or autoregressive models rely only on previous data in the series. A key requirement in the use of these models is that the process generating the data does not change over time. There are three general possible results which may obtain—a time series could be classified as one of the following models:

1. Trend Stationary or Mean-Reverting
2. Random Walk
3. Random Walk with Drift

If a stochastic process that produces a time series is fixed in time, it is a trend stationary process (Figure 1). The mean of a trend stationary process is fixed (hence the alternate term *mean-reverting*), and the variance and covariance of the process are also fixed. It is most desirable that a series to be modeled is stationary as this allows the building of an equation with fixed coefficients that can use past data to predict future results.

A random walk (Figure 2) model does not have a fixed mean. It is not possible to develop an effective forecasting model of a random walk process. The forecast value for the next period is always the value of the current period—next year's timber price is the same as this year's timber price. However, the confidence intervals around the forecast increase rapidly as the forecast is extended further in time, resulting in a forecast that is of little value.

A random walk with drift (Figure 3) is essentially a random walk process that steadily increases or decreases.

Figure 1—Trend Stationary or Mean-Reverting Time Series

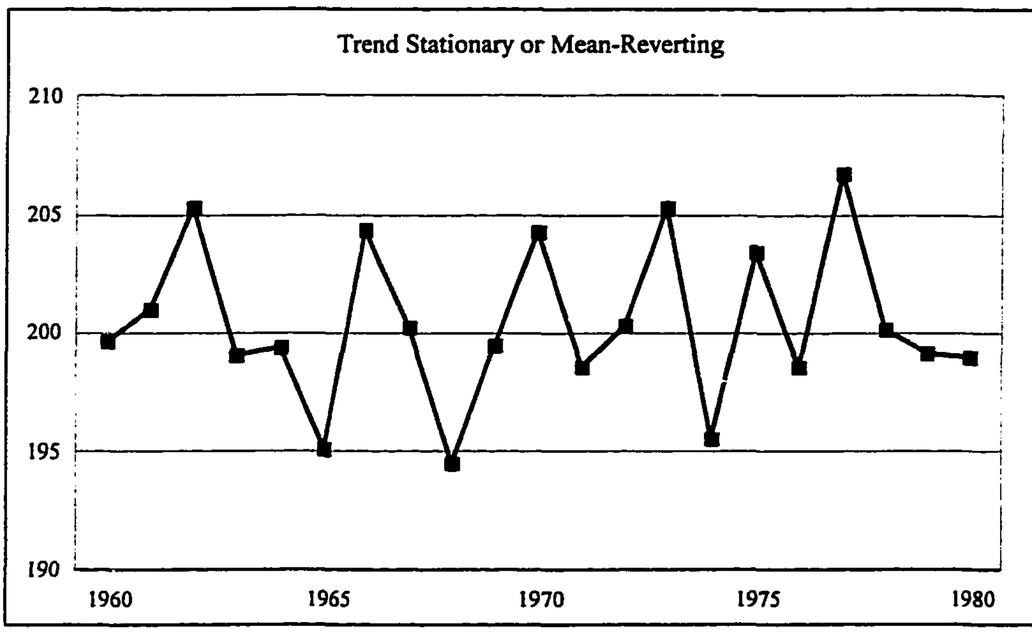


Figure 2—Random Walk Time Series

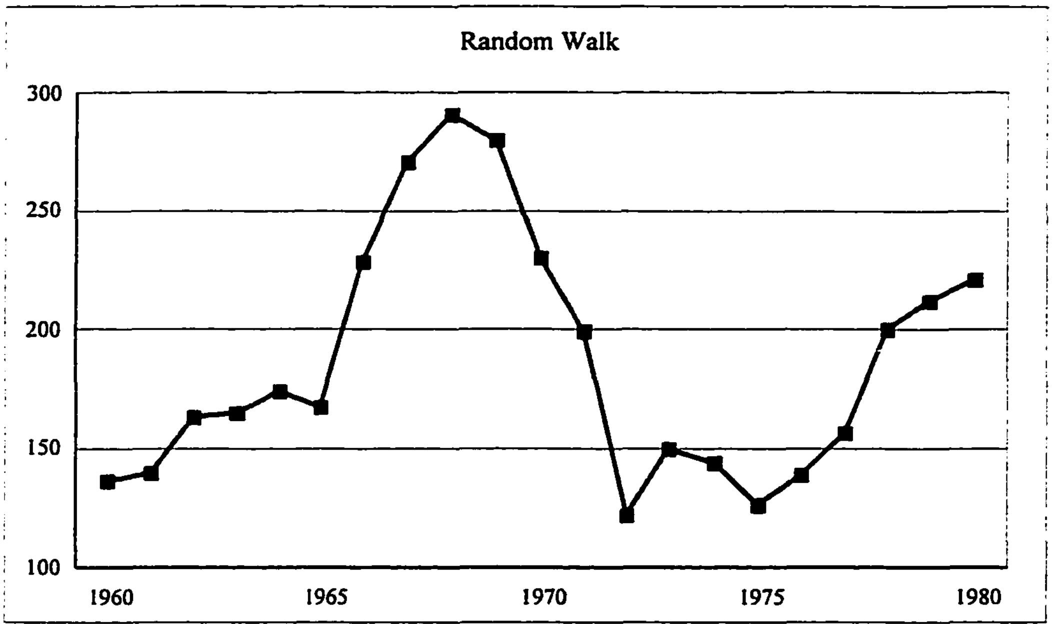
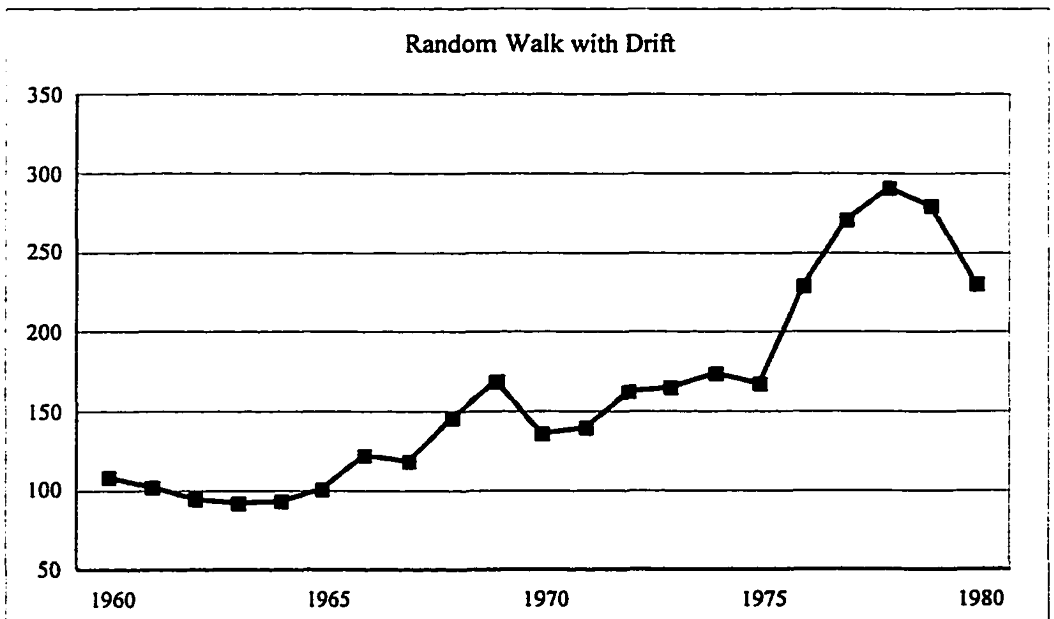


Figure 3—Random Walk with Drift Time Series



Most business and economic series are probably not trend stationary (Newbold and Bos 1990). However, for many such "level" series (the original price series), the *period-to-period changes* or *first differences* will be stationary. This suggests the average change is mean-reverting—the trend in the *change* is fixed. The first difference is calculated by subtracting each previous period price (y_{t-1}) from each price (y_t):

$$x_t = y_t - y_{t-1}$$

where x_t is the first differenced value in time t.

In some cases, the series will need to be differenced more than once to obtain stationarity. The second difference is calculated by subtracting each previous period change from each change:

$$w_t = x_t - x_{t-1}$$

where w_t is the second differenced value in time t. In the second differenced case, the average change in the change is fixed—the acceleration in the price change is constant.

Tests for Stationarity

There are several stationarity tests available.

Durbin-Watson Statistic

The Durbin-Watson statistic is frequently used to test for autocorrelation in econometric models. However, it is not appropriate for use in time series models, as it requires an intercept in the model and prohibits lagged dependent variables. Because time series models are made up of one or more lagged dependent variables, the Durbin-Watson statistic is not relevant.

Autocorrelation Function

One method of testing whether or not a time series is stationary is to develop the *sample autocorrelation function* (ρ_k):

$$\hat{\rho}_k = \frac{\sum_{t=1}^{T-k}(y_t - \bar{y})(y_{t+k} - \bar{y})}{\sum_{t=1}^{T}(y_t - \bar{y})^2}$$

In this equation, ***k*** is the lag value. When ***k***=1, the previous price in the price series is used, when ***k***=2, the next previous price series is used. The value of the autocorrelation function (ρ_k) decreases rapidly as ***k*** increases when a time series is stationary. This relationship occurs because in a stationary series, any value is not dependent upon any previous value, so there is little correlation between time periods. A sharp drop in ρ_k suggests a price may be strongly related to the previous price, but not to the price or prices before that.

There is no clear definition of "decreases rapidly". There is no critical value or test statistic for accepting or rejecting a null hypothesis of no autocorrelation with respect to the value of ρ_k. This leads to a certain level of subjectivity in using this test. An example in Appendix C describes a price series where ρ_k=0 when ***k***=36, and the series appears to have an upward trend, but the series is described as "possibly stationary". However, the series appears to have an upward trend, so further tests are conducted on the series differenced a number of times.

If a series is not stationary, ρ_k can be calculated for the differenced series. In the example mentioned above and discussed in Appendix C, in the first differenced series

ρ_k=0 when k=2, in the second differenced series ρ_k=0 when k=1. The conclusion is that differencing once or twice would produce stationarity in the series.

Partial Autocorrelation

A second test involves calculating the *sample partial autocorrelation of order **k***: Partial autocorrelation (ρ_k) is calculated by regressing y_t on $y_{t-1}, \ldots y_{t-k}$.

A equation for calculating ρ_k is:

$$r_j = \hat{\phi}_{k1} r_{j-1} + \hat{\phi}_{k2} r_{j-2} + \ldots \hat{\phi}_{kk} r_{j-k}, \rightarrow j = 1,2,\ldots,k$$

where ϕ is the autoregressive parameter. For moderately large sample sizes, the sample partial autocorrelations are distributed approximately normally with a mean of zero and a standard error of $n^{-1/2}$, where n is the sample size (Newbold and Bos 1990). The test for stationarity is a two step process. The partial autocorrelation function is plotted along with upper and lower limits of $\pm 2\ n^{-1/2}$. Then the number of plotted values exceeding the upper and lower limits are counted. If most of the plotted values do not exceed the two-standard error limits, the series should be considered stationary. There are, however, no test statistics or critical values against which to compare the number of plotted values that exceed the limits.

Unit Root Tests

Another group of tests is the unit root tests. If a series has a unit root, it is not stationary. Two unit root tests are used: the Augmented Dickey-Fuller (ADF) test and the Phillips-Perron test.

The ADF test regresses the first difference of the price series, Δy_t, against a single lagged price, $\beta_1 y_{t-1}$, one or more lagged first differenced prices, $\beta_x \Delta y_{t-x}$, and an error term ε_t:

$$\Delta y_t = \beta_1 y_{t-1} + \beta_2 \Delta y_{t-1} + \varepsilon_t$$

A constant and a trend may be included in the regression.

The null hypothesis in the ADF test is that the series has a unit root. This is accepted or rejected by testing the statistical significance of β_1 (the coefficient of y_{t-1}). If the coefficient is significantly different than zero, the null hypothesis is rejected and the price series is assumed to be stationary.

The Phillips-Perron test also tests the hypothesis that $\beta = 0$ in the equation:

$$\Delta y_t = \mu + \beta_1 y_{t-1} + \varepsilon_t$$

Unlike the ADF test, there are no lagged difference terms. The equation is estimated by ordinary least squares (with the optional inclusion of constant and time trend) and then the *t*-statistic of the coefficient is corrected for serial correlation in *t*.

Tests for Constant Variance

A short-coming of all the stationarity tests is that they are testing for only for a constant *mean*. However, a key assumption of stationarity is that the variance is also constant. Graphs of the first difference of the price series analyzed suggest that the volatility of all the series has changed over time, but a statistical method is needed to confirm this.

Shewhart Control Charts

One method of testing to determine whether the underlying process is changing is to use Shewhart control charts. These charts were popularized to a great extent through the quality control work of W. Edwards Deming (Scherkenbach 1987). They are commonly used in manufacturing to track such factors as defects or manufacturing tolerances or production rates. Production results (e.g., defects per thousand or units per hour) are compared to the average and control limits, which are usually set at plus or minus three standard deviations. Changes and trends within these limits are considered "in control", though quality control programs may focus on narrowing the limits. Observations outside the limits are of serious concern to production engineers. Most charts illustrate means of processes, but there are charts for analyzing variance.

In this study, instead of a "production" process, we are analyzing a "price" process. Instead of monitoring the size of a hole drilled in a pipe or the amount of time required to attach a resistor to a circuit board, we are monitoring the size of a timber price or the size of a *change* in a timber price. A key difference between production and price processes is that there is nothing we can do to narrow the control limits or adjust the process to cause the prices to remain "in control".

Many variations of the control chart technique exist. Testing here was done using a modification of Nelson's (1982) method that compares the individual observations to control limits of approximately the mean plus or minus three times the moving range. Two sets of control limits are shown here: the mean plus or minus two standard deviations (σ) of the observations and the mean plus or minus 2.576σ. The control limits of the mean plus or minus 2σ contain 95 percent of the observations of a normally distributed population, while the control limits of plus or minus 2.576σ contain 99 percent of the observations. Nelson does not develop a control chart for the range but Ishikawa's (1976) method was adapted to analyze the moving range.

A caveat on the control chart analysis is that use of the technique generally assumes that the data are normally distributed. In the case of the first difference of most timber prices, histograms are generally bell-shaped, but most have thick tails and/or a few outliers. Measurements for skewness, kurtosis and the Jarque-Bera statistic generally do not indicate normality.

A detailed discussion of control charts can be found in Appendix G.

Variance Test

Another test to confirm changes in variance is the variance ratio test (Hicks, 1982). The null hypothesis is that the variances of two normally distributed populations are equal. The variance of one population is divided by the variance of the other and the result is a test F-statistic with degrees of freedom of n-1 for each population. The price series were separated into groups based on information obtained from the control chart analysis and variance ratio tests were conducted. This test may not be definitive in this case because the price series are not perfect normal distributions.

Recent Trend Analysis

Once the start of the most recent trend is identified, it is then possible to test for stationarity in the process generating that subset. It is likely that a recent trend is different than the full-term historic trend. The autocorrelation function must be recalculated, the unit root tests rerun and the variance analyzed to determine if the most recent subset is stationary and what its trend may be. This provides an indication of what future prices may look like and whether or not a trend may last for a shorter or longer period.

Breakpoints

The tests above will determine whether the mean and/or variance of a series (or one of its differences) or a subset of a series is constant. But, do subsets of the timber price series behave differently than the entire series? It is unlikely that the processes underlying these price series have not changed in a century. Technological changes and macroeconomic shocks are likely to have had some impact.

Studies of financial data series (see Appendix B) have found, in some cases, that long-term data series may be stationary while shorter-term data series are not. Just the opposite may be true of timber prices. It is possible that while variances have not been constant for 50 or 100 years, they may be constant over a shorter period. If this *is* the case with timber prices, it would be important to determine the extent of such subsets. The starting and ending points of subsets are found by determining *breakpoints* in the price series.

A standard method for determining breakpoints is to use Chow tests (Sohngen and Haynes 1994), a two step process. First, a model or equation must be fitted to the data. The model must have one or more lagged price variables and an error term and may contain an intercept as shown in the equation here:

$$y_t = a_0 + a_1 y_{t-1} + \varepsilon$$

where y_t is the current price, a_0 is the intercept, y_{t-1} is the previous price, and ε is the error term.

The second step is to select breakpoints on an *a priori* basis. This was done by looking at charts of the price series and selecting years where it seemed that changes in the behavior of the series occurred—where prices turned sharply up or down, for example.

The Chow test divides the price series into groups above and below the breakpoint. The test then determines if the coefficients of the independent variables are constant across the subsets—whether the subsets both/all exhibit the same trends. The equation is fitted separately to each data subset. The residual sum of squares for each subset is summed with the others to obtain the unrestricted sum of squares and the restricted residual sum of squares is calculated from the full series. The F-statistic indicates the strength of the relationship between the two.

Some cautions are in order when using and interpreting the results of the Chow test: many different points can be significantly different than zero—the test indicates that the process below the selected point is different than the process above the selected point, but it does not necessarily indicate that the selected point is where the process changes. It is possible that several points on either side of the *a priori* breakpoint could test as significant. For example, 1972 may be selected *a priori* as a breakpoint and test as significant, but 1971 or 1973 or 1974 could also have been selected and test as significant. In this case, *all four* years would not be breakpoints, but *any* of the years could be a breakpoint. The Chow test answers the question "Is this a breakpoint?", it does not answer the question "Where are all the breakpoints?".

In addition, a combination of a number of closely spaced breakpoints may be indicated as statistically significant. Chow's breakpoint test requires a minimum number of data points between breakpoints—each data subset must contain more observations than the number of coefficients in the equation being estimated. The degrees of freedom for each subset are equal to ***n-k***, where ***n*** is the number of observations in each subset and ***k*** is the number of variables in the coefficients. The EViews™ statistical package used in the analysis of the price series deals with this issue by refusing to calculate breakpoints if there were too few data points.

Shocks

Understanding the type of events that cause a change in the underlying price process may help identify future breakpoints as they are encountered, or shortly thereafter, and allow adjustment of confidence intervals around forecasts. For example, if significant breakpoints are always found at the beginning of recessions, a forecast could be modified in anticipation of a recession. Breakpoints that are common among several price series could indicate a significant technological or macroeconomic shock. This will help indicate which shocks were significant and indicate where breakpoints might be found in other price series.

CHAPTER II

DATA

Four long-term price series (80-100$^+$ years long) and dozens of "short-term" price series (over 45 years long) were readily available for this study. A brief description appears here. A more complete description and discussion of the quality of the data can be found in Appendix D.

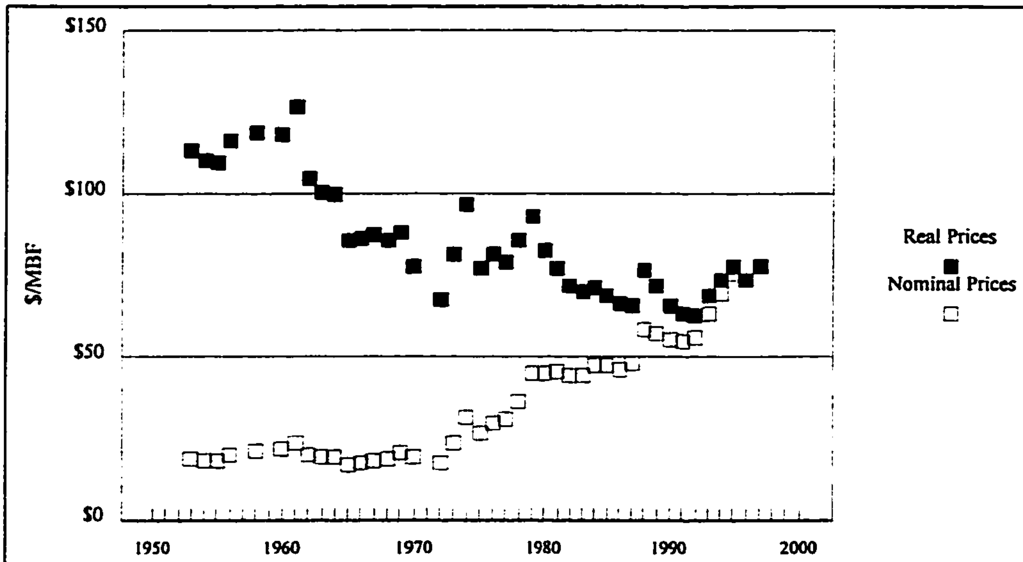
Real Prices

All price series were deflated—inflation was removed—before the analysis was conducted. The deflator used is the Consumer Price Index—Urban Worker (CPI-U) series produced by the US Department of Commerce Bureau of Labor Statistics, with 1996 as the base year (1996 = 100.0). The CPI-U was not actually reported back in 1890, but rates of change from other CPI indices were used to extend the CPI-U back to that time. This series was developed by Dr. Courtland L. Washburn at the Hancock Timber Resource Group (HTRG).

It could be argued that it is more appropriate to use a producer price index (PPI) to deflate timber prices because timber is used in the production of other goods and is not usually purchased directly by consumers. However, the CPI-U was used in this study because there was no readily available PPI series extending back to 1890. Moreover, the CPI and PPI are highly correlated.

Real prices were used to examine the behavior of timber prices without the impact of inflation. Since the inflation rate has generally been positive over the last century, analyzing nominal prices could have had either of two impacts: any price series exhibiting a negative real trend could exhibit stationarity (constant mean) when inflation was added in, and any real price series exhibiting stationarity could exhibit a positive trend with inflation added in. This is illustrated in Figure 4 which shows that nominal prices appear to increase over time, while the real (deflated) prices appear to decrease.

Figure 4—Comparison of real and nominal prices (New York white pine sawtimber stumpage prices)



Source: New York Division of Lands and Forests

Figure 4 also suggests that inflation might increase the volatility of timber prices. For example, the differences between the nominal prices during 1970 through 1975 appear to be greater than the differences between the real prices during that period.

Annual Prices

Annual prices were used for four reasons: 1) long series of annual prices are readily available, 2) some series are only available on an annual basis, 3) analysis of periods less than one year must take seasonality into account and 4) projections for timberland investments returns are long-term (10-50 years) and usually require forecasts of annual average prices.

Price Series Selection

The price series analyzed were chosen based on availability and relation to the other series used.

Long-term Price Series

The limited number of long-term series dictated that all four such series be used. These four series consisted of 1) Douglas-fir sawlog prices from the Pacific Northwest (PNW) Westside, 2) southern pine sawtimber stumpage prices, and 3) cut and 4) sold prices for Douglas-fir sawtimber stumpage from United States Forest Service (USFS) PNW Westside National Forests. These two species are utilized heavily in construction and are substitutes for each other to some extent.

Table 1 provides a summary of the four long-term price series.

Table 1—Long-term Data Series (80-100 Years)

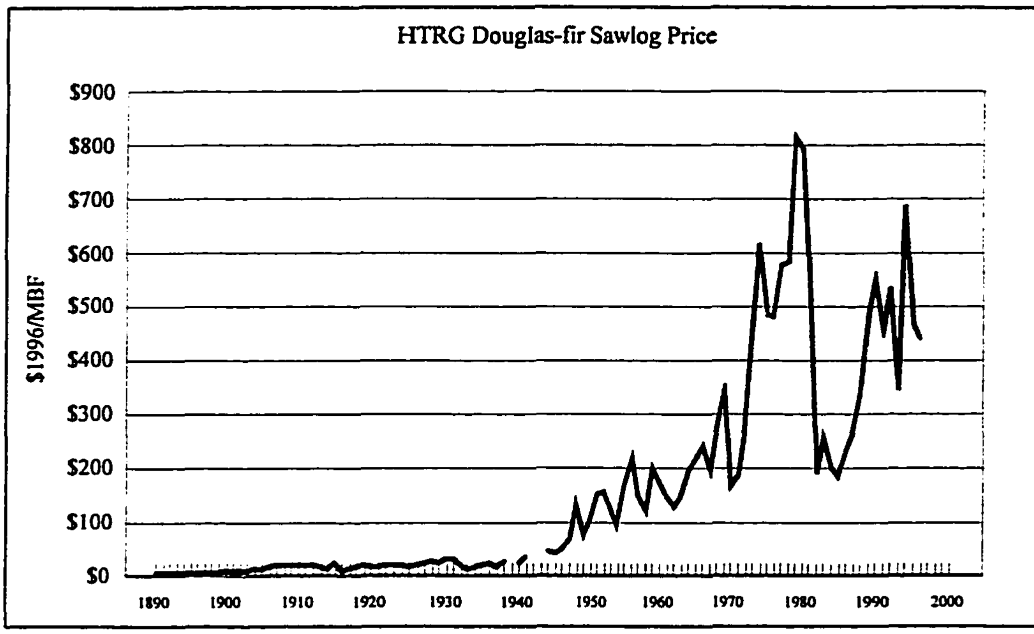
Price Series	Series Length	Series Source
PNW Westside Douglas-fir Sawlog	1890-1996	Hancock Timber Resource Group (HTRG)
Southern Pine Sawtimber Stumpage	1890-1996	HTRG
USFS PNW Westside Douglas-fir Cut Price	1910-1996	USDA Forest Service (USFS), Sohngen & Haynes
USFS PNW Westside Douglas-fir Sold Price	1910-1996	USFS, Sohngen & Haynes

An initial look at the four charts suggests timber prices are not stationary, as all four show upward trends (Figure 5 through Figure 8).

PNW Westside Douglas-fir Sawlog Prices The Douglas-fir sawlog price series was developed by Washburn at HTRG using a mix of private timber sales prices from Washington State and USFS PNW National Forest sales prices (related to those used by Sohngen and Haynes below), and prices from Log Lines™.

Figure 5 suggests three or four distinct periods in Douglas-fir prices. They were fairly low and stable from 1890 until the mid-1940's, when a major change in Forest Service policy resulted in substantially increased harvests from National Forests (Sohngen and Haynes 1994) and post-war consumer demand increased. Prices then rose more sharply from the mid-1940's until about 1970 and exhibited more volatility during that period. Since 1970, Douglas-fir prices have shown extreme volatility. It is possible that the great rise and fall between 1970 and 1985 is a separate period from the period after 1985. It is also possible that the *apparent* increase in volatility after 1970 is not statistically significant, and there is actually a single period from mid-1940's to the present.

Figure 5—PNW Westside Douglas-fir sawlog prices

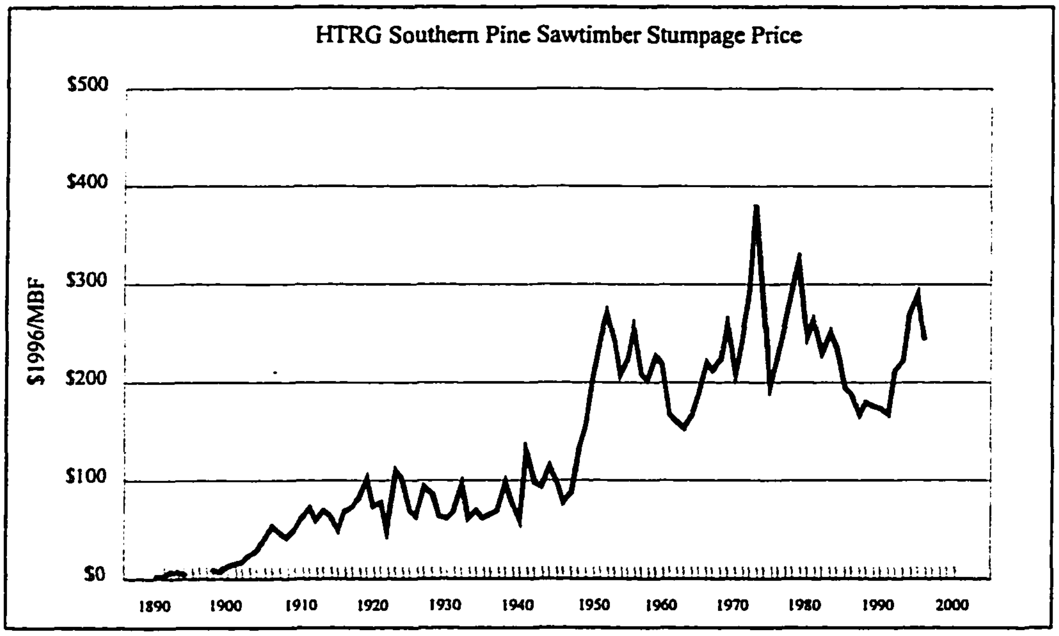


Fitting a trend line to these data is an interesting puzzle. A line fitted in 1975 using data through 1974 would look very different from a line fitted in 1985 using data through 1984. Would a trend line using data from 1946 through 1970 fit the data since 1970?

Southern Pine Sawtimber Stumpage Prices The southern pine sawtimber stumpage price series was also developed by Washburn at HTRG. He used a mix of private timber sales prices, primarily as reported by the State of Louisiana and some USFS southern National Forest data. Prices from Timber Mart-South™ have been included in the mix.

Figure 6 suggests three eras. There is a pre-1905 period with low volatility and prices increasing exponentially. Between 1905 and the mid-1940's, prices increased at a slow rate, but were much more volatile. It appears that the post World War II construction caused southern prices to rise very sharply (1945-1950), then level off at *about* $250/MBF, but they have been very volatile since then.

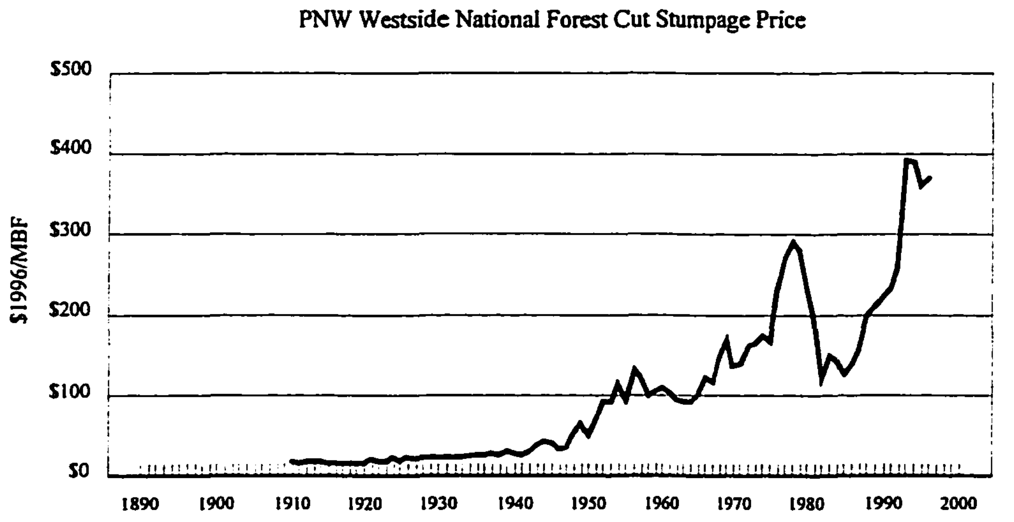
Figure 6—Southern pine sawtimber stumpage prices



<u>USFS PNW Westside Douglas-fir Stumpage Cut and Sold Prices</u> The USFS PNW Westside Douglas-fir cut and sold prices were obtained from Sohngen and Haynes (1994). Additional data through 1996 were obtained directly from the PNW Research Station.

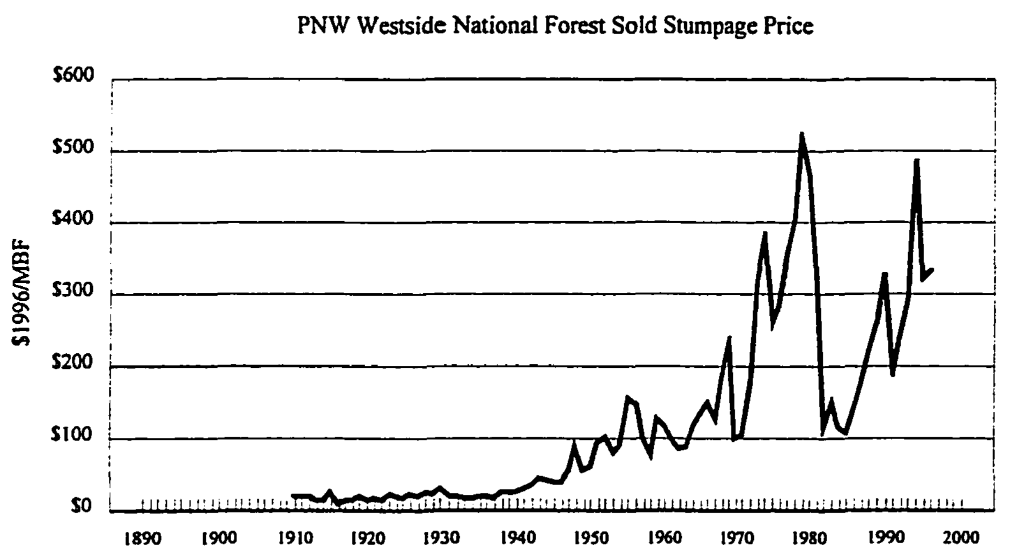
Figure 7 and Figure 8 suggest two distinct periods: 1910 through the mid-1940's, and mid-1940's to the present. While these prices are from the same region as those in Figure 5, they are stumpage prices from National Forests only, while the data from Figure 5 are for sawlogs from several sources.

Figure 7—USFS PNW Westside Douglas-fir stumpage cut prices



Source: Sohngen & Haynes 1994

Figure 8—USFS PNW Westside Douglas-fir stumpage sold prices



Source: Sohngen & Haynes 1994

Short-term Price Series

Table 2 summarizes the shorter-term data series sets used. The ponderosa pine stumpage sold price series from Pacific Southwest (PSW) National Forests was chosen because it was readily available, and covered a different region and different end markets than the four long-term price series. Douglas-fir and southern pine are used extensively as structural components in housing construction, while ponderosa pine is heavily used in millwork—doors and windows. All three species are used in new housing construction, but ponderosa pine would make up a greater portion of the wood used in remodeling and repair.

Southern pine pulpwood stumpage prices from Louisiana were used because they are likely to behave differently from sawtimber prices of any kind. Louisiana southern pine sawtimber prices were included to see if they behaved any differently than the long-term southern pine price series, which utilizes both the Louisiana data and some USFS data.

Four price series were selected from New York data. A sugar maple price series was included to provide some information on hardwoods in general (many other hardwood species price series are available from New York). Sugar maple prices are reported by the State of New York as *hard* maple, a term commonly used by the forest products industry in the northeastern United States. Sugar maple is referred to hereafter as hard maple. Red spruce sawtimber was selected because it is a substitute for southern pine and Douglas-fir in housing construction. Eastern white pine sawtimber was selected because it can substitute for ponderosa pine. Finally, spruce/fir pulpwood was selected to compare its behavior with southern pine pulpwood from Louisiana.

Table 2—Short-term Data Series (40-45 Years)

Price Series	Series Length	Series Source
Ponderosa pine sawtimber stumpage	1950-1996	Ulrich 1988, Warren, various
Southern pine pulpwood stumpage	1955-1997	Louisiana Department of Agriculture
Southern pine sawtimber stumpage	1955-1997	Louisiana Department of Agriculture
Hard maple sawtimber stumpage	1953-1997	NY Division of Lands and Forests
White pine sawtimber stumpage	1953-1997	NY Division of Lands and Forests
Red spruce sawtimber stumpage	1953-1997	NY Division of Lands and Forests
Spruce/fir pulpwood stumpage	1953-1997	NY Division of Lands and Forests

Many other series are available (see Appendix D).

Price Series Definitions

Stumpage refers to standing timber, sold "on-the-stump." Logs are usually priced at the delivery point, so log prices should be higher than stumpage prices because they include the cost of harvesting and transporting the wood. Sawlogs and sawtimber refer to larger logs used in producing lumber, in contrast to pulpwood stumpage or logs chipped in the pulp making process.

The PNW Westside region consists (by most definitions) of the areas of the states of Washington and Oregon to the west of the Cascade Mountains. This area receives much greater annual rainfall than the eastern slopes of those mountains, and the forest types differ from each other on each side of the range.

The "sold" price is the price at which National Forest timber sold at the time of the sale. Because Forest Service contracts run for two or three or more years, timber is not always cut in the year it is purchased. The Forest Service also records when the timber is actually cut and calculates the average price of the timber during the year in which it is cut. This is the "cut" price. During times of rising prices, the sold price will be higher than the cut price, as less expensive timber bought in prior years is harvested along with more expensive timber purchased in the current year. As prices drop, the cut price will be higher than the sold price as more expensive timber bought in prior years is harvested along with less expensive timber purchased in the current year.

Treatment of Missing Observations

There are missing data points in several of the series. For example, in the HTRG PNW Douglas-fir sawlog series (Figure 5), no prices are available for 1939, 1942, and 1943. There are also observations missing form the HTRG PNW southern pine sawtimber stumpage series (three points), and all four price series from New York (three points for each of the sawtimber series and seven points for the pulpwood series).

The EViews™ statistical software package used in the analysis adjusts the sample to exclude the missing observations. The package ignores the gap and uses the next available price. In the case of the Douglas-fir sawlogs, the package would not find a price in 1943 or 1942, so it would treat the price in 1941 as the price prior to price in 1944, the 1940 price as the price prior to *that* price, and so on. The *years* are not used in calculations in time series analysis.

This treatment of missing data may be important if the missing prices vary substantially from the prices immediately adjacent. For example, some price spikes in the series analyzed lasted for four or five years. If two or three years of missing data coincided with such a spike, the existence of the spike could be missed.

CHAPTER III

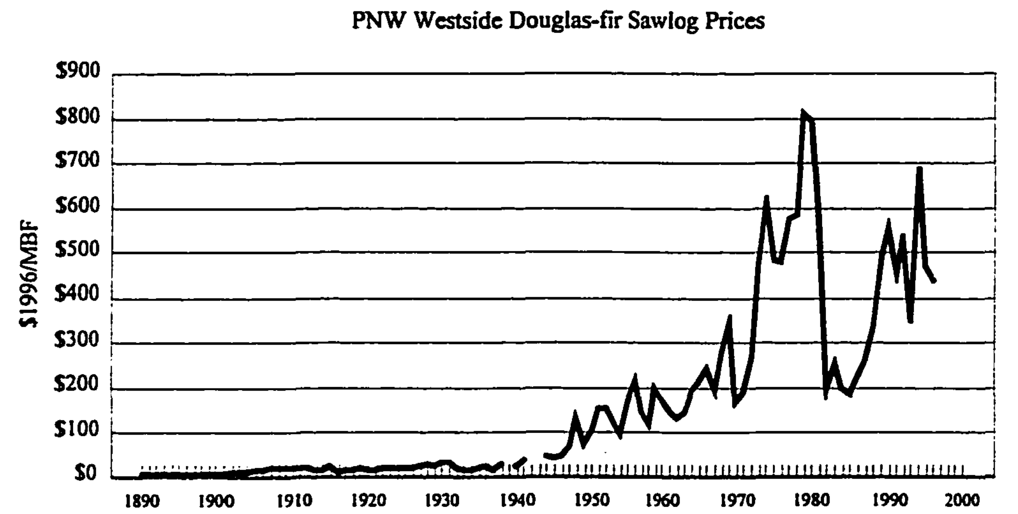
RESULTS

PNW Westside Douglas-fir Sawlog Prices

Stationarity of the Entire Series

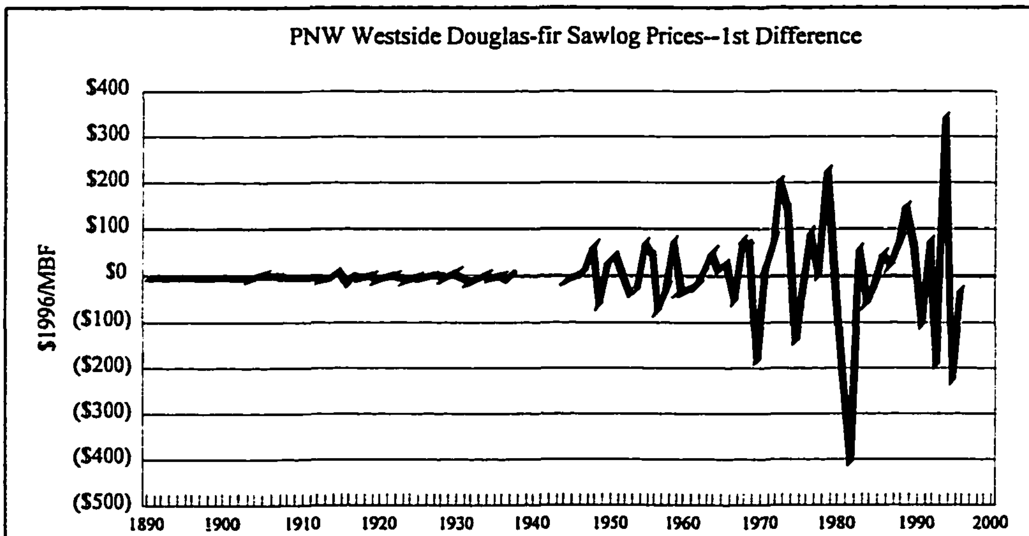
The level and first differenced PNW Westside Douglas-fir sawlog price series are shown in Figure 9 and Figure 10. (Figure 9 is the same as Figure 5 but is presented here again for the convenience of the reader.) Again, the level price series appears to have an upward trend. The first differenced series appears to have a fixed mean approximately equal to zero. However, the variance of the first differenced series appears to increase over time. It is possible that the commonly used stationarity tests, *which test for mean-reversion but not "variance-reversion"*, could indicate stationarity even though the series does not have a constant variance.

Figure 9—PNW Westside Douglas-fir sawlog prices



Source: Hancock Timber Resource Group

Figure 10—First differenced PNW Westside Douglas-fir sawlog prices



Source: Hancock Timber Resource Group

Table 3 summarizes the results of the autocorrelation function and unit root stationarity tests on both the level and first differenced series.

Table 3—Summary of the autocorrelation function and unit root tests on the PNW Westside Douglas-fir sawlog price series

	Series	
Test	Level	First Difference
Autocorrelation Function	maybe	yes
Partial Autocorrelation Function	yes	yes
ADF with Constant	no	***
ADF with Constant and Trend	no	***
ADF with no Constant or Trend	no	***
Phillips-Perron	no	***

*** exceeds 1% critical value
** exceeds 5% critical value
* exceeds 10% critical value

The autocorrelation function test disagrees with the unit root tests for the level series. The level series is indicated as stationary by the partial autocorrelation function, but as nonstationary by the unit root tests.

It is not the purpose of this work to determine which type of test is best for determining stationarity of a series, but it is important to establish a procedure for dealing with the conflicting results. In almost all cases of the price series studied, the autocorrelation function or partial autocorrelation function tests indicate stationarity for the level price series.

This could be considered a "worst-case" assumption for a timberland investor as it indicates that real timber prices are flat over time. This means, over the long term, timber price increases keep pace with but do not exceed the inflation rate, apparently limiting the real rate of return a timberland investor may expect to earn. However, if real timber prices are flat, the value of *well-managed* timberland must increase faster than inflation, because the volume and quality of timber on the timberland will increase over time.

But what if the autocorrelation functions were indicating incorrectly? In almost all cases, if the level series was not indicated as stationary by the unit root tests, then the first differenced series *was*. And, in most cases, both the autocorrelation functions and the unit root tests agreed on the stationarity of the first differenced series. This means that if the price series is not mean-reverting (with a constant mean), then the annual price change is mean-reverting—the annual *change* is constant. In most cases, this fixed change appears to be positive so real timber prices are increasing at some constant rate. This would obviously be more advantageous to timberland investors whose timberland would be subject to real price increases as well as volume and quality increases.

In this case, the level series (Figure 9) indicates an upward trend in prices, which suggests the autocorrelation function test is not a clear indicator. The tests for the first differenced series (Figure 10) all indicate stationarity around a fixed mean of $4.24/MBF. (The change in price each year is $4.24/MBF—on average, each year's price is $4.24 higher than the previous year's price).

Heteroskedasticity in the Series

However, these tests are testing for mean-reversion, but not variance-reversion. Visual examination of Figure 10 indicates an increase in volatility levels around 1945 and again around 1970. This increasing variance (heteroskedasticity) may be of particular importance in the use of the unit root tests. Both the ADF and Phillips-Perron tests use ordinary least squares (OLS) equations to test for stationarity. In the presence of heteroskedasticity, the test statistics are probably too high, indicating that the null hypothesis (stationarity) should be rejected when, in fact, it should not. The unit root tests indicate a unit root for the level series, even in the presence of heteroskedasticity. Any correction for heteroskedasticity would result in lower test statistics, providing no change in the test results.

The first differenced series is indicated as having no unit roots at the one percent confidence level. Assuming heteroskedasticity, the test statistics are too high. While the test statistics currently exceed the one percent critical values (Table 4 and Table 5), the "correct" test statistics will be lower. If the correct test statistics are only slightly lower than the current statistics, the ADF test statistics could still exceed the critical values at the five or ten percent level. A large difference could result in an indication of nonstationarity. A small difference between the current and "correct" test statistics for the Phillips-Perron test could result in no change in the results of the test, as the current statistic is much higher than the critical value.

Table 4—Details of the ADF unit root tests on the PNW Westside Douglas-fir sawlog price series

	R^2	ADF Test Statistic	Critical Value*		
6			1%	5%	10%
Level with Constant	.08	-1.204	-3.502	-2.893	-2.583
First Difference with Constant	.58	**-4.551**	-3.504	-2.894	-2.584
Level with Constant and Trend	.15	-2.954	-4.060	-3.459	-3.155
First Difference with Constant and Trend	.58	**-4.530**	-4.063	-3.460	-3.156
Level with no Constant or Trend	.06	-0.522	-2.588	-1.944	-1.618
First Difference with no Constant or Trend	.58	**-4.528**	-2.589	-1.944	-1.618

*MacKinnon critical values for rejection of hypothesis of a unit root

Table 5—Details of the Phillips-Perron unit root tests on the PNW Westside Douglas-fir sawlog price series

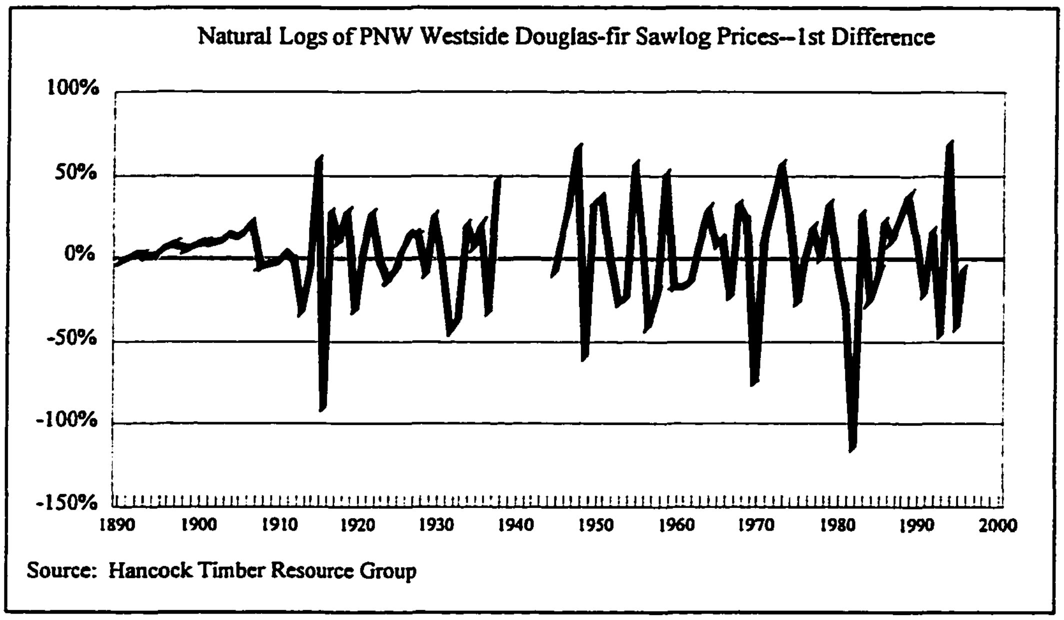
	R^2	PP Test Statistic	Critical Value		
lagged differences = 4 for all			1%	5%	10%
Level with Constant	.01	-0.929	-2.586	-1.943	-1.617
First Difference with Constant	.55	**-11.164**	-3.498	-2.891	-2.582

In summary, while the unit root tests indicate stationarity for the entire first differenced series, the apparent increase in variance renders the test results uncertain.

Natural Logs of Timber Prices

One method of dealing with heteroskedasticity is through log transformation (Gujarati 1978). The first differenced natural logs of the PNW Westside Douglas-fir sawlog prices are presented in Figure 11. It appears that the variance has remained fairly constant since about 1910, with changes generally less than plus or minus 50 percent accompanied by occasional spikes. However, the behavior of the first differenced natural logs of prices before that time seems to be less volatile. As a result, even though the price series has been transformed, we still must deal with heteroskedasticity.

Figure 11—First differenced natural logs of PNW Westside Douglas-fir sawlog prices



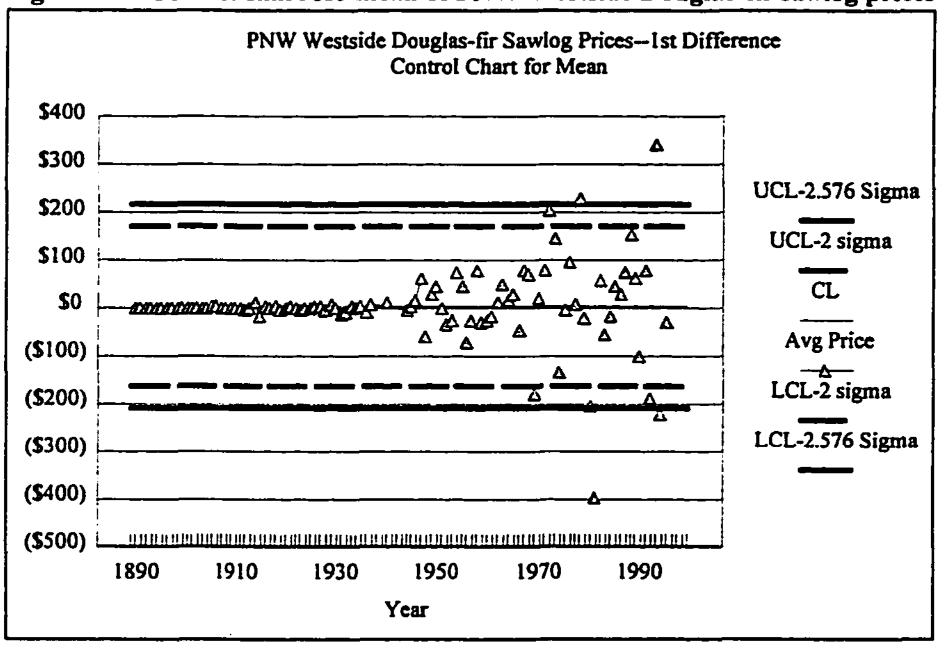
In summary, the first differenced price series and the first differenced natural logs of the price series are subject to changes in variance. However, the variances in both cases do not appear to be constantly increasing, but they increase at a point in time and remain at that increased level over a number of years. If the variance and the mean have been constant over some recent subset of years, then that subset is stationary and can be used in forecasting.

Process Control Chart Analysis

Shewhart control charts were used to determine if there are any recent trends subsets with a fixed variance. Control charts using an adaptation of Nelson's individual measurements method (Nelson 1982) were used to analyze the first differenced price series (Figure 12 and Figure 13). Figure 12 supports the conclusion that the process generating this series has changed over time. Four observations fall outside the 99 percent confidence limits (control lines) while eight fall outside the 95 percent confidence limits. With 101 observations, there should only be one and five outside the limits, respectively. The number of expected observations exceeding the confidence limits is calculated by multiplying the number of observations by the one minus the confidence limit: with 101 observations, the number expected to exceed the 95 percent confidence limits is 101 * (1-.95) = 5.05.

However, all of the "out-of-control" observations have occurred since 1970, and the dispersion of the observations has increased since 1946.

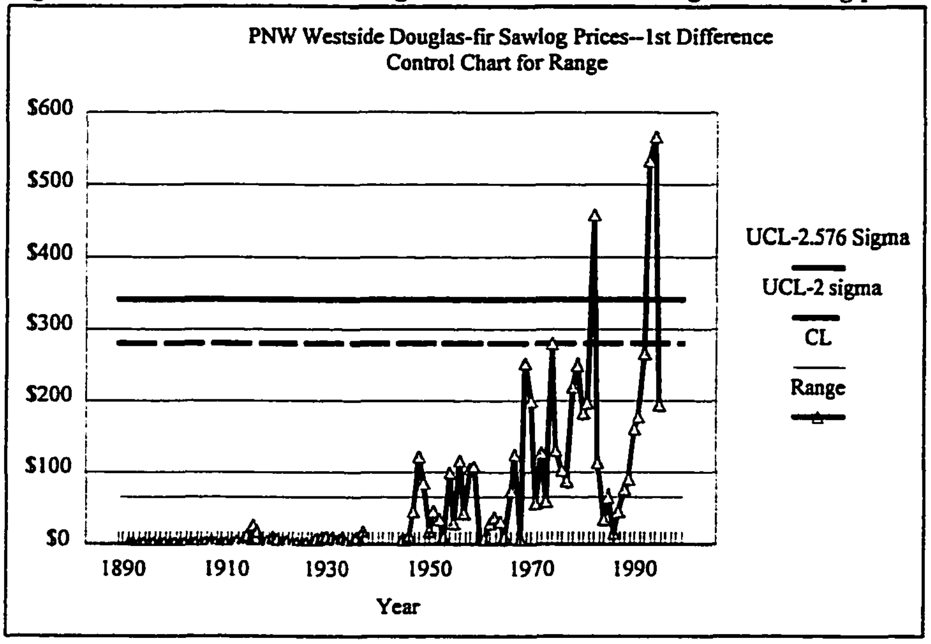
Figure 12—Control chart for mean of PNW Westside Douglas-fir sawlog prices



The control chart for the range (Figure 13) clearly shows a process out of control. While only three of the 98 observations actually fall outside the control line, the distribution of observations is clearly not normal. The first fifty observations (1890-1940) are very close to zero and none come close to the level of the mean. The observations oscillate around the mean between 1945 and 1970, then, except for the

1980's , are generally higher than the mean. The chart shows a process with increasing variance.

Figure 13—Control chart for range of PNW Westside Douglas-fir sawlog prices



Both control charts indicate that the process since 1970 has been out of control in relation to the process before that time. The next step is to determine if the price changes since 1970 have been generated by a stable process. This was done by developing control charts for the price series since 1970 (Figure 14 and Figure 15). Both charts clearly show a process that is stable, but has some fluctuation. The average change in price between 1970 and 1996 is $10.49/MBF. The average change in the average price has been $179.82.

Figure 14—Control chart for mean of recent first differenced PNW Westside Douglas-fir sawlog prices

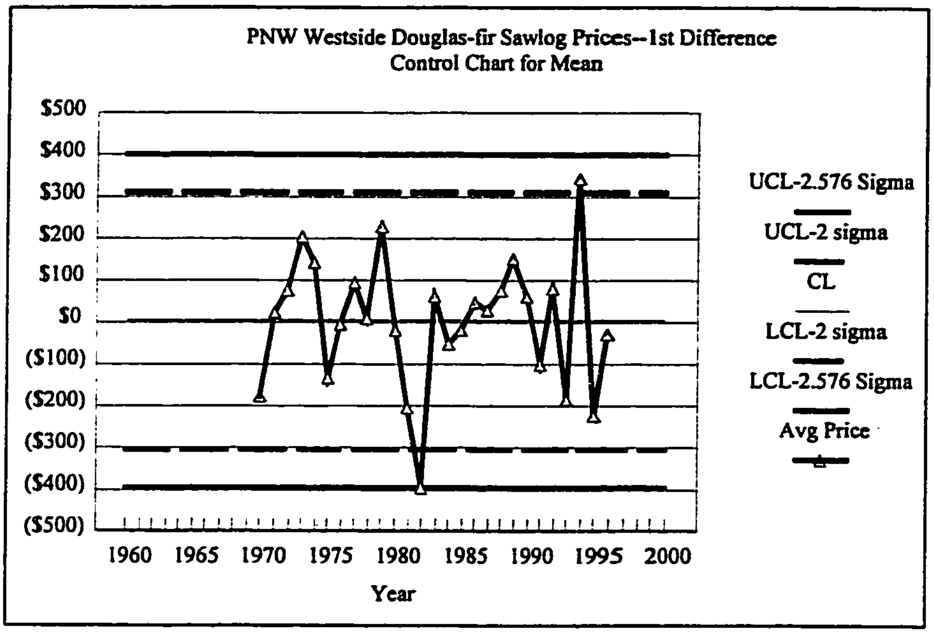
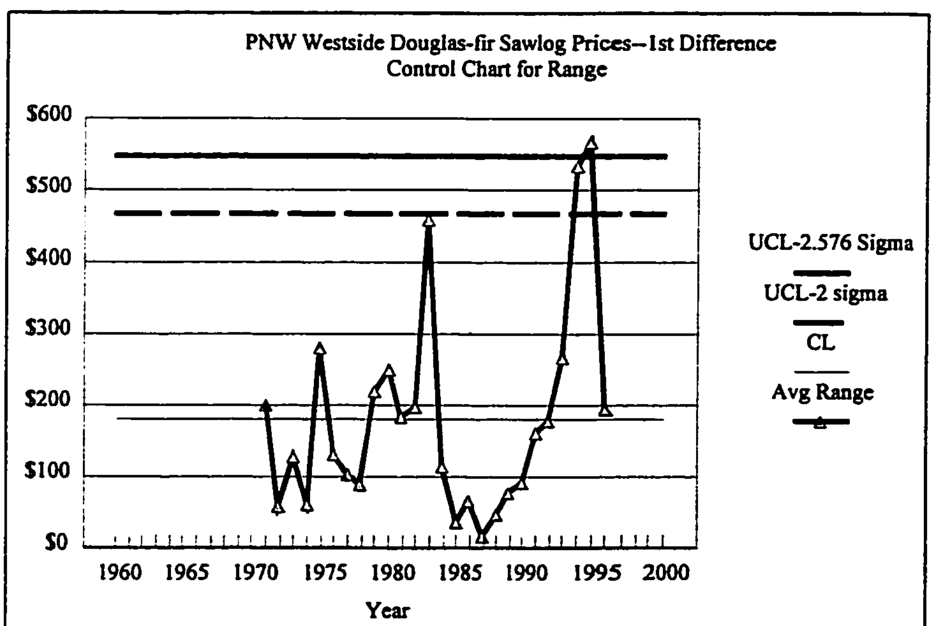


Figure 15—Control chart for range of recent first differenced PNW Westside Douglas-fir sawlog prices



Interpretation of Results

There are two observations outside the 96 percent confidence limits and 1 outside the 99 percent confidence limits in Figure 15. With 27 observations, there should be 1.35 (27*5/100) and 0.27 (27*1/100) outliers, respectively. While the two observations outside the 95 percent confidence limit exceed the expected number of 1.35, another interpretation is that there can be more than one, but not more than two outliers. In other words, if ***k*** is the expected number of observations exceeding the confidence limits and ***n*** is the actual number, we would normally assume a process is out of control if ***n*>*k***. However, since ***k*** is rarely a whole number for any of the series or subsets of series analyzed, this study will use a test of ***n*-1>*k***, where ***k*** is *not* a whole number and ***n*>*k***. where ***k*** *is* a whole number. This can be considered a liberal or optimistic interpretation of the test results, but a review of the charts lends some support to this approach.

In almost all series analyzed, the outlying points are also separated by a number of years, so the outliers do not appear to be part of a trend towards more (or fewer) outliers—the variance is not *increasing*. This separation of the outliers suggests they are the result of independent shocks that do not contribute to an overall trend. Finally, in all subsets of the series, when one or two of the outliers are removed from the series, the series then fits within the confidence limits (Figure 16 and Figure 17). These factors suggest the test of ***n*-1>*k*** is a reasonable test.

Figure 16—Control chart for mean of recent first differenced PNW Westside Douglas-fir sawlog prices—outliers removed

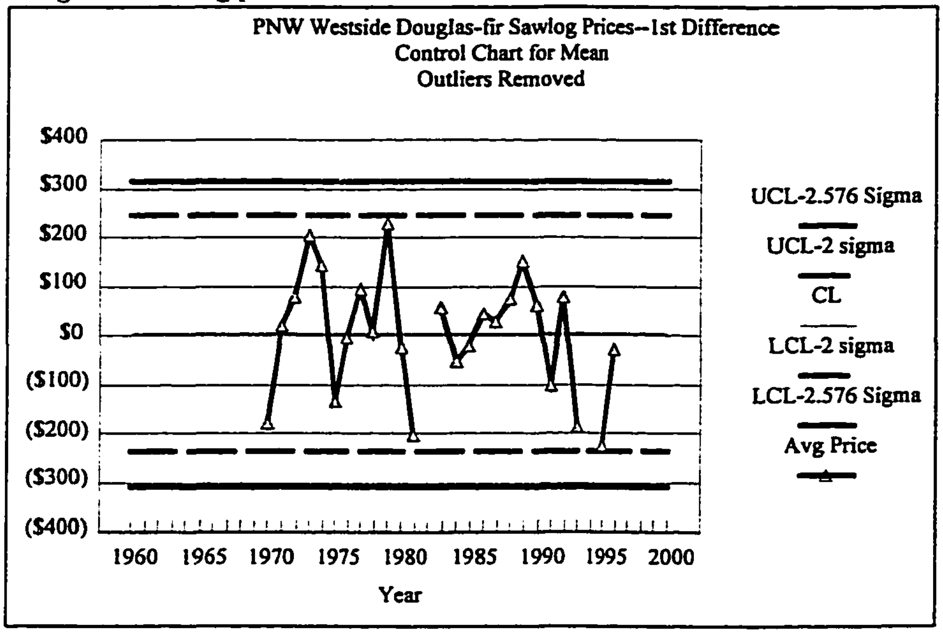
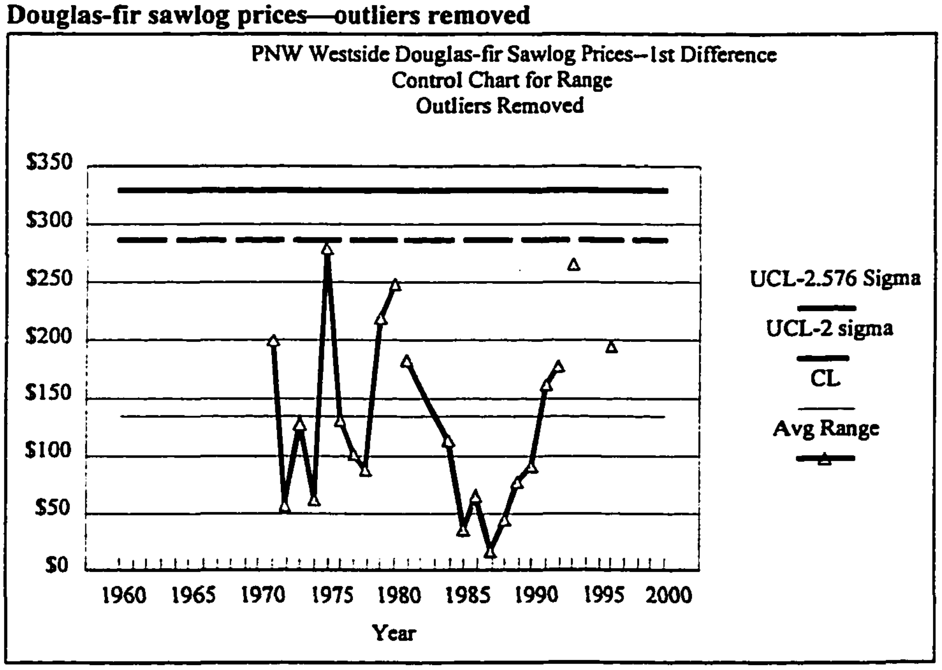


Figure 17—Control chart for range of recent first differenced PNW Westside Douglas-fir sawlog prices—outliers removed



Variance Ratio Test

The process control charts indicate the variance after 1970 is different than the variance prior to that year. This can be tested by calculating the variance ratio and comparing it to the *F* distribution. In this case the variance for the period 1970-1996 is statistically different (at the one percent level) from the variance for the period 1890-1970.

Stationarity of the Current Trend

Figure 18 and Figure 19 show the level and first differenced price series since 1970. The level series exhibits high volatility, but also seems to be moving around a level mean ($452/MBF). The final step is to determine the stationarity of the series since 1970. The process control charts indicate a stable process, but is it trend stationary?

The autocorrelation function (ρ_k) for the level series indicates the level price series since 1970 is stationary (Table 6). However, the unit root tests present a different picture: the level series never exceeds the critical value.

As with the entire series, the indicators of stationarity disagree on this subset. The full and partial autocorrelation function suggest the level series is *probably* stationary and the first differenced series is *definitely* stationary, but the unit root tests indicates that the level series is not stationary.

Figure 18—Recent PNW Westside Douglas-fir sawlog prices

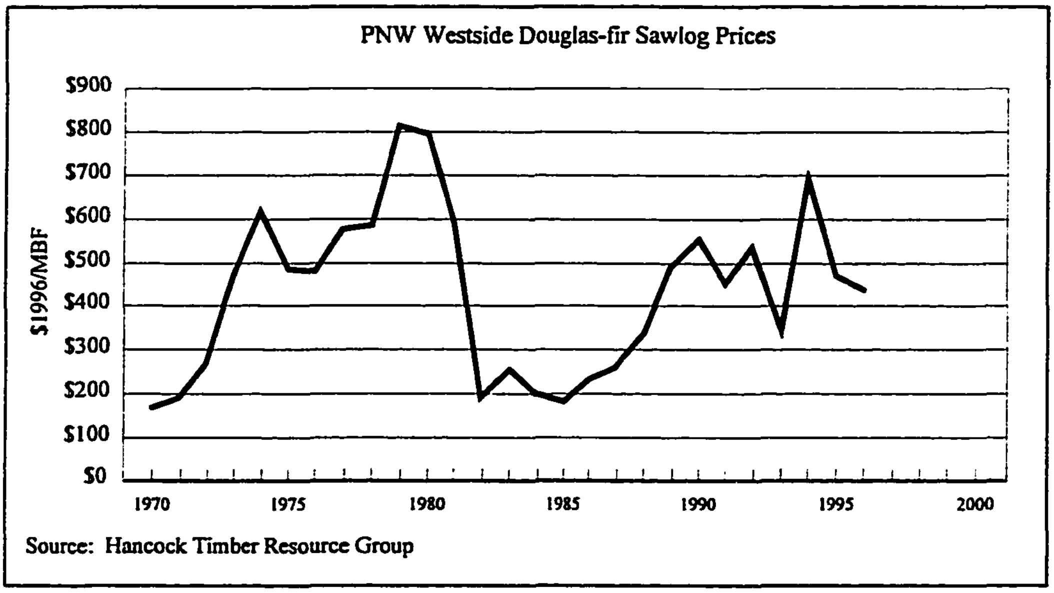


Figure 19—Recent first differenced PNW Westside Douglas-fir sawlog prices

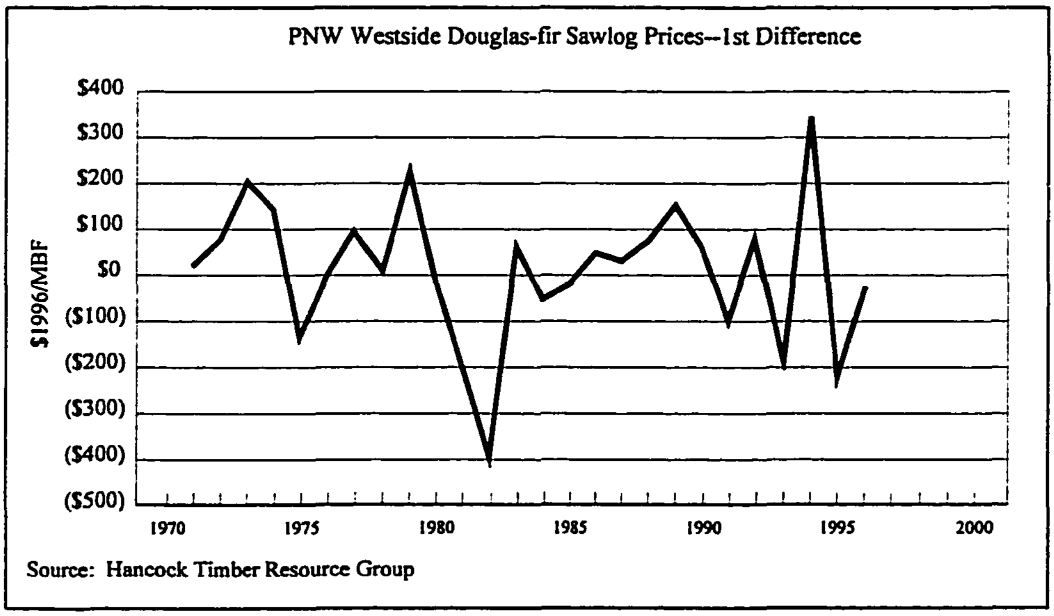


Table 6—Summary of the autocorrelation function and unit root tests on the PNW Westside Douglas-fir sawlog price series since 1970

	Series	
Test	Level	First Difference
Autocorrelation Function	yes	yes
Partial Autocorrelation Function	yes	yes
ADF with Constant	no	**
ADF with Constant and Trend	no	*
ADF with no Constant or Trend	no	***
Phillips-Perron	no	***

*** exceeds 1% critical value
** exceeds 5% critical value
* exceeds 10% critical value

In summary, the *level* PNW Westside Douglas-fir sawlog price series is not stationary. The first differenced series may have a constant mean over the entire series (1890-1996), but the variance is not constant so the first differenced series is not stationary over the entire time span.

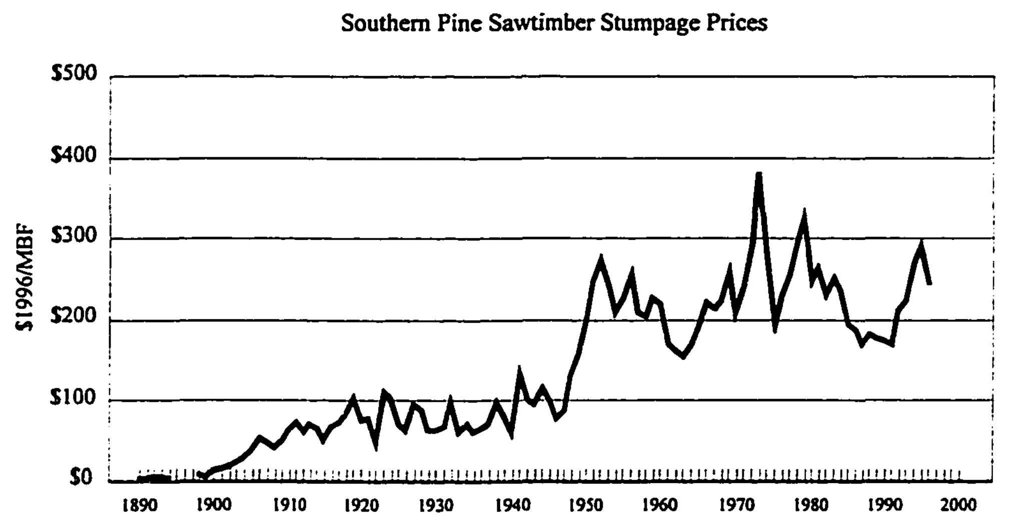
The first differenced series *is* stationary over the period 1970-1996. This means time series techniques may be applied in forecasting the Douglas-fir sawlog series. The series shows some fluctuations around the means for both price and range, and, as a result, the control lines and confidence intervals around this sub-period are wider than around the entire series.

Southern Pine Sawtimber Stumpage Prices

Stationarity of the Entire Series

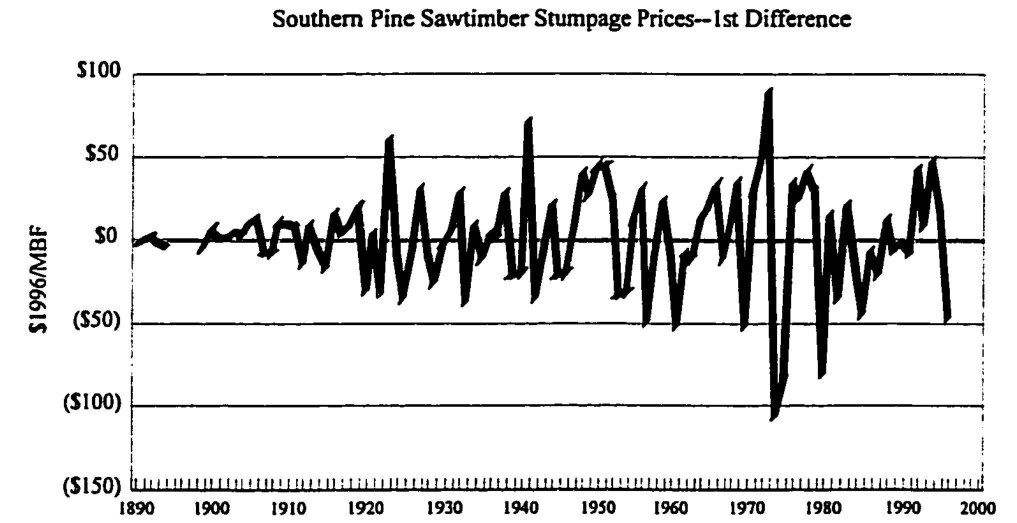
The level and first differenced southern pine sawtimber stumpage price series are shown in Figure 20 and Figure 21. As with the Douglas-fir sawlog series above, the level series appears to have an upward trend while the first differenced series appears to have a fixed mean.

Figure 20—Southern pine sawtimber stumpage prices



Source: Hancock Timber Resource Group

Figure 21—First differenced southern pine sawtimber stumpage prices



Source: Hancock Timber Resource Group

Table 7 summarizes the results of the autocorrelation function and unit root stationarity tests on the level and first differenced series.

Table 7—Summary of the autocorrelation function and unit root tests on the southern pine sawtimber stumpage price series

	Series	
Test	Level	First Difference
Autocorrelation Function	maybe	probably
Partial Autocorrelation Function	yes	yes
ADF with Constant	no	***
ADF with Constant and Trend	no	***
ADF with no Constant or Trend	no	***
Phillips-Perron	no	***

*** exceeds 1% critical value
** exceeds 5% critical value
* exceeds 10% critical value

As was the case with the Douglas-fir price series, the level series is probably not stationary, but the first differenced series is certainly stationary.

Process Control Chart Analysis

While the tests for stationarity and Figure 21 indicate that the first differenced price series has a constant mean, the figure also indicates some changes in variability. For example, variability seems to have increased from 1900 through 1920. There are sharp spikes at about 1920, 1940 and 1970. Shewhart control charts (Figure 22 and Figure 23) were used to analyze this variability. Five observations exceed the 95 percent confidence limits (5.01 expected) and four exceed the 99 percent confidence limits (1.02 expected) in the mean chart. Seven observations exceed the 95 percent confidence limits (5.00 expected) and four exceed the 99 percent confidence limits (1.00 expected) in the range chart. One of the outliers occurs in the mid-1940's, the others all occur in the 1970's.

Figure 22—Control chart for mean of first differenced southern pine sawtimber stumpage prices

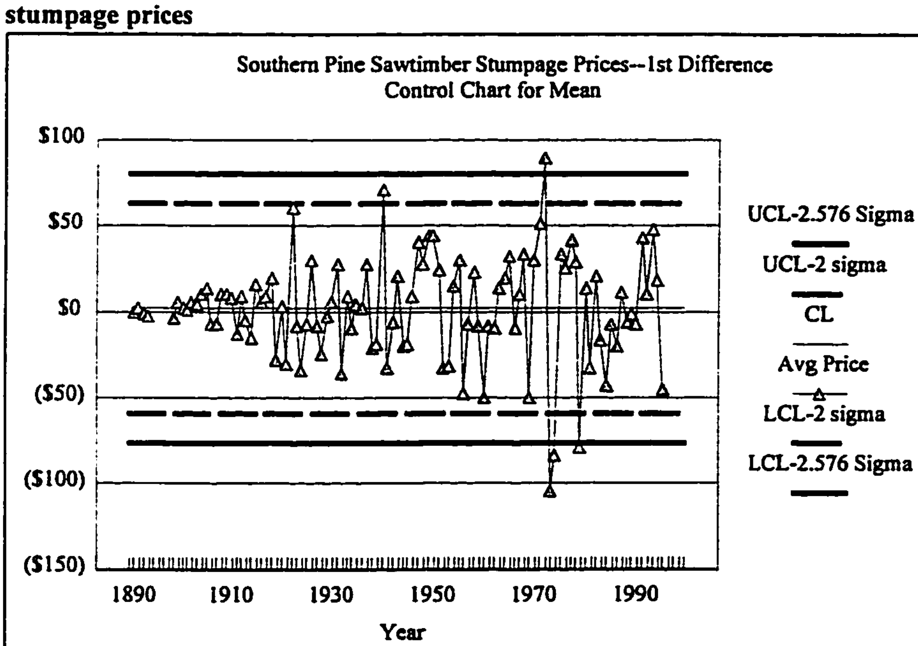
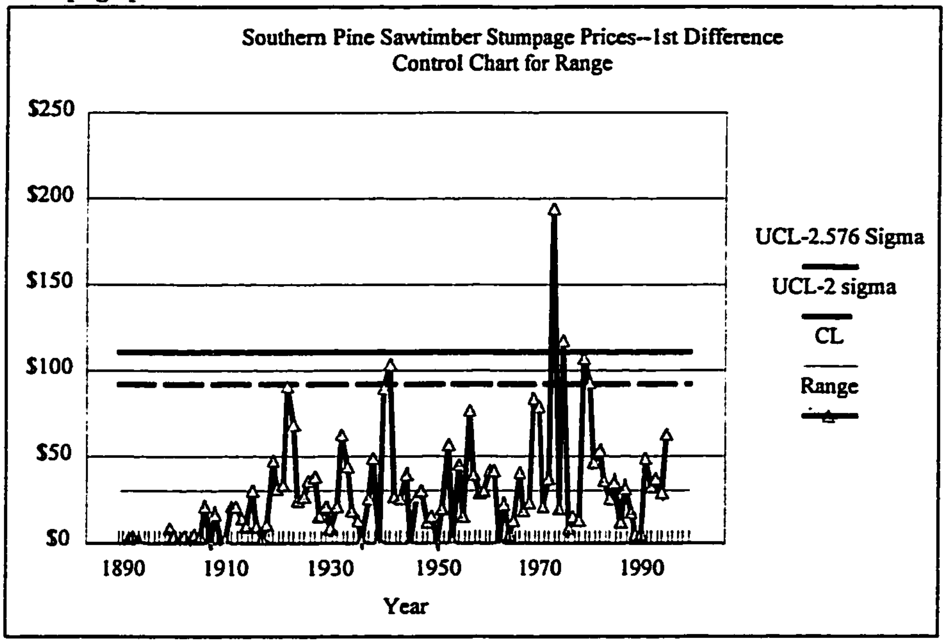


Figure 23—Control chart for range of first differenced southern pine sawtimber stumpage prices



The variance in the 1970's is largely the result of the high price in 1973. If this point is treated as an outlier and removed from the data set, the entire series is otherwise stable. As a consequence, the entire series could be used in forecasting southern pine sawtimber prices. However, Figure 20 shows a sharp climb in prices between 1945 and 1952. While each price change was within the bounds of the control lines, there were several positive price changes in a row—instead of a very large jump in prices, there was a series of average size changes. The average price between 1920 and 1945 was under $100/MBF, while the average price after 1952 has been over $200/MBF. This is important information to take into account when forecasting southern pine prices. For this reason, 1952 was selected as a starting point for further analysis. Figure 24 and Figure 25 are control charts for the southern pine prices since 1952.

Figure 24—Control chart for mean of recent first differenced southern pine sawtimber stumpage prices

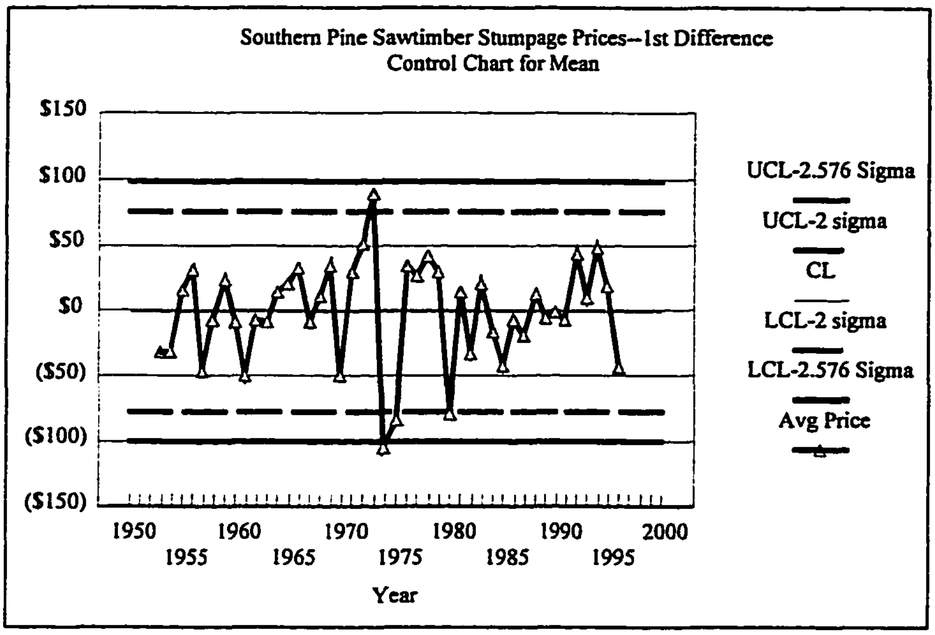
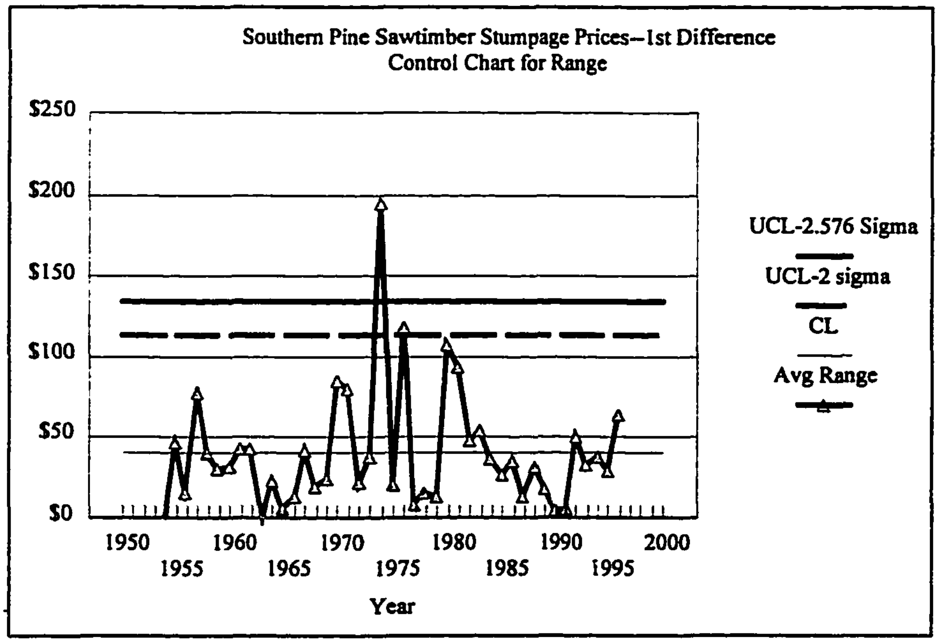


Figure 25—Control chart for range of recent first differenced southern pine sawtimber stumpage prices



Four observations exceed the 95 percent confidence limits (2.20 expected) and one exceeds the 99 percent confidence limits (0.44 expected) in the mean chart. Two observations exceed the 95 percent confidence limits (2.15 expected) and one exceeds the 99 percent confidence limits (0.43 expected) in the range chart. The mean chart indicates an out-of-control process.

Figure 26 and Figure 27 present the series with the 1973 price removed. The number of observations outside the confidence limits (control lines) is now within expectations.

Figure 26—Control chart for mean of recent first differenced southern pine sawtimber stumpage prices—outlier removed

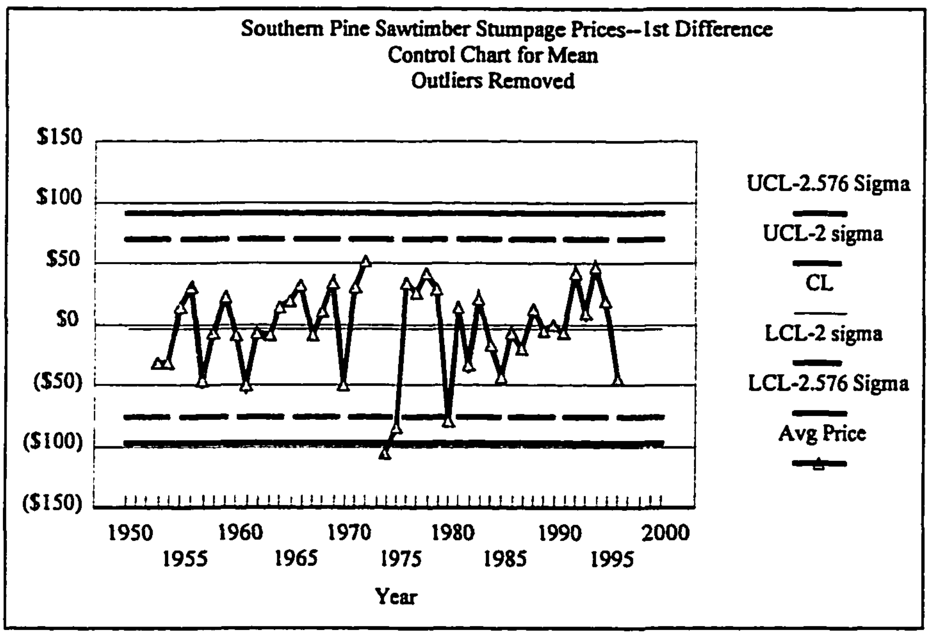
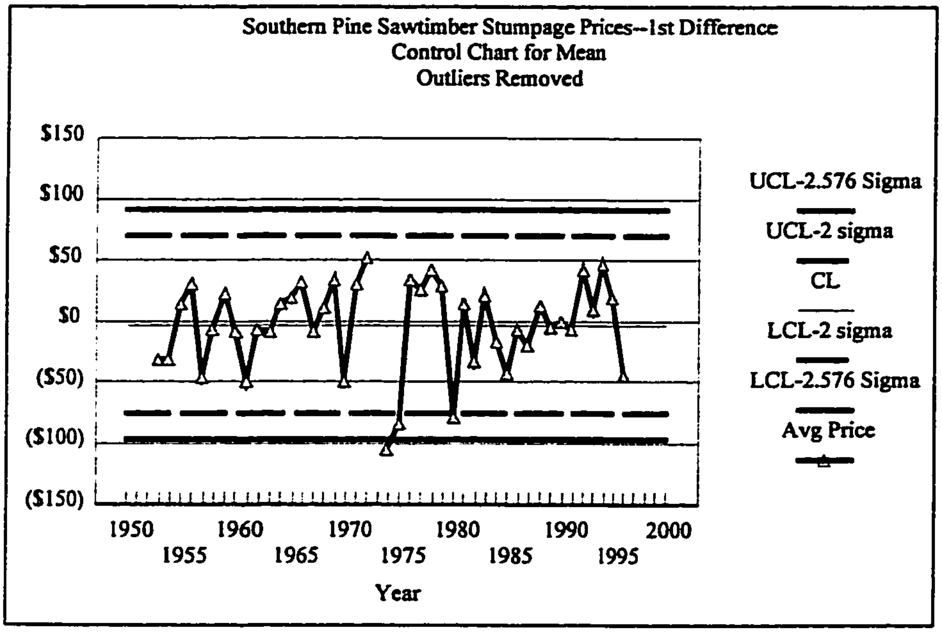


Figure 27—Control chart for range of recent first differenced southern pine sawtimber stumpage prices—outliers removed



Variance Ratio Test

The process control charts indicate the variance is stationary after 1920. Table 8 presents the results of the variance ratio test for several subsets of the price series. The variance of the series from 1890-1920 is significantly different than the variance of the rest of the series. and the null hypothesis that the series are part of the same process is rejected. For the other combinations of subsets, the null hypothesis cannot be rejected. (The exception to this is that the null hypothesis can be rejected at the five percent significance level for the comparison of the 1920-1946 subset variance with the 1946-1996 subset variance, but not at the one percent level. This adds support to the use of 1952 as the starting point for analyzing the data series for forecasting.)

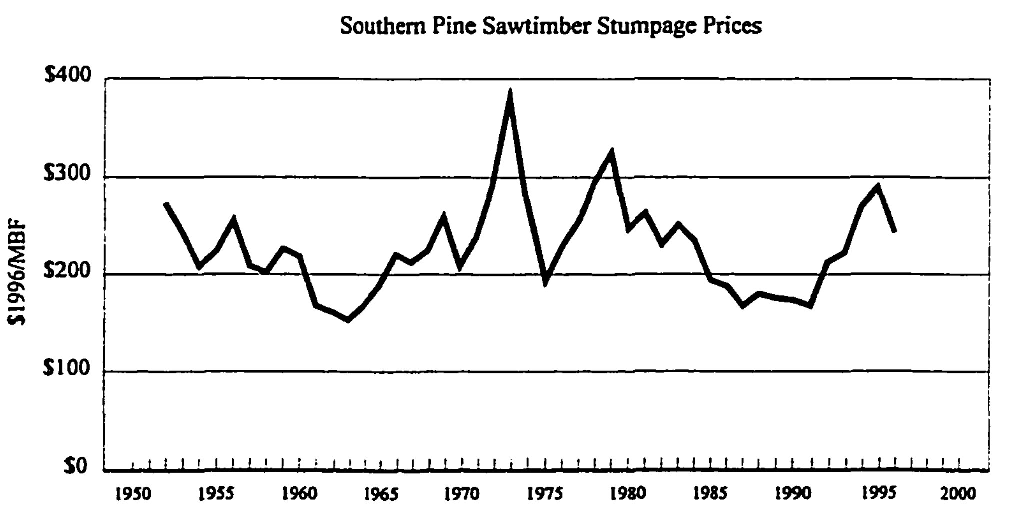
Table 8—Variance ratio tests for southern pine sawtimber stumpage price series

Comparison	*F*-Statistic	Reject Null?	Significance Level
1890-1920 vs. 1920-1996	11.39	Yes	0.01
1920-1952 vs. 1952-1996	1.88	No	0.05
1920-1946 vs. 1946-1996	1.98	No	0.01
1920-1946 vs. 1946-1952	1.59	No	0.05

Stationarity of the Current Trend

Figure 28 shows the price series since 1952. The series seems to be moving around a level mean ($228/MBF). The autocorrelation function and two of the unit root equations indicate the level series is stationary (Table 9). While this has some statistical validity, we are again left with a forecasting challenge. We apparently have a mean-reverting price series with an average of $228/MBF, but with historical highs and lows of about $150 and $400, respectively.

Figure 28—Recent southern pine sawtimber stumpage prices



Source: Hancock Timber Resource Group

Figure 29—Recent first differenced southern pine sawtimber stumpage prices

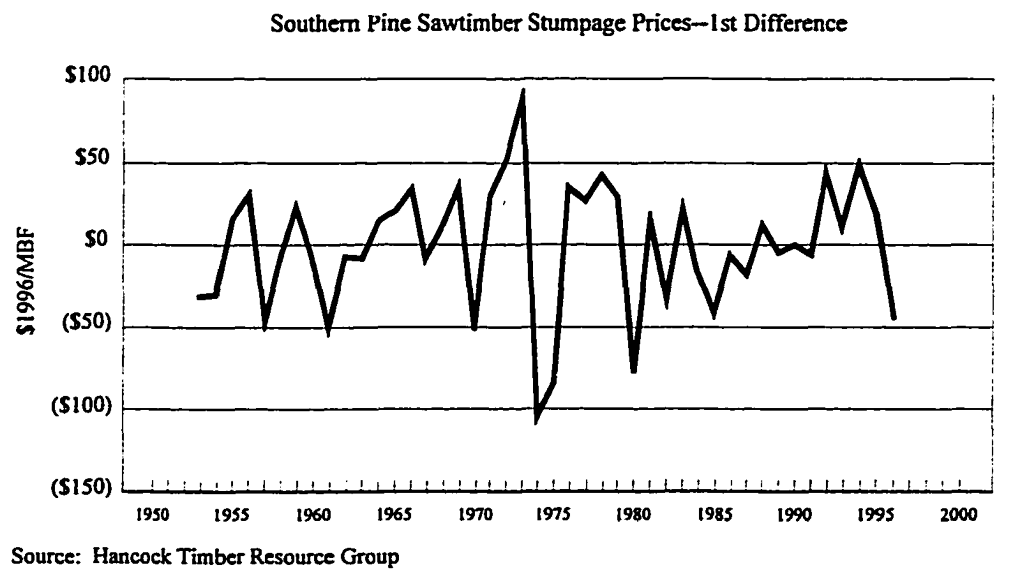


Table 9—Summary of the autocorrelation function and unit root tests on the southern pine sawtimber stumpage price series since 1952

	Series	
Test	Level	First Difference
Autocorrelation Function	yes	yes
Partial Autocorrelation Function	yes	yes
ADF with Constant	**	***
ADF with Constant and Trend	*	***
ADF with no Constant or Trend	no	***
Phillips-Perron	no	***

*** exceeds 1% critical value
** exceeds 5% critical value
* exceeds 10% critical value

In summary, the level southern pine sawtimber stumpage price is not stationary over the entire series, but *might* be considered stationary between 1952 and 1996. The first differenced series is indicated by the autocorrelation function and unit root tests as mean-reverting, but there is a significant change in the variance at about 1920. The variance is constant after that, so the series is technically trend stationary from 1920 to 1996. However, there is a significant change in the mean of the first differenced series after 1946. This change in the mean would have a significant impact on price forecasting. Tests indicate the first differenced series is trend stationary between 1952 and 1996.

USFS PNW Westside Douglas-fir Stumpage Cut Prices

Stationarity of the Entire Series

The level and first differenced USFS PNW Westside Douglas-fir stumpage cut price series are shown in Figure 30 and Figure 31. This series behaves similarly, but not identically, to the Douglas-fir sawlog prices (Figure 9). The level series exhibits an upward trend and increasing volatility over time. The first differenced series appears to be mean-reverting, but with increasing variance. There may be an upward trend in the differenced series between 1980 and 1990.

Figure 30—USFS PNW Westside Douglas-fir stumpage cut prices

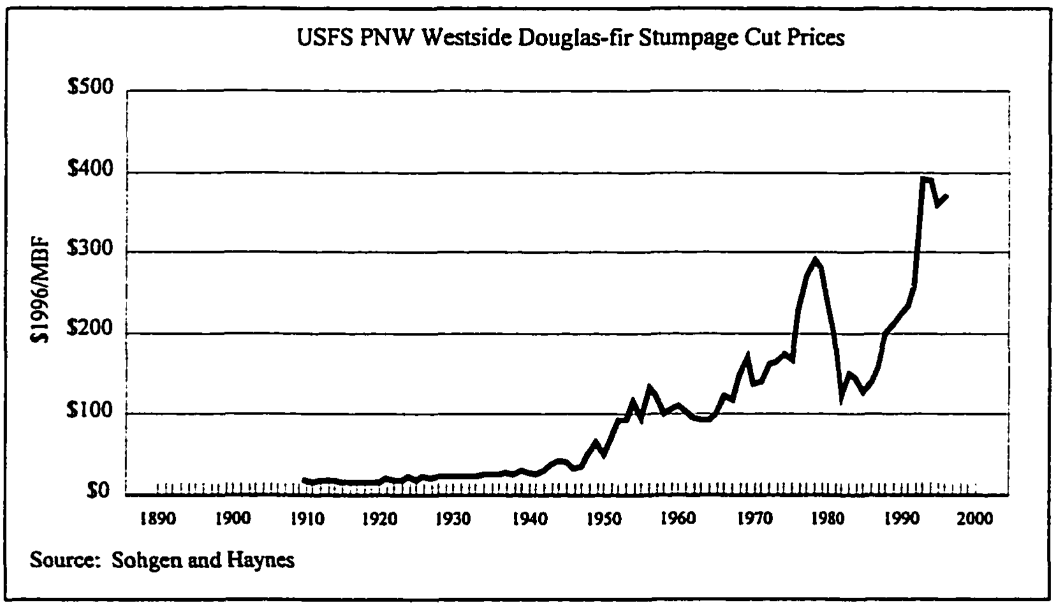
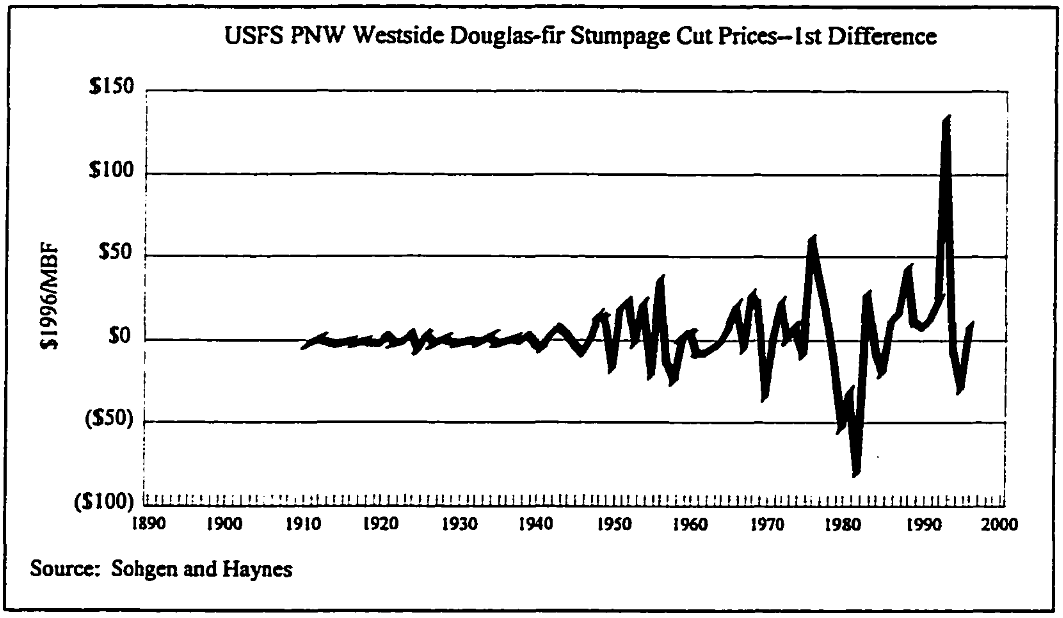


Figure 31—First differenced USFS PNW Westside Douglas-fir stumpage cut prices



The results of the tests on the USFS PNW Westside Douglas-fir stumpage cut price series are mixed (Table 10). The level series might be stationary, the first difference probably is, and the second differenced series is certainly stationary. The second differenced series was included in the table here because the first differenced series was not *certainly* stationary.

Table 10—Summary of the autocorrelation function and unit root tests on the USFS PNW Westside Douglas-fir stumpage cut price series

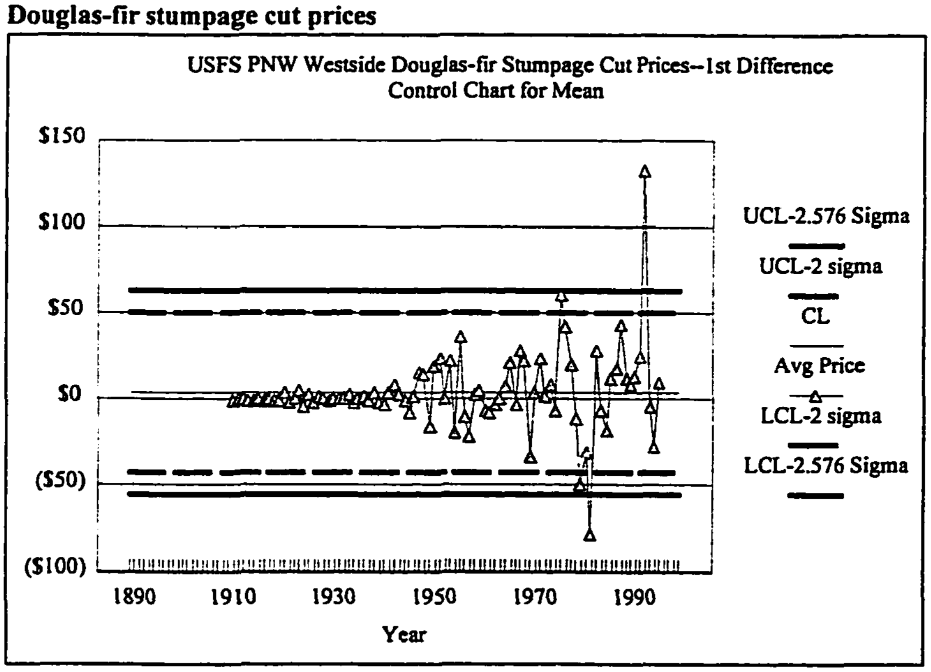
	Series		
Test	Level	First Difference	Second Difference
Autocorrelation Function	maybe	yes	yes
Partial Autocorrelation Function	yes	yes	probably
ADF with Constant	no	**	***
ADF with Constant and Trend	no	*	***
ADF with no Constant or Trend	no	***	***
Phillips-Perron	no	***	***

*** exceeds 1% critical value
** exceeds 5% critical value
* exceeds 10% critical value

Process Control Chart Analysis

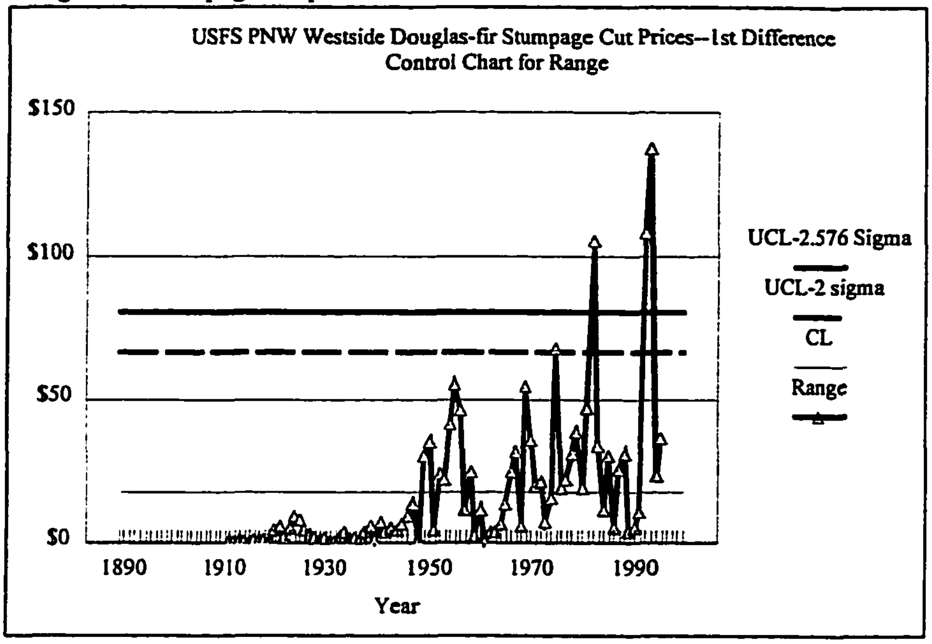
While the tests for stationarity and Figure 31 indicate that the first differenced price series has a constant mean, the figure also indicates increasing changes in variability. Shewhart control charts (Figure 32 and Figure 33) were used to analyze this variability. Four observations exceed the 95 percent confidence limits (4.30 expected) and two exceed the 99 percent confidence limits (0.86 expected) in the mean chart. Four observations exceed the 95 percent confidence limits (4.25 expected) and three exceed the 99 percent confidence limits (0.85 expected) in the range chart. All of the outliers occur after 1970.

Figure 32—Control chart for mean of first differenced USFS PNW Westside Douglas-fir stumpage cut prices



The range chart is out of control, but the whole series has an upward trend. Another interpretation of the range chart is that the variance increased after 1950 and seemed to oscillate around the mean range, but was subjected to a number of spikes.

Figure 33—Control chart for range of first differenced USFS PNW Westside Douglas-fir stumpage cut prices



1970 was chosen as the beginning point for analysis of the current process (Figure 34 and Figure 35). The volatility of the average price changes increased after this time and the range chart shows a series of steadily higher spikes. Two observations exceed the 95 percent confidence limits (1.55 expected) and one exceeds the 99 percent confidence limits (0.29 expected) in the mean chart. Three observations exceed the 95 percent confidence limits (1.40 expected) and one exceeds the 99 percent confidence limits (0.28 expected) in the range chart. When the outlying price of 1993 is removed from the series, the observations fall within expected results. The two charts show a process that is technically stable, with a great deal of fluctuation and one out-of-control observation. Given the level of volatility, this series would probably require wider confidence intervals around its forecast than either of the previous two series.

Figure 34—Control chart for mean of recent first differenced USFS PNW Westside Douglas-fir stumpage cut prices

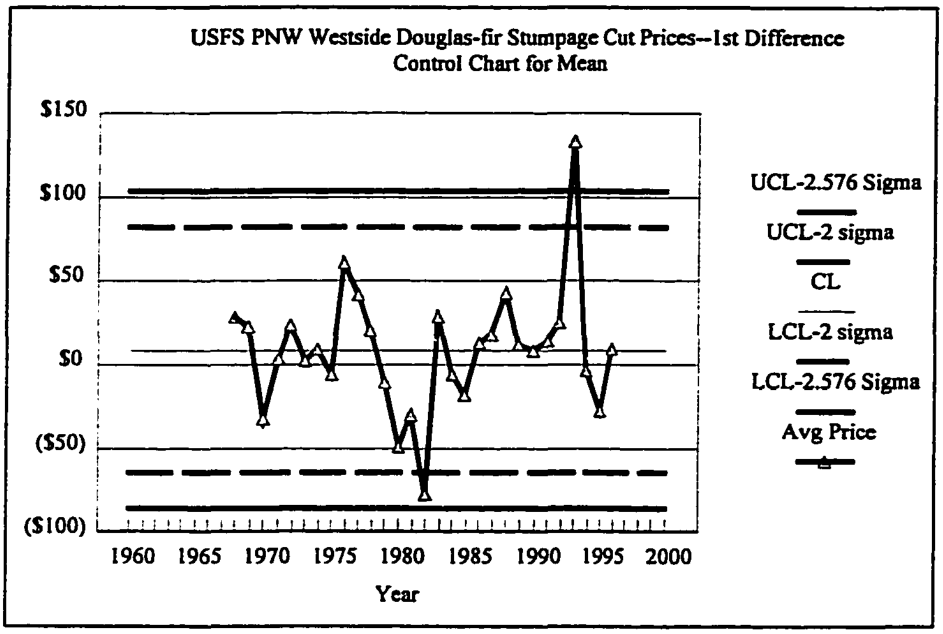
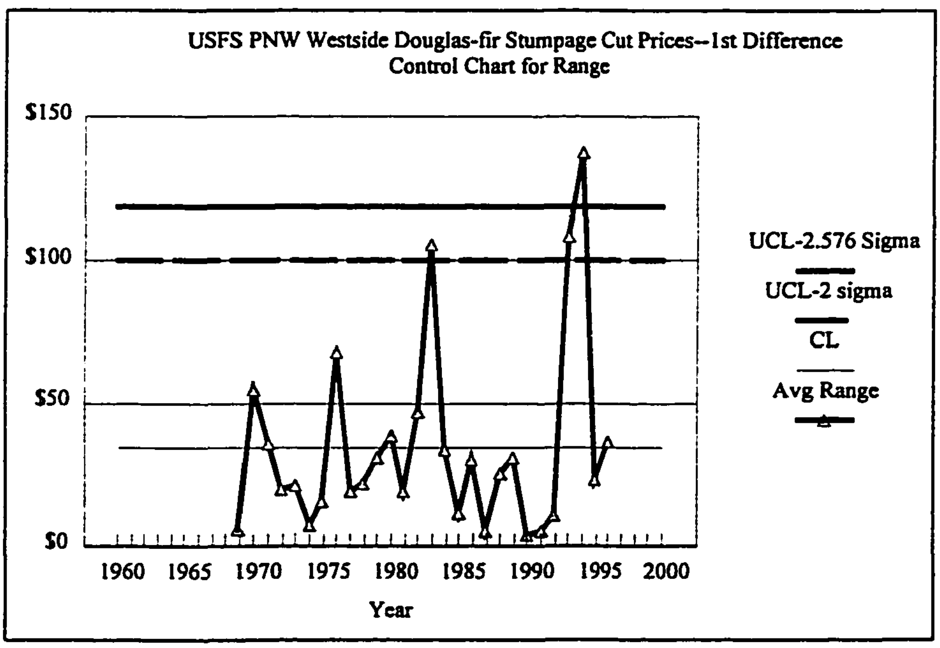


Figure 35—Control chart for range of recent first differenced USFS PNW Westside Douglas-fir stumpage cut prices



Variance Ratio Test

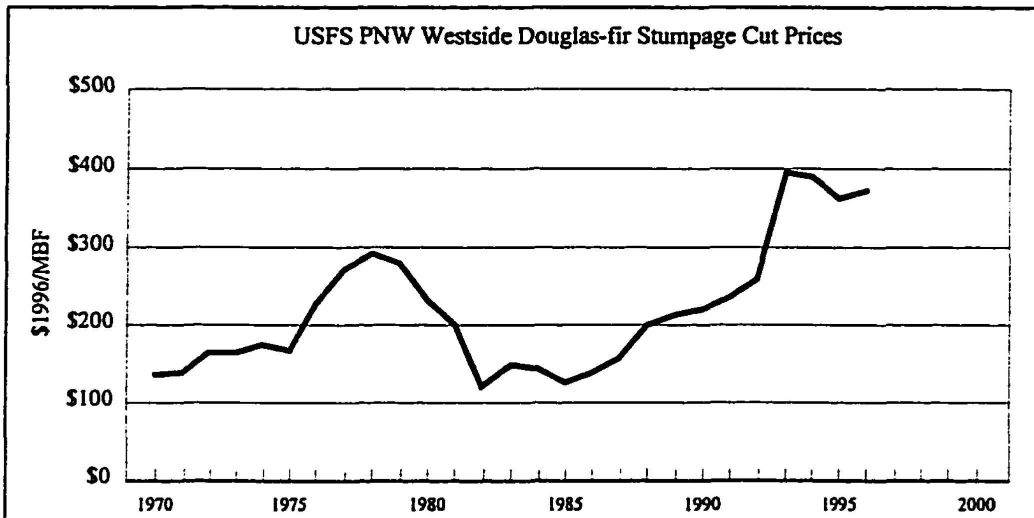
The process control charts indicate the variance after 1970 is different than the variance prior to that year. This is supported by the variance ratio test: the variance for the period 1970-1996 is statistically different (at the one percent level) from the variance for the period 1910-1970.

Stationarity of the Current Trend

Figure 36 and Figure 37 show the level and first difference price series since 1970. The level series is a good illustration of a random walk. The first differenced series shows a high, but probably fixed, level of volatility, and is oscillating around a fixed mean.

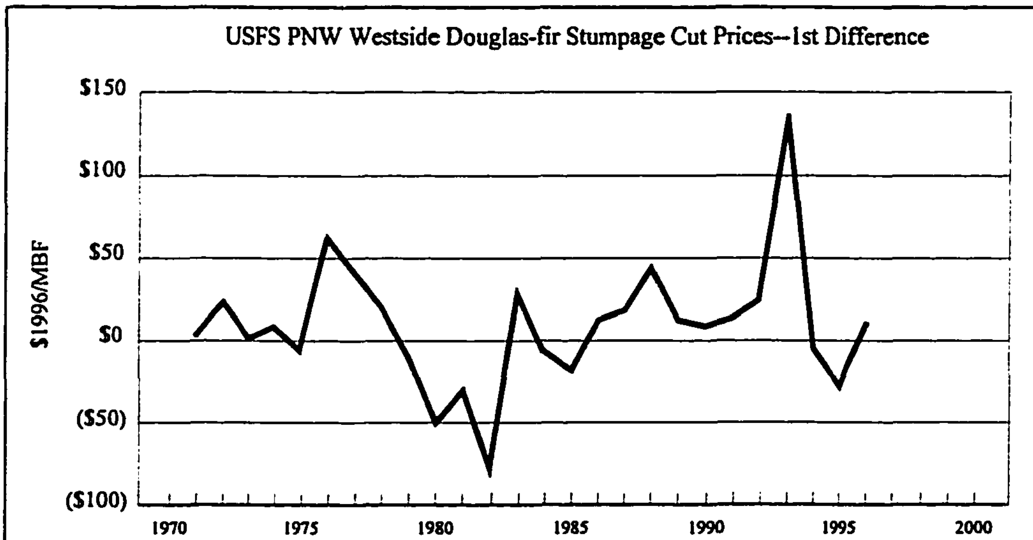
Table 11 presents a summary of the stationarity test on the recent prices. The autocorrelation functions indicate the level series is stationary, but this is contradicted by the unit root tests. The first differenced series is indicated as stationary, but not to the same statistical significance as the sawlog price series.

Figure 36—Recent USFS PNW Westside Douglas-fir stumpage cut prices



Source: Hancock Timber Resource Group

Figure 37—Recent first differenced USFS PNW Westside Douglas-fir stumpage cut prices



Source: Hancock Timber Resource Group

Table 11—Summary of the autocorrelation function and unit root tests on the USFS PNW Westside Douglas-fir stumpage cut price series since 1985

	Series		
Test	Level	First Difference	Second Difference
Autocorrelation Function	yes	yes	yes
Partial Autocorrelation Function	yes	yes	yes
ADF with Constant	no	**	***
ADF with Constant and Trend	no	*	***
ADF with no Constant or Trend	no	***	***
Phillips-Perron	no	****	***

*** exceeds 1% critical value
** exceeds 5% critical value
* exceeds 10% critical value

In summary, the *level* USFS PNW Westside Douglas-fir stumpage cut price series is not stationary. The first differenced series may have a constant mean over the entire series (1910-1996), but the variance is not constant so the first differenced series is not stationary over the entire time span.

The first differenced series *is probably* stationary over the period 1970-1996, so time series techniques may be applied in forecasting series. The forecaster should note that the series shows some fluctuations around the means for both price and range, and, as a result, the control lines and confidence intervals around this sub-period are wider than around the entire series.

USFS PNW Westside Douglas-fir Stumpage Sold Prices

Stationarity of the Entire Series

The level and first differenced USFS PNW Westside Douglas-fir stumpage sold price series are shown in Figure 38 and Figure 39. The patterns are nearly identical to those of the Douglas-fir sawlog series. An important distinction is that the prices in this series are lower because they do not include the cost of harvesting and transporting the logs.

Figure 38—USFS PNW Westside Douglas-fir stumpage sold prices

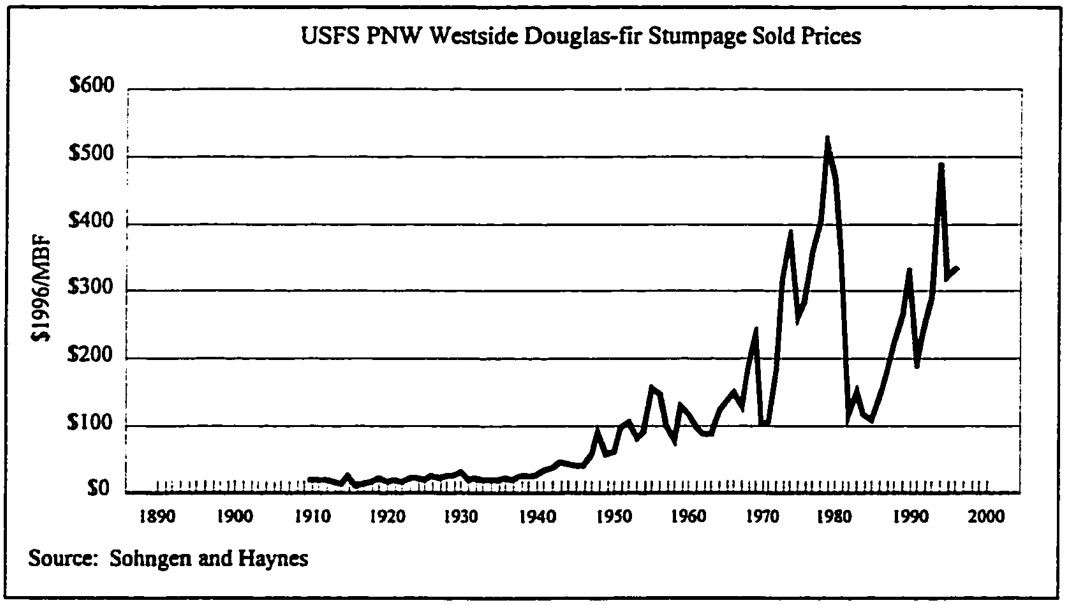
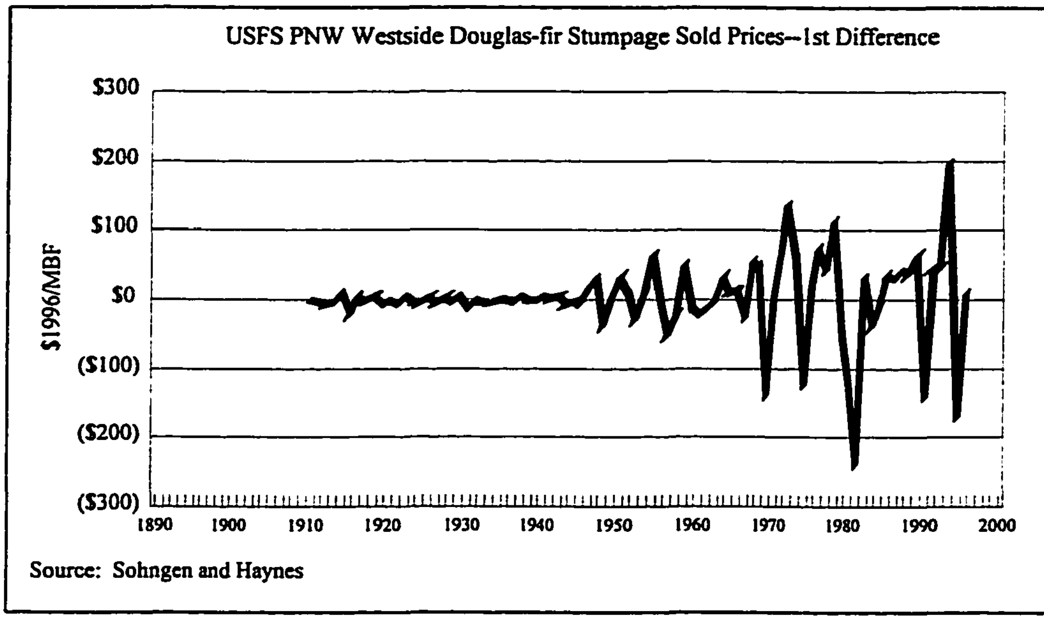


Figure 39—First differenced USFS PNW Westside Douglas-fir stumpage sold prices



The results of the test on the USFS PNW Westside Douglas-fir stumpage sold price series are mixed (Table 12). The level series may be stationary, and the first differenced series certainly is.

Table 12—Summary of the autocorrelation function and unit root tests on the USFS PNW Westside Douglas-fir stumpage sold price series

	Series	
Test	Level	First Difference
Autocorrelation Function	yes	yes
Partial Autocorrelation Function	yes	yes
ADF with Constant	no	***
ADF with Constant and Trend	*	***
ADF with no Constant or Trend	no	***
Phillips-Perron	no	***

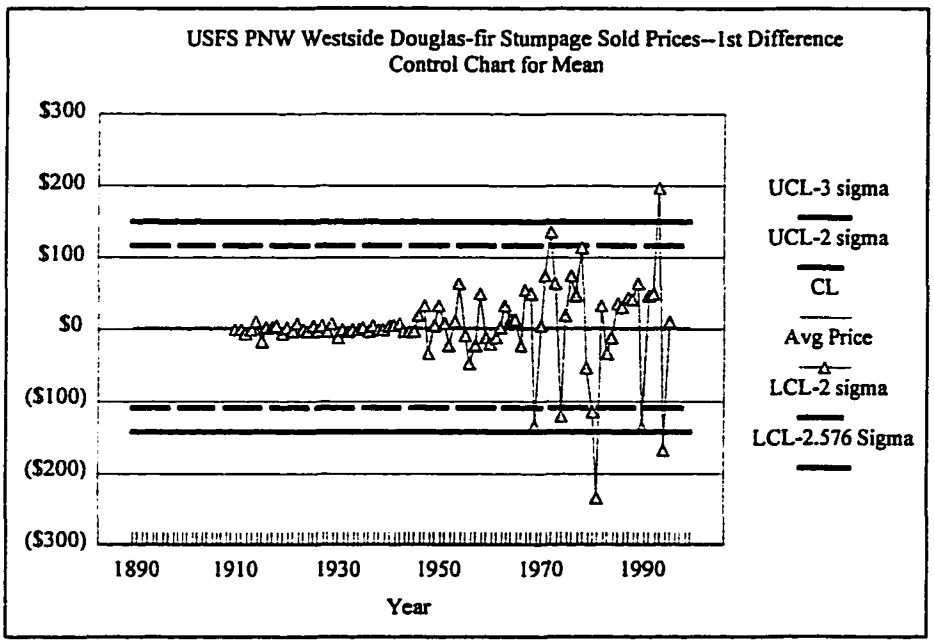
*** exceeds 1% critical value
** exceeds 5% critical value
* exceeds 10% critical value

Process Control Chart Analysis

While the tests for stationarity and Figure 39 indicate that the first differenced price series has a constant mean, the figure also indicates increasing changes in

variability. Shewhart control charts (Figure 40 and Figure 41) were used to analyze this variability. The first differenced series was very steady from 1910 to about 1945. The variance increased to a new level at that time. Another increase in the variance occurred in 1970. Eight observations exceed the 95 percent confidence limits (4.30 expected) and three exceed the 99 percent confidence limits (0.86 expected) in the mean chart. Six observations exceed the 95 percent confidence limits (4.25 expected) and two exceed the 99 percent confidence limits (0.85 expected) in the range chart.

Figure 40—Control chart for mean of first differenced USFS PNW Westside Douglas-fir stumpage sold prices



The control chart for the range (Figure 41) clearly shows a process out of control. Further analysis was performed on prices since 1970, to see if the apparent volatility after that period was in fact part of a stable process.

Figure 41—Control chart for range of first differenced USFS PNW Westside Douglas-fir stumpage sold prices

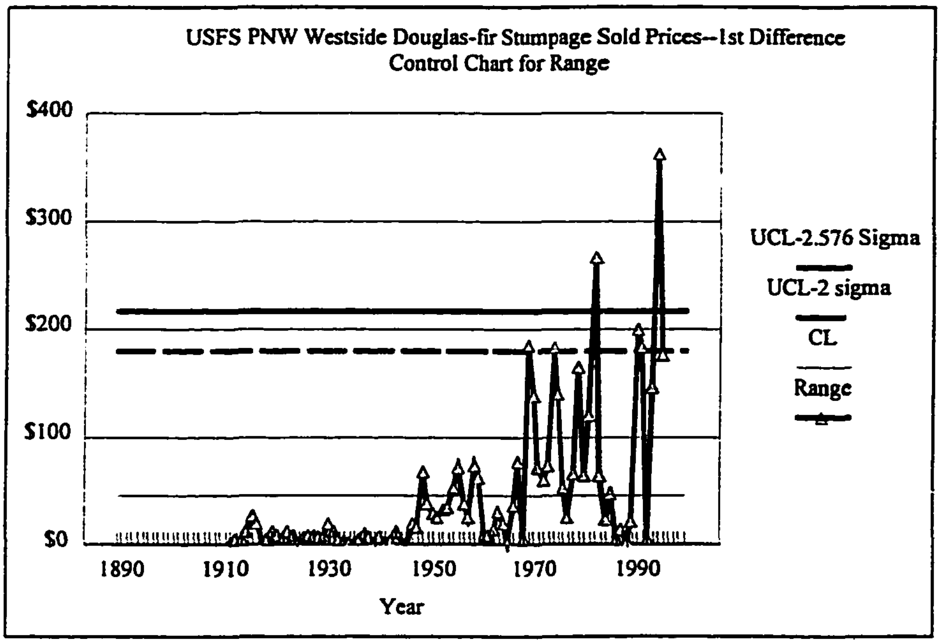


Figure 42 and Figure 43 indicate that the prices since 1970 are being generated by a stable, though fluctuating, process. One observations exceed the 95 percent confidence limits (1.30 expected) and none exceed the 99 percent confidence limits (0.29 expected), in the mean chart. One observation exceeds the 95 percent confidence limits (1.25 expected) and one exceeds the 99 percent confidence limits (0.25 expected) in the range chart..

Figure 42—Control chart for mean of recent first differenced USFS PNW Westside Douglas-fir stumpage sold prices

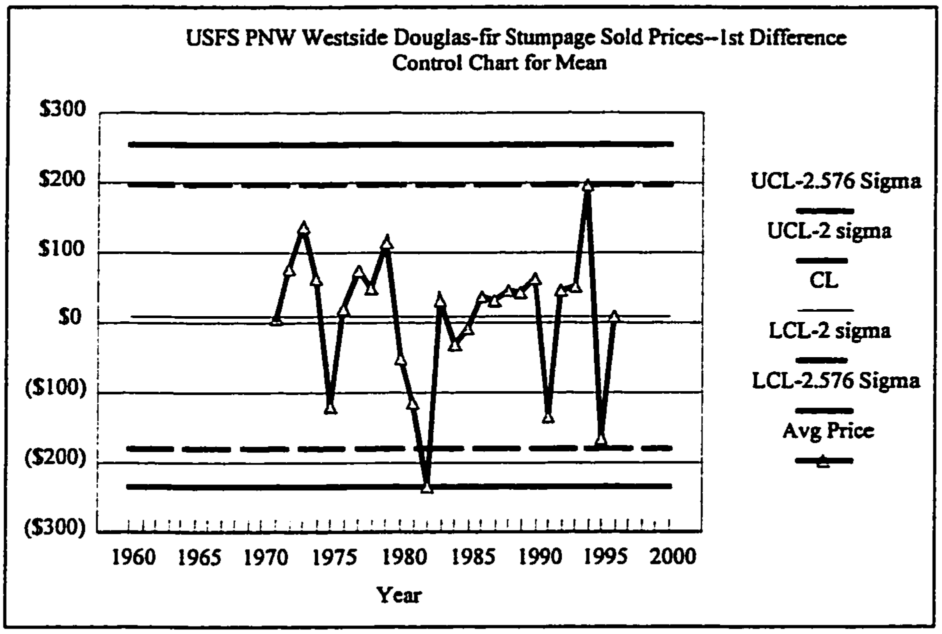
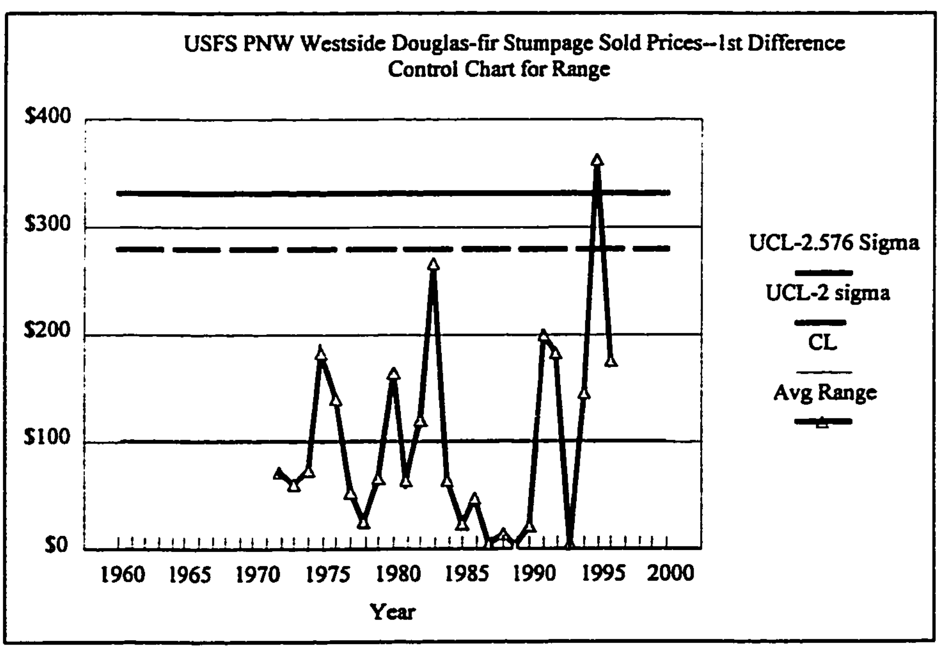


Figure 43—Control chart for range of recent first differenced USFS PNW Westside Douglas-fir stumpage sold prices



Variance Ratio Test

The process control charts indicate the variance after 1970 is different than the variance prior to that year. This is supported by the variance ratio test: the variance for the period 1970-1996 is statistically different (at the one percent level) from the variance for the period 1910-1970.

Stationarity of the Current Trend

Figure 44 and Figure 45 show the level and first differenced price series since 1970. The autocorrelation function tests indicate the level series is stationary, while the results of the unit root tests are negative (Table 13). All the tests indicate that the first differenced series is stationary.

Figure 44—Recent USFS PNW Westside Douglas-fir stumpage sold prices

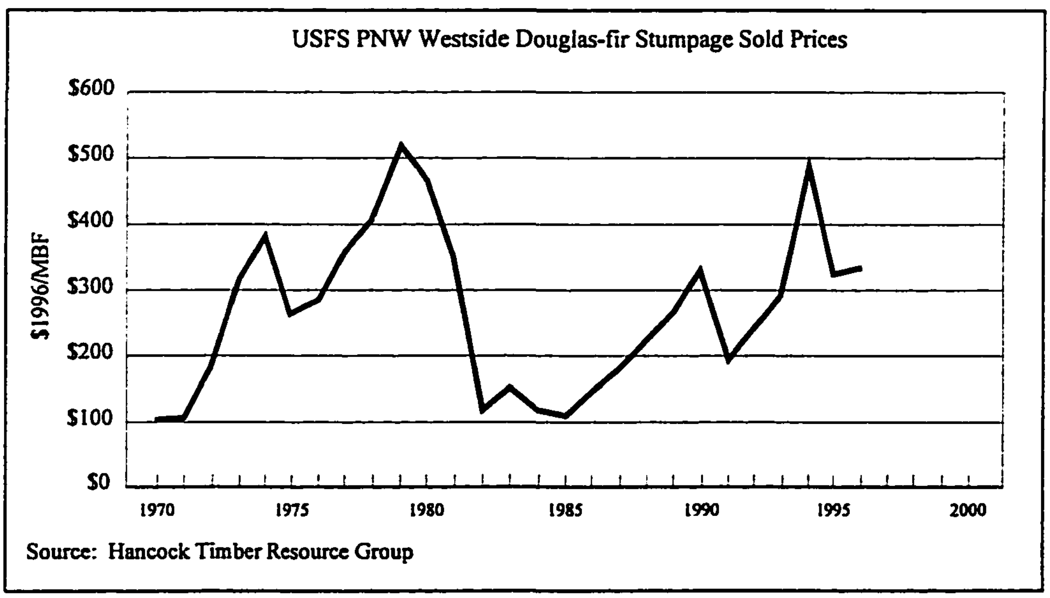


Figure 45—Recent first differenced USFS PNW Westside Douglas-fir stumpage sold prices

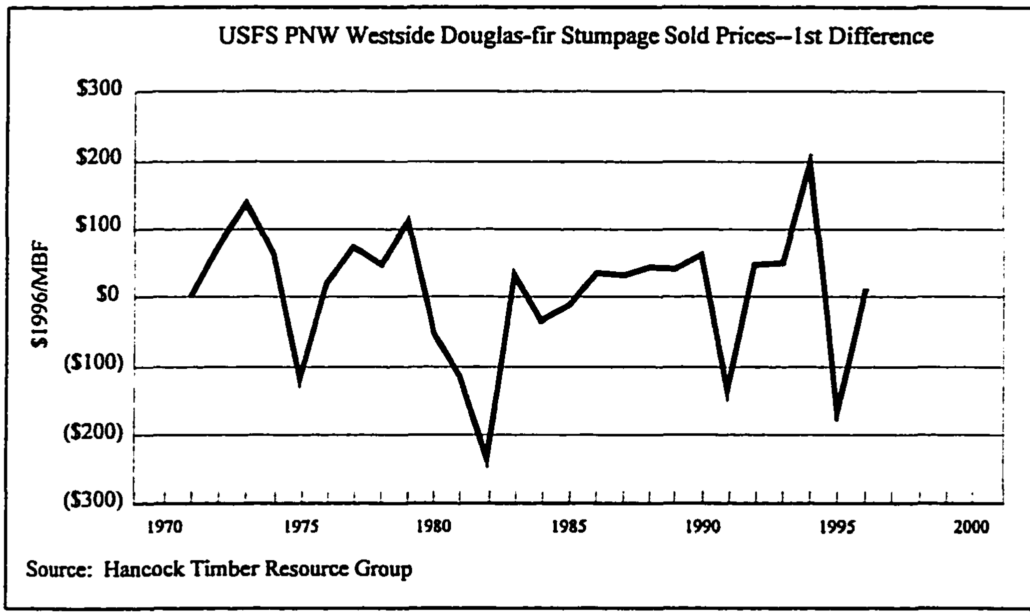


Table 13—Summary of the autocorrelation function and unit root tests on the USFS PNW Westside Douglas-fir stumpage sold price series since 1985

	Series	
Test	Level	First Difference
Autocorrelation Function	yes	yes
Partial Autocorrelation Function	yes	yes
ADF with Constant	no	***
ADF with Constant and Trend	no	**
ADF with no Constant or Trend	no	***
Phillips-Perron	no	***

*** exceeds 1% critical value
** exceeds 5% critical value
* exceeds 10% critical value

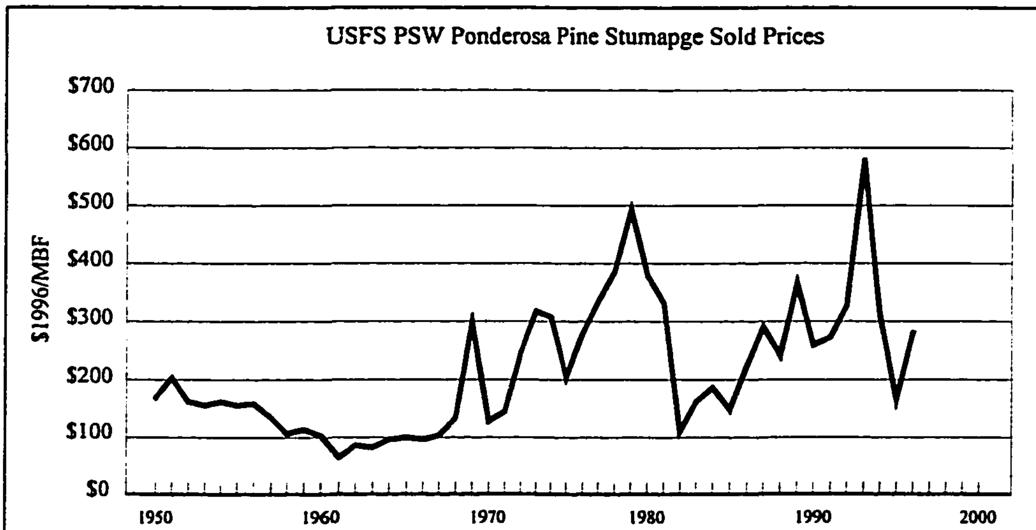
In summary, this series is very similar to the Douglas-fir sawlog series. The level series is not stationary, nor is the first differenced series stationary over the length of the entire series (1910-1996). A changing variance is the reason the first differenced series fails to meet the criteria for stationarity. However, the first differenced series *is* stationary over the period 1970-1996.

USFS PSW Ponderosa Pine Stumpage Sold Prices

Stationarity of the Entire Series

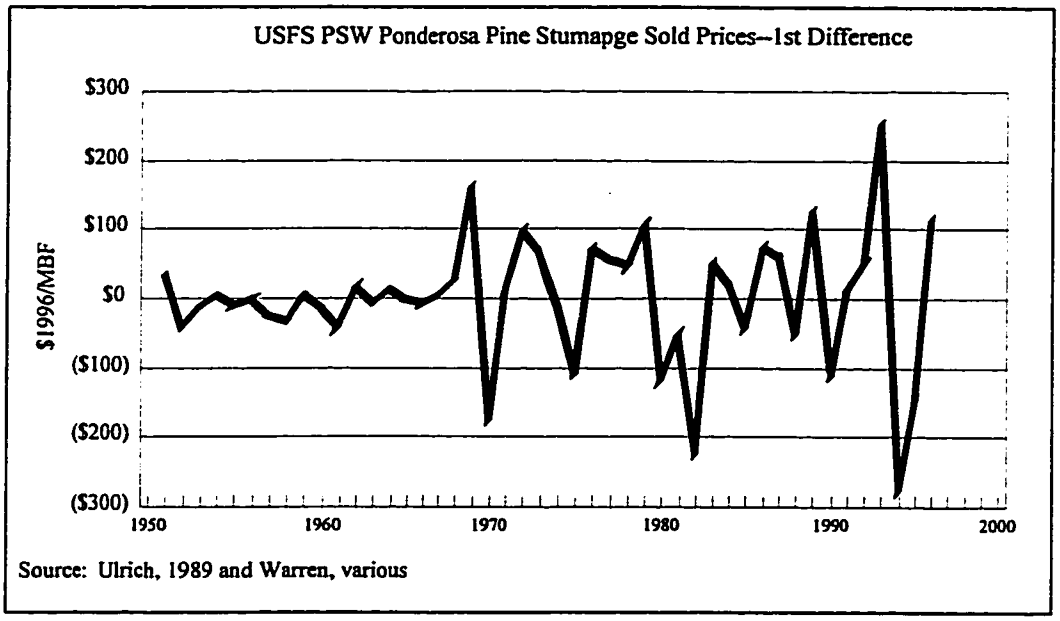
The level and first differenced USFS PSW ponderosa pine stumpage sold prices are shown in Figure 46 and Figure 47. After drifting downward through the 1950's, prices seem to have risen and crashed twice since then. Prices rose from 1961 to 1979, with a number of sharp peaks along the way. Between 1979 and 1981, prices fell about $400/MBF, a drop of 80 percent. They rose again during the 1980's and up until 1993, when they fell from a peak of nearly $600/MBF to about $150/MBF. The first differenced series shows an increase in volatility beginning around 1970.

Figure 46—USFS PSW ponderosa pine stumpage sold prices



Source: Ulrich, 1989 and Warren, various

Figure 47—First differenced USFS PSW ponderosa pine stumpage sold prices



The autocorrelation functions indicate the level series is stationary, while the results of the unit root tests are mixed (Table 14). The first differenced series is indicated as stationary.

Table 14—Summary of the autocorrelation function and unit root tests on the ponderosa pine sawtimber stumpage sold price series

	Series	
Test	Level	First Difference
Autocorrelation Function	probably	yes
Partial Autocorrelation Function	yes	yes
ADF with Constant	no	***
ADF with Constant and Trend	**	***
ADF with no Constant or Trend	no	***
Phillips-Perron	no	***

*** exceeds 1% critical value
** exceeds 5% critical value
* exceeds 10% critical value

Process Control Chart Analysis

While the tests for stationarity and Figure 47 indicate that the first differenced price series has a constant mean, the figure also indicates increasing changes in

variability. Shewhart control charts (Figure 48 and Figure 49) were used to analyze this variability. The first differenced series was very steady from 1950 to 1968. The variance increased at that time. Three observations exceed the 95 percent confidence limits (2.30 expected) and two exceed the 99 percent confidence limits (0.46 expected) in the mean chart. Two observations exceed the 95 percent confidence limits (2.25 expected) and one exceeds the 99 percent confidence limits (0.45 expected) in the range chart.

Figure 48—Control chart for mean of first differenced USFS PSW ponderosa pine stumpage sold prices

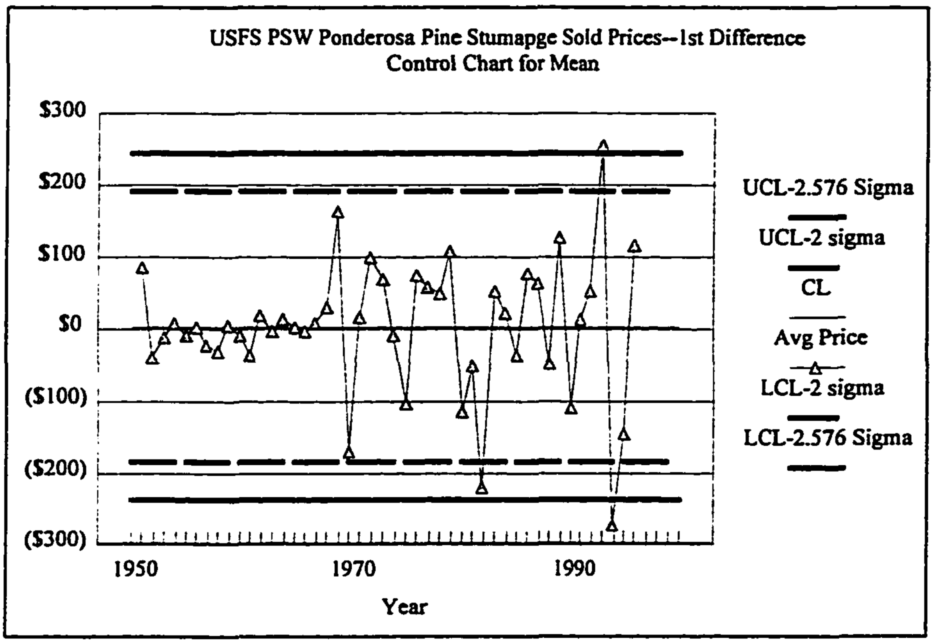
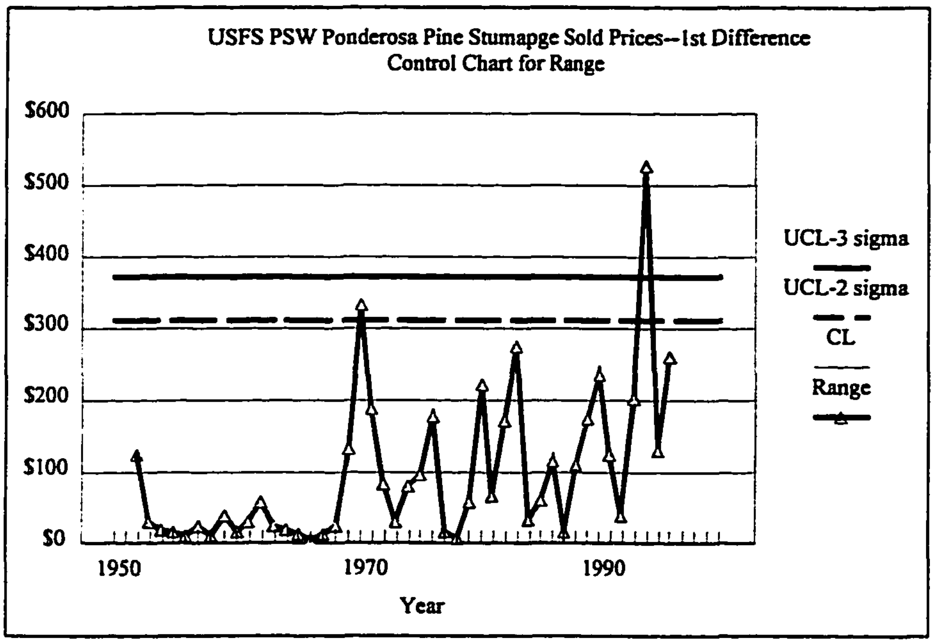


Figure 49—Control chart for range of first differenced USFS PSW ponderosa pine stumpage sold prices



Process control charts for the series since 1968 (Figure 50 and Figure 51) indicate a stable process for the period 1968 through 1996. Two observations exceed the 95 percent confidence limits (1.40 expected) and none exceed the 99 percent confidence limits (0.28 expected) in the mean chart. One observation exceeds the 95 percent confidence limits (1.35 expected) and one exceeds the 99 percent confidence limits (0.27 expected) in the range chart. A high price in 1993 is responsible for much of the increased volatility in the early 1990's. Other than this point, the variance appears to be stable over this period.

Figure 50—Control chart for mean of recent first differenced USFS PSW ponderosa pine stumpage sold prices

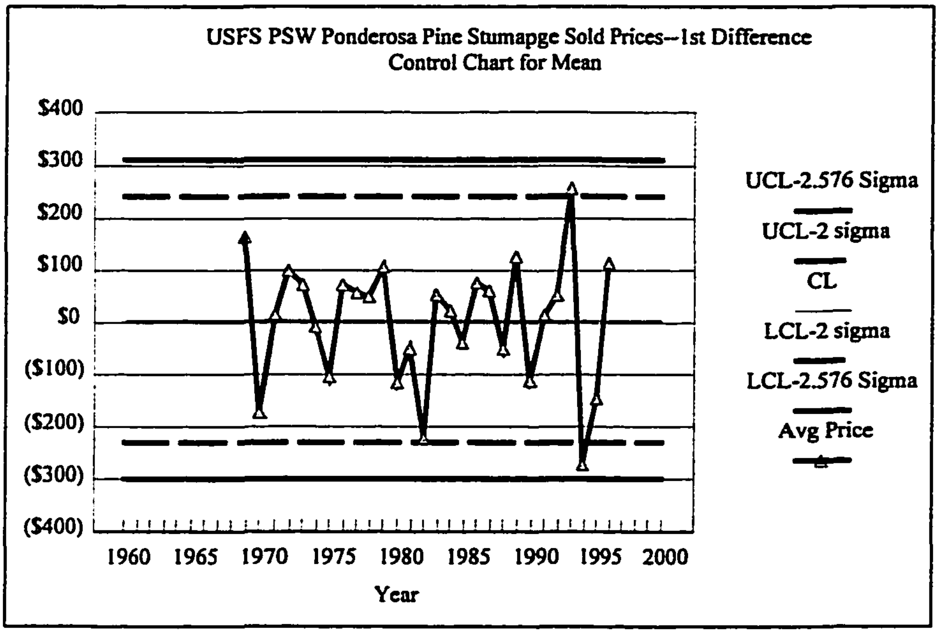
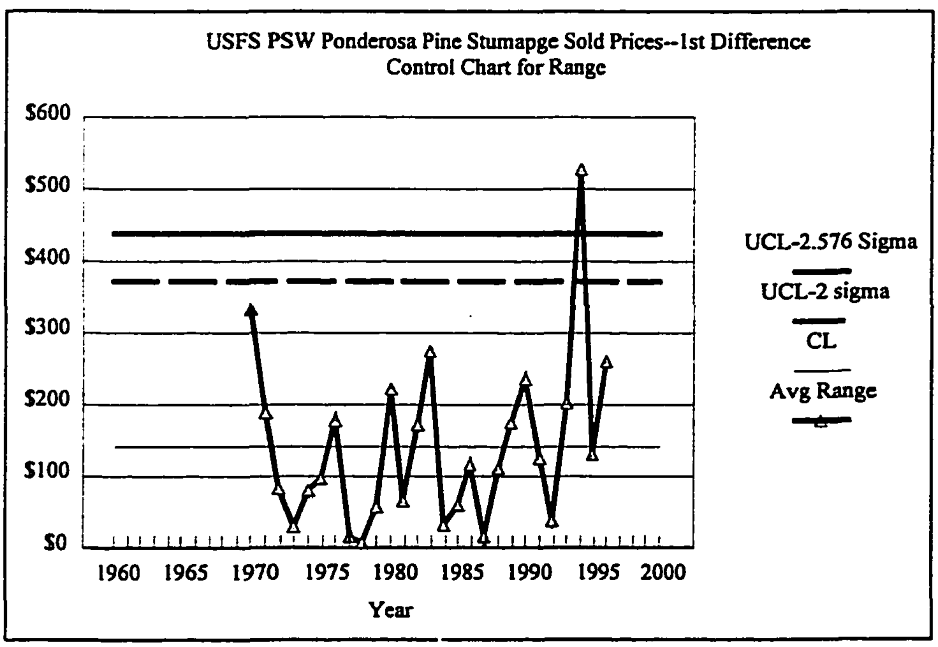


Figure 51—Control chart for range of recent first differenced USFS PSW ponderosa pine stumpage sold prices



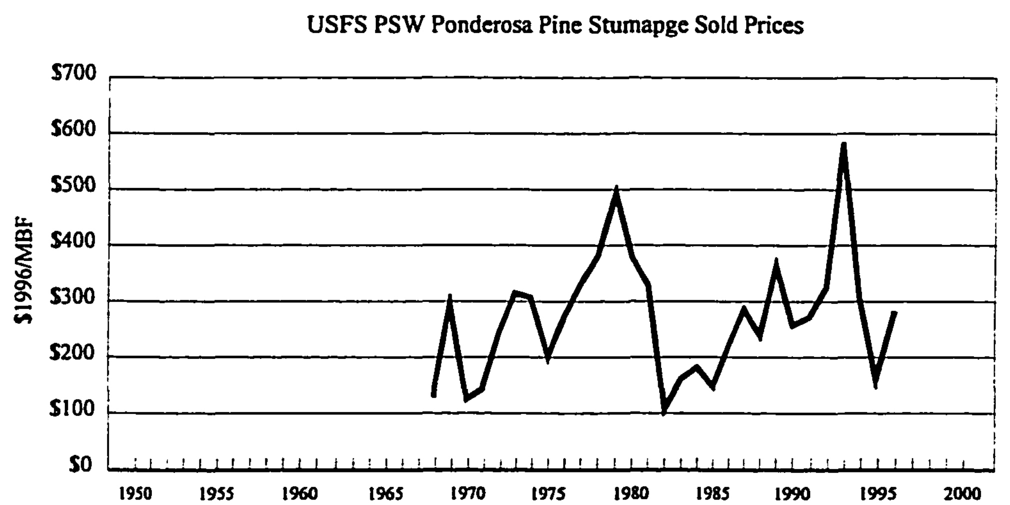
<u>**Variance Ratio Test**</u>

The process control charts indicate the variance after 1968 is different than the variance prior to that year. This is supported by the variance ratio test: the variance for the period 1968-1996 is statistically different (at the one percent level) from the variance for the period 1950-1968.

<u>**Stationarity of the Current Trend**</u>

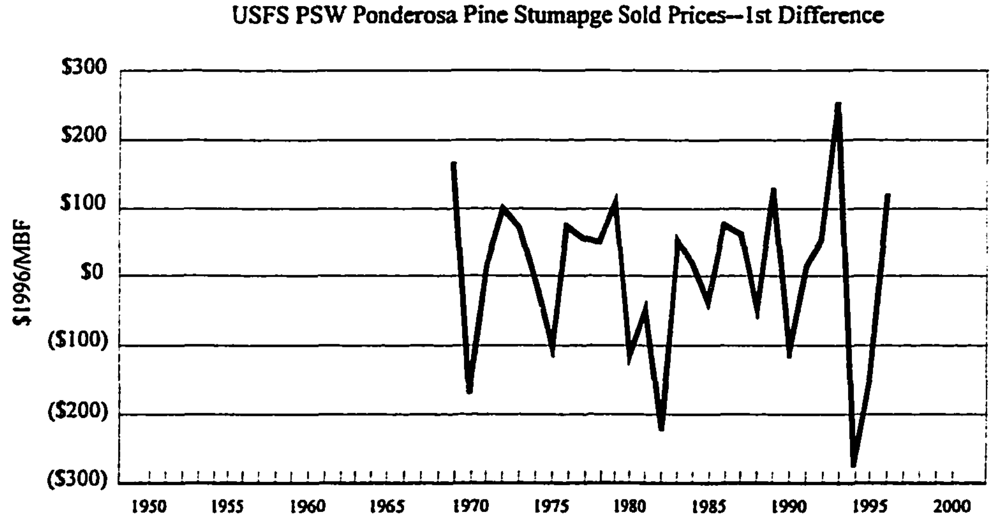
Figure 52 and Figure 53 show the level and first differenced price series since 1968. The autocorrelation functions indicate the level series is stationary, while the unit root tests give mixed results (Table 15). The first differenced series is indicated as stationary by all the tests.

Figure 52—Recent USFS PSW ponderosa pine stumpage sold prices



Source: Hancock Timber Resource Group

Figure 53—Recent first differenced USFS PSW ponderosa pine stumpage sold prices



Source: Hancock Timber Resource Group

Table 15-Summary of the autocorrelation function and unit root tests on the USFS PSW ponderosa pine stumpage sold price series since 1968

	Series	
Test	Level	First Difference
Autocorrelation Function	yes	yes
Partial Autocorrelation Function	yes	yes
ADF with Constant	**	***
ADF with Constant and Trend	*	***
ADF with no Constant or Trend	no	***
Phillips-Perron	no	***

*** exceeds 1% critical value
** exceeds 5% critical value
* exceeds 10% critical value

In summary, the level USFS PSW ponderosa pine stumpage price series is not stationary. The first differenced series may have a constant mean, but not a constant variance over the span of the series (1950-1996). The first differenced series is stationary over the period 1968-1996.

Louisiana Southern Pine Pulpwood Stumpage Prices

Stationarity of the Entire Series

The level and first differenced Louisiana southern pine pulpwood stumpage prices as reported by the Louisiana Department of Agriculture and Forestry are shown in Figure 54 and Figure 55. Prices fell slowly between the 1950's and 1972, leveled off (or rose very slightly) until 1972, then have exhibited a much higher level of volatility and probably a greater rate of increase since then.

Figure 54—Louisiana southern pine pulpwood stumpage prices

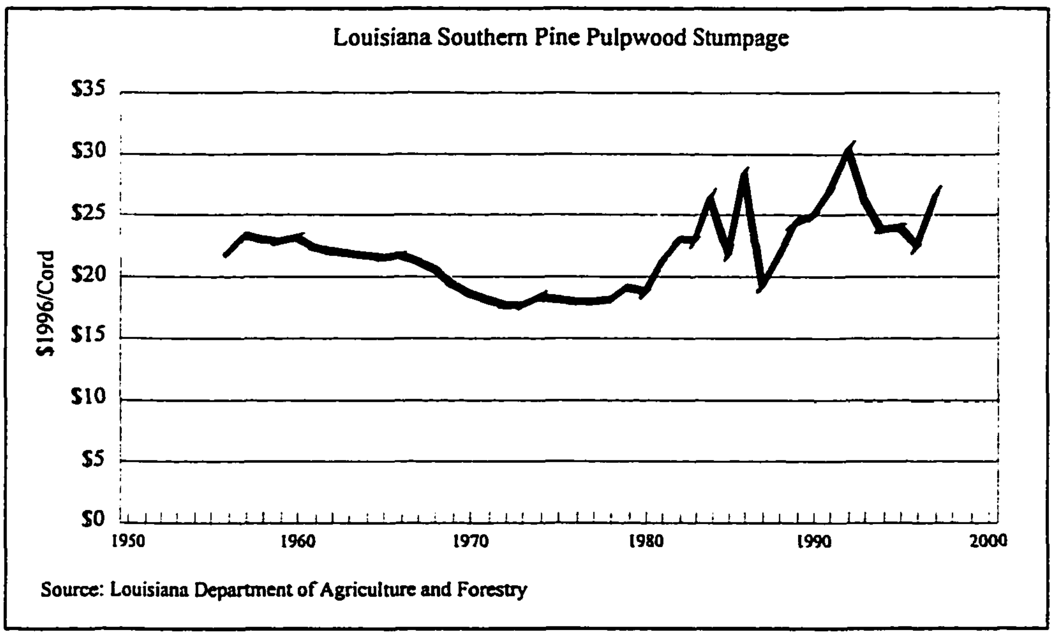
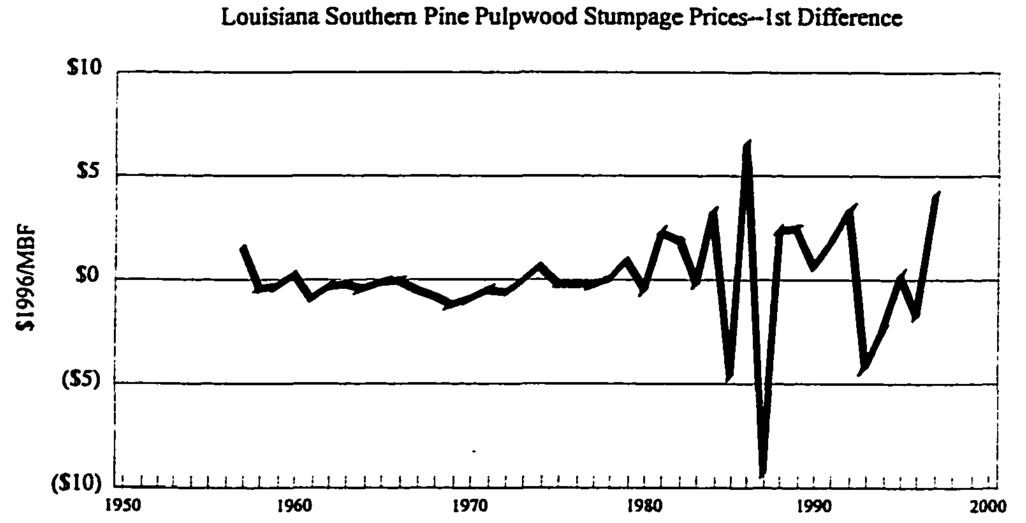


Figure 55—First differenced Louisiana southern pine pulpwood stumpage prices



Source: Louisiana Department of Agriculture and Forestry

The autocorrelation functions indicate the level series is stationary, while the unit root tests indicate it is not (Table 16). The first differenced series is indicated as stationary.

Table 16—Summary of the autocorrelation function and unit root tests on the Louisiana southern pine pulpwood stumpage price series.

	Series	
Test	Level	First Difference
Autocorrelation Function	probably	yes
Partial Autocorrelation Function	yes	yes
ADF with Constant	no	***
ADF with Constant and Trend	no	***
ADF with no Constant or Trend	no	***
Phillips-Perron	no	***

*** exceeds 1% critical value
** exceeds 5% critical value
* exceeds 10% critical value

Process Control Chart Analysis

While the tests for stationarity and Figure 55 indicate that the first differenced price series has a constant mean, the figure also indicates increasing changes in variability. Shewhart control charts (Figure 56 and Figure 57) were used to analyze this variability. The first differenced series was steady from 1955 to 1980. The variance increased at that time and there were sharp swings in 1986 and 1987. Two observations exceed the 95 percent confidence limits (2.05 expected) and two exceed the 99 percent confidence limits (0.41 expected) in the mean chart. Three observations exceed the 95 percent confidence limits (2.00 expected) and two exceed the 99 percent confidence limits (0.40 expected) in the range chart.

Figure 56—Control chart for mean of first differenced Louisiana southern pine pulpwood stumpage prices

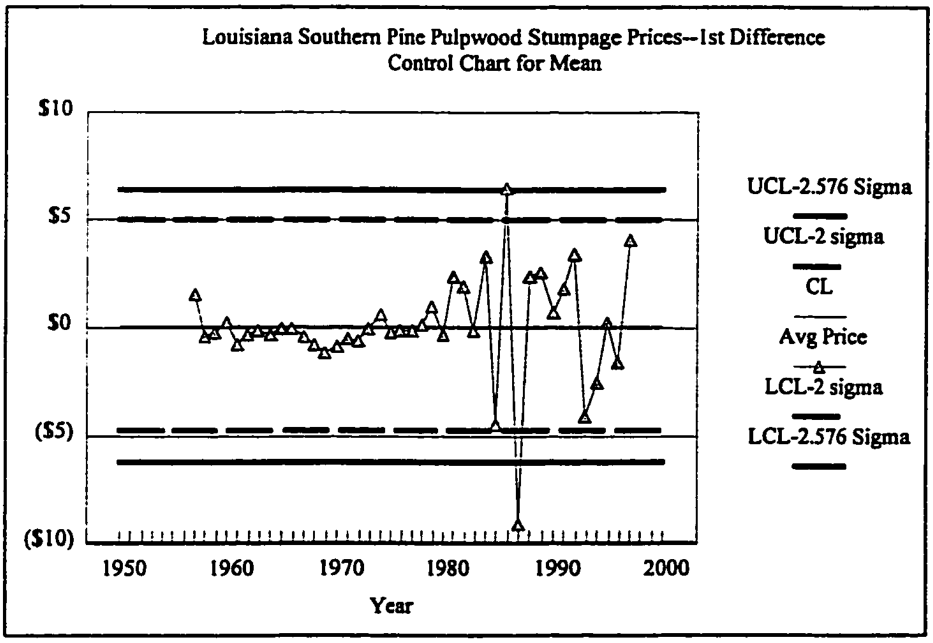
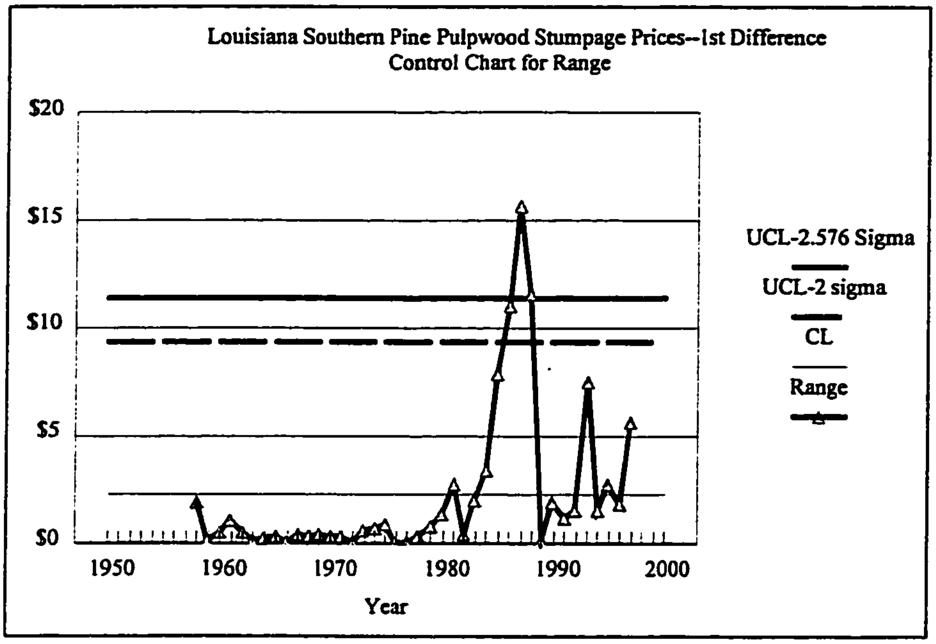


Figure 57—Control chart for range of first differenced Louisiana southern pine pulpwood stumpage prices



Control charts for the price series since 1980 (Figure 58 and Figure 59) show a stable process, though the range chart indicates major fluctuations in the 1980's due to a sharp cycle in prices between 1985 and 1987. One observation exceeds the 95 percent confidence limits (0.90 expected) and one exceeds the 99 percent confidence limits (0.18 expected) in the mean chart. One observation exceeds the 95 percent confidence limits (0.85 expected) and none exceed the 99 percent confidence limits (0.17 expected) in the range chart.

Figure 58—Control chart for mean of recent first differenced Louisiana southern pine pulpwood stumpage prices

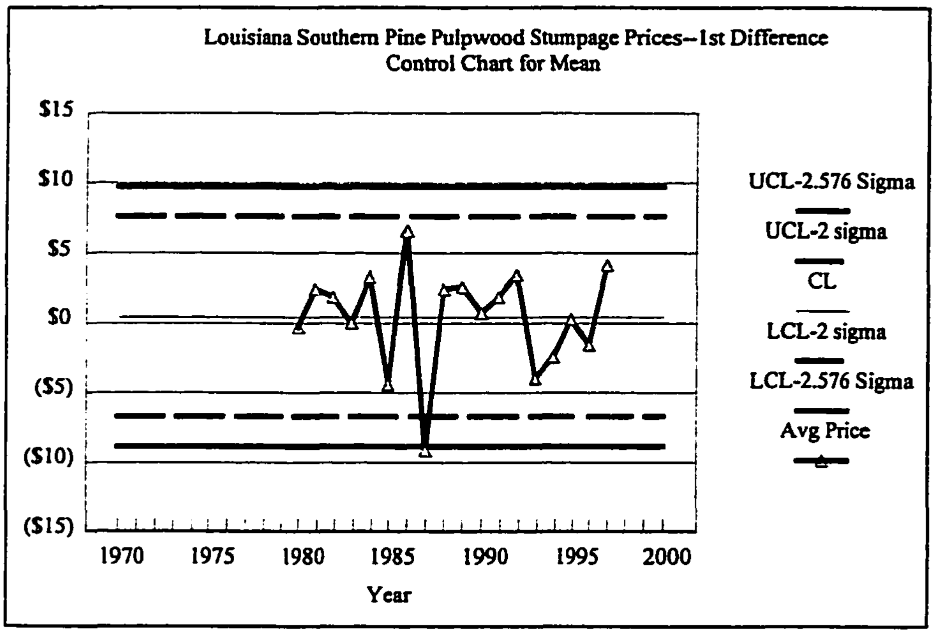
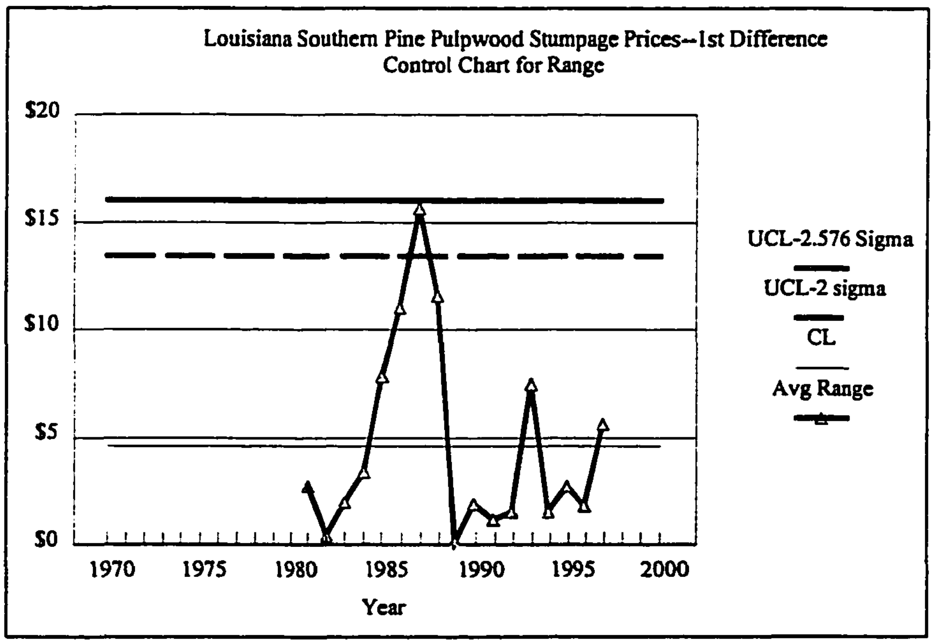


Figure 59—Control chart for range of recent first differenced Louisiana southern pine pulpwood stumpage prices



Variance Ratio Test

The process control charts indicate the variance after 1980 is different than the variance prior to that year. This is supported by the variance ratio test: the variance for the period 1980-1997 is statistically different (at the one percent level) from the variance for the period 1955-1980.

Stationarity of the Current Trend

Figure 60 and Figure 61 show the level and first difference price series since 1980. The autocorrelation functions indicate the level series is stationary, while the unit root tests give mixed results (Table 17). The first differenced series is indicated as stationary.

Figure 60—Recent Louisiana southern pine pulpwood stumpage prices

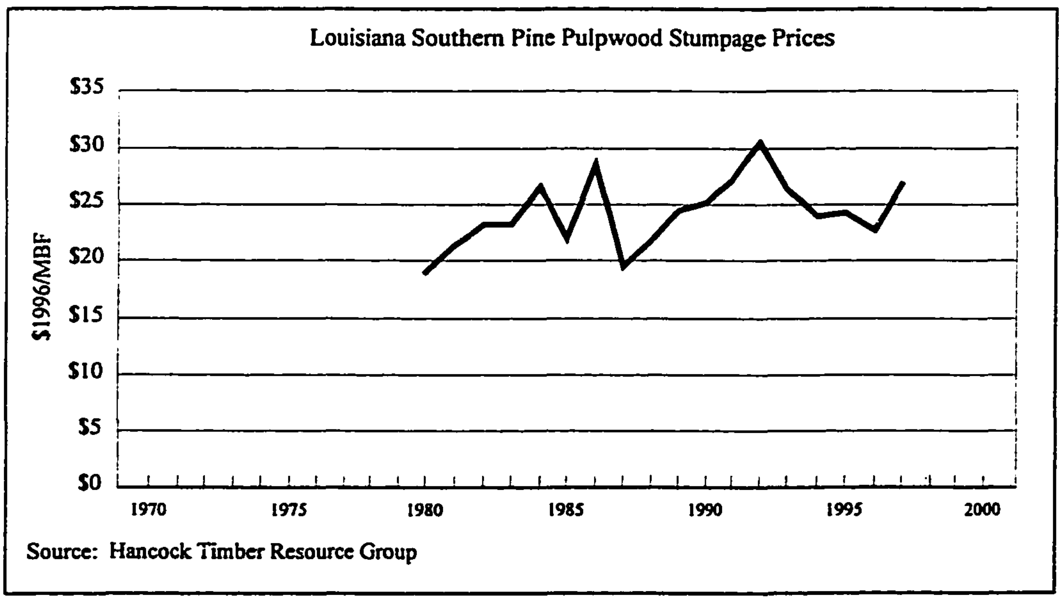


Figure 61—Recent first differenced Louisiana southern pine pulpwood stumpage prices

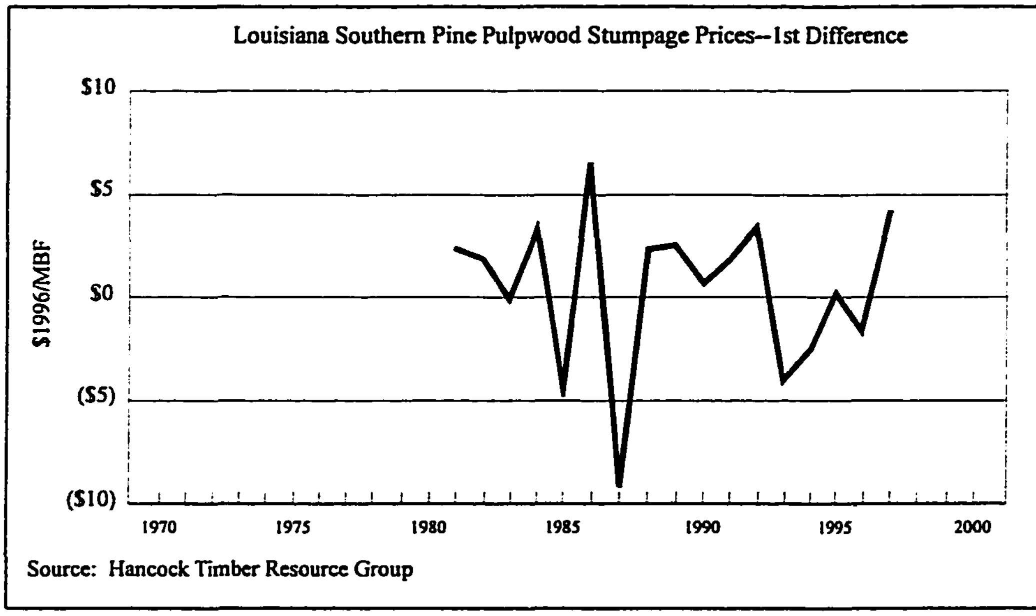


Table 17—Summary of the autocorrelation function and unit root tests for the Louisiana southern pine pulpwood stumpage price series since 1980

	Series	
Test	Level	First Difference
Autocorrelation Function	yes	yes
Partial Autocorrelation Function	yes	yes
ADF with Constant	no	**
ADF with Constant and Trend	no	*
ADF with no Constant or Trend	no	***
Phillips-Perron	**	***

*** exceeds 1% critical value
** exceeds 5% critical value
* exceeds 10% critical value

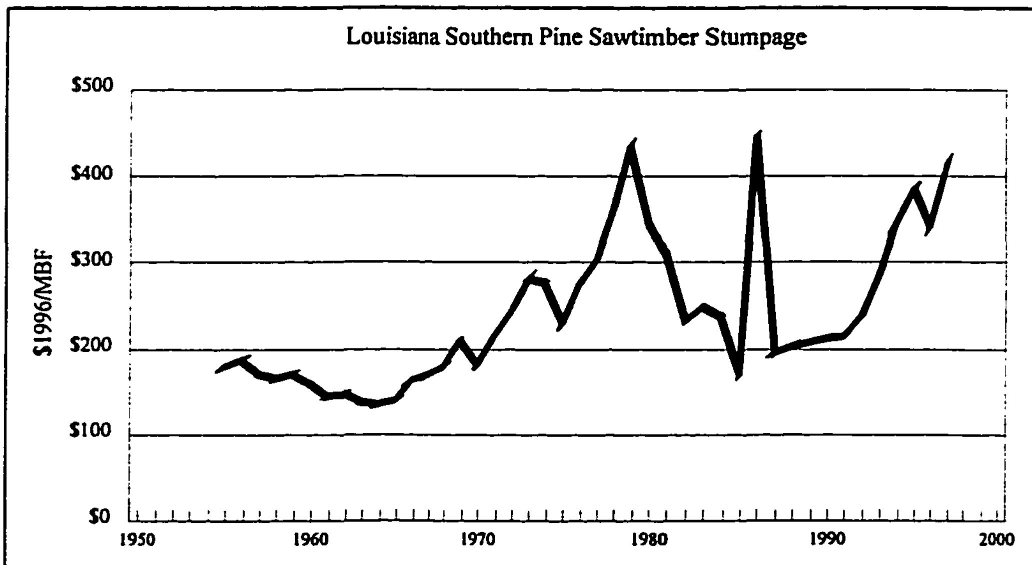
In summary, the level Louisiana southern pine pulpwood stumpage price series is not stationary. The first differenced series has a constant mean and variance over the period 1980-1997.

Louisiana Southern Pine Sawtimber Stumpage Prices

Stationarity of the Entire Series

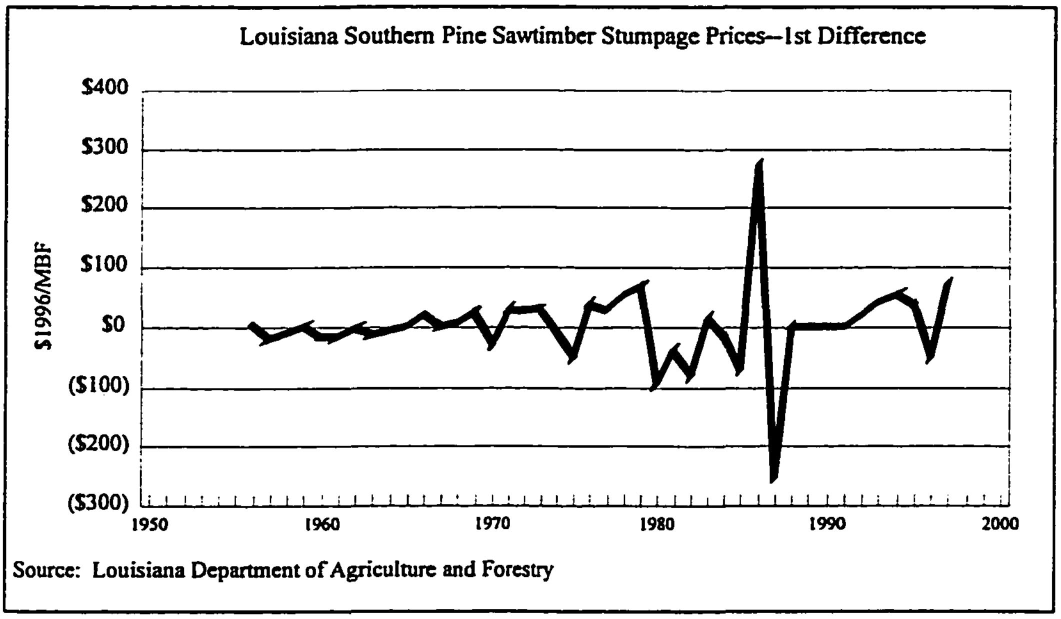
The level and first differenced Louisiana southern pine sawtimber stumpage prices as reported by the Louisiana Department of Agriculture and Forestry are shown in Figure 62 and Figure 63. Prices drifted downward until 1962, then rose steadily until 1979. They then fell quickly until 1985, when there was a very sharp spike, with prices jumping from about $275/MBF to $450/MBF in 1986, then falling back to $200/MBF in 1987. Price have risen since then.

Figure 62—Louisiana southern pine sawtimber stumpage prices



Source: Louisiana Department of Agriculture and Forestry

Figure 63—First differenced Louisiana southern pine sawtimber stumpage prices



The autocorrelation functions indicate the level series is stationary, while the unit root tests indicate it is not (Table 18). The first differenced series is indicated as stationary.

Table 18—Summary of the autocorrelation function and unit root tests on the Louisiana southern pine sawtimber stumpage price series.

	Series	
Test	Level	First Difference
Autocorrelation Function	probably	yes
Partial Autocorrelation Function	yes	yes
ADF with Constant	no	***
ADF with Constant and Trend	no	***
ADF with no Constant or Trend	no	***
Phillips-Perron	no	***

*** exceeds 1% critical value
** exceeds 5% critical value
* exceeds 10% critical value

Process Control Chart Analysis

While the tests for stationarity and Figure 63 indicate that the first differenced price series has a constant mean, the figure also indicates increasing changes in

variability. Shewhart control charts (Figure 64 and Figure 65) were used to analyze this variability. The first differenced series was very steady from 1950 to 1968. The variance increased at that time. Two observations exceed the 95 percent confidence limits (2.05 expected) and two exceed the 99 percent confidence limits (0.41 expected) in the mean chart. Two observations exceed the 95 percent confidence limits (2.00 expected) and two exceed the 99 percent confidence limits (0.40 expected) in the range chart.

Figure 64—Control chart for mean of first differenced Louisiana southern pine sawtimber stumpage prices

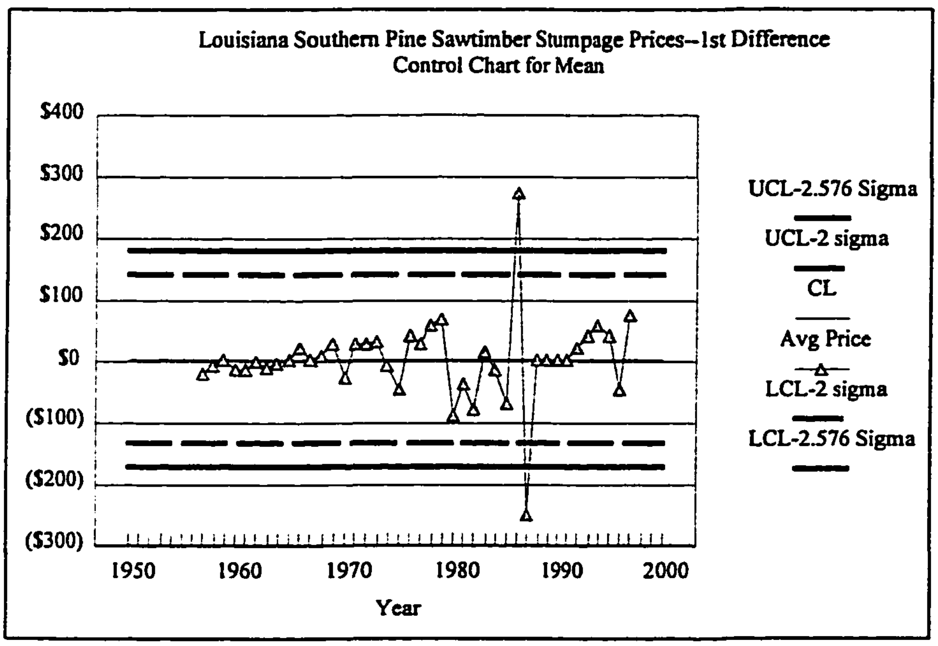
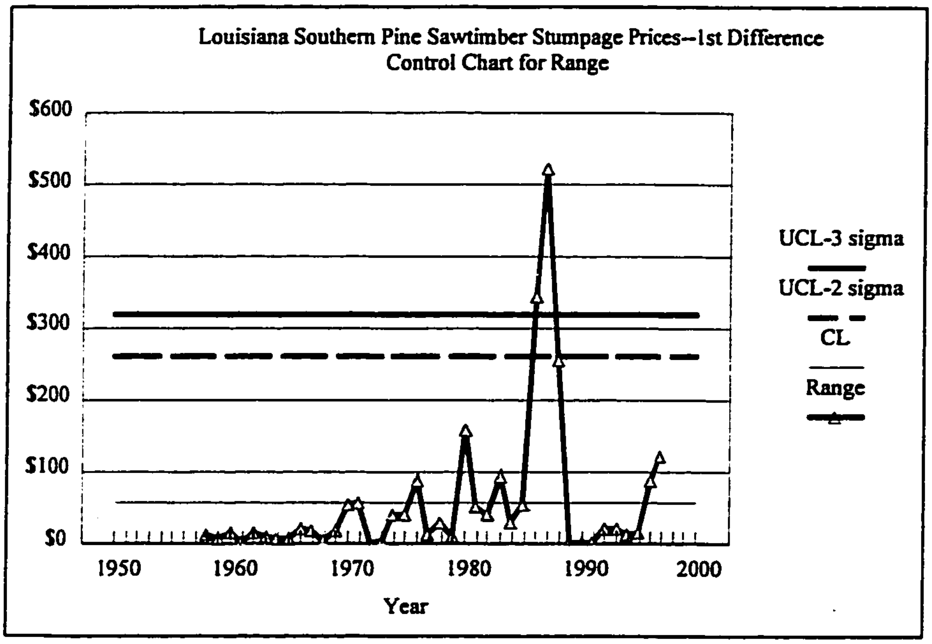


Figure 65—Control chart for range of first differenced Louisiana southern pine sawtimber stumpage prices



Control charts (Figure 66 and Figure 67) for the series since 1970 still have outlying points in the mid-1980's. Two observations exceed the 95 percent confidence limits (1.35 expected) and two exceed the 99 percent confidence limits (0.27 expected) in the mean chart. Two observations exceed the 95 percent confidence limits (1.30 expected) and one exceeds the 99 percent confidence limits (0.26 expected) in the range chart.

Figure 66—Control chart for mean of recent first differenced Louisiana southern pine sawtimber stumpage prices

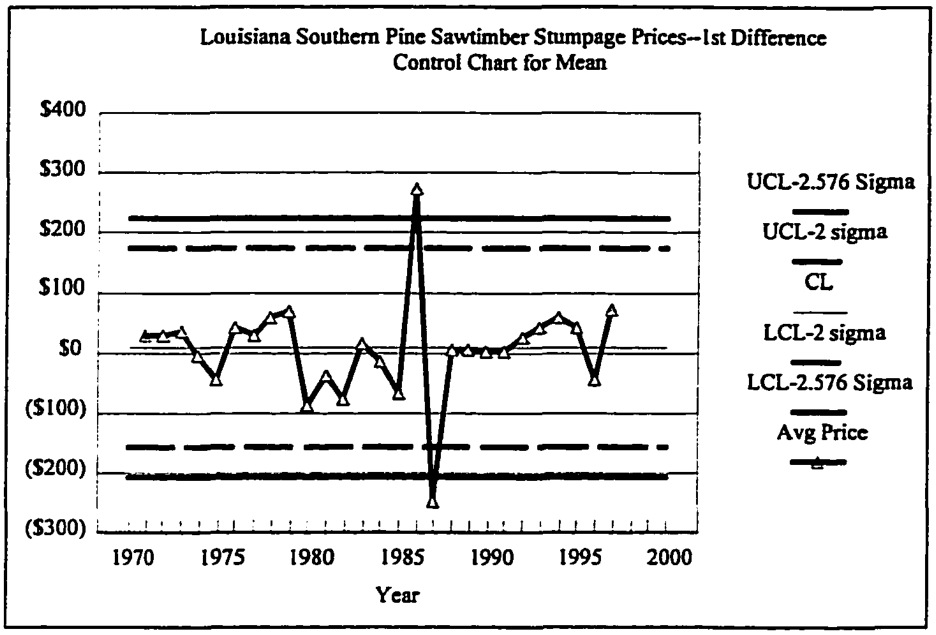
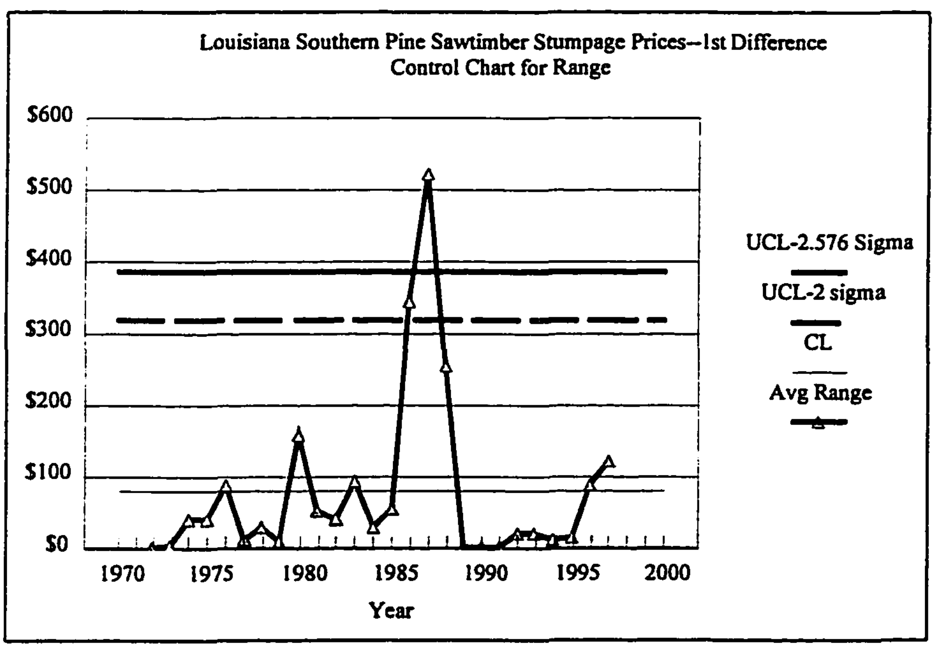


Figure 67—Control chart for range of recent first differenced Louisiana southern pine sawtimber stumpage prices



When the high price from 1986 is removed from the series, all observations fall within the expected limits.

Variance Ratio Test

The process control charts indicate the variance after 1970 is different than the variance prior to that year. This is supported by the variance ratio test: the variance for the period 1970-1997 is statistically different (at the one percent level) from the variance for the period 1955-1970.

Stationarity of the Current Trend

Figure 68 and Figure 69 show the price series since 1970. The autocorrelation functions indicate the levei series is stationary, while the unit root tests give mixed results (Table 19). All tests indicate the first differenced series is stationary.

Figure 68—Recent Louisiana southern pine sawtimber stumpage prices

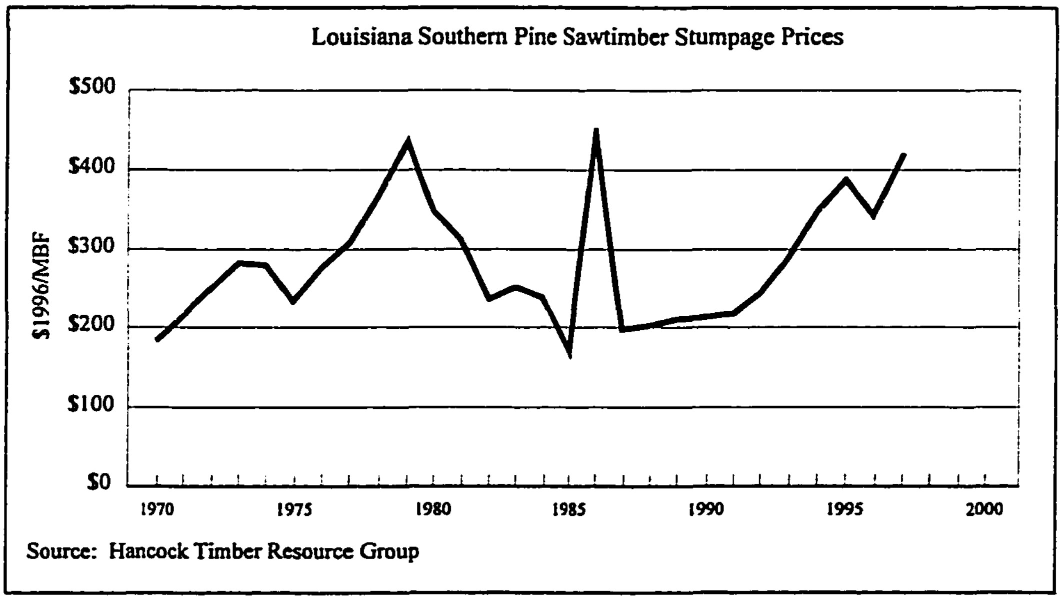


Figure 69—Recent first differenced Louisiana southern pine sawtimber stumpage prices

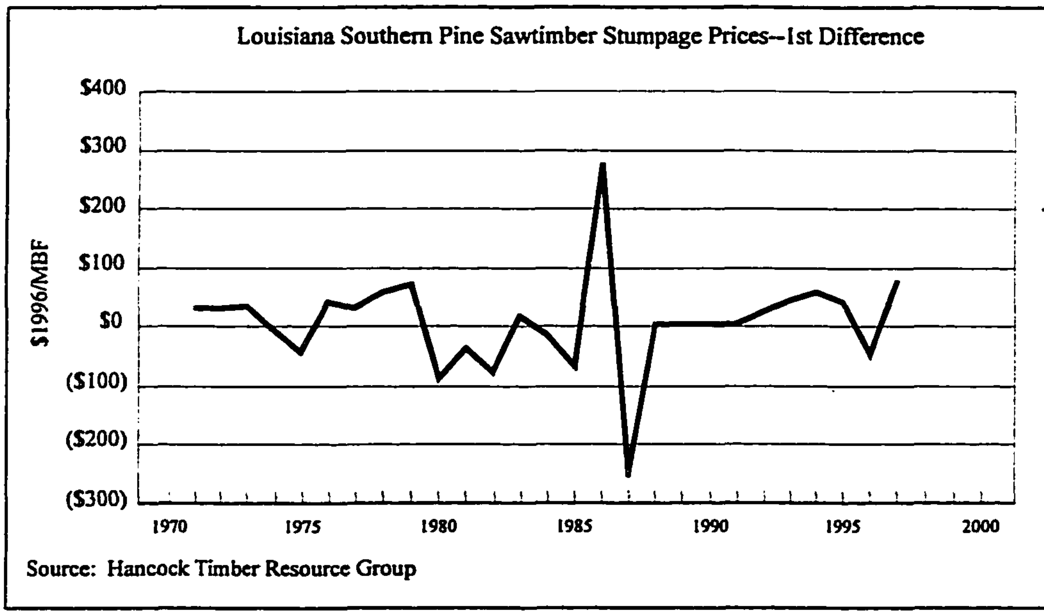


Table 19—Summary of the autocorrelation function and unit root tests on the Louisiana southern pine sawtimber stumpage price series since 1970

	Series	
Test	Level	First Difference
Autocorrelation Function	yes	yes
Partial Autocorrelation Function	yes	yes
ADF with Constant	no	***
ADF with Constant and Trend	no	***
ADF with no Constant or Trend	no	***
Phillips-Perron	**	***

*** exceeds 1% critical value
** exceeds 5% critical value
* exceeds 10% critical value

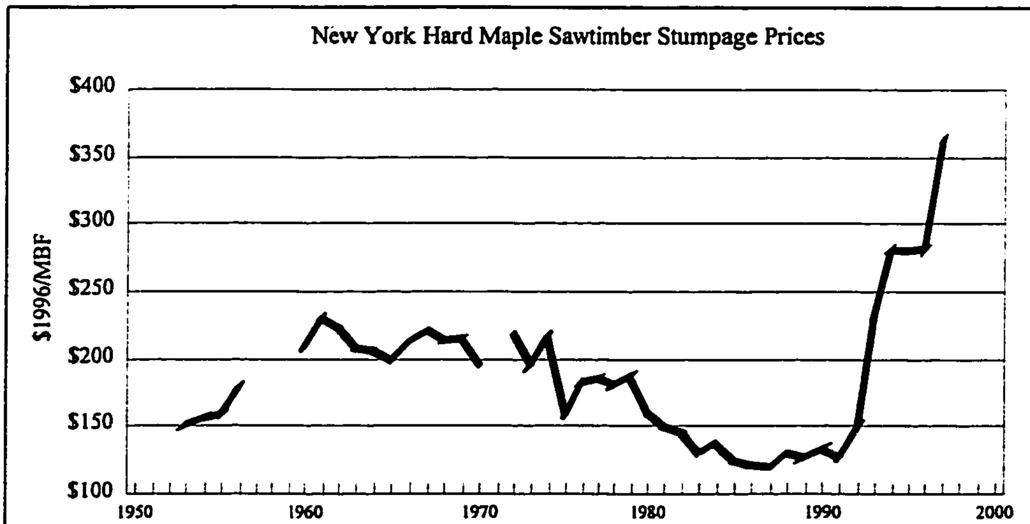
In summary, the first differenced Louisiana southern pine sawtimber stumpage price series is stationary for the period 1970-1997. The first differenced series is probably mean-reverting over its entire range, but the variance is not constant so the series cannot be stationary.

New York Hard Maple Sawtimber Stumpage Prices

Stationarity of the Entire Series

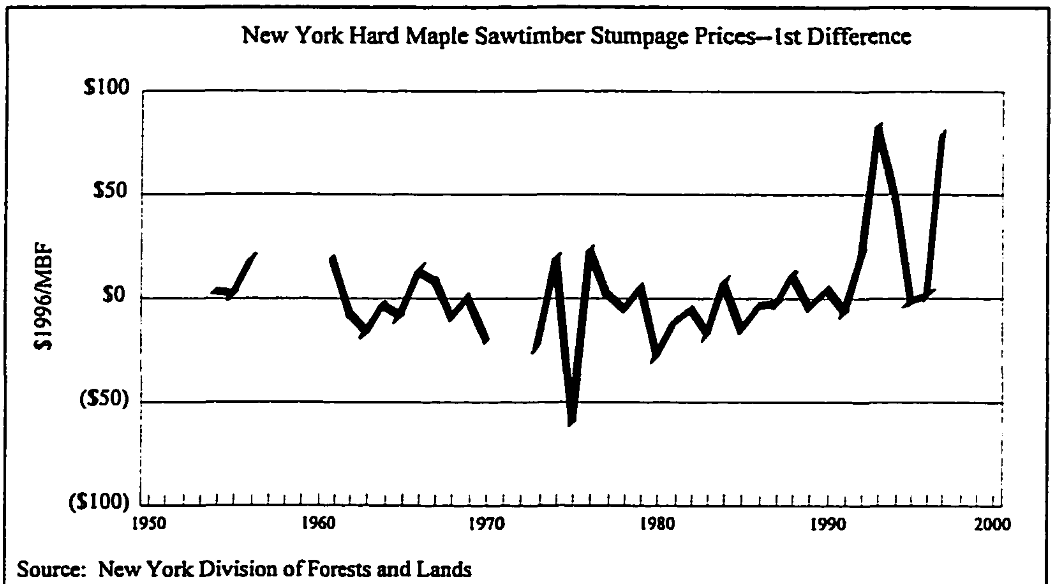
Figure 70 and Figure 71 show the level and first differenced New York hard maple sawtimber stumpage prices as reported by the New York Division of Lands and Forests since 1953. Prices appear to have been level between 1960 and 1974, then fell between 1974 and 1990, and then rose sharply after 1990. Other interpretations are: that prices fell from 1974 to 1985, then were level until 1990; or prices fell between 1960 and 1985. This clearly shows the subjectivity of visual analysis and the influence of end points in deciding whether a series goes up or down.

Figure 70—New York hard maple sawtimber stumpage prices



Source: New York Division of Forests and Lands

Figure 71—First differenced New York hard maple sawtimber stumpage prices



The autocorrelation functions indicate the level series is stationary, while the unit root tests indicate it is not (Table 20). The first differenced series is indicated as probably stationary, while the second differenced series is certainly stationary.

Table 20—Summary of the autocorrelation function and unit root tests on the New York hard maple sawtimber stumpage price series.

	Series		
Test	Level	First Difference	Second Difference
Autocorrelation Function	yes	yes	yes
Partial Autocorrelation Function	yes	yes	yes
ADF with Constant	no	no	***
ADF with Constant and Trend	no	*	***
ADF with no Constant or Trend	no	**	***
Phillips-Perron	no	***	***

*** exceeds 1% critical value
** exceeds 5% critical value
* exceeds 10% critical value

Process Control Chart Analysis

The stationarity tests on the first differenced series do not conclusively indicate stationarity. Figure 71 indicates a constant mean until about 1990, when a jump occurred. Shewhart control charts (Figure 72 and Figure 73) were used to analyze this variability. The first differenced series was steady from 1950 to 1991, with a spike about 1975. Three observations exceed the 95 percent confidence limits (1.90 expected) and two exceed the 99 percent confidence limits (0.38 expected) in the mean chart. Three observations exceed the 95 percent confidence limits (1.75 expected) and one exceeds the 99 percent confidence limits (0.35 expected) in the range chart.

Figure 72—Control chart for mean of first differenced New York hard maple sawtimber stumpage prices

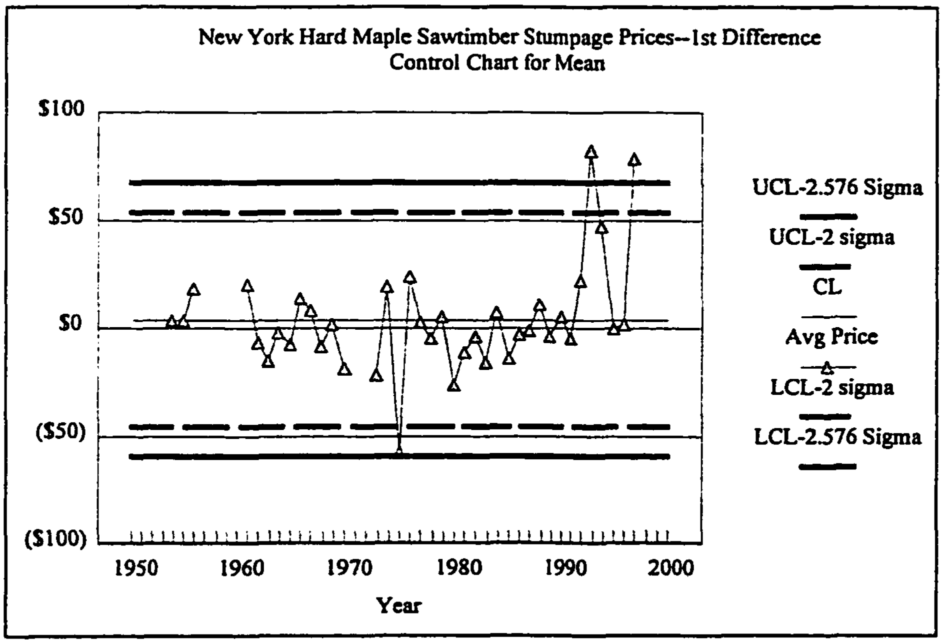
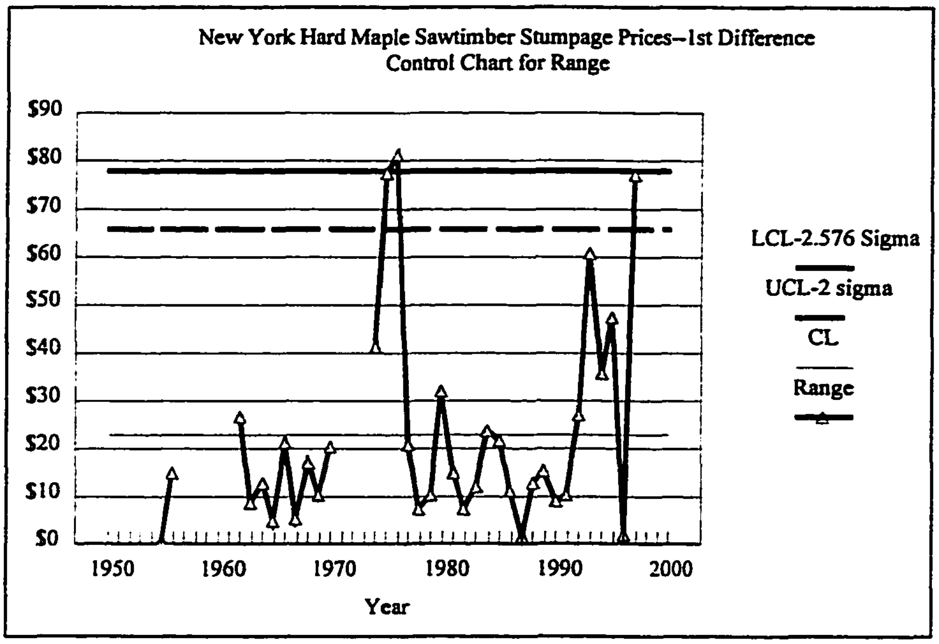


Figure 73—Control chart for range of first differenced New York hard maple sawtimber stumpage prices



Control charts for the period 1991-1997 show a somewhat more stable process (Figure 74 and Figure 75). The control line intervals are much wider for the subset than for the entire series, but no value exceeds any confidence limit.

Figure 74—Control chart for mean of recent first differenced New York hard maple sawtimber stumpage prices

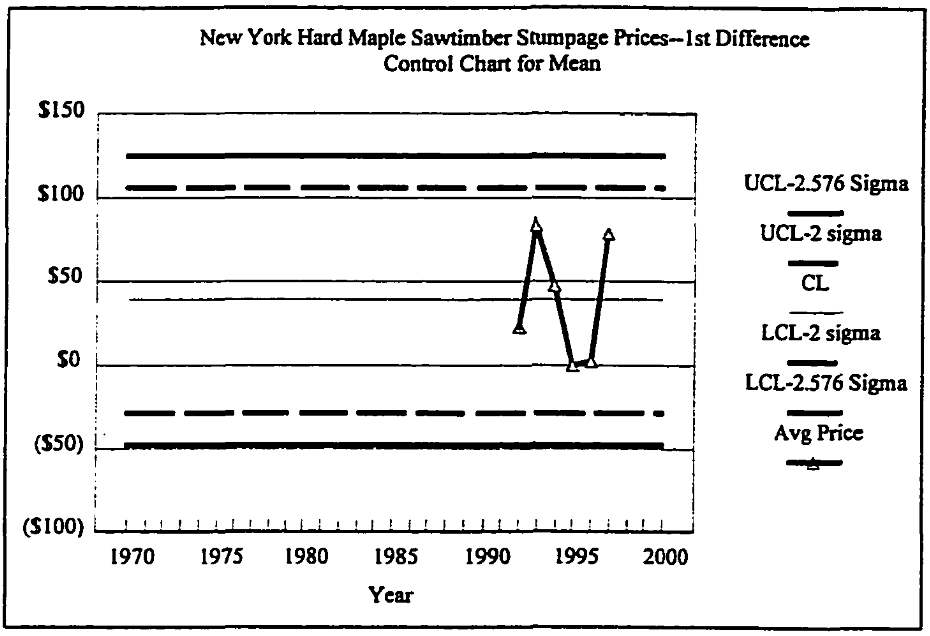
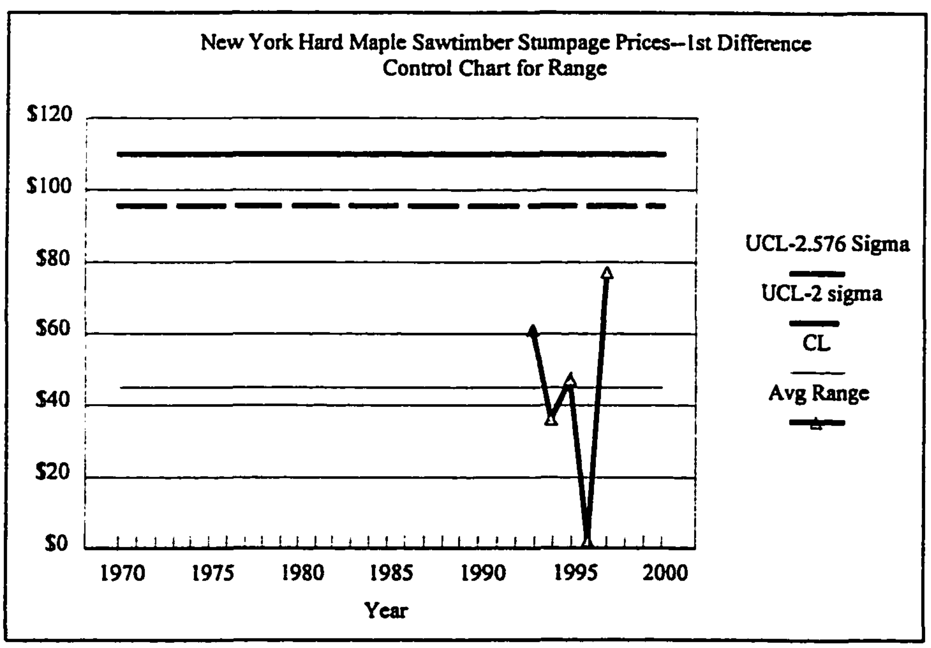


Figure 75—Control chart for range of recent first differenced New York hard maple sawtimber stumpage prices



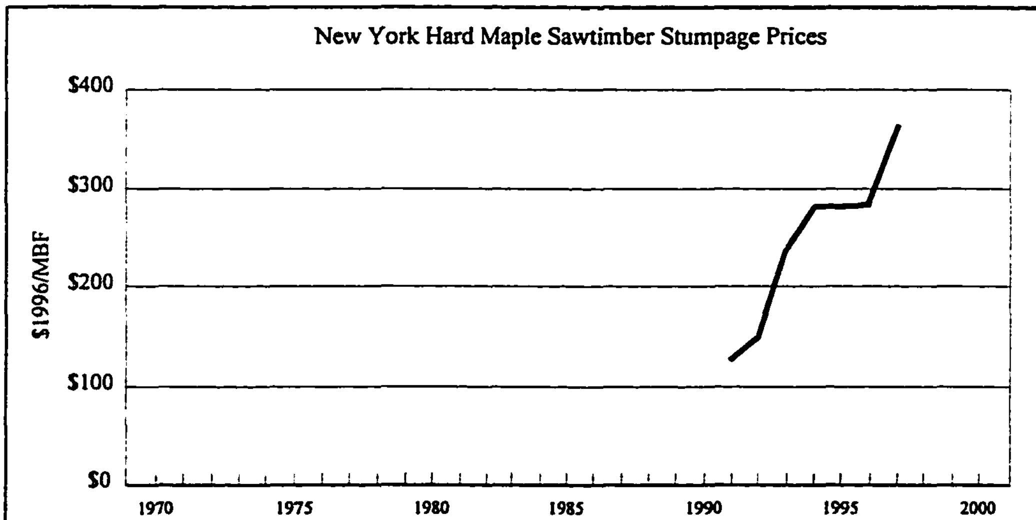
Variance Ratio Test

The process control charts indicate the variance after 1991 is different than the variance prior to that year. This is supported by the variance ratio test: the variance for the period 1991-1997 is statistically different (at the one percent level) from the variance for the period 1950-1991.

Stationarity of the Current Trend

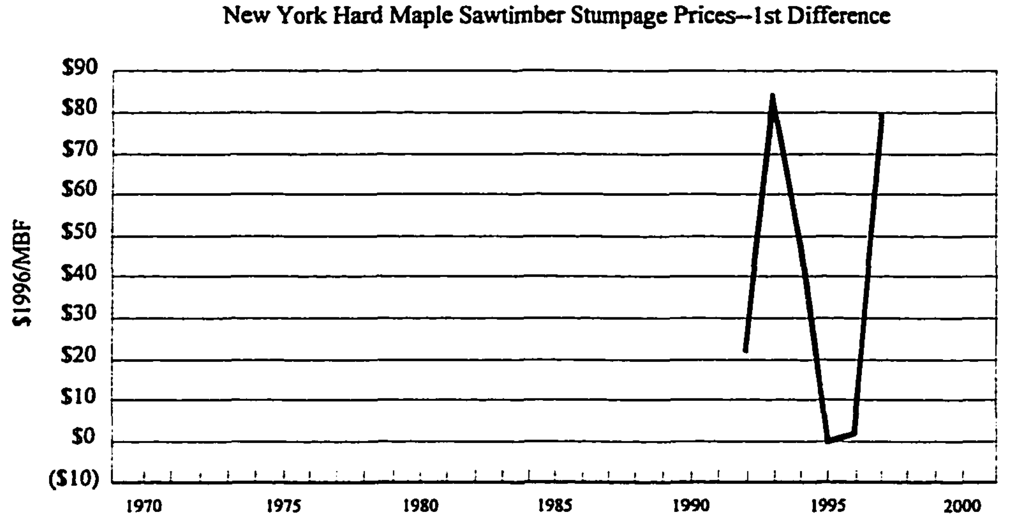
Figure 76 and Figure 77 show the price series since 1991. The autocorrelation functions indicate the level series is stationary, while the unit root tests give mixed results (Table 21). They indicate the level series and first differenced series are probably not stationary, while second differenced series is probably stationary.

Figure 76—Recent New York hard maple sawtimber stumpage prices



Source: Hancock Timber Resource Group

Figure 77—Recent first differenced New York hard maple sawtimber stumpage prices



Source: Hancock Timber Resource Group

Table 21-Summary of the autocorrelation function and unit root tests for the New York hard maple sawtimber stumpage price series since 1991

	Series		
Test	Level	First Difference	Second Difference
Autocorrelation Function	yes	yes	yes
Partial Autocorrelation Function	yes	yes	yes
ADF with Constant	no	no	*
ADF with Constant and Trend	**	*	*
ADF with no Constant or Trend	no	no	***
Phillips-Perron	no	no	no

*** exceeds 1% critical value
** exceeds 5% critical value
* exceeds 10% critical value

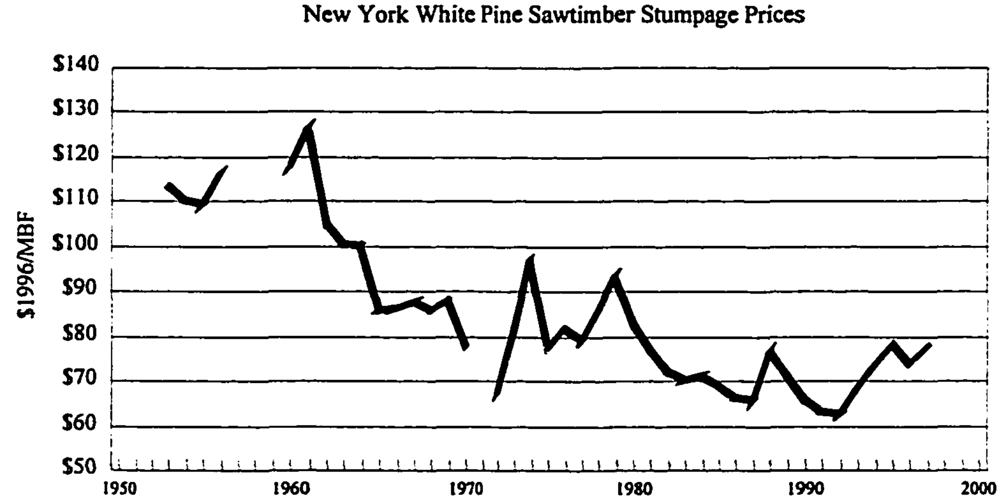
In summary, the level New York hard maple sawtimber stumpage price series is not stationary. The process generating the price series changed in 1991, but tests for stationarity indicate that the level and first differenced series are probably not stationary even for that subset. Only the second differenced series for the period 1991-1997 is probably stationary.

New York White Pine Sawtimber Stumpage Prices

Stationarity of the Entire Series

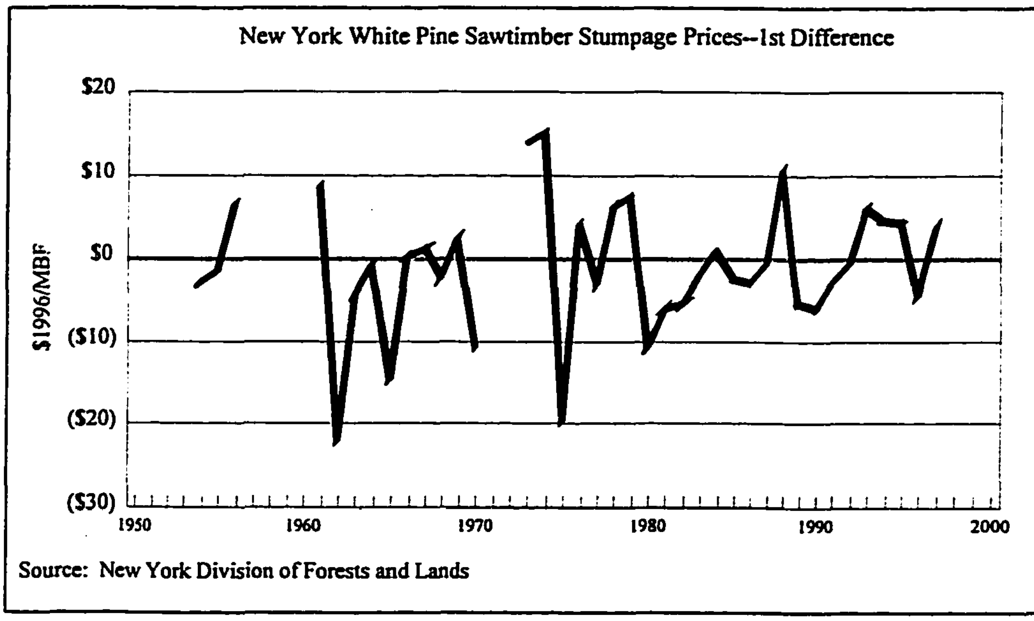
Figure 78 and Figure 79 show the level and first differenced New York white pine sawtimber stumpage prices as reported by the New York Division of Lands and Forests since 1953. There was a fairly steady drop in prices between 1960 and 1970. Price appear to have been level between 1970 and 1997. An alternative interpretation is that prices fell slowly between 1970 and 1990, and have risen slightly since then.

Figure 78—New York white pine sawtimber stumpage prices



Source: New York Division of Forests and Lands

Figure 79—First differenced New York white pine sawtimber stumpage prices



The autocorrelation functions indicate the level series is stationary, while the unit root tests indicate it is probably not (Table 22). The first differenced series is indicated as stationary.

Table 22— Summary of the autocorrelation function and unit root tests on the New York white pine sawtimber stumpage price series.

	Series	
Test	Level	First Difference
Autocorrelation Function	yes	yes
Partial Autocorrelation Function	yes	yes
ADF with Constant	*	***
ADF with Constant and Trend	*	***
ADF with no Constant or Trend	no	***
Phillips-Perron	no	***

*** exceeds 1% critical value
** exceeds 5% critical value
* exceeds 10% critical value

Process Control Chart Analysis

While the tests for stationarity and Figure 79 indicate that the first differenced price series has a constant mean, the figure also indicates increasing changes in variability. Shewhart control charts (Figure 80 and Figure 81) were used to analyze this variability. The first differenced series shows substantial variability, which may have decreased over time. Three observations exceed the 95 percent confidence limits (1.90 expected) and one exceeds the 99 percent confidence limits (0.38 expected) in the mean chart. Two observations exceed the 95 percent confidence limits (1.75 expected) and two exceed the 99 percent confidence limits (0.35 expected) in the range chart. The range observations are generally lower after 1980, though they are not especially stable.

Figure 80—Control chart for mean of first differenced New York white pine sawtimber stumpage prices

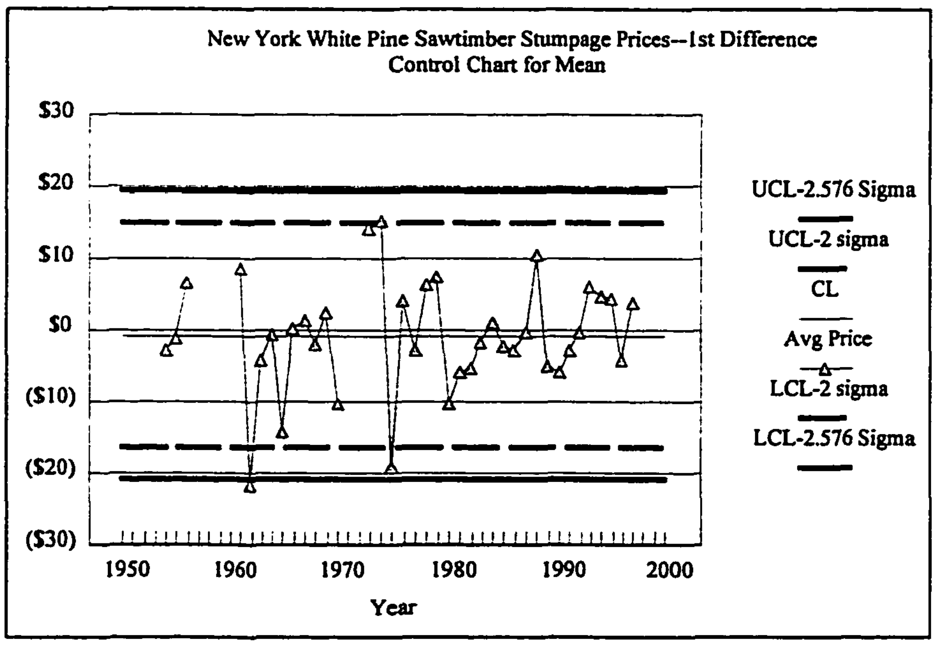


Figure 81—Control chart for range of first differenced New York white pine sawtimber stumpage prices

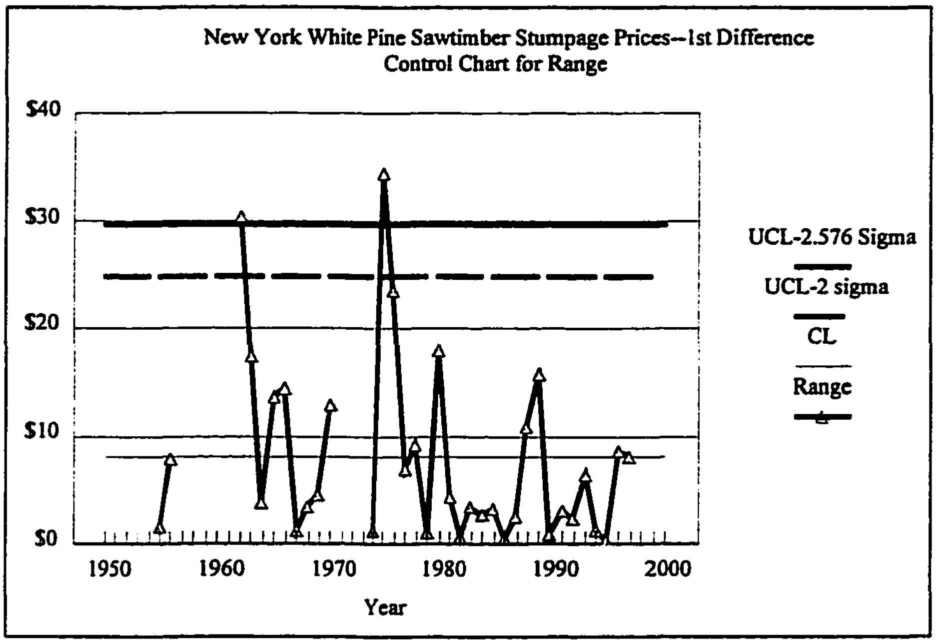


Figure 82 and Figure 83 are mean and range control charts for the period 1980-1997. One observation exceeds the 95 percent confidence limits (0.85 expected) and none exceed the 99 percent confidence limits (0.17 expected) in the mean chart. One observation exceeds the 95 percent confidence limits (0.80 expected) and one exceeds the 99 percent confidence limits (0.16 expected) in the range chart.

Figure 82—Control chart for mean of recent first differenced New York white pine sawtimber stumpage prices

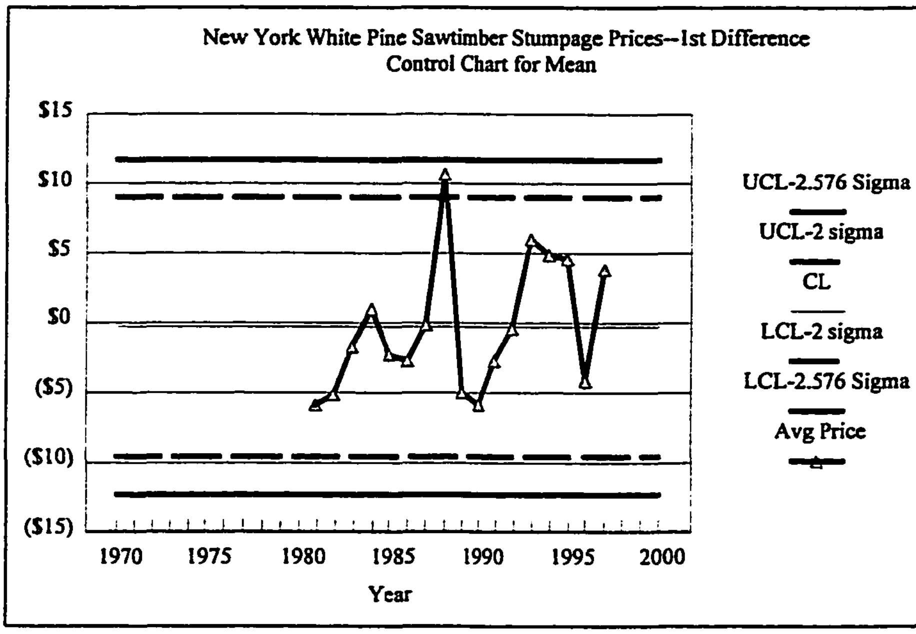
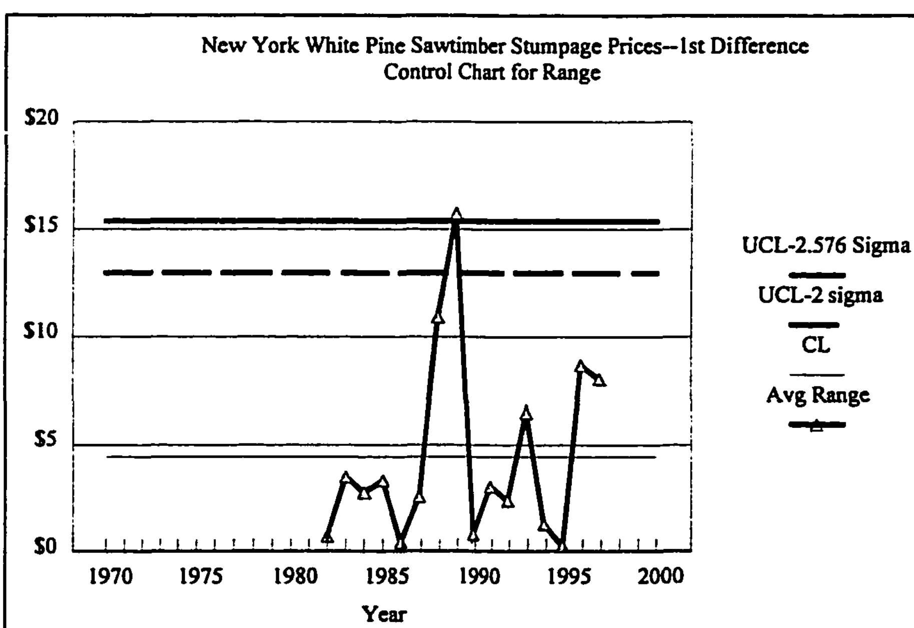


Figure 83—Control chart for range of recent first differenced New York white pine sawtimber stumpage prices



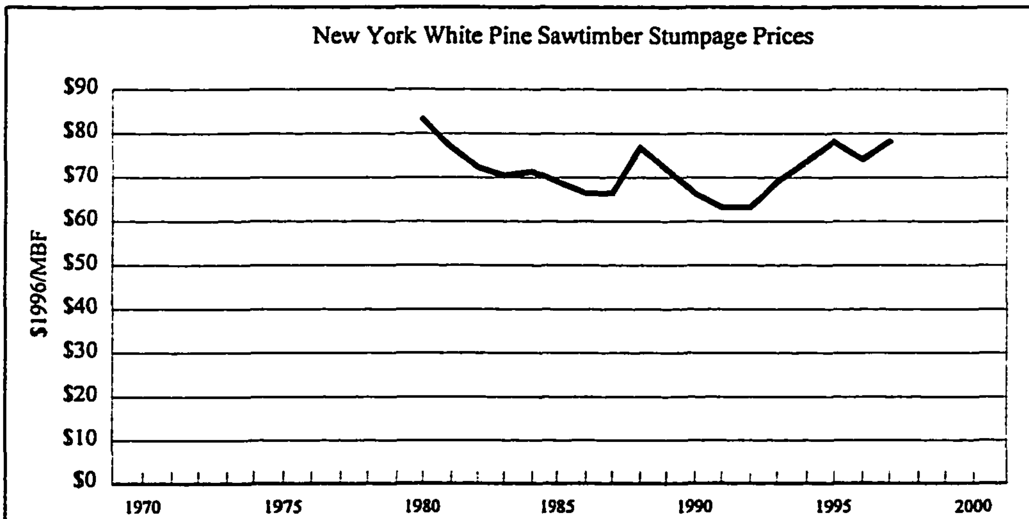
Variance Ratio Test

The process control charts indicate the variance after 1980 may be different than the variance prior to that year. This is supported by the variance ratio test: the variance for the period 1980-1997 is statistically different (at the one percent level) from the variance for the period 1950-1980.

Stationarity of the Current Trend

Figure 84 and Figure 85 show the price series since 1980. The autocorrelation functions indicate the level series is stationary, while the unit root tests give mixed results (Table 23). They indicate the level series might be stationary. The first differenced series is indicated as stationary.

Figure 84—Recent New York white pine sawtimber stumpage prices



Source: Hancock Timber Resource Group

Figure 35—Recent first differenced New York white pine sawtimber stumpage prices

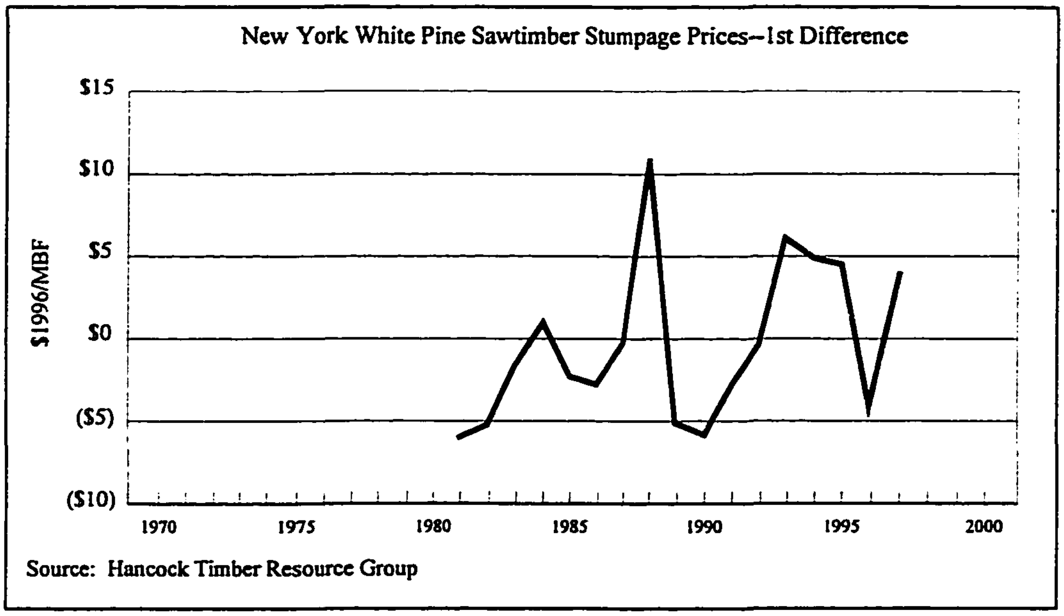


Table 23—Summary of the autocorrelation function and unit root tests for the New York white pine sawtimber stumpage price series since 1980

	Series	
Test	Level	First Difference
Autocorrelation Function	yes	yes
Partial Autocorrelation Function	yes	yes
ADF with Constant	**	**
ADF with Constant and Trend	no	***
ADF with no Constant or Trend	no	***
Phillips-Perron	**	***

*** exceeds 1% critical value
** exceeds 5% critical value
* exceeds 10% critical value

In summary, the level New York white pine sawtimber stumpage price series is not stationary. The first differenced series is stationary for the period 1980-1997.

New York Red Spruce Sawtimber Stumpage Prices

Stationarity of the Entire Series

Figure 86 and Figure 87 show the level and first differenced New York red spruce sawtimber stumpage prices as reported by the New York Division of Lands and Forests since 1953. These prices seem to follow a pattern similar to those of hard maple: prices fell until 1980, leveled off until 1991, then increased. The red spruce sawtimber prices appear to have dropped more steadily and not risen as sharply.

Figure 86—New York red spruce sawtimber stumpage prices

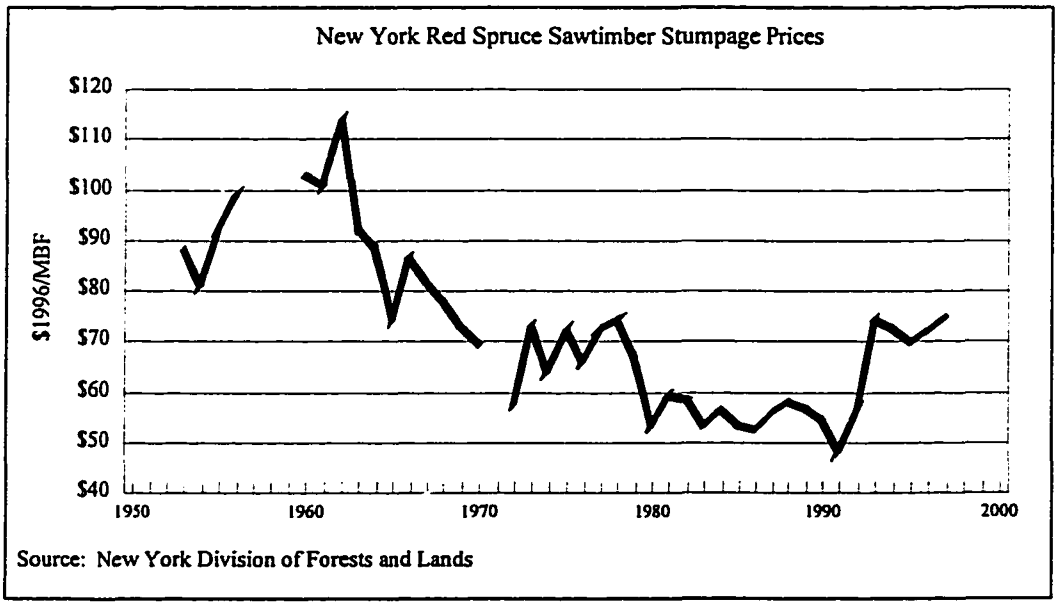
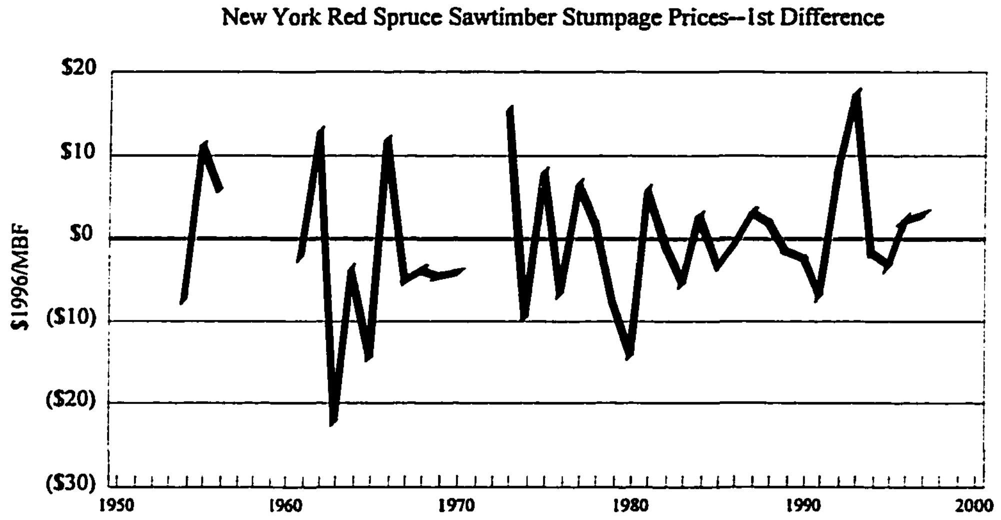


Figure 87—First differenced New York white pine sawtimber stumpage prices



Source: New York Division of Forests and Lands

The autocorrelation functions indicate the level series is stationary, while the unit root tests indicate it is not (Table 24). The first differenced series is indicated as stationary.

Table 24—Summary of the autocorrelation function and unit root tests on the New York red spruce sawtimber stumpage price series.

	Series	
Test	Level	First Difference
Autocorrelation Function	probably	yes
Partial Autocorrelation Function	yes	probably
ADF with Constant	no	***
ADF with Constant and Trend	no	***
ADF with no Constant or Trend	no	***
Phillips-Perron	no	***

*** exceeds 1% critical value
** exceeds 5% critical value
* exceeds 10% critical value

Process Control Chart Analysis

While the tests for stationarity and Figure 87 indicate that the first differenced price series has a constant mean, the figure also suggests a increase in variability.

Shewhart control charts (Figure 88 and Figure 89) were used to analyze this variability. The first differenced series decreased in volatility from 1953 to 1980. Volatility has been less since then, except for a spike in 1992 and 1993. The range chart shows generally decreasing observations except for a spike in the 1990's. Two observations exceed the 95 percent confidence limits (1.90 expected) and one exceeds the 99 percent confidence limits (0.38 expected) in the mean chart. One observation exceeds the 95 percent confidence limits (1.75 expected) and one exceeds the 99 percent confidence limits (0.35 expected) in the range chart.

Figure 88—Control chart for mean of first differenced New York red spruce sawtimber stumpage prices

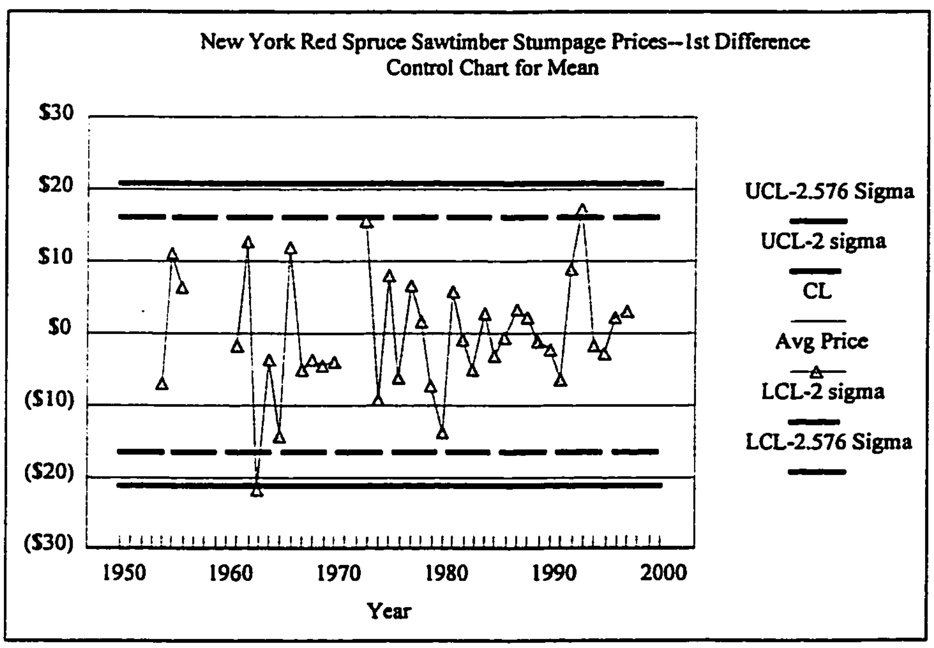


Figure 89—Control chart for range of first differenced New York red spruce sawtimber stumpage prices

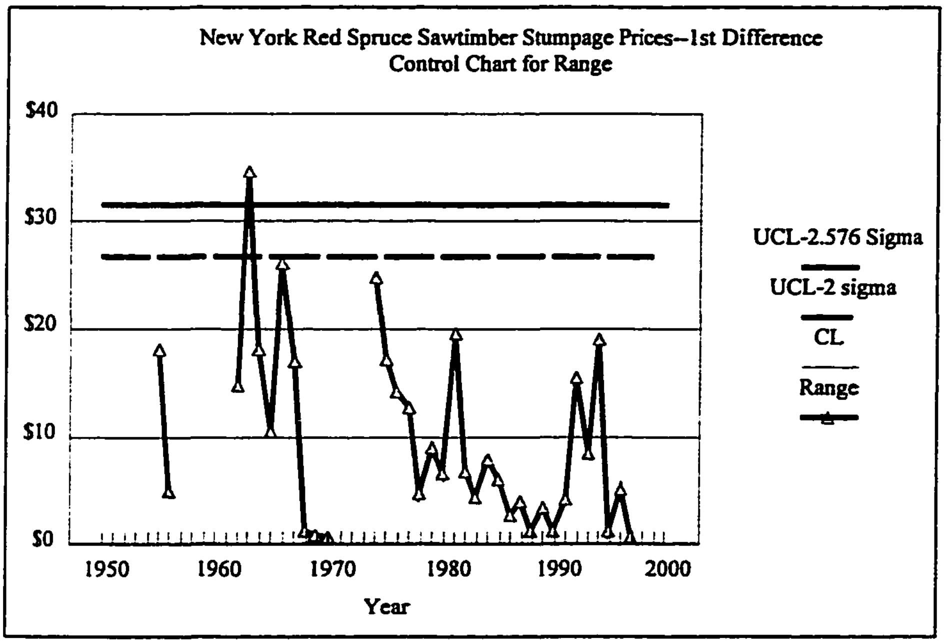


Figure 90 and Figure 91 are control charts for the period 1980-1997. Here the control lines/confidence intervals are much closer together, but the mean control chart shows one observation outside the 99 percent confidence limits as a result of an increase in price in 1993. The removal of this outlier price change results in no observations outside the 99 percent confidence limits and a narrower control line interval.

Figure 90—Control chart for mean of recent first differenced New York red spruce sawtimber stumpage prices

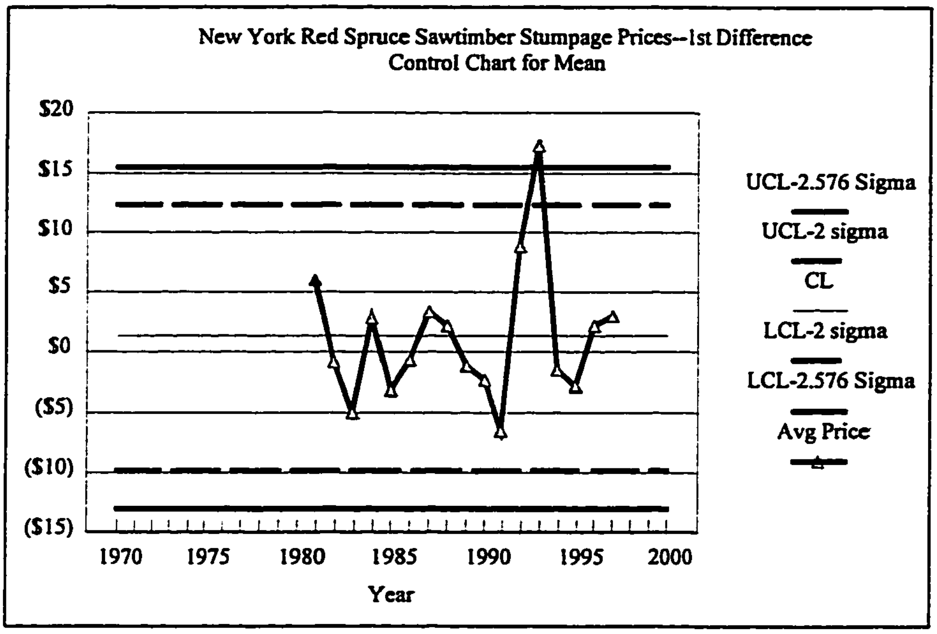
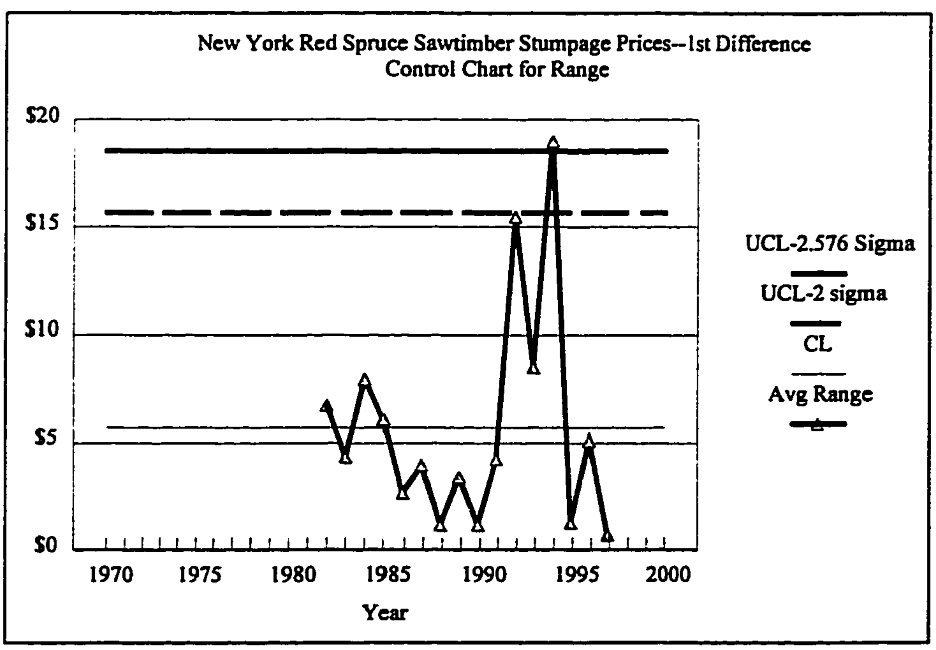


Figure 91—Control chart for range of recent first differenced New York red spruce sawtimber stumpage prices



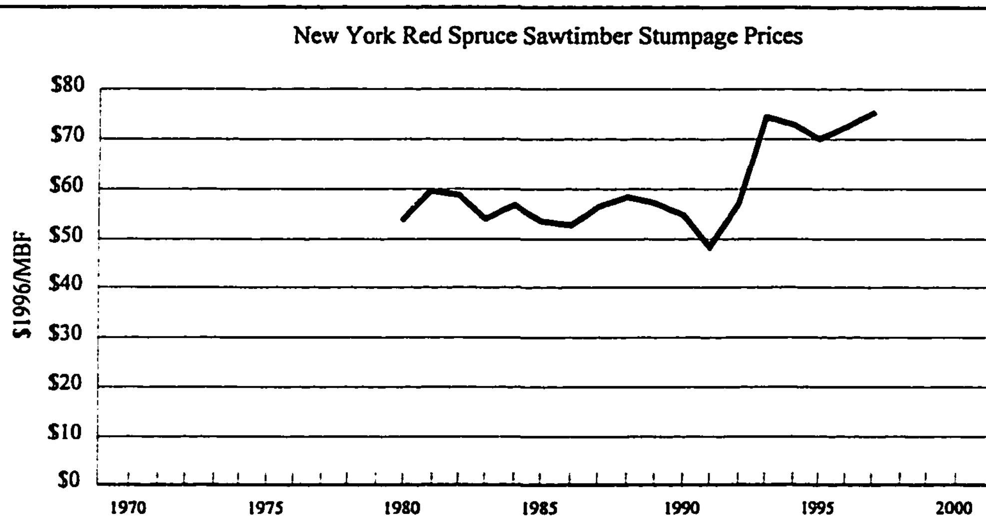
Variance Ratio Test

The process control charts indicate the variance after 1980 is different than the variance prior to that year. This is supported by the variance ratio test: the variance for the period 1980-1997 is statistically different (at the five percent level) from the variance for the period 1950-1980.

Stationarity of the Current Trend

Figure 92 and Figure 93 show the level and first differenced price series since 1980. The autocorrelation functions indicate the level series is stationary, while the unit root tests indicate it is not (Table 25). The first differenced series is stationary.

Figure 92—Recent New York red spruce sawtimber stumpage prices



Source: Hancock Timber Resource Group

Figure 93—Recent first differenced New York red spruce sawtimber stumpage prices

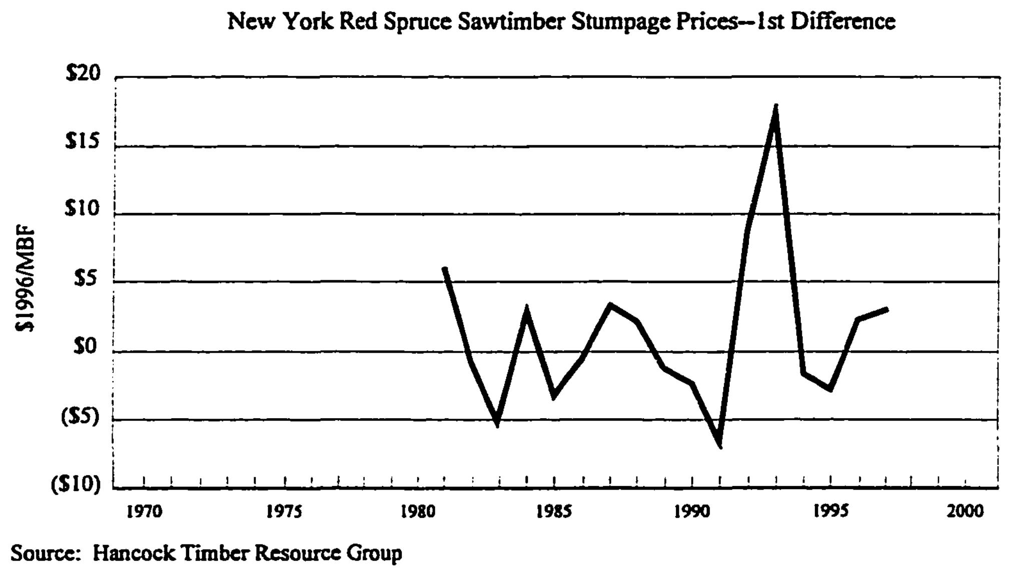


Table 25—Summary of the autocorrelation function and unit root tests for the New York white pine sawtimber stumpage price series since 1980

	Series	
Test	Level	First Difference
Autocorrelation Function	yes	yes
Partial Autocorrelation Function	yes	yes
ADF with Constant	no	***
ADF with Constant and Trend	no	***
ADF with no Constant or Trend	no	***
Phillips-Perron	no	**

*** exceeds 1% critical value
** exceeds 5% critical value
* exceeds 10% critical value

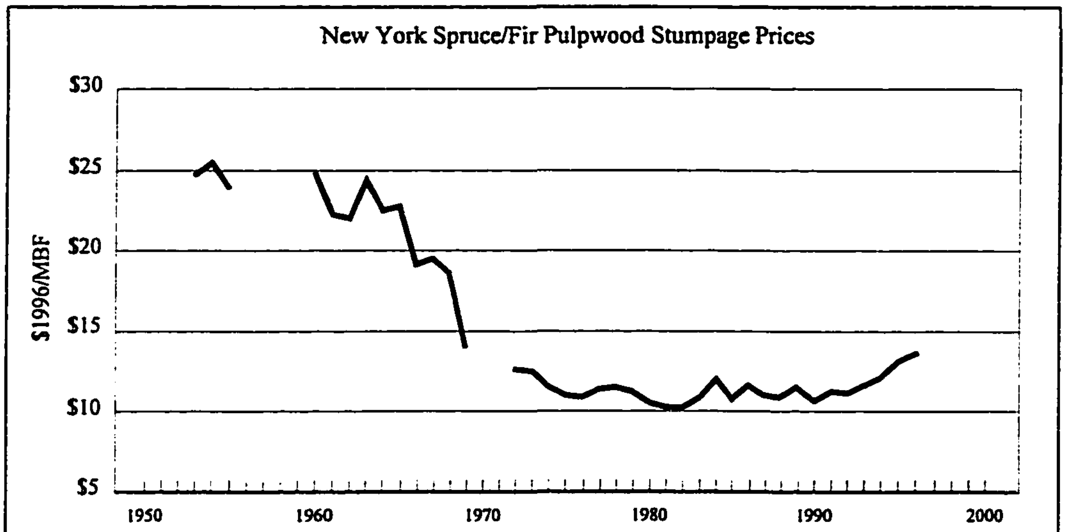
In summary, the first differenced New York red spruce sawtimber stumpage price series is stationary over the period 1980-1997.

New York Spruce/Fir Pulpwood Stumpage Prices

Stationarity of the Entire Series

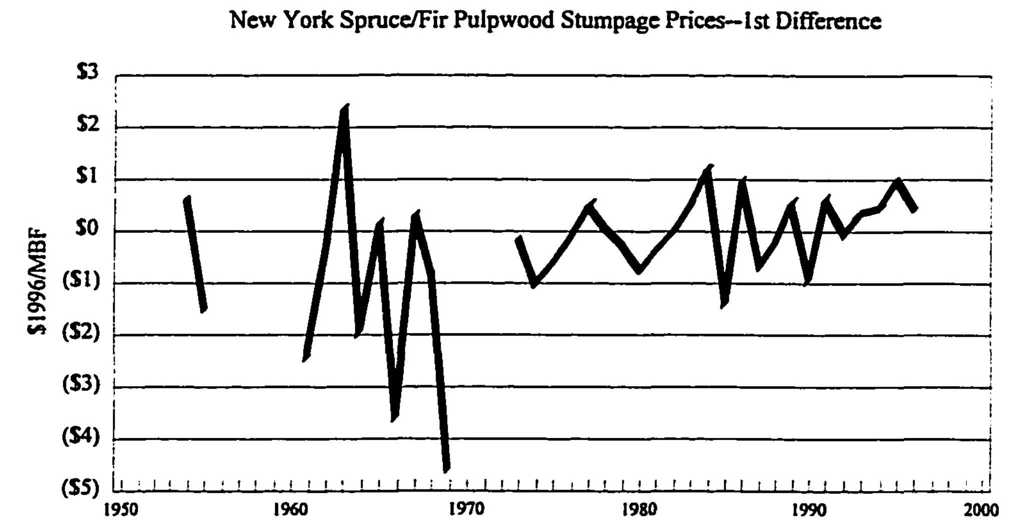
Figure 94 and Figure 95 show the level and first differenced New York spruce/fir pulpwood stumpage prices as reported by the New York Division of Lands and Forests since 1953. Spruce/fir pulpwood prices fell steadily until 1970 (or 1975), and have remained fairly level since then. It is possible they have been rising since 1991, but this apparent trend may not be statistically significant.

Figure 94—New York spruce/fir pulpwood stumpage prices



Source: New York Division of Forests and Lands

Figure 95—First differenced New York spruce/fir pulpwood stumpage prices



Source: New York Division of Forests and Lands

The autocorrelation functions indicate the level series is stationary, while the unit root tests indicate it might be (Table 26). The first differenced series is stationary.

Table 26—Summary of the autocorrelation function and unit root tests on the New York spruce/fir pulpwood stumpage price series.

	Series	
Test	Level	First Difference
Autocorrelation Function	probably	yes
Partial Autocorrelation Function	yes	yes
ADF with Constant	no	**
ADF with Constant and Trend	no	**
ADF with no Constant or Trend	**	***
Phillips-Perron	**	***

*** exceeds 1% critical value
** exceeds 5% critical value
* exceeds 10% critical value

Process Control Chart Analysis

While the tests for stationarity and Figure 95 indicate that the first differenced price series has a constant mean, the figure also indicates decreasing changes in variability. Shewhart control charts (Figure 96 and Figure 97) were used to analyze this variability. The first differenced series was very volatile in the 1960's. The variance decreased to a new level in the 1970's, but the timing of this change is uncertain as no data are available for 1970 or 1971. Three observations exceed the 95 percent confidence limits (1.55 expected) and two exceed the 99 percent confidence limits (0.29 expected) in the mean chart. Three observations exceed the 95 percent confidence limits (1.40 expected) and two exceed the 99 percent confidence limits (0.28 expected) in the range chart.

Figure 96—Control chart for mean of first differenced New York spruce/fir pulpwood stumpage prices

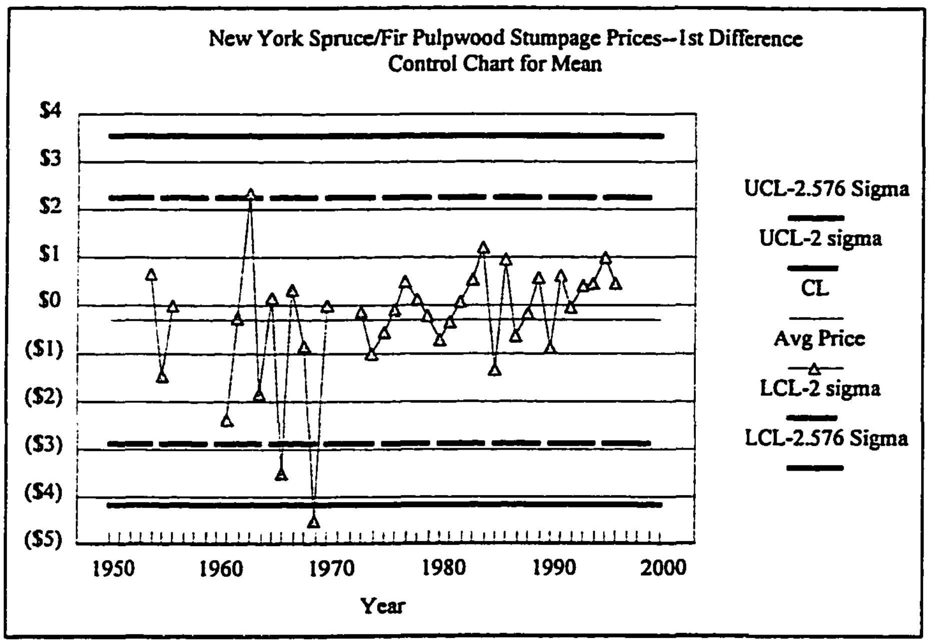


Figure 97—Control chart for range of first differenced New York spruce/fir pulpwood stumpage prices

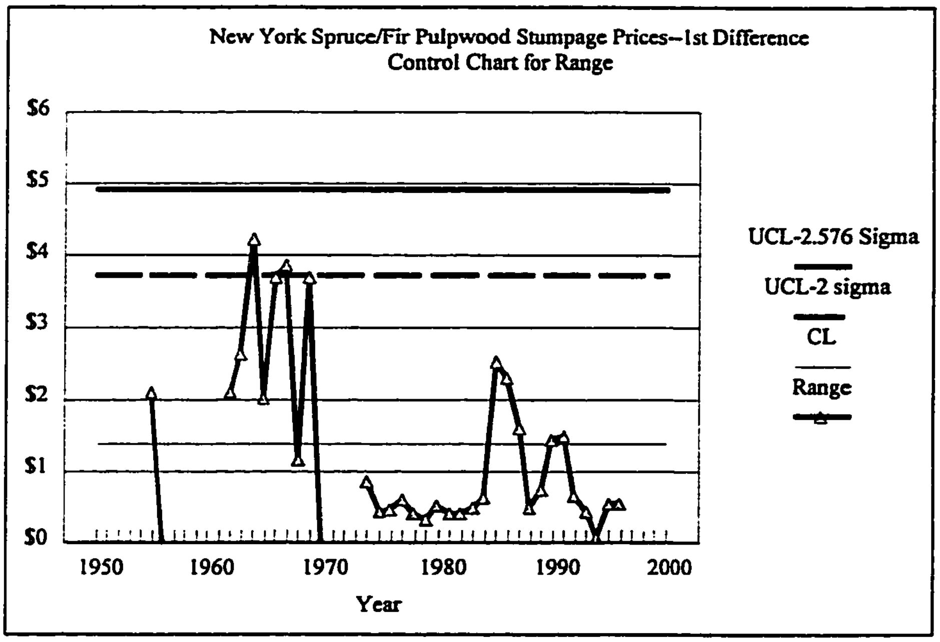


Figure 98 and Figure 99 are the control charts for the pulpwood stumpage prices beginning in 1972. One observations exceeds the 95 percent confidence limits (1.20 expected) and none exceed the 99 percent confidence limits (0.24 expected) in the mean chart. Two observations exceed the 95 percent confidence limits (1.15 expected) and one exceeds the 99 percent confidence limits (0.23 expected) in the range chart.

Figure 98—Control chart for mean of recent first differenced New York spruce/fir pulpwood stumpage prices

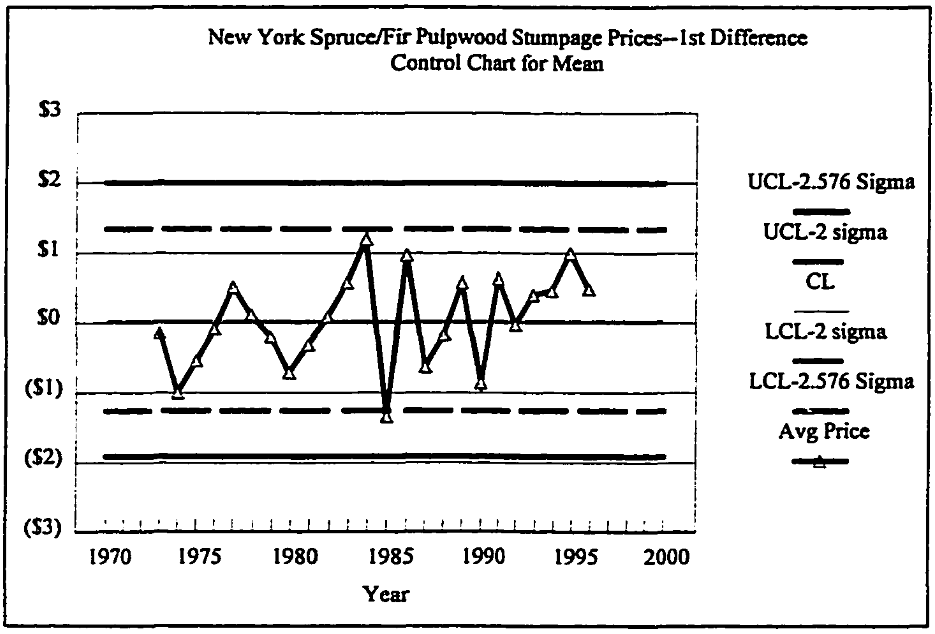
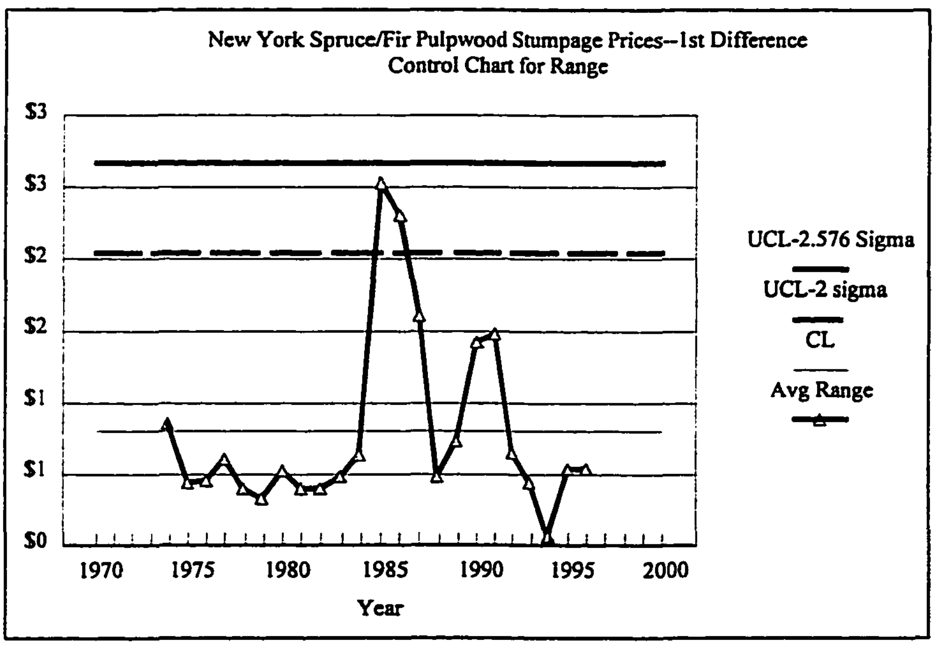


Figure 99—Control chart for range of recent first differenced New York spruce/fir pulpwood stumpage prices



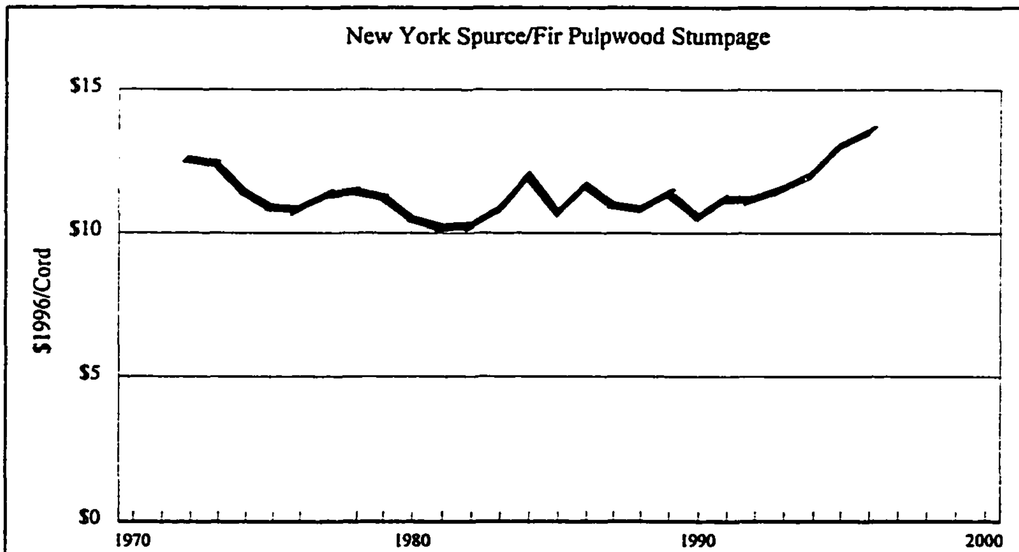
Variance Ratio Test

The process control charts indicate the variance after 1972 is different than the variance prior to that year. This is supported by the variance ratio test: the variance for the period 1972-1997 is statistically different (at the one percent level) from the variance for the period 1950-1969.

Stationarity of the Current Trend

Figure 100 and Figure 101 show the level and first differenced price series since 1972. The autocorrelation functions indicate the level series is stationary, while the unit root tests give mixed results (Table 27). They indicate the level series is not stationary, the first differenced series may be stationary, and the second differenced series is stationary.

Figure 100—Recent New York spruce/fir pulpwood stumpage prices



Source: New York Division of Lands and Forests

Figure 101—Recent first differenced New York spruce/fir pulpwood stumpage prices

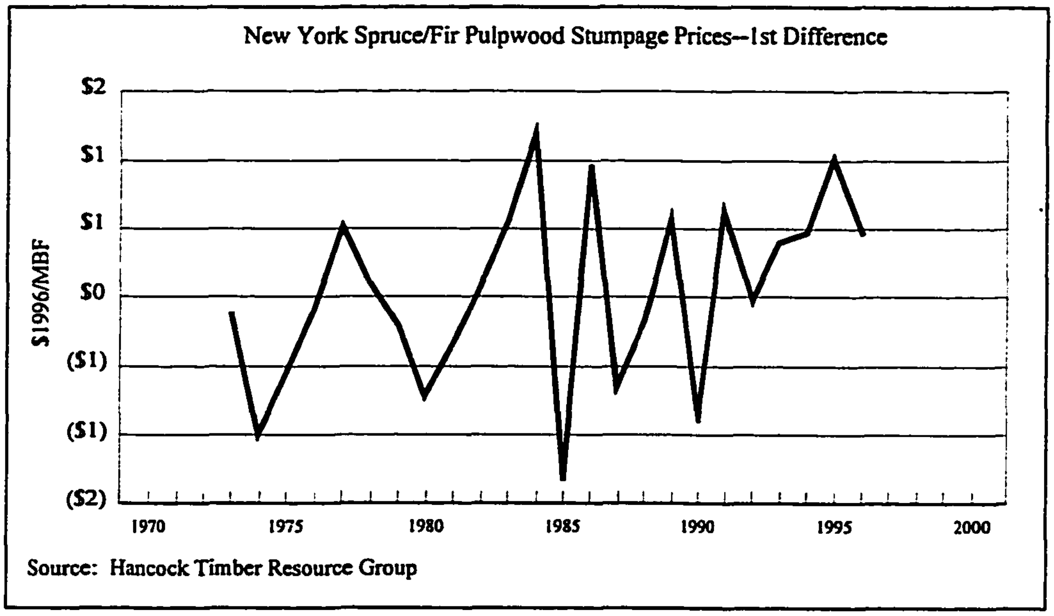


Table 27—Summary of the autocorrelation function and unit root tests for the New York spruce/fir pulpwood stumpage price series since 1972

	Series	
Test	Level	First Difference
Autocorrelation Function	yes	yes
Partial Autocorrelation Function	yes	yes
ADF with Constant	no	*
ADF with Constant and Trend	no	*
ADF with no Constant or Trend	no	***
Phillips-Perron	no	***

*** exceeds 1% critical value
** exceeds 5% critical value
* exceeds 10% critical value

In summary, the first differenced New York spruce/fir pulpwood stumpage price series is stationary over the period 1972-1997.

Log Transformations of Price Series

The discussion of the PNW Westside Douglas-fir sawlog price series introduced the concept of using the natural logs of the series to deal with heteroskedasticity in the data. Some timber price forecasters may prefer forecasting first differenced natural logs because they are forecasting a *percentage change* in prices (e.g., "Prices will rise three percent."), rather than a *price change* (e.g., "Prices will rise $3.00/MBF."). A brief review of the transformation of two of the price series is presented here.

The first differenced natural logs of the Douglas-fir series was shown to be subject to a change in variance around 1910. This is confirmed by Shewhart mean and range control charts for the series (Figure 102 and Figure 103). Six observations exceed the 95 percent confidence limits (5.05 expected) and three exceed the 99 percent confidence limits (1.01 expected) in the mean chart. Six observations exceed the 95 percent confidence limits (4.90 expected) and three exceed the 99 percent confidence limits (0.98 expected) in the range chart.

Figure 102—Control chart for mean of first differenced natural logs of PNW Westside Douglas-fir sawlog prices

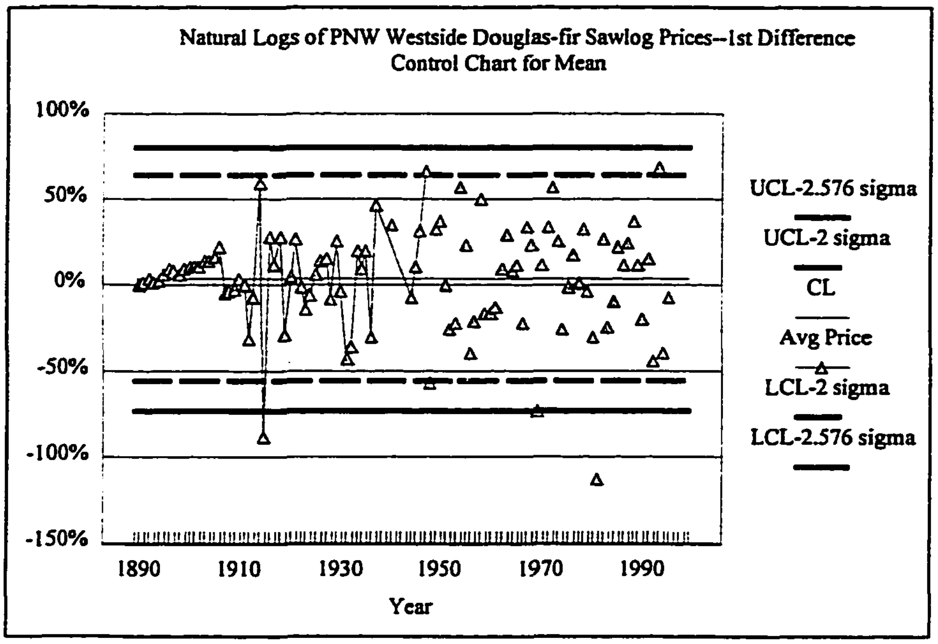
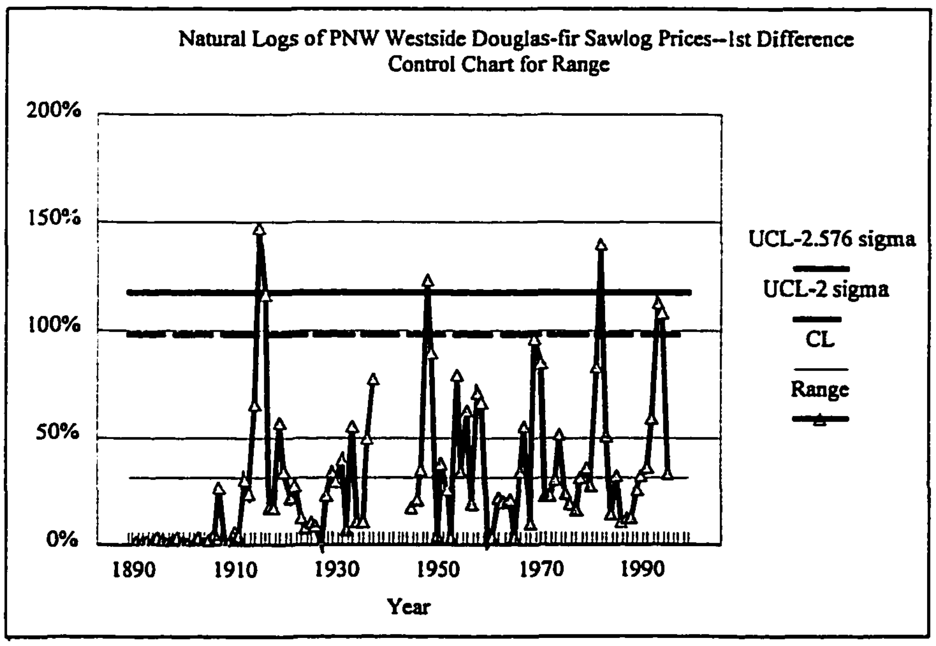


Figure 103—Control chart for range of first differenced natural logs of PNW Westside Douglas-fir sawlog prices



In attempting to determine a starting point for a recent subset, it was discovered that the variance over the period 1910 to 1950 is different enough from the period 1950-

1996 to the present to warrant using 1950 as the starting date for the "most recent" subset. Figure 104 and Figure 105 are control charts for Douglas-fir sawlogs since 1950. One observation exceeds the 95 percent confidence limits (2.30 expected) and none exceed the 99 percent confidence limits (0.46 expected) in the mean chart. Two observations exceed the 95 percent confidence limits (2.20 expected) and none exceed the 99 percent confidence limits (0.44 expected) in the range chart.

Figure 104—Control chart for mean of recent first differenced natural logs of PNW Westside Douglas-fir sawlog prices

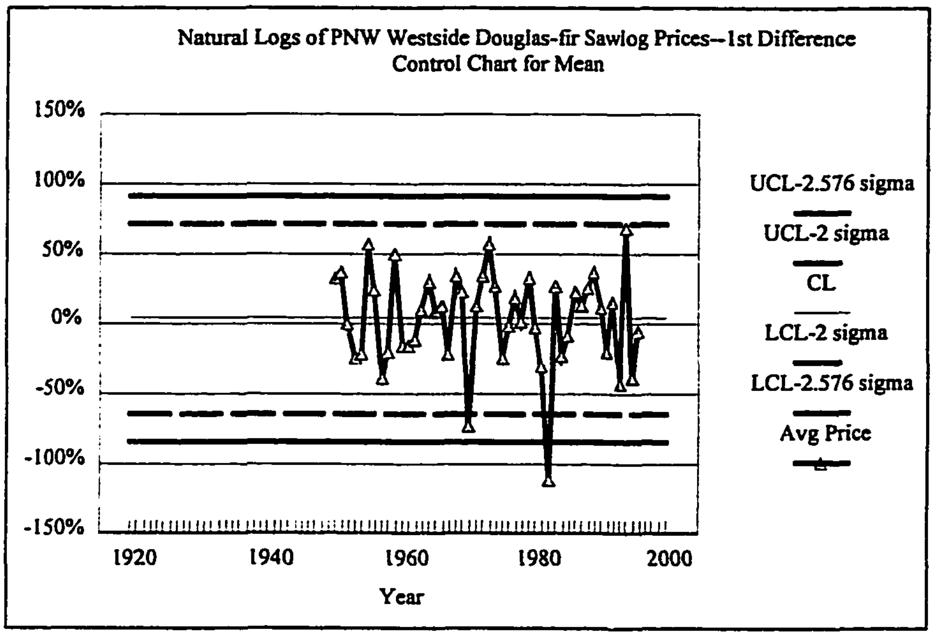
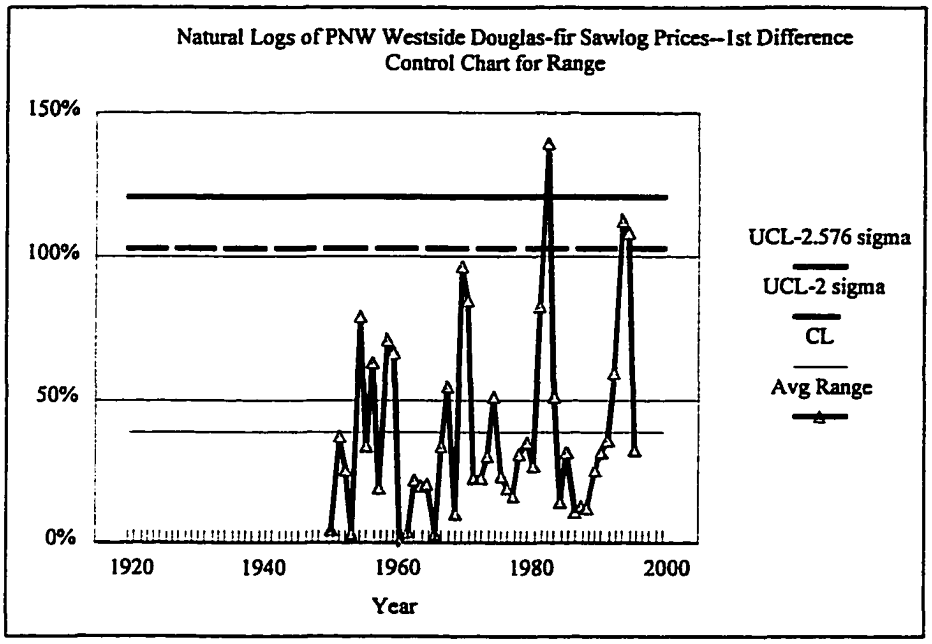


Figure 105—Control chart for range of recent first differenced natural logs of PNW Westside Douglas-fir sawlog prices



The starting point for the most recent subset of first differenced *natural logs* is 1950, twenty years earlier than the starting point for first differenced *prices*. The average annual change since 1950 has been 3.78 percent.

Transforming the southern pine sawtimber price series to natural logs does not eliminate the problem of heteroskedasticity (Figure 106 and Figure 107). Six observations exceed the 95 percent confidence limits (5.01 expected) and two exceed the 99 percent confidence limits (1.02 expected) in the mean chart. Six observations exceed the 95 percent confidence limits (5.00 expected) and four exceed the 99 percent confidence limits (0.99 expected) in the range chart. In this series, the variance seems to decrease over time—the volatility after 1950 seems to be less than the volatility before that time.

Figure 106—Control chart for mean of first differenced natural logs of southern pine sawtimber stumpage prices

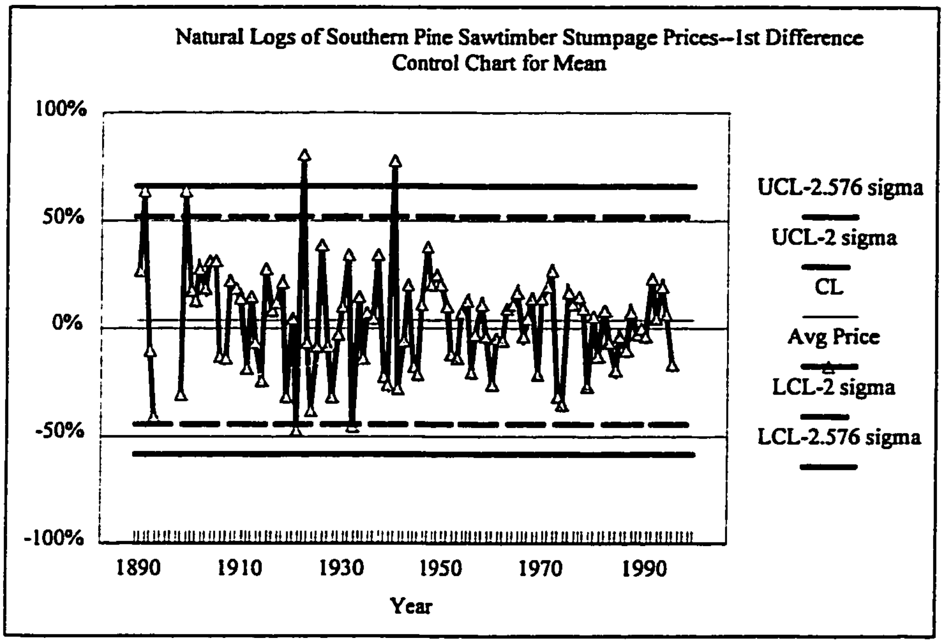


Figure 107—Control chart for range of first differenced natural logs of southern pine sawtimber stumpage prices

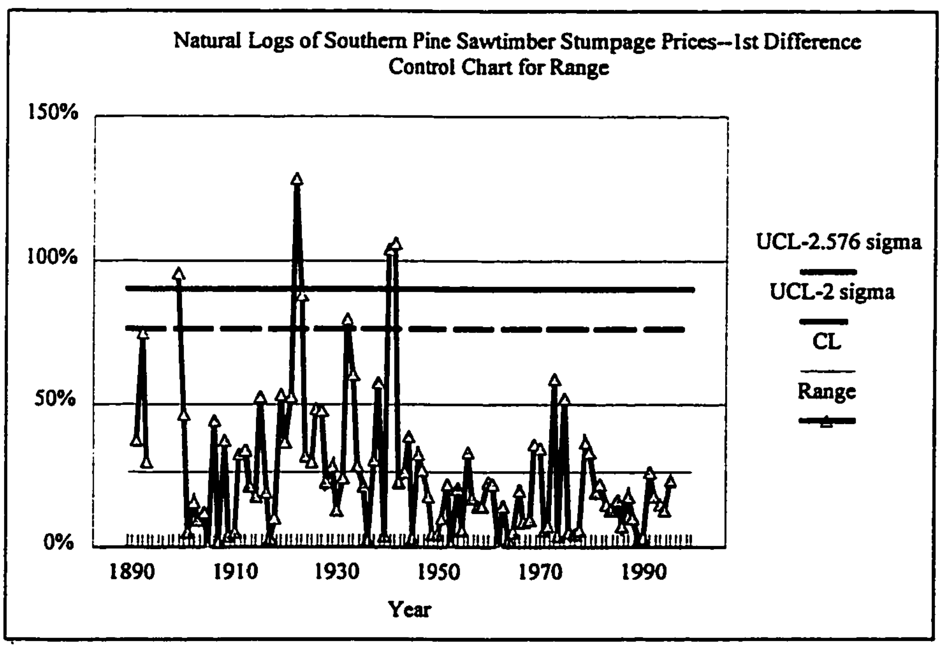


Figure 108 and Figure 109 are the control charts for the first differenced natural logs of southern pine stumpage prices. Here, the mean chart is in control, but the range chart is not unless the 1973 price is removed from the series. The average annual change since 1950 has been 0.90 percent.

Figure 108—Control chart for mean of recent first differenced natural logs of southern pine sawtimber stumpage prices

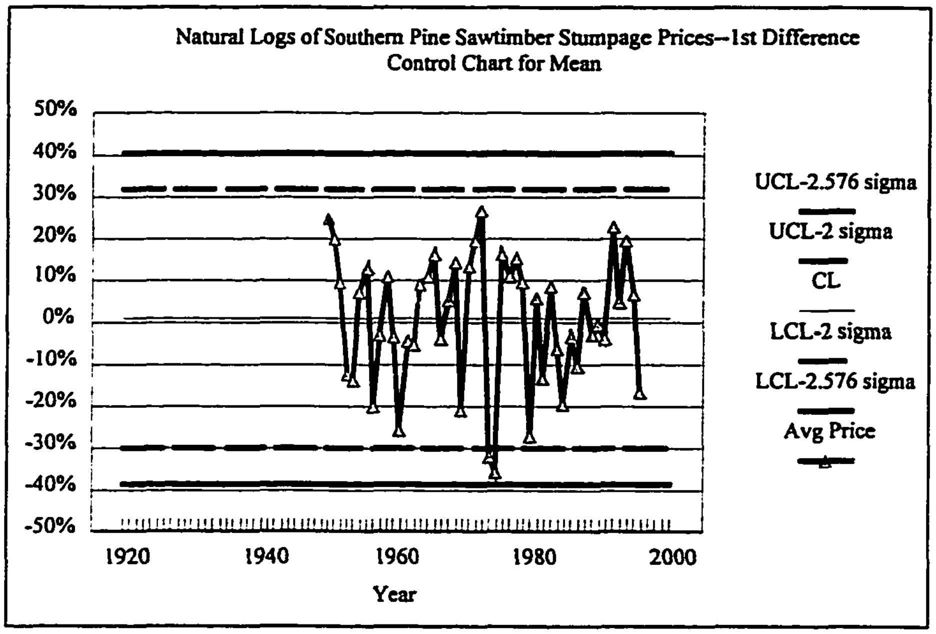
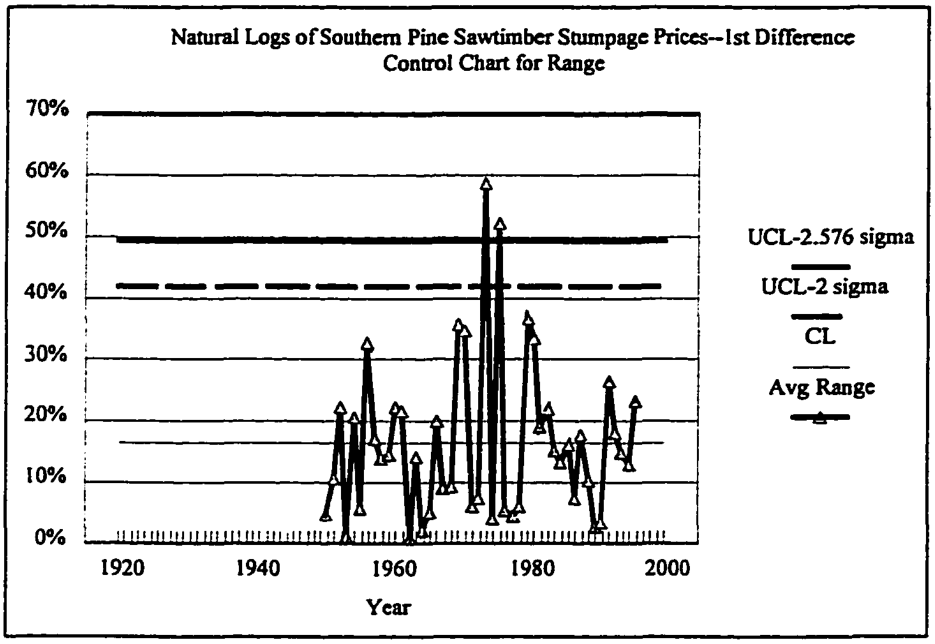


Figure 109—Control chart for range of recent first differenced natural logs of southern pine sawtimber stumpage prices



In summary, transforming the price series to natural logs can be a useful tool in learning about the processes that generate the series. Shewhart control charts can be used to track changes in variance for natural logs as well as prices. This means forecasters who prefer to use percent changes can use these techniques.

Summary of Analysis of Price Series

None of the eleven level price series tested as stationary. This means timber prices themselves cannot readily be forecasted using time series techniques. However, all eleven price series analyzed are first difference stationary over the most recent subset, the length of which varies by price series. The subset is distinguished mainly by a change in the level of volatility, since most of the series have constant means since inception. As a result, time series (autoregressive) forecasting techniques can be applied to timber prices by forecasting the change in price or change in the natural log of the price.

These results can probably be applied to many other species and regions, given the wide range of species and regions included in this study. Three slightly different Westside Douglas-fir sawtimber series all exhibited similar results—all three were first difference stationary for the period 1970-1996. Two slightly different southern pine sawtimber series were first difference stationary over the most recent subset of prices, but the length of that subset differed between the two price series. These groups of similar series indicate that slight differences in price series do not result in substantial differences in stationarity. This means we might expect first differenced southern pine prices in individual states in the South to have been stationary over the past 20-40 years, or first differenced Douglas-fir prices as reported by the Oregon Department of Forestry have been stationary.

Because the Douglas-fir and southern pine series all show stationarity over a recent subset, we may expect species from different regions but with similar end-uses will show similar results. The hypothesis is supported by the results of the analysis of red spruce sawtimber, as it is a substitute for both the Douglas-fir and southern pine, and it is first difference stationary over the period 1980-1997. Extending these results, we might expect all species used in housing construction--radiata pine, western hemlock, and spruce-pine-fir (SPF), for example--to be first difference stationary over a subset beginning at some time in the past 20-40 years.

The results also show that species with very different end uses have also been stationary over some recent period. Species used in housing construction (Douglas-fir, southern pine and red spruce), millwork, remodeling and repair (ponderosa and eastern white pine), furniture (hard maple) and paper (southern pine and spruce/fir) all were stationary over a recent subset of the series.

Given the wide range of regions, species and end uses analyzed here, it is not unreasonable to expect any and all timber price series to be first difference stationary.

CHAPTER IV

TIMBER PRICE SHOCKS

Breakpoints of Timber Price Series

For forecasting purposes, it would be useful to determine if the breakpoints were related to identifiable shocks. In identifying these shocks, it may be possible to recognize future shocks as they occur and adjust timber price forecasts to account for them. It is important to recognize that this process would identify *what* caused the change in price behavior, but not *why*. As a hypothetical example, if timber price breakpoints commonly occur at the beginning of recessions, we could adjust our forecasts to anticipate changes resulting from expected recessions, but time series techniques, unlike econometric methods, do not tell us *why* those changes occur.

Breakpoint Selection

Breakpoints were selected on an *a priori* basis by examining the level series price charts (e.g., Figure 5 and Figure 6). Selection was made based on perceived changes in direction or overall behavior of the price series. In order to provide some statistical basis or validity to these breakpoints, they were tested using Chow's breakpoint test.

Breakpoint Equations

Chow's breakpoint test requires that subsets of the price series be tested with an equation. The equation may consist of an intercept, one or more lagged price variables, and an error term:

$$y_t = a_0 + a_1 y_{t-1} + a_2 y_{t-2} + ... + \varepsilon$$

Table 28 presents the statistics for the equations used in the Chow breakpoint tests for the eleven price series. In the table, a_0 is the value of the intercept (if any), a_1 is the coefficient of the first lagged variable, and a_2 is the coefficient of the second lagged variable (if any). Several different equations were tested for each price series, these are the strongest based on the statistical significance of the coefficients and R^2s. No equation used more than two lagged variables. Further details on the selection of these equations can be found in Appendix E.

Table 28—Statistics for equation used in running Chow test for breakpoints

Variable	a_0		a_1		a_2		F-statistic	R^2
Price Series	value	*t*-statistic	value	*t*-statistic	value	*t*-statistic		
Doug-fir	16.9	.1096	-.92	22.3600	n.a.	n.a.	499.88	.83
So Pine	10.69	1.9529	.94	54.2911	n.a.	n.a.	804.81	.89
Doug-fir cut	n.a.	n.a.	1.03	56.2089	n.a.	n.a.	n.a.*	.94
Doug-fir sold	14.75	1.7392	.91	19.5840	n.a.	n.a.	345.36	.91
Ponderosa	76.04	2.7973	.66	5.8702	n.a.	n.a.	34.46	.44
LA Pulp	6.58	2.4733	.71	5.8983	n.a.	n.a.	34.79	.47
LA Sawtimber	n.a.	n.a.	.57	3.8585	.45	2.9883	34.62	.47
NY Maple	n.a.	n.a.	1.16	5.8223	-.13	-0.6615	122.64	.79
NY Pine	14.01	2.1880	.83	11.0829	n.a.	n.a.	122.83	.77
NY Spruce	12.23	2.0349	.83	10.0900	n.a.	n.a.	101.81	.74
NY Pulp	1.02	1.6573	.91	23.2074	n.a.	n.a.	538.58	.94

*No F-statistic is calculated for single-variable models

Chow's breakpoint test divides the price series into groups above and below the breakpoint. The test tests the null hypothesis that the coefficients of the equation are constant across the subsets.

Common Breakpoints

Each price series was tested for a number of breakpoints. These breakpoints are arranged into groups below (Table 29). These are the largest groups of statistically significant breakpoints for each price series. While several price series have individual breakpoints or smaller groups that are statistically significant at higher levels of confidence, this provided the greatest number of breakpoints to analyze. There are a number of clearly common breakpoints—1946, 1969/1970, 1972/1973, 1979 and 1985.

There are some other groups that are not quite strongly clustered. There are groupings of breakpoints in the early 1960's, in the early 1980's, in 1986/1987, and in the early 1990's.

There are also some breakpoints that seem to relate to a single price series: 1919 and 1941 for the HTRG southern pine sawtimber stumpage price series and 1967 for ponderosa pine are examples.

Table 29—Statistically significant common breakpoints for the timber price series

Price Series	Breakpoint Year Groups										
Doug-fir			1946				1972	1979	1982		1986	1993
So Pine	1919	1941	1946	1952	1963		1973	1979			1987	1991
Doug-fir cut			1946			1969		1978		1985		
Doug-fir sold			1946	1955		1970		1979	1982	1985		
Ponderosa						1967			1981			1992
LA Pulp*							1973		1980		1986	1992
LA Sawtimber					1964			1979		1985	1987	
NY Maple					1961			1979				1991
NY Pine						1970		1979			1987	
NY Spruce					1962	1970			1980			1991
NY Pulp**							1972		1983			

*The combination of breakpoints is statistically significant at the 10% level.
** The combination of breakpoints is not statistically significant (see discussion of this price series).

The relationship of the shock to the breakpoint may vary, depending on the type of shock For example, because housing starts were formerly considered a leading indicator, historic sawtimber and sawlog prices might be expected to lead past economic changes—rise just before expansions begin and fall just before recessions begin. For other types of shocks, changes in timber prices might occur *after* the shock. This could be caused by lagged effects of economic shocks—recessions may begin at different times in different parts of the country. A sharp rise in one species may not be immediately matched with a sharp rise in a substitute species. It may take time for red spruce sawtimber prices to respond to a rise in Douglas-fir sawtimber prices, for example.

The probability that changes in timber prices lead or lag economic shocks is supported by the low correlation between timber prices and economic indicators (Table 30). The low or negative correlation between GDP and Douglas-fir log prices (0.48) and southern pine stumpage prices (-0.28), suggests timber prices will *not* show an immediate response to changes in GDP, either in magnitude or direction.

Table 30—Correlation coefficients of selected forest products variables and GDP, 1978-1996

GDP ($92)	1.0000
U.S. Paper Consumption	0.9872
Repair & Remodeling ($92)	0.8598
N.A. Lumber Production	0.7886
Douglas-fir Log Price ($96)	0.4769
Timberland Returns	0.2775
Douglas-fir Lumber Price ($96)	-0.1317
So. Pine Stumpage Price ($96)	-0.2822
Housing Starts	-0.2958

Source: Hancock Timber Resource Group and Resource Information Systems, Inc.

In addition, the table indicates that there is not a high level of correlation among timber price series. The correlation coefficient for Douglas-fir log prices and southern pine stumpage prices is 0.56. This means different timber price series will respond at different times to changes in economic conditions.

Shocks

The common breakpoints in Table 29 were compared to a list of shocks. These shocks are part of a list developed in anticipation of testing the secondary hypothesis, that timber prices do not test as stationary because they are subjected to many shocks. The results of the stationarity analysis showed that changes in timber prices are stationary for periods of time in spite of a continuous series of shocks. For this reason, the development of the comprehensive list of shocks was halted. A non-technical discussion of these shocks appears in Appendix F.

1944--Post-War USFS Policy Change and Economy

The 1946 breakpoint probably reflects economic changes at the end of the Second World War. War-related price controls were removed and four years of pent-up consumer demand for housing (and consumer goods shipped in wood boxes) could finally be addressed. This economic shock would have occurred simultaneously—with the end of the war—across the nation, rather than spreading from one region to another. The surge in demand for wood products lasted well into the 1950's.

Sohngen and Haynes (1994) report a major shift in Forest Service policy at the end of the Second World War that they think had an impact on Douglas-fir log prices. Before that time, National Forest timber sales had occurred as local mills asked the Forest

Service for timber. After the war, the Forest Service became "...an active part of the timber supply"[1] and produced increasing amounts of timber into the 1960's.

Southern pine sawtimber stumpage prices (Figure 6) do not show an increase in volatility, but do increase sharply at this time, perhaps as a result of the post-war economy. Without the change in Forest Service policy, would Douglas-fir prices have behaved more like southern pine prices--less volatile, but rising more sharply?

In summary, the breakpoints of 1946 in the series may point to either the change to a post-war economy in 1945 and/or the change in USFS policy announced in 1944.

1960's—Economic Expansion

Five of the timber price series indicated breakpoints between 1961 and 1967. This coincided with an economic expansion between February, 1961 and December, 1969 (Hall 1990). However, these five series exhibit three different behavior changes at these breakpoints. New York hard maple sawtimber (1961) and red spruce (1962) both turned down, the HTRG southern pine sawtimber (1963) and Louisiana southern pine pulpwood (1964) turned up, and ponderosa pine (1967) increased in volatility, but did not change direction.

Red spruce and southern pine sawtimber are substitutes, but prices moved in different directions. While they may react at different times due to regional lags in reacting to changes in the overall economy, as substitutes they should move in the same direction.

Because of the different directions of the changes and the spread in years among the breakpoints, it is difficult to attribute these breakpoints to the start of the economic

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[1] Sohngen and Haynes, 1994, p. 11

expansion in 1961. It is not possible to predict that timber prices move up or down at the beginning of an expansion based on this example. This result is consistent with the lack of strong correlation between timber prices and GDP.

1970--USFS Timber Sale Crisis

In the Pacific Northwest Westside, the supply of mature timber from private lands was believed to be becoming scarce and Forest Service sale volumes had leveled off in 1969 (Mattey 1990). Mill owners got into a bidding war to keep their mills running.

PNW Westside timber prices rose sharply after 1972. Douglas-fir stumpage prices jumped $100/MBF in 1973 and 1974—probably as a result of OPEC (the Organization of Petroleum Exporting Countries) actions, energy shortages, and resulting rising prices. There was a brief respite in 1975 and 1976 as the world adjusted to new price levels for energy, then timber prices rose even more sharply, up more than $250/MBF between 1976 and 1979. This steady increase in stumpage prices continued in the face of falling lumber prices. (See Federal Reserve policy change, below).

This price rise lasted until 1979. The stumpage buyers and the US Forest Service were aware that the prices being paid for stumpage were much higher than justifiable, given lumber prices at that time, but both groups assumed lumber prices would rebound and cover the high stumpage costs. This did not happen.

By 1982, stumpage prices had fallen over $300/MBF. The Forest Service allowed stumpage contract holders to extend contracts up to two years as long as interest payments were made. By the end of 1982, many of these extended contracts were beginning to expire. Given lumber prices and conversion costs at the time, the maximum that could be paid for stumpage was $60/MBF, but most of the contracts called for payments near $300/MBF.

The lumber industry asked Congress to nullify the overpriced contracts. President Reagan authorized five-year extensions in 1983, and Congress passed the Federal Timber Contract Modifications Act of 1984, which became law in October of that year. The Act allowed companies to buyout a maximum of 55 percent or 200 MMBF of contracts purchased before 1982, with the "buyout fee" depending upon the solvency of the company.

Four timber price series indicate breakpoints at the beginning of this period: USFS PNW Douglas-fir cut price series (1969), USFS PNW Douglas-fir sold price series (1970), New York white pine (1970) and red spruce (1970). Red spruce can be substituted for Douglas-fir and so could be expected to respond to Douglas-fir price increases, but it is not clear why white pine should react at the same time. In this case, four breakpoints coincide with a shock.

1973--OPEC and the Energy Crisis

In October, 1973, OPEC announced that member nations would be allowed to set their own prices for crude oil and an embargo on shipments to nations supporting Israel. Prices rose from around $3 per barrel to $11.65 by January of 1974 (Putnam 1975).

Howard and Chase (1995) studied stumpage prices in Maine from 1963 to 1990 and reviewed other studies in the region. They found evidence of impact on timber prices from the OPEC oil embargo. Post-oil-crisis sawlog and veneer prices grew at higher nominal rates than pre-crisis prices. However, boltwood prices grew at a slower rate, which they attribute to a decline in Maine's wood-turning industry. They noted that between 1974 and 1990 real price changes ranged from -1.5 percent (red maple and beech) to 5.3 percent (oak) and were not significantly different than zero for spruce/fir, white and yellow birch and sugar maple. In a review of other studies in eastern states, they noted that Remington and Davis (1986) found a sharp rise in real prices for all timber species and products in New Hampshire beginning with the oil crisis in 1974.

Sohngen and Haynes note a real price increase in western National Forest stumpage prices at the time of the energy crisis, but note that prices fell quickly again due to a drop in Gross National Product (GNP) and housing starts. These are the data presented in Figure 7 and Figure 8, and, while both do show prices increased, neither series indicated 1973 or 1974 as a breakpoint.

Only two of the analyzed price series indicated breakpoints in 1973. The HTRG southern pine sawtimber stumpage series reached a peak in 1973 and then declined after that. The Louisiana southern pine pulpwood stumpage series had declined from the late 1950's to 1973, at which time it leveled off. Given that the oil price increase came late in the year, it is likely that the breakpoints are not the result of the OPEC actions.

1979—Second OPEC Price Hike and Federal Reserve Policy

OPEC activities raised prices significantly for a second time in 1979 (Gever, et al, 1986). Six of the timber price series indicated 1979 as a breakpoint. However, unlike the first OPEC price hike in 1973 after which timber prices rose, 1979 was a peak year for these six series and prices dropped sharply for the next few years. In this case it is unlikely that the second OPEC price hike was the shock behind the 1979 breakpoint.

Another shock that occurred that year was a change in Federal Reserve (the Fed) policy. In October of 1979, the Fed announced it would pursue a policy of controlling the growth in the money supply, rather than trying to prevent short-term fluctuations in the Federal Funds rate (Mattey, 1990). The Fed then set low growth targets for the money supply. "The tight-money, loose-fiscal-policy mix had a disinflationary effect. The GNP deflator slowed to about a 3-1/2 percent annual rate of increase in the last quarter of 1982, after beginning the decade at an 8-3/4 percent pace."[2] This resulted in a recession that dropped timber prices sharply and kept them low until 1985.

The breakpoint year of 1979, common to six of the eleven timber price series, coincides with the Fed policy change of that year. While time series techniques say nothing about the relationship between prices and the policy change, an econometric model could test that relationship. One hypothesis is that tight monetary policy led to higher interest rates. Since higher interest rates would impact mortgage rates, housing starts would fall, lowering the demand for lumber. In turn, the lower demand for lumber would result in lower derived demand for stumpage and lower timber prices

1982—End of Recession

Six of the eleven timber price series indicate breakpoints between 1980 and 1983 with all of them either turning up, or leveling off from a decline. This may coincide with the end of the recession that began in 1979 with the change in Federal Reserve monetary policy (above), but there is such a range in breakpoint years that this is not certain. If this recession end is the cause of these breakpoints, it suggests recessions are not good indicators of breakpoints. In fact, it suggests that some timber price breakpoints are leading indicators of recession ends. The range of years supports the concept of lags in economic changes as the economy moves into and out of recessions and expansions.

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[2] Mattey, 1990, p. 13

1993--Spotted Owl Crisis

In the late 1980's, there was increasing debate on the fate of old-growth forests on federal ownership in the West. This debate took on many forms—below-cost timber sales, the long-term contracts on the Tongass National Forest in Alaska, biodiversity, sustainability, and finally, the northern spotted owl.

As the debate continued, stumpage prices on PNW National Forests rose (see Figure 7). When National Forest sales were virtually halted in 1992/1993, lumber prices shot up and pulled log prices with them. Between 1985 and 1994, sold stumpage prices rose from around $100/MBF to nearly $500/MBF and cut prices went from $125/MBF to $400/MBF.

While prices have moderated somewhat since their highs in 1994, Figure 5, Figure 7 and Figure 8 show prices for Douglas-fir logs and stumpage from Westside National Forests are still higher (and more volatile) than prices before 1972. While current real prices are higher than those before 1972, the "spotted owl crisis" did not send prices as high as the "timber sale crisis" of the previous decade. There may be a number of reasons why an event that physically removed a major portion of the nation's timber supply from the market did not cause prices to rise as high as a "perceived" timber shortage.

The shock may have been anticipated by some. The judicial order shutting down timber sales was "sudden", but a number of industry players may have assumed such a decision was inevitable and assembled a private timber supply. These firms would not have been dependent upon public timber and would not have helped drive bid prices up higher.

Some companies may have been less dependent on old-growth. After the 1970's' timber sale crisis, some firms renovated old mills or built new mills designed to process second growth timber. These facilities do not depend on old-growth timber from public forests and would not have helped drive up prices.

Some timber buyers were able to turn to other regions of the world for their wood supply. Large volumes of logs from the Pacific Northwest are exported to Pacific Rim countries like Japan, Taiwan and Korea. (National Forest and state timber are prohibited by law from the export markets, but industry could export their own logs and replace them in their mills with public timber.) As prices for logs from the US rose, the Pacific Rim countries looked for other sources of supply. The great radiata pine plantations of New Zealand and Chile were coming on line at this time. Korea is perhaps the most startling example of a country that found other sources. Korea's western hemlock/radiata pine import relationship was 90 percent hemlock/10 percent pine in 1980, and reversed to 10 percent hemlock/90 percent pine by 1996 (Davidson 1996).

It is also likely that substitution of other wood products and non-wood products helped moderate price increases. This shock occurred as Oriented-Strand Board (OSB) production was exploding. Production capacity of OSB in North America rose from 1,863 million square feet (MSF) in 1980 to 19,490 MSF by 1996 (C. C. Crow Publications, Inc., 1996). The reduction in supply of peeler logs for producing western plywood occurred as OSB was putting price pressures on western plywood. With plywood prices under pressure, higher prices could not be paid for these logs.

Interestingly, six of the timber price series indicated breakpoints between 1991 and 1993, but the USFS PNW Westside stumpage series (from Sohngen and Haynes) did not. Only the HTRG Douglas-fir sawlog series indicated 1993 as a breakpoint. In summary, the breakpoint analysis did not indicate 1993 as a shock, but several series appeared to be leading indicators for the change in policy.

Summary of Timber Breakpoints and Shocks

It is apparent that the *a priori* selection of breakpoints is not a satisfactory method of identifying shocks. Our *ex post* analysis showed that two breakpoints coincided with events that were considered to be significant shocks.

One part of the explanation for this problem (as stated in Chapter II) is that the breakpoint test indicates that the series behaves differently above and below that point, but it does not explicitly state that a change in series behavior occurred *at that point*. It is possible that the breakpoint test would indicate one of several nearby points as a breakpoint.

Another reason for the failure of this method may be the derived demand for timber. There is likely a lag between the shocks and their impact on timber prices as changes work their way through the economy. (This is supported by the lack of correlation between timber prices and GDP.) But time series techniques cannot be used to follow these changes.

A third reason may be the use of annual data. Annual data tends to smooth out peaks, and may shift the peak from one year to another. This shift may cause the breakpoint to be shifted as well. While using quarterly or monthly data might eliminate this problem, the lack of long-term quarterly and monthly series and the complexities added by seasonality create other problems with which to contend.

CHAPTER V

CONCLUSIONS

A favorable result for timberland investors would be to find that real timber prices were first difference stationary, with a positive mean for the first differenced price series, implying that the average change is fixed and positive. This results in real price increases for timber over time.

A level stationary real price series (fixed mean) would keep pace with, but not exceed, the rate of inflation. This would be better for investors than a first differenced stationary series with a negative mean, which would indicate decreasing real timber prices.

A second differenced stationary series with a positive mean might seem desirable. This indicates a positive acceleration in timber prices. However, over the long-term, prices would rise high enough to encourage substitution of other timber species and, ultimately, of other materials.

Tests on eleven price series indicate that timber price series are first difference stationary over the most recent subset of prices. Most first differenced series appear to have fixed mean over the entire series, but all are subject to variances changing over time.

An attempt to relate breakpoints common to several price series to identify significant price shocks proved unsatisfactory. Only two of nine shocks examined were so indicated. The uncertainty that a breakpoint is located at the actual point of price behavior change, the lag in the impact of the shock on timber prices, and the smoothing effect of annual data may account for this.

Areas for Further Research

Competition and Variance

It is also important to note that the beginning point for the most recent subset of most of these first differenced timber price series is usually determined by a change in variance rather than a change in mean. What has caused these changes in variance? It may be that they have been caused by changes in the level of competition for wood.

All the Douglas-fir price series exhibited increased volatility beginning in the late 1940's, but the southern pine sawtimber series do not. This increased volatility may have been caused by the expansion of timber harvesting on the western National Forests and a growth in production and increased competition for wood in the region. This increase in competition in the West was not accompanied by an increase in wood supplied by National Forests or competition in the South, so the variance did not increase there.

The Douglas-fir, southern pine and ponderosa pine series all showed increases in volatility around 1970. It is hypothesized that increased global competition and/or anti-trust activity at that time (and a resulting increase in competition) by the U.S. Department of Justice may be responsible for this increase in variance. (It is interesting to note that, if the increase in variance *was* due to Justice Department activity, the result was *not* an increase in prices, but an increase in the volatility of price changes. The fact that the southern pine pulpwood prices did not show an increase in variance until 1980 works against the hypothesis that anti-trust activity caused the increase in variance.

The four price series from New York all showed a *decrease* in volatility over time. Could this have been caused by a decline in competition in the forest products industry in that state since 1950?

Price Series

Appendix D lists a number of other readily available timber price series. Analysis of more of these series would confirm whether or not most timber price series were first difference stationary.

The New York prices used in this analysis were statewide average prices. The data could be split into groups to examine the Adirondack and southern tier regions separately. New York prices could be compared to the long-term series from New Hampshire and Maine to see if those markets differ substantially.

Other

As stated in the discussion of shocks, there does not appear to be a way to determine the causes of shocks to timber price using time series analysis techniques. It may be possible to do this using econometric models. It might be possible, for example, to determine that Douglas-fir prices peak one year after housing starts peak, and southern pine prices peak one year after *that*. This would have to be done outside the time series analysis process and the information used to adjust forecasts.

This research was conducted using annual prices. There may be some value in a study using quarterly or monthly prices. Such series usually do not extend further back than ten or twenty years, but may help timber price forecasters produce better short-term forecasts than can be made with annual data.

Seasonality will be an important consideration in such work. Usually harsh or mild winters can have a significant impact on prices in the Northeast as heavy snow reduces timber harvesting or bare, frozen ground enables production to increase. Unusually wet or dry summers can impact any region as flooding or fire danger reduces timber harvesting. An economist forecasting quarterly or monthly timber prices must also be a meteorologist.

Finally, information developed in this study could be used to forecast timber prices.

LITERATURE CITED

Adams, D.M., K.C. Jackson, and R.W. Haynes. 1988. Production, consumption, and prices of softwood products in North America: Regional time series data, 1950 to 1985. USDA For. Serv. Res. Bull. PNW-RB-151.

ANSI/ASQC Standard AI-1978. 1978. Definitions, symbols, formulas and tables for control charts. American Society for Quality Control.

Baldwin. H.I., E.L. Heermance. 1949. Wooden dollars: A report on the forest resources of New England, their condition, economic significance and potentialities. Federal Reserve Bank of Boston, Boston, MA.

Ball, R. and S. P. Kothari. 1989. Nonstationary expected returns: Implications for tests of market efficiency and serial correlation in returns. Journal of Financial Economics 25:51-74.

Basu, P. 1993. Mean reversion in GNP and stock prices: An adjustment cost hypothesis. Kyklos 46(1): 87-104.

Bessembinder, H., et al. 1995. Mean reversion in equilibrium asset prices: Evidence from the futures term structure. Journal of Finance L(1):361-375.

Cecchetti, S.G., P.S. Lam., and N.C. Mark.. 1990. Mean reversion in equilibrium asset prices. Economic Review 80(3):398-418.

Cochrane, J.J. 1988. How big is the random walk in GNP?. Journal of Political Economy 96(5):893-920.

Cribari-Neto, F. 1994. Canadian economic growth: random walk or just a walk?. Applied Economics 26:437-444.

C.C. Crow Publications. Inc. 1996. An OSB production profile by region. Forest Industry Journal 11(4):16-18.

Davidson, S. 1996. Pacific Rim export log overview, particularly Korea. P. 34-44 *in* Conference Proceedings: Marketing Logs and Timber of the Pacific Rim: Emphasis on Timber Supply. Gates, J. (ed.). Jay Gruenfeld Associates, Inc., Gig Harbor, WA.

DeJong, D.N. and C.H. Whiteman. 1991. Reconsidering 'Trends and random walks in macroeconomic time series'. Journal of Monetary Economics 28:221-254.

Fama, E.F. and K.R. French. 1988. Permanent and temporary components of stock prices. Journal of Political Economy 96(2):246-273.

Gever, J., et al. 1986. Beyond oil. Ballinger Publishing Company, Cambridge, MA.

Goetzmann, W.N. 1993. Patterns in three centuries of stock market prices. Journal of Business 66(2):249-270.

Gujarati, D. 1978. Basic econometrics. McGraw-Hill Book Company, New York, NY.

Hall, T.E. 1990. Business cycles: The nature and causes of economic fluctuations. Praeger, New York., NY.

Hicks, C.R. 1982. Fundamental concepts in the design of experiments, third edition. Holt, Rinehart and Winston, New York, NY.

Hogg. R.V. and E.A. Tanis. 1983. Probability and statistical inference, second edition. MacMillan Publishing, Inc., New York, NY.

Howard, T. and C. Warren. 1995. Maine stumpage prices: Characteristics and trends from 1963 to 1990. Forest Products Journal 45(1):31-36.

Irland, L.C. 1982. Wildlands and woodlots: The story of New England's forests. University Press of New England, Hanover, NH.

Ishikawa, K. 1976. Guide to quality control. Asian Productivity Organization, Tokyo, Japan.

Kupiec, P.H.. 1993. Do stock prices exhibit excess volatility, frequently deviate from fundamental values, and generally behave inefficiently: A guide to understanding the excess stock price volatility and mean-reversion literatures. New York University Salomon Center, New York, NY.

Lutz, J., T.E. Howard, and P.E. Sendak. 1992. Stumpage price reporting in the northern United States. Northern Journal of Applied Forestry, 9(2):29-33.

Lutz, J. and L.C. Irland. 1990. Generating electricity with wood: Where do we stand in the North? The Northern Logger and Timber Processor, 39(5):24-25.

Mattey, J.P., 1990. The timber bubble that burst: Government policy and the bailout of 1984. Oxford University Press, New York, NY.

Metcalf, G.E., and K.A. Hassett. 1995. Investment under alternative return assumptions: Comparing random walks and mean reversion. Journal of Economic Dynamics and Control 19(1995):1471-1488.

Miller, M.H., J. Muthuswamy and R.E. Whaley. 1994. Mean reversion of Standard & Poor's 500 Index basis changes: Arbitrage-induced or statistical illusion?. The Journal of Finance XLIX(2):479-513.

Nelson, C.R., C.I. Plosser. 1982. Trends and random walks in macroeconomic time series: Some evidence and implications. Journal of Monetary Economics 10:139-162.

Newbold, P. and T. Bos. 1990. Introductory business forecasting. South-Western Publishing Company, Cincinnati, OH.

Nelson, L.S. 1982. Control charts for individual measurements. Journal of Quality Technology 14(3):172-173.

Pindyck., R.S. and D.L. Rubinfeld. 1976. Econometric models and economic forecasts. McGraw-Hill Book Company, New York, NY.

Poterba, J.M., and L.H. Summers.1988. Mean reversion in stock prices: Evidence and implications. Journal of Financial Economics 22:27-59.

Putnam, J.T. 1975. The Arab World, Inc. National Geographic 148(4):494-533.

Raj, B. 1993. The size of the random walk in macroeconomic time series. Journal of Macroeconomics 15(1):139-151.

Remington, S B. and D. F. Dennis. 1986. New Hampshire's stumpage and roadside prices: Characteristics and trends. USDA For. Serv. Res. Note NE-332.

Scherkenbach, W.W. 1987. The Deming route to quality and productivity. Mercury Press, Rockville, MD.

Sinclair, S.A.. 1992. Forest products marketing. McGraw-Hill Book Company, New York, NY.

Sohngen, B.L., and R.W. Haynes. 1994. The "great" price spike of '93: An analysis of lumber and stumpage prices in the Pacific Northwest. USDA For. Serv. Res. Pap. PNW-RP-476.

Sokal, R.R. and F.J. Rohlf. 1981. Biometry, second edition. W. H. Freeman and Company, New York, NY.

Ulrich, A.H. 1989. U.S. timber production, trade, consumption, and price statistics 1950-87. USDA For. Serv. Misc. Pub. No. 1471.

Urrutia, J.L. 1995. Tests of random walk and market efficiency for Latin American emerging equity markets. Journal of Financial Research 18(3):299-309.

Warren, D.D. Production, prices, employment, and trade in Northwest forest industries. USDA For. Serv., PNW Research Station Research Bulletin published quarterly.

Young, R. 1997. Untangling the web of cycles. *keynote address* Diverging paths within the forest products industry: Impacts of economic, investment. and inventory cycles. Annual Forest Products Conference, Resource Information Systems, Inc., Bedford, MA.

APPENDICES

APPENDIX A

MACROECONOMIC MODELS AND TIMBER PRICES

Derived Demand for Timber

Econometric models are frequently used to discover the structure of the process underlying some data. The problem in modeling timber markets is that the demand for timber is derived through several layers of derived demand for combinations of other products, and there are a number of substitutes for each timber species.

Most wood produced in the United States goes to four end uses: pulp and paper, housing construction, remodeling and repair of existing housing, and export. Figure A1 presents a simplified diagram of wood flows (and demand paths) in the United States.

This diagram ignores panels and engineered wood products. A plywood plant would take in large logs and produce plywood for housing starts and repair and remodeling and chips for pulpmills or the export market. Engineered wood products and panel products such as OSB would take in smaller and poorer quality logs and produce panels and other products for housing starts and repair and remodeling, and chips for pulpmills and export. The omission of these products does not significantly change the discussion.

Figure A1—Simplified diagram of derived demand for timber

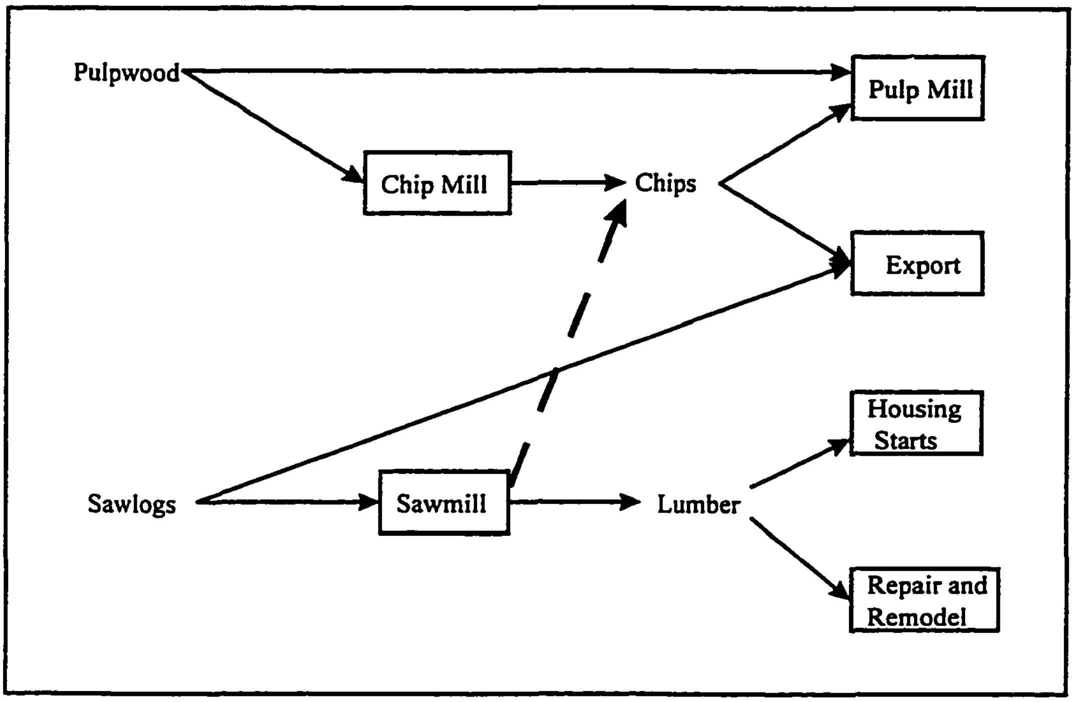


Figure A1 looks simple, but the system is complicated by the lack of correlation among the final demand nodes (pulp and paper, export, housing starts, and repair and remodel). U. S. pulp and paper consumption is closely correlated with repair and remodeling expenditures. However, both are poorly correlated with housing starts. Finally, exports depend heavily on the condition of economies in the Pacific Rim, especially Japan, Korea and Taiwan.

Pulpwood is perhaps easiest to deal with. Since any small or low quality wood can be used as pulpwood (or chipped), the supply of pulpwood is never in question—increased demand for pulpwood rarely causes prices to rise. Pulpwood prices *may* be affected by seasonal factors such as mud, rain, snow.

However, the role of sawmills as chip suppliers can have some interesting impacts. Occasionally, demand for chips either domestically or internationally can cause sawmills to operate (producing lumber) even when demand for lumber is low. This is particularly true of Chip N Saw/studwood mills. Such mills are often closely associated with pulpmills that *require* those chips.

Because pulp production uses pulpwood and chips, as demand for pulp and paper increases, demand for pulpwood and chips increases. As the demand for chips increases, sawmill production of chips *and lumber* must increase to meet that demand. This increase in production may coincide with a period of low demand for lumber. The net result is rising chip prices, falling lumber prices and rising log prices. This illustrates why lumber prices are not a perfect predictor of log prices.

Housing construction uses lumber and plywood. As housing starts increase, demand for lumber and plywood increases. Shifts in prices among different species of lumber (e.g., western hemlock or southern pine) can cause substitution of one species for another. Econometric models of sawlog prices must account for this species substitution across a number of species, possibly by including a variable representing each species that may be substituted for another.

Correlation Among Forest Products Variables

Table A1 presents correlation coefficients of annual data for a number of variables related to forest products consumption and prices for the period 1978 through 1996. (The results are shown graphically in Figure A2.) These are variables which might be considered appropriate for use in constructing an econometric model to explain timber price behavior. GDP is included here because it may be one of the foundations of a forecast: given expectations for the economy as a whole (GDP), how might paper and lumber an log prices behave?

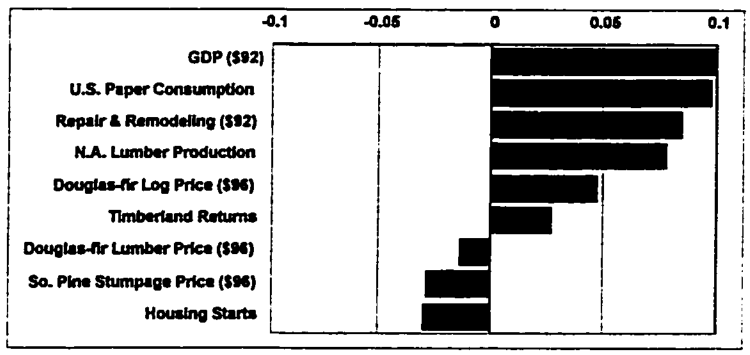
U.S. paper consumption is *very* closely correlated with GDP—a correlation coefficient of nearly 98 percent. Repair and remodeling expenses and North American softwood lumber production are strongly correlated, with coefficients of 80 percent or higher. From that point on, the correlations drop off sharply At the bottom of the table, Douglas-fir lumber prices, southern pine stumpage prices and housing starts are negatively correlated with GDP.

Table A1—Correlation coefficients of selected forest products variables and GDP, 1978-1996

GDP ($92)	1.0000
U.S. Paper Consumption	0.9872
Repair & Remodeling ($92)	0.8598
N.A. Lumber Production	0.7886
Douglas-fir Log Price ($96)	0.4769
Timberland Returns	0.2775
Douglas-fir Lumber Price ($96)	-0.1317
So. Pine Stumpage Price ($96)	-0.2822
Housing Starts	-0.2958

Source: Resource Information Systems, Inc. and Hancock Timber Resource Group

Figure A2—Correlation coefficients of selected forest products variables and GDP, 1978-1996



These data again show the complexities encountered in creating an econometric model to explain timber prices. While paper consumption (and, therefore, pulp and paper production) and repair and remodeling expenses are closely correlated with GDP, housing starts are not.

Housing starts are a major consumer of softwood lumber, yet softwood lumber volumes and housing starts are nearly uncorrelated (13 percent). One of the reasons these two seemingly related variables are so poorly correlated is the relationship between lumber and pulp chip production described above. This may explain why paper production and lumber production are highly correlated (83 percent) while lumber production and Douglas-fir lumber prices are not correlated (minus 5 percent).

Table A2 suggests that forest products *prices* are not closely correlated with forest products *volumes*. This can be seen more clearly by calculating the correlation again using Douglas-fir log prices as a base and then using southern pine sawtimber stumpage prices as a base. The resulting coefficients are shown in Table A2 and Figure A3 and Figure A4. Douglas-fir log prices are more strongly positively correlated with the other forest products variables than are southern pine sawtimber stumpage prices, but they are more strongly correlated with other prices than with any of the demand indicators.

Table A2—Correlation coefficients of GDP, selected forest products variables and timber prices, 1978-1996

Correlation with:	Douglas-fir Log Price	Southern Pine Sawtimber Stumpage Price
Douglas-fir Log Price ($96)	1.0000	0.5624
Douglas-fir Lumber Price ($96)	0.6303	0.7231
So. Pine Stumpage Price ($96)	0.5624	1.0000
U.S. Paper Consumption	0.4789	-0.2442
GDP ($92)	0.4769	-0.2822
Timberland Returns	0.2784	-0.0363
N.A. Lumber Production	0.1278	-0.4652
Repair & Remodeling ($92)	0.1219	-0.5577
Housing Starts	-0.2276	0.2564

Figure A3—Correlation coefficients of GDP, selected forest products variables and Douglas-fir log prices, 1978-1996

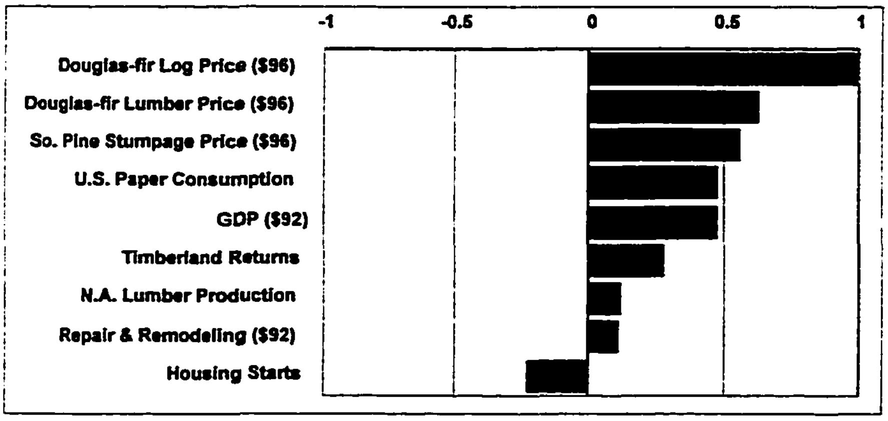
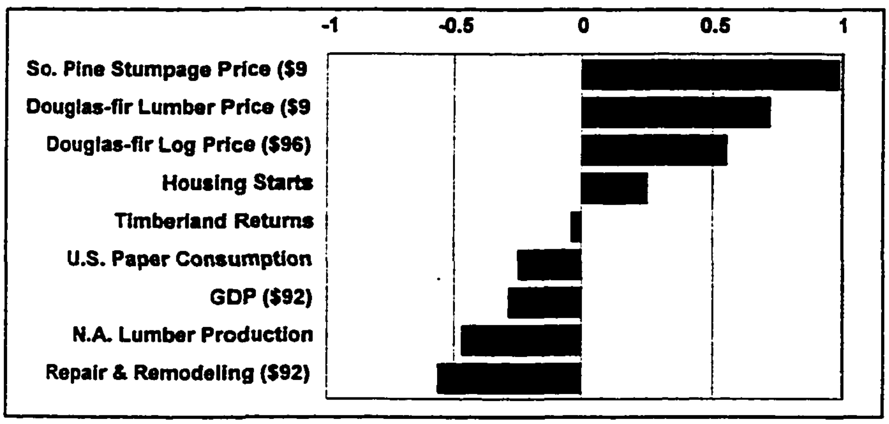


Figure A4—Correlation coefficients of GDP, selected forest products variables and southern pine sawtimber stumpage prices, 1978-1996



While this does not mean an econometric model is inappropriate, it does suggest a time series model may be as useful in explaining the process behind a price series as an econometric model.

While none of the above means that it would be *impossible* to construct a good econometric model to explain timber prices, it does suggest that it would be easier to construct a model to explain *forest products demand.* The relatively weak correlation between price and volume variables suggest wider confidence intervals around the parameter coefficients than might be the case if the variables were more closely correlated.

This level of uncertainty would be compounded when forecasting. To forecast timber prices using an econometric model, the independent variables would have to be forecasted, adding more uncertainty (from the forecast of the independent variables) to an already uncertain process. One of the strengths of a time series model is that it does not depend on forecasts of other variables.

Timber Price Forecasting Services

There are two prominent commercial timber price forecasting services: Resource Information Systems, Inc. (RISI) of Bedford, Massachusetts and Clear Vision Associates (CVA) of San Rafael, California. Both use an econometric approach in making their forecasts. While each service forecasts a number of timber prices (Table A3 and Table A4), they both focus on western sawtimber, southern pine sawtimber, and southern pulpwood. Neither service forecasts sawtimber prices in the Northeastern or North Central United States. Neither service forecasts more that a couple of grades for western sawtimber species. This is in part an indicator of the difficulty in using econometric models to forecast timber prices.

Table A3—Stumpage and log prices forecast by Resource Information Systems, Inc.

Size	Product	Species	Grade	Region	Subregion
Pulpwood	Logs	Hardwood		NC	
Pulpwood	Logs	Hardwood		NE	
Pulpwood	Logs	Hardwood		SO	ATL
Pulpwood	Logs	Hardwood		SO	ESC
Pulpwood	Logs	Hardwood		SO	WSC
Pulpwood	Logs	Softwood		NC	
Pulpwood	Logs	Softwood		NE	
Pulpwood	Logs	Southern Pine		SO	ATL
Pulpwood	Logs	Southern Pine		SO	ESC
Pulpwood	Logs	Southern Pine		SO	WSC
Pulpwood	Stumpage	Hardwood		NC	
Pulpwood	Stumpage	Hardwood		NE	
Pulpwood	Stumpage	Hardwood		SO	ATL
Pulpwood	Stumpage	Hardwood		SO	ESC
Pulpwood	Stumpage	Hardwood		SO	WSC
Pulpwood	Stumpage	Softwood		NC	
Pulpwood	Stumpage	Softwood		NE	
Pulpwood	Stumpage	Southern Pine		SO	ATL
Pulpwood	Stumpage	Southern Pine		SO	ESC
Pulpwood	Stumpage	Southern Pine		SO	WSC
Sawlogs	Logs	Douglas-fir		PNW	
Sawlogs	Logs	Douglas-fir	#2 Sawmill	PNW	Westside
Sawlogs	Logs	Radiata Pine	Export	NZ	
Sawlogs	Logs	Softwood	Export	PNW	
Sawlogs	Logs	Whitewoods	Camprun	PNW	Eastside
Sawlogs	Logs	Whitewoods	#2 Sawmill	PNW	Westside
Sawtimber	Stumpage	Douglas-fir		PNW	Westside
Sawtimber	Stumpage	Hemlock		PNW	Westside
Sawtimber	Stumpage	Ponderosa Pine		PNW	Eastside
Sawtimber	Stumpage	Softwood		PNW	Westside
Sawtimber	Stumpage	Southern Pine		SO	0
Sawtimber	Stumpage	Southern Pine		SO	ATL
Sawtimber	Stumpage	Southern Pine		SO	ESC
Sawtimber	Stumpage	Southern Pine		SO	WSC
Sawtimber	Stumpage	True Firs		PNW	Westside

Table A4—Stumpage and log prices forecast by Clear Vision Associates

Size	Product	Species	Grade	Region	Subregion
	Chips		Domestic		
	Chips		Domestic		
	Chips		Domestic		
	Chips	Douglas-fir	Export		
	Chips	Southern			
	Chips	Southern			
Sawlogs	Logs	All Species	Japan		
Sawlogs	Logs	Douglas-fir	#2 Export		
Sawlogs	Logs	Hemlock	#2 Export		
Sawlogs	Logs	Radiata Pine	New Zealand		
Sawtimber	Stumpage		Washington		
Sawtimber	Stumpage		USFS California		
Sawtimber	Stumpage	Douglas-fir			
Sawtimber	Stumpage	Southern Pine			
Pulpwood	Logs	Southern Pine			

APPENDIX B

LITERATURE REVIEW

No literature on timber prices and random walks was found. However, there is a body of economic literature debating whether stocks and economic growth rates are mean-reverting or follow a random walk. This literature was explored to see if the methodology used in those studies could be applied to timber prices.

Kupiec (1993) discusses mean-reversion in terms of stock market efficiency. Stock prices are too volatile for that volatility to be a function of dividend timing variation alone *if discount rates are constant.* However, "[e]xpected rates of return on equity are not observable."[3] Any variation in stock prices not explained by dividend changes is empirically attributed to differences in rates of return, but may in fact be due to factors such as fads or other non-rational behavior. A large literature (see below) finds that changes in stock prices are not strongly linked to changes in macroeconomic fundamentals. If stock markets were efficient, these links would be strong.

Efficient market theory holds that stocks are always in equilibrium and, as a result, it is impossible assemble a portfolio with a return that is consistently better than the return for the market as a whole. An important component of the theory is assumptions about information. The theory assumes that every investor has access to all available information about the stock and that current market prices reflect this.

[3] Kupiec, 1993, p. 2

Timber Prices

Fewer participants, less frequent trading and less liquidity suggest that timber markets are less efficient than stock markets. If timber markets are less efficient than stock markets, they should show weaker tendencies toward mean-reversion.

Fewer players and less frequent participation in the timber markets make should make timber markets less efficient than the stock markets, primarily because less information is available to the players. While hundreds or thousands of people trade stocks daily, comparatively few people trade timber daily. In between the stock markets and timber markets is a range of markets that are assumed to be less efficient as one moves from finished wood products towards the stump. Hundreds of people across the country buy and sell lumber daily. Some mill owners/procurement foresters will purchase logs on the spot market (whenever a truckload arrives at the mill), but most wood will arrive at a mill under a previously negotiated contract.

Selling timber on a quarterly basis is common in the Pacific Northwest where bids are solicited quarterly. Annual or semi-annual contracts for logs are common in the Northeast. Independent consulting foresters may sell timber a few times each year. Private timberland owners holding 40 acres may sell timber every decade or so through those independent foresters.

Information is not readily available in the timber markets. Timber prices are not as widely reported as stock prices. Stock prices are reported constantly during market hours (often with a reporting delay of a few minutes), but timber prices are reported monthly (e.g., Log Lines or Pacific Rim Wood Market Report) or quarterly (e.g., Timber

Mart-South) or annually (e.g., New Hampshire Forest Market Report). Factors affecting timber prices are not as well understood or widely reported.

The markets for timber are not as wide open as the markets for stocks—*anyone* can buy *any share* sold on the stock exchanges or NASDAQ. Stocks are more liquid than timber. Any reasonable number of shares in a company can be bought or sold within hours of placing an order. A timber sale (or purchase) can take days to execute. Logs can be sold at the gate, but logs must be cut and sorted. Logging can take time. Prices may change significantly between the time a decision to log is made and when the logs can be delivered. Log prices may be highest when logging is impossible/impractical—deep snow or high fire danger. These liquidity problems contribute to the lower efficiency of timber markets by increasing the uncertainty about prices. Buyers and sellers are not as certain about timber prices as they can be about stock prices.

Problems similar to these may be encountered when dealing with a particular company stock, but the major stock markets (NYSE, AMEX, NASDAQ, etc.) are more efficient than timber markets.

Mean-Reversion in Stock Prices

When studying stock prices, Fama and French (1988), Basu (1993), Cecchetti, et al. (1990) and Poterba and Summers (1988) found evidence of mean-reversion. In most cases, the mean reversion was more apparent in long-horizon returns than in daily or weekly holding periods. Goetzmann (1993) used stock prices from 1700 through 1989 and finds that returns with horizons greater than 5 years are "strongly persistent." In his conclusion he writes "The same test used in previous research to demonstrate the lack of long-term memory in NYSE stock market prices during the various periods from 1872 to

1987 suggest that long-term memory may exist in LSE [London Stock Exchange] prices over the period 1700-1989 and in deviations from 20-year means in both markets."[4] Ball and Kothari (1989) attributed most of the "negative serial correlation" (mean-reversion) to variation in expected returns.

In contrast, Miller, et al. (1994) found that mean reversion in stocks is actually a statistical illusion caused by the fact that many of the stocks in the portfolio are infrequently traded. Urrutia (1995) looked at Latin American stock markets and found them to be weak-form efficient. He rejected the hypothesis that the markets followed a random walk, but he could not prove they were mean-reverting.

Mean-Reversion in GNP

There have been a number of conflicting studies of mean-reversion in Gross National Product (GNP). Cochrane (1988) found GNP reverts to a trend over several years. This was in contrast to work done in the 1980's had suggested that fluctuations in GNP are permanent. Basu (1993) showed that "[a]n economy with a higher cost of adjustment for capital movement exhibits a greater degree of mean reversion in output. Given the observed mean reversion in real GNP and stock prices for several OECD countries…"[5]. In contrast, Cribari-Neto (1994) found Canadian GNP to have characteristics of a random walk and "in important periods of Canadian economic growth, its GNP evolved as a random walk with constant drift.[6] Cribari-Neto attributes movements in the Canadian GNP to a series of shocks. In a reconsideration of *that* work, Dejong and Whiteman (1991) found mean-reversion in GNP and other economic

[4] Goetzmann, 1993, p. 268
[5] Basu, 1993, p. 103
[6] Cribari-Neto, 1994, p. 437

variables. Raj (1993) finds "...the size of the random walk in most macroeconomic time series, with the exception of the industrial production variable, in not as small as was found by Cochrane (1988) for the U. S. per capita GNP variable. Moreover, the confidence intervals for the size of the random walk are large, suggesting that the estimate of the size of random walk is far from precise"[7]

Mean-Reversion in Other Assets

Bessembinder, et al. (1995) looked at the futures term structure and found strong mean reversion in agricultural commodities and crude oil, less in metals and almost none in financial assets. Metcalf and Hassett (1995) looked at "investment under alternative return assumptions" equating the random walk with Geometric Brownian Motion. They found that mean reversion is a better explanation for firm behavior.

[6] Cribari-Neto, 1994, p. 437
[7] Raj, 1993, p. 149

APPENDIX C

STOCHASTIC TIME SERIES MODELS

Stochastic time series models assume that the time series to be forecasted is generated by a *stochastic process*—each value in the series is drawn randomly from a probability distribution. Unfortunately, the accurate specification of the probability distribution function is almost always impossible. However, it usually is possible to construct a model of the time series which explains its randomness in a manner that is useful for forecasting purposes.

Random Walk

One type of stochastic time series is the *random walk* process. While very few series are actually random walk processes, the random walk model may be useful in describing some.

In the random walk model, the value of an observation (y) in the current period is equal to the value of y in the previous period plus some disturbance (ε) in the current period:

$$y_t = y_{t-1} + \varepsilon_t$$

where the expected mean and variance for the error term is 0.

The forecast for y, represented by $\hat{y}_{t\_1}$ (called y "hat") is based on the current value of y (y_t), which is based on the value of y in the previous period (y_{t-1}), which is based on the value of y in the period before *that* (y_{t-2}), etc. In equation form, the forecast is represented as:

$$\hat{y}_{t+1} = E[y_{t+1} | y_t, y_{t-1}, y_{t-2}, \ldots y_0]$$

But, the value of y in the next period (y_{t+1}) is equal the value of y in the current period (y_t) plus the value of the disturbance term in the next period (ε_{t+1}):

$$\hat{y}_{t+1} = y_t + \varepsilon_{t+1}$$

Since the expected value of the disturbance term is 0, the forecasted value of y_{t+1} is actually the value of y in the current period. **The forecast for y_{t+k} is always y_t.** Although the *forecast* is always y_t, the variance of the forecast error will increase as the time period gets further out—as *k* increases. In the forecast for the next period, the forecast error is calculated as the difference between the forecasted value of y ($\hat{y}_{t+1}$) and the actual value of y (y_{t-1}) or, stated differently, the disturbance term in the next period:

$$e_1 = y_{t+1} - \hat{y}_{t+1} = y_t + \varepsilon_{t+1} - y_t = \varepsilon_{t+1}$$

and its variance is $E[\varepsilon^2_{t+1}] = \sigma_\varepsilon^2$. In the forecast for two periods ahead, the forecast error is the sum of the disturbance terms for each of the next two periods

$$e_2 = y_{t+2} - \hat{y}_{t+2} = y_t + \varepsilon_{t+1} + \varepsilon_{t+2} - y_t = \varepsilon_{t+1} + \varepsilon_{t+2}$$

and its variance is $E[(\varepsilon_{t+1} + \varepsilon_{t+2})^2] = E[\varepsilon^2_{t+1}] + E[\varepsilon^2_{t+2}] + 2E[\varepsilon_{t+1}\varepsilon_{t+2}]$. Since ε_{t+1} and ε_{t+2} are independent, the third term is 0, and the error variance is $2\sigma_\varepsilon^2$. To apply this progression to an indefinite series, for the k-period forecast the error variance is $k\sigma_\varepsilon^2$. The *standard error of forecast*—the standard deviation of the forecast error—increases with the square root of k.

This standard error of the forecast can be used to calculate confidence intervals for forecasts of y_{t+k}. A chart of the forecast of y and confidence intervals of plus or minus one standard deviation around y would show a horizontal line for all values of y (since the forecast for the value of y at any period in the future is equal to the value of y in the current period) with confidence intervals increasing with the square root of k.

Random Walk With Drift

By definition any time series created by a random walk process would have a constant mean. As mentioned above, most timber price series seem to show signs of increases in the mean price over time. It is possible that timber prices follow a random walk around a trend line—a random walk with drift. The model is this case is similar to the random walk model, but with a trend built in:

$$y_t = y_{t-1} + d + \varepsilon_t$$

where d is the drift or trend. The forecast for the next period is

$$\hat{y}_{t+1} = E[y_{t+1} | y_t, y_{t-1}, y2, \ldots, y_0] = y_t + d$$

or the value of y in the next period is equal to the value of y in the current period plus the trend change. The forecast for the value of y k periods ahead is:

$$\hat{y}_{t+k} = y_t + kd$$

In the case of random walk with drift, the series will move upward (for d > 0) or downward (for d < 0). The standard error of the forecast is the same as for the random walk model; it increases with the square root of k

Stationary and Nonstationary Time Series

Stochastic models are grouped into two categories, depending on the state of the stochastic process behind the model. If the stochastic process does not change over time, the process is a called a *stationary* stochastic process. If the process *does* change, the process is labeled *nonstationary*. When building an econometric model, it is *most useful* if the relationships between the dependent and independent variables are fixed. Likewise, when building a stochastic time series model, it is *most useful* if the stochastic process is fixed. In such cases a model can be developed using historical data to provide information to calculate coefficients for the model. It is difficult to model a nonstationary process with a simple algebraic model.

Stationary stochastic time series models are built assuming that the stochastic processes on which the model is based are in equilibrium around a constant mean and constant variance. Any observation at any time may differ from the mean, but the probability that any observation exhibits that difference is the same in any period—the differences do not grow (or shrink) over time.

Pindyck and Rubinfeld (1976) suggest that most business and economic time series are not generated by stationary processes. This would apply to timber prices as well. However, it is possible to *transform* some nonstationary processes into stationary processes (see below). Once transformed, these series can be manipulated and analyzed using stationary time series modeling techniques.

Properties of Stationary Processes

A stochastic time series is assumed to have been generated by a set of jointly distributed random variables—the data in the series are particular outcomes of the *joint probability function*. Similarly, a *future* observation (y_{t+1})can be thought of as being generated by a *conditional probability distribution function*. For a stationary process neither of these probability functions change over time. If the series is stationary the following applies:

the *mean* of the series, $\mu_y = E[y_t]$ must be stationary

so $E[y_t] = E[y_{t+k}]$ for any *t* and *k*.

the *variance* of the series, $\sigma_y^2 = E[(y_t - \mu_y)^2]$ must be stationary,

so $E[(y_t - \mu_y)^2] = E[(y_{t+m} - \mu_y)^2]$

the *covariance* of the series, $\gamma_k = COV(y_t, y_{t+k}) = E[(y_t - \mu_y)(y_{t+k} - \mu_y)]$ must be stationary,

so $COV(y_t, y_{t+k}) = COV(y_{t+m}, y_{t+m+k})$ for any lag *k*

If a stochastic process is stationary, the probability distribution is the same for each period. The shape of the probability function can be determined by looking at a histogram of all the observations.

The Autocorrelation Function

The autocorrelation function measures the correlation between data in the series. *Autocorrelation with lag k* is defined by Pindyck and Rubinfeld (1976) as

$$\rho_k = \frac{E[(y_t - \mu_y)(y_{t+k} - \mu_y)]}{\sqrt{E[(y_t - \mu_y)^2 (y_{t+k} - \mu_y)^2]}}$$

In practice, an *estimate* of the autocorrelation function must be calculated—the *sample autocorrelation function.*

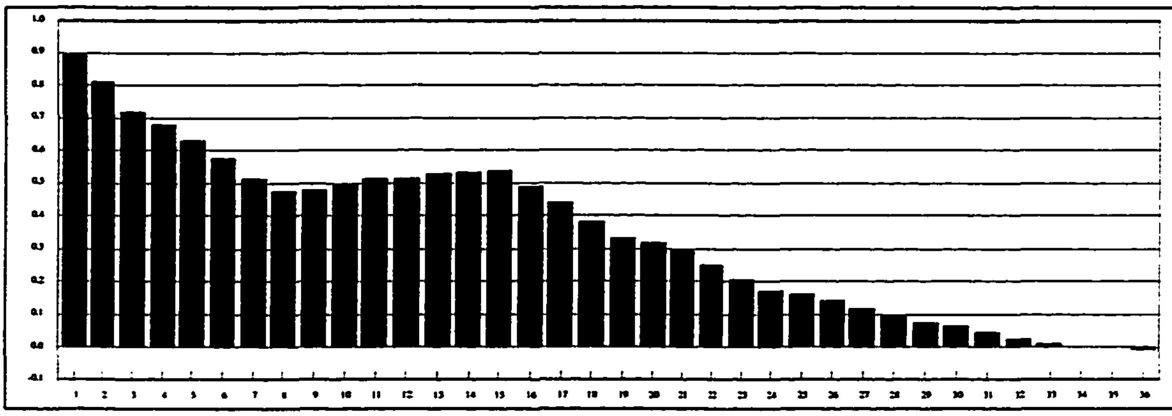
$$\hat{\rho}_k = \frac{\sum_{t=1}^{T-k} (y_t - \bar{y})(y_{t+k} - \bar{y})}{\sum_{t=1}^{T} (y_t - \bar{y})^2}$$

In this equation, ***k*** is the lag value—when ***k***=1, the previous price in the price series is used, when ***k***=2, the next previous price series is used. The value of the autocorrelation function (ρ_k) drops off quickly as ***k*** increases when a time series is stationary. This relationship occurs because in a stationary series, any value is not dependent upon any previous value, so there is little correlation between time periods. This means a price might be strongly related to the previous price, but should not be related to the price before that.

ρ_k usually does not drop off for a nonstationary series. As a value is more dependent on the previous value and the value before that and so on, the amount of correlation increases among them.

The results of calculating the autocorrelation function are often plotted on a bar chart called a correlogram (Figure C1). The correlogram demonstrates whether or not the function drops off quickly.

Figure C1—Sample correlogram: Autocorrelation function for PNW Westside Douglas-fir sawlog prices



There is no critical value or test statistic to which ρ_k can be compared. This requires subjective judgments to be made as the whether a series is stationary or not. How quickly the autocorrelation function must decrease to be called stationary is subjective, and this presents one of the limitations of this technique. For example, Pindyck and Rubinfeld present an example where $\rho_k = 0$ when $k = 36$. They state that "...one might at first suspect the series is stationary."[8] However, they point out that the example series has an upward trend and "...the autocorrelation function declines only slowly."[9]

If a series is not stationary, ρ_k can be calculated for the differenced series. In Pindyck and Rubinfeld's example above, in the first differenced series ρ_k=0 when k=2, in

[8] Pindyck and Rubinfeld, page 443
[9] Pindyck and Rubinfeld, page 443—should read "ibid." if no footnotes inserted between.

the second differenced series ρ_k=0 when k=1. They conclude that differencing once or twice would produce stationarity in the series.

The EViews™ statistical package calculates the autocorrelation function and plots the results on a correlogram, along with the results from the partial autocorrelation function test discussed below. Examples of the statistical output (minus the correlograms) appear in Appendix E.

Partial Autocorrelation

It is not always easy to determine stationarity by looking at the correlogram. It is often useful to look at a plot of the *sample partial autocorrelation of order k*: Partial autocorrelation is the regression coefficient on y_t at lag k when y_t is regressed on $y_{t-1}, \ldots y_{t-k}$.

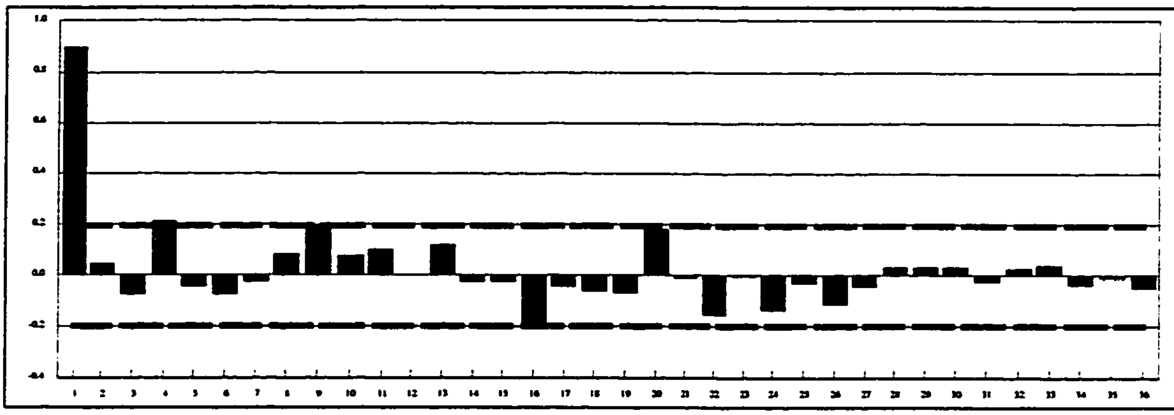
Newbold and Bos (1990) use the following equation for calculating partial autocorrelation, which they designate as r_j:

$$r_j = \hat{\phi}_{k1} r_{j-1} + \hat{\phi}_{k2} r_{j-2} + \ldots \hat{\phi}_{kk} r_{j-k}, \rightarrow j = 1,2,\ldots,k$$

where r is the autocorrelation parameter and ϕ is the autoregressive parameter.

For moderately large sample sizes, the sample partial autocorrelations of order greater than k for an autoregressive process of order k have a distribution that is approximately normal, with a mean of zero and a standard error of $n^{-1/2}$ (where n is the sample size). To test for stationarity the sample partial autocorrelations are compared with limits of $\pm 2\ n^{-1/2}$ (Figure C2):

Figure C2—Sample correlogram: Partial autocorrelation function for PNW Westside Douglas-fir sawlog prices



If most plotted values do not exceed the two-standard error limits, the series should be considered stationary.

As with the (full) autocorrelation function, use of the test statistic is subjective. The definition of "most plotted values" is unclear. There is no critical value or test statistic to which the number of observations exceeding the limits can be compared. This requires subjective judgments to be made as the whether a series is stationary or not.

Unit Root Tests

Two unit root tests are used: the Augmented Dickey-Fuller (ADF) test and the Phillips-Perron test. Unit root tests are based on the following equation:

$$\Delta y_t = \mu + \rho y_{t-1} + \varepsilon_t$$

where μ and ρ are parameters and the error terms (ε_t) are independently distributed with zero mean and constant variance. The process is stationary if the absolute value of ρ less than one. If ρ=1 the process is a random walk with drift and y is not stationary. The equation is usually adapted by setting $\beta_1 = \rho$-1 and replacing ρ in the equation with β_1:

$$\Delta y_t = \mu + \beta_1 y_{t-1} + \varepsilon_t$$

This results in a null hypothesis of H_0: $\beta = 0$—that y contains a unit root. If the coefficient of y_{t-1} is significantly different from zero then the null hypothesis is rejected and the price series is considered is stationary.

The ADF test regresses the first difference of the price series against the lagged series, one or more lagged first difference terms and an error term:

$$\Delta y_t = \beta_1 y_{t-1} + \beta_2 \Delta y_{t-1} + \varepsilon_t$$

A constant and a trend may be included in the regression. The calculated for the ADF t-statistic does not have the standard t distribution. Critical values developed by Dickey and Fuller, *augmented* by MacKinnon and provided by EViews™ are used.

The Phillips-Perron test also tests of the hypothesis that $\beta = 1$ in the equation:

$$\Delta y_t = \beta_1 y_{t-1} + \varepsilon_t$$

Unlike the ADF test, there are no lagged difference terms. The equation is estimated by ordinary least squares (with the optional inclusion of constant and time trend) and then the *t*-statistic of the coefficient is corrected for serial correlation in *t*. This correction is handled automatically by EViews™.

APPENDIX D

DATA

Table D1 provides a summary of the four long-term data series.

Table D1—Long-term Data Series (80-100 Years)

	Sohngen & Haynes 1994, 1997		HTRG Long-term Data	
Years	1910-1996	1910-1996	1890-1996	1890-1996
Dollars	nominal, deflated using 1996$—CPI	nominal, deflated using 1996$—CPI	nominal, deflated using 1996$—CPI	nominal, deflated using 1996$—CPI
Species	Douglas-fir	Douglas-fir	Douglas-fir	Southern Pine
Product	Stumpage	Stumpage	Logs	Stumpage
Price	Cut Price	Sold Price		
Region	PNW	PNW	PNW	SO
Data Sources:	Pacific Northwest Region National Forest timber sales data		calculated using private sales in the State of Washington, and USFS Pacific Northwest Region National Forest timber sales data and Log Lines data	calculated using private sales, USFS Southern Region data and Timber Mart-South data

Table D2 presents the data in tabular form

Table D2—Long-term data series

Real Prices (1996$)				
	Hancock Timber Resource Group		USFS PNW Westside Douglas-fir Stumpage	
Year	Douglas-fir	Southern Pine	Cut	Sold
1890	$4.64	$2.91		
1891	$4.64	$3.82		
1892	$4.73	$7.27		
1893	$4.90	$6.54		
1894	$5.00	$4.36		
1895	$5.17			
1896	$5.53			
1897	$6.07			
1898	$6.61	$9.51		
1899	$7.06	$6.97		
1900	$7.78	$13.29		
1901	$8.68	$15.91		
1902	$9.67	$18.07		
1903	$10.83	$23.92		
1904	$12.55	$28.88		
1905	$14.52	$39.50		
1906	$17.21	$54.14		
1907	$21.51	$47.70		
1908	$20.70	$41.31		
1909	$20.14	$51.89		
1910	$19.77	$62.71	$17.43	$20.22
1911	$20.65	$71.99	$17.06	$20.74
1912	$20.65	$59.78	$18.04	$20.56
1913	$15.25	$69.51	$18.39	$14.98
1914	$14.34	$65.14	$17.47	$13.98
1915	$25.96	$50.94	$16.92	$25.96
1916	$10.73	$67.44	$16.99	$10.38
1917	$14.30	$73.55	$16.35	$14.12
1918	$16.07	$82.86	$16.61	$15.63
1919	$21.41	$103.03	$16.15	$21.68
1920	$16.03	$75.24	$15.67	$16.38
1921	$16.89	$79.11	$20.00	$19.20
1922	$22.20	$49.11	$18.56	$15.19
1923	$22.18	$110.56	$18.90	$22.36
1924	$19.49	$103.19	$24.18	$21.17
1925	$18.58	$70.27	$19.73	$19.20
1926	$19.77	$64.33	$23.18	$23.90
1927	$22.94	$95.32	$21.74	$21.10
1928	$26.85	$87.59	$23.52	$26.11
1929	$24.95	$64.05	$23.66	$24.40
1930	$32.45	$62.24	$22.81	$31.86
1931	$31.52	$68.80	$23.37	$20.33
1932	$20.61	$96.97	$24.12	$21.70
1933	$14.48	$61.28	$24.25	$19.30
1934	$17.73	$70.80	$27.07	$19.27

1935	$19.52	$61.65	$25.83	$19.75
1936	$23.81	$66.33	$25.85	$21.88
1937	$17.60	$69.53	$27.28	$19.03
1938	$28.28	$98.53	$27.15	$25.57
1939		$78.64	$30.80	$26.14
1940	$25.90	$60.47	$28.83	$26.24
1941	$36.92	$132.10	$26.05	$32.92
1942		$99.72	$30.33	$37.93
1943		$94.45	$38.76	$46.22
1944	$46.35	$115.86	$42.16	$42.96
1945	$43.59	$96.69	$41.33	$40.80
1946	$48.71	$78.38	$33.87	$39.26
1947	$66.98	$87.96	$35.86	$57.92
1948	$131.09	$128.85	$51.12	$91.50
1949	$74.50	$157.72	$65.50	$57.18
1950	$104.06	$202.09	$49.75	$61.74
1951	$152.19	$247.33	$69.08	$95.63
1952	$153.21	$272.74	$93.05	$105.11
1953	$119.24	$240.85	$93.09	$81.58
1954	$96.09	$210.14	$115.36	$91.76
1955	$170.80	$225.65	$96.45	$155.73
1956	$216.54	$256.29	$133.08	$147.39
1957	$146.12	$209.59	$123.03	$100.61
1958	$119.45	$203.29	$101.15	$78.08
1959	$198.70	$226.73	$104.00	$128.24
1960	$170.21	$218.94	$108.99	$116.97
1961	$145.88	$168.97	$102.48	$97.36
1962	$129.50	$161.98	$95.35	$86.32
1963	$143.30	$153.78	$92.09	$89.01
1964	$193.40	$168.32	$92.89	$121.93
1965	$212.15	$188.35	$100.60	$135.76
1966	$240.96	$221.93	$121.88	$150.41
1967	$195.04	$213.70	$118.43	$129.42
1968	$273.34	$224.83	$146.67	$184.77
1969	$345.96	$259.60	$169.07	$235.56
1970	$167.13	$209.85	$136.42	$101.40
1971	$189.12	$240.33	$139.91	$106.25
1972	$267.64	$292.12	$163.31	$182.42
1973	$473.76	$382.23	$165.18	$319.42
1974	$618.77	$277.93	$174.17	$382.82
1975	$484.29	$194.29	$167.80	$263.57
1976	$480.24	$228.95	$229.27	$284.11
1977	$576.72	$255.30	$271.25	$358.16
1978	$586.05	$297.35	$291.17	$406.56
1979	$815.04	$326.51	$280.08	$520.13
1980	$794.63	$248.21	$230.48	$468.30
1981	$591.05	$263.29	$199.90	$352.91
1982	$192.07	$230.74	$121.94	$118.22
1983	$252.97	$252.04	$149.98	$150.91
1984	$200.12	$236.41	$143.91	$118.60

1985	$183.14	$194.46	$126.25	$108.65
1986	$230.59	$187.98	$138.99	$145.29
1987	$261.41	$169.05	$156.73	$177.34
1988	$336.93	$181.63	$200.26	$223.02
1989	$490.25	$176.08	$212.51	$266.16
1990	$552.87	$175.44	$221.25	$330.00
1991	$454.28	$169.06	$235.11	$193.64
1992	$533.37	$212.36	$259.68	$240.83
1993	$345.64	$223.00	$393.04	$292.39
1994	$691.13	$271.22	$388.81	$490.16
1995	$468.46	$290.35	$361.29	$323.55
1996	$440.00	$246.00	$370.63	$333.41
1997				
1998				
1999				
2000	NA	NA	NA	NA

Table D3 presents a summary of the shorter-term data

Table D3—Short-term Data Series (40-45 Years)

Series	National Forest Sales	Louisiana	New York
Years	1950-1996	1955-1997	1950-1997
Dollars	nominal, deflated using 1996$—CPI	nominal, deflated using 1996$—CPI	nominal, deflated using 1996$—CPI
Species	Ponderosa Pine	Southern Pine	Hard Maple White Pine Red Spruce (Spruce/Fir)
Product	Stumpage	Stumpage	Stumpage
Size		Sawtimber, Pulpwood	Sawtimber, Pulpwood
Region	PSW	SO	NE
Data Sources:	USFS National Forest Sales	Louisiana Department of Agriculture & Forestry	New York Division of Lands & Forests

Table D4 presents the data in tabular form

Table D4—Short-term data

Real Stumpage Prices							
	USFS PSW	Louisiana		New York			
	Ponderosa Pine	Southern Pine	Sawtimber	Hard Maple	White Pine	Red Spruce	Spruce/Fir
Year		Pulpwood	Sawtimber	Sawtimber	Sawtimber	Sawtimber	Pulpwood
1950	$116.12						
1951	$201.32						
1952	$162.71						
1953	$152.89			$152.60	$113.75	$88.55	$24.79
1954	$161.33			$156.70	$110.97	$81.55	$25.44
1955	$154.26		$182.62	$160.28	$109.81	$92.79	$24.00
1956	$156.23	$22.00	$189.49	$178.92	$116.54	$99.08	
1957	$134.97	$23.59	$172.62				
1958	$104.66	$23.23	$168.38	$190.52	$119.18	$109.59	
1959	$111.23	$23.00	$171.65				
1960	$101.60	$23.30	$160.37	$211.22	$118.35	$103.09	$24.68
1961	$63.95	$22.52	$147.25	$231.24	$127.06	$101.32	$22.30
1962	$84.07	$22.25	$148.20	$224.75	$105.38	$114.26	$22.04
1963	$81.15	$22.14	$138.93	$209.50	$101.13	$92.45	$24.40
1964	$96.45	$21.83	$137.11	$207.21	$100.61	$88.83	$22.54
1965	$98.61	$21.81	$141.43	$200.10	$86.45	$74.70	$22.71
1966	$95.42	$21.83	$166.27	$214.12	$86.75	$86.75	$19.18
1967	$103.84	$21.42	$172.08	$222.83	$88.17	$81.85	$19.50
1968	$134.88	$20.72	$181.96	$214.56	$86.15	$78.16	$18.67
1969	$298.82	$19.57	$211.03	$216.46	$88.68	$73.65	$14.14
1970	$128.04	$18.75	$185.04	$198.01	$78.34	$69.80	
1971	$145.12	$18.29	$215.94				
1972	$245.61	$17.77	$247.52	$219.15	$67.86	$57.86	$12.62
1973	$316.64	$17.80	$282.71	$197.74	$81.96	$73.52	$12.49
1974	$307.55	$18.50	$277.90	$217.55	$97.25	$64.41	$11.49
1975	$203.43	$18.31	$233.00	$159.74	$77.94	$72.51	$10.94
1976	$277.46	$18.21	$275.50	$183.48	$82.26	$66.31	$10.85
1977	$335.46	$18.08	$306.08	$186.55	$79.60	$72.94	$11.36
1978	$385.62	$18.24	$365.68	$182.30	$86.14	$74.74	$11.47
1979	$493.90	$19.24	$436.14	$188.28	$93.74	$67.51	$11.26
1980	$378.93	$18.94	$347.82	$162.18	$83.40	$53.74	$10.54
1981	$329.45	$21.33	$312.19	$151.05	$77.52	$59.68	$10.21
1982	$108.71	$23.27	$234.89	$147.12	$72.34	$58.90	$10.29
1983	$162.81	$23.22	$251.61	$131.32	$70.62	$53.82	$10.85
1984	$184.76	$26.56	$239.17	$139.12	$71.63	$56.72	$12.05
1985	$147.15	$22.06	$171.46	$125.26	$69.35	$53.52	$10.71
1986	$224.71	$28.61	$447.22	$122.38	$66.62	$52.92	$11.68
1987	$287.66	$19.46	$198.43	$121.10	$66.41	$56.27	$11.04
1988	$239.72	$21.89	$203.95	$132.65	$77.14	$58.45	$10.87
1989	$367.20	$24.47	$209.63	$129.00	$72.09	$57.26	$11.45
1990	$257.97	$25.20	$214.18	$134.20	$66.25	$54.92	$10.59

1991	$273.28	$27.11	$217.53	$129.18	$63.46	$48.37	$11.21
1992	$326.70	$30.52	$242.71	$151.29	$63.07	$57.28	$11.19
1993	$582.15	$26.47	$287.56	$234.46	$69.15	$74.70	$11.60
1994	$308.66	$23.97	$346.03	$281.88	$73.97	$73.10	$12.07
1995	$163.63	$24.25	$388.37	$281.88	$78.53	$70.26	$13.08
1996	$280.22	$22.68	$343.07	$283.96	$74.38	$72.50	$13.56
1997		$26.77	$417.77	$363.22	$78.31	$75.48	
1998							
1999							
2000							

Table D5 presents a summary of data available from Ulrich (1988).

Table D5—Short-term Data Series (40-45 Years) Available from Ulrich 1988

Series	National Forest Sales	Louisiana		Wisconsin	PNW Westside sawlogs
Years	1950-1987	1955-1987	1955-1987	1950-1987	1950-1983
Dollars	nominal	nominal	nominal	nominal	nominal
Species	7 Douglas-fir Southern Pine Ponderosa Pine Western Hemlock Hardwood Mix Oak Sugar Maple	4 Southern Pine Oak Ash Gum	4 Southern Pine Oak Ash Gum	4 Aspen Basswood Hard Maple Yellow Birch Grade 1 Grade 2 Grade 3 Woodsrun	Douglas-fir Average Grade 1 Grade 2 Grade 3
Product	Stumpage	Stumpage	Logs	Logs	Logs
Size		Sawtimber	Sawtimber	Sawtimber	Sawtimber
Region	6	SO	SO	NE	PNW
Table	Table 18	Table 20	Table 21	Table 22	Table 23
Data Sources:	USFS National Forest Sales	Louisiana Department of Agriculture		University of Wisconsin	Industrial Forestry Association

Table D5—Short-term Data Series (40-45 Years) Available from Ulrich 1988—continued

Series	Veneer	PNW Westside veneer logs	Pulpwood Prices	Pulpwood Prices
Years	1950-1983	1950-1983	1950-1987	1950-1987
Dollars	nominal	nominal	nominal	nominal
Species	7 Walnut White Oak Aspen Basswood Hard Maple Yellow Birch Yellow Poplar Prime Select	Douglas-fir Average Grade 1 Grade 2 Grade 3		6 Southern Pine Hardwood Mix Hemlock Pine Spruce Aspen
Product	Logs	Logs	Stumpage	Logs
Size	Veneer	Veneer	Pulpwood	Pulpwood
Region	IL, IN, WI	PNW	LA, NH, WI	Midsouth, Southeast, LA, NH, WI
Table	Table 24	Table 26	Table 27	Table 27
Data Sources:	IL—na, IN—na, University of Wisconsin	Industrial Forestry Association	LA Dept. of Agric, Univ of NH, and Univ of WI	LA Dept. of Agric, Univ of NH, and Univ of WI

Table D6 presents a summary of data available from Adams, Jackson & Haynes (1988).

Table D6—Short-term Data Series (40-45 Years) Available from Adams, Jackson & Haynes 1988

Series	National Forest Sales—timber sold	National Forest Sales—timber harvested	Delivered pulpwood	Chips and Residues	
Years	1950-1987	1950-1987	1950-1987	1950-1987	1950-1987
Dollars	nominal	nominal	nominal	nominal	nominal
Species	mixed	mixed	Southern Pine		
Product	Stumpage	Stumpage	Logs	Chips	Chips
Size			Pulpwood		
Region	9 USFS regions	9 USFS regions	South Central, Southeast	PNW	South Central, Southeast
Table	Table 13	Table 14	Table 15	Table 15	Table 15
Data Sources:	USFS National Forest Sales		USFS research notes	North West Pulp Producers Association	USFS research notes

Data Quality

One concern in dealing with timber price data is the quality of the data collected. Data collecting and reporting methods used vary among private reporting services and state agencies. Most states and Cooperative Extension Services in the Northeast simply collect what data they can, with no quality control system to verify the data collected (Lutz, Howard and Sendak 1992). In most cases, no volume data is collected with price data, so there is no way of calculating a true weighted average. The number of sample points is frequently an issue in timber price reporting. Many reports will indicate that too few prices were collected to report on a particular species or grade in a particular month or quarter. This is especially true of private price reporting companies such as Log Lines™ and Pacific Rim Wood Marketing Report™, but is also true of some public agencies such as The University of Vermont School of Natural Resources and the Pennsylvania Cooperative Extension Service.

Of additional concern when dealing with long-term price series is changes in the collecting and reporting system over time, particularly over 50-100 year periods. Data suppliers come and go as individuals retire and are replaced. Agencies or companies compiling reporting prices also undergo changes in personnel. There will be a period of disturbance while contacts between data suppliers and collectors is reestablished after such turnover.

Price reports themselves may undergo changes over time as funding or industry conditions change. For example, New York began reporting stumpage prices for fourteen multi-county regions in 1953. In 1967, the Division of Lands and Forests consolidated these into five regions, then returned to fourteen regions in 1973 (Lutz, Howard and Sendak 1992). Most recently, in 1995, the report was revised to twelve regions.

Timber Mart-South™ currently reports prices on a quarterly basis for two substate regions in each of eleven southern states. In the past, this publication has reported prices on a monthly basis and has reported prices for three substate regions in each state. At one time, prices for Kentucky and Oklahoma were reported, but these states have been dropped from the publication.

In summary, timber price data are collected and reported under less rigorous statistical controls and conditions than many other data sets (e.g., Standard and Poor's 500). This does not mean timber price data sets are invalid, but the researcher must be aware of this limitation. Some apparent changes in the behavior of a price series may be due to the collection and reporting system—perhaps because of a change in personnel—and not due to actual changes in price.

APPENDIX E

RESULTS OF BREAKPOINT ANALYSIS

The data series were analyzed using EViews© statistical package. All series were deflated using a CPI price index developed at the Hancock Timber Resource Group that has been extended back to 1890, using 1996 as the base year (1996 = 100).

The analysis of each price series consisted of the following steps:

1. The full series was analyzed for stationarity using autocorrelation functions, and Augmented Dickey-Fuller (ADF) and Phillips-Perron unit root tests. The results of these tests are presented in this Appendix and summarized in Chapter III. **Because each series exhibited changes in volatility over time, the results of these tests of the entire series *may* not be statistically valid.**
2. Shewhart process control charts were used to determine if there was a recent subset of the price series that exhibited a constant variance. This analysis is presented in Chapter III.
3. Chow's breakpoint test was used to further statistically support selection of recent subsets. Breakpoints were selected on an *a priori* basis from the graphs and control charts of timber prices. Regression models were fit to the data for use in Chow's breakpoint tests and the selected breakpoints were tested. The results are shown in this Appendix
4. The prices from the most recent breakpoint to the end of the series were analyzed for stationarity using autocorrelation functions, and Augmented

Dickey-Fuller (ADF) and Phillips-Perron unit root tests. The results of these tests are presented in this Appendix and summarized in Chapter III. Because these subset have constant variances, the stationarity tests *are* statistically valid.

Most of the price series were analyzed by four regression models: an intercept with a single lagged price variable, an intercept with two lagged price variables, a single lagged price variable with no intercept, and two lagged price variables with no intercept. Initially, other, more complex models were tried, but none were significantly better than these four types.

The alternative models included those with three or four lagged price variables, and others with an AR (autoregressive) term. In general, as more lagged variables were added, the less statistically significant the new variables were, and the lower the F-statistic for the equation as a whole. Models with an intercept, single lagged price variable and an AR term had statistics nearly identical to models with an intercept and two lagged price variables.

PNW Westside Douglas-fir Sawlog Price Series

PNW Westside Douglas-fir Sawlog Price Series—Stationarity of Full Series

The autocorrelation function is used to test whether or not series is stationary. The autocorrelation function decreases as k increases for a stationary series. Table E1 presents the autocorrelation functions and partial autocorrelation functions for the PNW Westside Douglas-fir sawlog price series.

The bold value in the first column indicates the last positive value for the autocorrelation function. Pindyck and Rubinfeld (1976) suggest that an autocorrelation function of this shape indicates these price series are stationary, but not clearly so, especially when prices seem to increase over time. They recommend looking at differenced data to see if such data more clearly indicate stationarity.

The partial autocorrelation function is shown in the second column. In this case, stationarity is indicated if the values fall within the limits of $\pm 2\boldsymbol{n}^{-1/2}$ where $\boldsymbol{n}$ is the number of observations. Those values for each series that exceed this limit are in bold in the table. There are only three cases where the value of the partial autocorrelation function exceeds the limit, which is an indication of stationarity.

For the first differenced series, there is a very strong indication of stationarity in the autocorrelation function, with $\rho \rightarrow 0$ after k=4. There are only three cases where the value of the partial autocorrelation function exceeds the limit, which also indicates stationarity.

The full autocorrelation function indicates stationarity for the second differenced price series. However, the values for the partial autocorrelation function exceed the limit more often for the second differenced series than for either the level or first differenced series

Unit root tests were run for the series. Table E2 presents the results of the ADF unit root test on the Douglas-fir series. The bold statistics are those that are higher then the critical values.

Table E3 presents the results of the Phillips-Perron unit root test on the Douglas-fir series. The results of these tests were summarized in the body of the report—the autocorrelation function and partial autocorrelation function suggest the level series is stationary and the unit root tests suggests it is not. In almost all tests, the first differenced series is indicated as stationary.

Table E1—Autocorrelation functions for the PNW Westside Douglas-fir sawlog price series

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.8951	**0.8951**	-0.1084	-0.1084	**-0.5490**	**-0.5490**
2	0.8100	0.0441	-0.0101	-0.0221	0.1410	**-0.2290**
3	0.7182	-0.0722	-0.1981	**-0.2041**	-0.1750	**-0.3100**
4	0.6800	**0.2129**	**-0.0234**	-0.0726	0.0440	**-0.3260**
5	0.6302	-0.0431	0.0664	0.0466	0.0630	-0.1910
6	0.5756	-0.0750	0.0091	-0.0219	0.0340	-0.0600
7	0.5118	-0.0211	-0.1144	-0.1394	-0.0260	-0.0200
8	0.4744	0.0824	-0.1787	**-0.2046**	-0.0770	-0.1040
9	0.4780	0.1940	-0.0737	-0.1473	0.0160	-0.1260
10	0.4927	0.0777	-0.0069	-0.1267	-0.0490	**-0.2530**
11	0.5131	0.0991	0.1674	0.0472	0.2100	-0.0070
12	0.5115	-0.0013	-0.1258	-0.1824	-0.2050	-0.1470
13	0.5300	0.1185	0.0328	-0.0519	0.0870	-0.1690
14	0.5340	-0.0264	0.0039	-0.0024	-0.1110	**-0.2480**
15	0.5395	-0.0231	0.1991	0.1181	0.2220	0.0300
16	0.4908	**-0.1972**	-0.0890	-0.1600	-0.1770	-0.0920
17	0.4417	-0.0442	0.0254	-0.0450	0.0620	-0.1800
18	0.3794	-0.0590	0.0149	0.0708	0.0710	0.1150
19	0.3314	-0.0650	-0.1666	**-0.2250**	-0.1850	-0.0770
20	0.3162	0.1820	0.0670	-0.0511	0.0760	**-0.2660**
21	0.2936	-0.0084	0.1278	0.1827	0.1190	0.0530
22	0.2489	-0.1540	-0.0811	-0.1232	-0.1310	-0.1130
23	0.2079	-0.0060	0.0128	0.0410	0.0690	-0.1020
24	0.1735	-0.1367	-0.0428	0.0527	-0.0870	-0.0990
25	0.1615	-0.0323	0.0894	0.0762	0.0940	0.0510
26	0.1428	-0.1104	0.0089	-0.0682	0.0080	0.0350
27	0.1172	-0.0434	-0.0959	-0.0554	-0.1070	-0.0710
28	0.0907	0.0314	0.0486	0.0587	0.0810	-0.0200
29	0.0715	0.0304	0.0121	0.0241	-0.0090	-0.0010
30	0.0614	0.0299	-0.0049	0.0259	-0.0040	0.0200
31	0.0422	-0.0253	-0.0144	0.0122	0.0020	0.0700
32	0.0236	0.0262	-0.0283	-0.0447	-0.0370	-0.1170
33	0.0084	0.0390	0.0428	0.1662	0.0750	0.0820
34	0.0002	-0.0376	-0.0563	-0.0238	-0.0860	0.1150
35	**0.0011**	-0.0081	0.0409	-0.0711	0.0760	0.0890
36	-0.0117	-0.0461	-0.0330	-0.0520	-0.0370	-0.0590
n		104		101		98
limit		0.1961		0.1990		0.2020

Table E2—Results of ADF unit root tests on the PNW Westside Douglas-fir sawlog price series

	R^2	ADF Test Statistic	Critical Value*		
lagged differences = 4 for all			1%	5%	10%
Level with Constant	.08	-1.204	-3.502	-2.893	-2.583
First Difference with Constant	.58	**-4.551**	-3.504	-2.894	-2.584
Second Difference with Constant	.95	**-13.131**	-3.507	-2.895	-2.584
Level with Constant and Trend	.15	-2.954	-4.060	-3.459	-3.155
First Difference with Constant and Trend	.58	**-4.530**	-4.063	-3.460	-3.156
Second Difference with Constant and Trend	.94	**-13.053**	-4.067	-3.462	-3.157
Level with no Constant or Trend	.06	-0.522	-2.588	-1.944	-1.618
First Difference with no Constant or Trend	.58	**-4.528**	-2.589	-1.944	-1.618
Second Difference with no Constant or Trend	.95	**-13.210**	-2.590	-1.944	-1.618

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E3—Results of Phillips-Perron unit root test on the PNW Westside Douglas-fir sawlog price series

	R^2	PP Test Statistic	Critical Value*		
lagged differences = 4 for all			1%	5%	10%
Level with Constant	.01	-0.929	-2.586	-1.943	-1.617
First Difference with Constant	.55	**-11.164**	-3.498	-2.891	-2.582
Second Difference with Constant	.90	**-38.122**	-3.501	-2.8922	-2.583

*MacKinnon critical values for rejection of hypothesis of a unit root

PNW Westside Douglas-fir Sawlog Price Series Equations

The next step in the analysis is to determine where any breakpoints may occur, and whether or not there is a "useful" trend. A useful trend is defined here as a series that is strong enough and lasts long enough to be used in forecasting from the trend.

Establishing breakpoints requires development of a model or equation with which to test the model. Below are the statistics for the main equation covering the entire data series. The coefficient of the single variable (the price lagged a single year) is statistically significant and the R^2 is strong at .89.

Equation used in Chow's breakpoint test
LS // Dependent Variable is HTRGDOUGFIR96
Date: 08/17/97 Time: 14:26
Sample(adjusted): 1891 1996
Included observations: 101
Excluded observations: 5 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	16.89645	10.46494	1.614576	0.1096
HTRGDOUGFIR96(-1)	0.919938	0.041146	22.35811	0.0000
R-squared	0.834693	Mean dependent var		162.3159
Adjusted R-squared	0.833023	S.D. dependent var		201.6299
S.E. of regression	82.39163	Akaike info criterion		8.842571
Sum squared resid	672049.7	Schwarz criterion		8.894356
Log likelihood	-587.8626	F-statistic		499.8852
Durbin-Watson stat	2.165182	Prob(F-statistic)		0.000000

Adding more lagged variables did not improve the model. For example, the equation for a model with two lagged price variables appears below: The second lagged variable is not statistically significant.

Alternative model #1
LS // Dependent Variable is HTRGDOUGFIR96
Date: 08/27/97 Time: 14:03
Sample(adjusted): 1892 1996
Included observations: 98
Excluded observations: 7 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	16.70349	10.95370	1.524917	0.1306
HTRGDOUGFIR96(-1)	0.858270	0.102337	8.386712	0.0000
HTRGDOUGFIR96(-2)	0.066975	0.103367	0.647935	0.5186
R-squared	0.833247	Mean dependent var		166.4159
Adjusted R-squared	0.829737	S.D. dependent var		203.3009
S.E. of regression	83.88801	Akaike info criterion		8.889099
Sum squared resid	668533.9	Schwarz criterion		8.968231
Log likelihood	-571.6218	F-statistic		237.3528
Durbin-Watson stat	2.017214	Prob(F-statistic)		0.000000

PNW Westside Douglas-fir Sawlog Price Series Chow Breakpoint Tests

The Chow test is conducted by dividing the price series into groups above and below a breakpoint selected on an *a priori* basis. These breakpoints were selected by examining charts of the price series and choosing years that appeared to represent sudden changes in the trend or volatility of the series.

The test then determines if the coefficients of the independent variables are constant across the subsets—whether the subsets both/all exhibit the same trends. The equation is fitted separately to each data subset. The residual sum of squares for each subset is summed with the others to obtain the unrestricted sum of squares and the restricted residual sum of squares is calculated from the full series. The *F*-statistic indicates the strength of the relationship between the two.

There are a number of breakpoints that seem to apply to the Douglas-fir prices. These appear below. The series can be broken down into a large number of short-term trends.

Chow Breakpoint Test: 1946

F-statistic	3.356652	Probability	0.038946
Log likelihood ratio	6.758861	Probability	0.034067

Chow Breakpoint Test: 1946 1969

F-statistic	4.129311	Probability	0.003964
Log likelihood ratio	16.19054	Probability	0.002774

Chow Breakpoint Test: 1946 1972

F-statistic	5.633023	Probability	0.000411
Log likelihood ratio	21.49629	Probability	0.000252

Chow Breakpoint Test: 1946 1972 1979

F-statistic	4.479482	Probability	0.000500
Log likelihood ratio	25.64045	Probability	0.000260

Chow Breakpoint Test: 1946 1972 1979 1985

F-statistic	3.839176	Probability	0.000626
Log likelihood ratio	29.37177	Probability	0.000273

Chow Breakpoint Test: 1946 1972 1979 1982 1986 1993

F-statistic	16.91929	Probability	0.000000
Log likelihood ratio	121.6122	Probability	0.000000

Chow Breakpoint Test: 1946 1972 1974 1976 1979 1982 1985 1990 1993

F-statistic	17.18936	Probability	0.000000
Log likelihood ratio	158.8472	Probability	0.000000

Chow Breakpoint Test: 1946 1972 1982

F-statistic	7.264987	Probability	0.000002
Log likelihood ratio	38.82275	Probability	0.000001

Chow Breakpoint Test: 1946 1972 1979 1982

F-statistic	7.226157	Probability	0.000000
Log likelihood ratio	49.67239	Probability	0.000000

Chow Breakpoint Test: 1946 1972 1976 1979 1982

F-statistic	5.685070	Probability	0.000002
Log likelihood ratio	49.88866	Probability	0.000000

PNW Westside Douglas-fir Sawlog Price Series—Stationarity of Current Trend

Table E4 presents the autocorrelation functions for the Douglas-fir prices since 1972. Both the full and partial autocorrelation functions indicate stationarity for the level series. For the full function, $\rho \rightarrow 0$ after k=3, while only one value exceeds the limit of $\pm 2n^{-1/2}$ in the partial function. Both the full and partial functions indicate stationarity for the first differenced Douglas-fir prices since 1972. For the full function, $\rho \rightarrow 0$ after k=1, while no values exceed the limit of $\pm 2n^{-1/2}$ in the partial function. For the second differenced series, the full function indicates stationarity because $\rho \rightarrow 0$ after k=1, while only one value exceeds the limit of $\pm 2n^{-1/2}$ in the partial function.

Table E5 presents the results of the ADF unit root tests on the PNW Westside Douglas-fir Sawlog price series. It suggests that the level and first differenced series are *not* stationary, but the second differenced equation is.

Table E6 presents the results of the Phillips-Perron unit root test. This test indicates that the level series has a unit root, the first differenced series does not have a unit root at critical values below one percent, and the second differenced series does not have a unit root at any critical value. The Phillips-Perron test suggests the level series has a unit root but the first and second differenced series do not.

Table E4—Autocorrelation functions for the PNW Westside Douglas-fir sawlog price series since 1972

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.5950	**0.5950**	**-0.0950**	-0.0950	**-0.5790**	**-0.5790**
2	0.3310	-0.0370	0.0590	0.0510	0.2050	-0.1960
3	**0.0690**	-0.1760	-0.1970	-0.1880	-0.2050	-0.2760
4	-0.0890	-0.0800	-0.0340	-0.0730	0.0690	-0.2780
5	-0.2200	-0.1330	-0.0080	0.0010	-0.0230	-0.2370
6	-0.3150	-0.1520	0.0550	0.0230	0.0930	-0.0950
7	-0.4480	-0.2740	-0.0740	-0.0930	0.0250	0.0840
8	-0.4480	-0.1190	-0.2560	-0.2960	-0.1750	-0.1520
9	-0.2550	0.1360	-0.0570	-0.1080	0.0830	-0.1710
10	-0.0810	0.0050	-0.0380	-0.0720	-0.0810	-0.2250
11	-0.0090	-0.1490	0.1650	0.0450	0.2570	0.1120
12	-0.0450	-0.2380	-0.2060	-0.3000	-0.2980	-0.1740
13	0.0600	0.1000	0.0720	-0.0590	0.1660	-0.2470
14	0.1020	-0.0510	-0.0060	0.0530	-0.1440	-0.2520
15	0.1610	-0.0770	0.2000	0.1050	0.2000	0.0040
16	0.0770	-0.1810	-0.0210	-0.1500	-0.1200	-0.0560
17	0.0280	0.0260	0.0310	-0.1020	0.0480	-0.2360
18	-0.0020	0.0360	-0.0080	0.0890	0.0250	-0.0320
19	-0.0130	-0.1840	-0.1130	-0.0970	-0.1300	-0.0040
20	0.0280	-0.0400	0.0740	-0.1170	0.0950	-0.1300
21	0.0340	0.0800	0.0430	0.0070	0.0250	-0.1010
22	-0.0580	-0.1390	-0.0450	-0.0310	-0.0400	-0.1940
23	-0.0040	0.0150	-0.0380	0.0720	-0.0060	-0.0090
n		25		25		25
limit		0.4000		0.4000		0.4000

Table E5—Results of ADF unit root tests on the PNW Westside Douglas-fir sawlog price series since 1972

	R^2	ADF Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.23	-2.4836	-3.7204	-2.9850	-2.6318
First Difference with Constant	.55	**-3.2865**	-3.7204	-2.9850	-2.6318
Second Difference with Constant	.94	**-9.3526**	-3.7204	-2.9850	-2.6318
Level with Constant and Trend	.23	-2.4248	-4.3738	-3.6027	-3.2367
First Difference with Constant and Trend	.55	**-3.2479**	-4.3738	-3.6027	-3.2367
Second Difference with Constant and Trend	.94	**-9.1908**	-4.3738	-3.6027	-3.2367
Level with no Constant or Trend	.01	-0.5074	-2.6603	-1.9552	-1.6228
First Difference with no Constant or Trend	.54	**-3.3381**	-2.6603	-1.9552	-1.6228
Second Difference with no Constant or Trend	.95	**-9.5762**	-2.6603	-1.9552	-1.6228

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E6—Results of Phillips-Perron unit root test on the PNW Westside Douglas-fir sawlog price series since 1972

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.01	-0.5844	-2.6603	-1.9552	-1.6228
First Difference with Constant	.55	**-5.2617**	-3.7204	-2.9850	-2.6318
Second Difference with Constant	.90	**-14.3117**	-3.7204	-2.9850	-2.6318

*MacKinnon critical values for rejection of hypothesis of a unit root

Southern Pine Sawtimber Stumpage Price Series

Southern Pine Sawtimber Stumpage Price Series—Stationarity of Full Series

Table E7 shows the autocorrelation functions for the southern pine sawtimber stumpage price series. For the level series, the full autocorrelation function, $\rho \rightarrow 0$ after k=36. As with the PNW Westside Douglas-fir sawlog series, this is not a real strong indication of stationarity, although the series does not exhibit as strong an upward trend. The partial correlation function indicates stationarity, as only when k=1 does the value exceed the limit of $\pm 2n^{-1/2}$. The full and partial functions indicate stationarity for the first differenced series. For the second differenced series, the full function indicates stationarity. Four values of the partial function exceed the limit of $\pm 2n^{-1/2}$, more than either the level or second differenced series. However, this is probably not enough to indicate nonstationarity.

Table E8 presents the results of ADF unit root tests series. The test indicates the level series has a unit root (is not stationary), but the differenced series do not (are stationary).

Table E9 presents the results of the Phillips-Perron unit root test. Again, the level series seems to have a unit root, while the first and second differenced series do not.

Table E7—Autocorrelation functions for the southern pine sawtimber stumpage price series

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.9074	**0.9074**	-0.0309	-0.0309	-0.3820	**-0.3820**
2	0.8118	-0.0649	-0.2509	**-0.2521**	-0.1620	**-0.3600**
3	0.7470	0.1222	**-0.1267**	-0.1541	**-0.0290**	**-0.3370**
4	0.7214	0.1809	0.0376	-0.0456	0.0660	**-0.2560**
5	0.6924	-0.0166	0.0853	0.0147	0.0550	-0.1560
6	0.6800	0.1494	-0.0036	-0.0181	-0.0610	-0.1780
7	0.6675	0.0356	0.0346	0.0654	0.0840	-0.0050
8	0.6522	0.0169	-0.0997	-0.0888	-0.0650	-0.0270
9	0.6276	0.0040	-0.0942	-0.0921	-0.0640	-0.1080
10	0.6123	0.0549	0.0266	-0.0275	0.0800	-0.0350
11	0.5896	-0.0423	-0.0089	-0.0895	0.0360	0.0150
12	0.5662	0.0001	-0.1368	-0.1972	-0.1420	-0.1790
13	0.5549	0.0741	0.0382	-0.0052	0.0880	-0.0820
14	0.5401	-0.0541	0.0523	-0.0420	0.0230	-0.0740
15	0.5189	-0.0070	-0.0068	-0.0405	0.0180	-0.0150
16	0.4952	-0.0117	-0.0791	-0.0798	-0.1470	-0.1750
17	0.4817	0.0241	0.0999	0.0866	0.1550	0.0070
18	0.4452	-0.1484	0.0190	-0.0359	0.0520	0.1100
19	0.4094	-0.0012	-0.1632	-0.1663	-0.1270	0.0600
20	0.3994	0.1014	-0.0927	-0.1774	-0.1110	-0.1630
21	0.4076	0.0324	0.2094	0.0889	0.1640	-0.0530
22	0.3989	-0.0344	0.1130	0.0172	0.0260	-0.0500
23	0.3595	-0.1496	-0.0443	-0.0011	-0.0230	0.0140
24	0.3115	-0.0674	-0.0589	-0.0174	-0.0590	-0.0600
25	0.2721	-0.0279	0.0316	0.0811	0.0910	0.1320
26	0.2465	0.0095	-0.0738	-0.1108	-0.1060	0.0320
27	0.2331	0.0080	-0.0060	-0.0664	-0.0430	-0.0760
28	0.2142	-0.0650	0.1948	0.1046	0.1830	0.0200
29	0.1687	-0.1549	0.0090	0.0481	-0.0490	0.0790
30	0.1322	0.0099	-0.0866	-0.0179	-0.0510	0.0690
31	0.1030	-0.0285	-0.0566	-0.0363	-0.0690	-0.0540
32	0.0818	0.0003	0.1076	0.1134	0.1720	0.0990
33	0.0409	-0.1175	-0.0826	-0.0359	-0.0750	0.1510
34	0.0224	0.0647	-0.1296	-0.1622	-0.1350	-0.0770
35	0.0234	0.0916	0.0964	0.0249	0.1760	0.0470
36	**0.0023**	-0.1465	-0.0568	-0.0981	-0.0770	-0.0690
n		104		102		100
limit		0.1961		0.1980		0.2000

Table E8—Results of ADF unit root tests on the southern pine sawtimber stumpage price series

	R^2	ADF Test Statistic	Critical Value*		
lagged differences = 4 for all			1%	5%	10%
Level with Constant	.11	-1.3639	-3.5007	-2.8922	-2.5829
first Difference with Constant	.55	**-4.9570**	-3.5015	-2.8925	-2.5831
second Difference with Constant	.93	**—13.1518**	-3.5031	-2.8932	-2.5834
Level with Constant and Trend	.15	-2.4468	-4.0580	-3.4576	-3.1545
first Difference with Constant and Trend	.55	**-4.9352**	-4.0591	-3.4581	-3.1548
second Difference with Constant and Trend	.93	**-13.0673**	-4.0613	-3.4591	-3.1554
Level with no Constant or Trend	.08	0.3590	-2.5878	-1.9435	-1.6175
first Difference with no Constant or Trend	.55	**-4.8154**	-2.5880	-1.9436	-1.6175
second Difference with no Constant or Trend	.93	**-13.2318**	-2.5883	-1.9437	-1.6176

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E9—Results of Phillips-Perron unit root test on the southern pine sawtimber stumpage price series

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.00	0.0326	-2.5860	-1.9432	-1.6174
first Difference with Constant	.51	**-10.4495**	-3.4965	-2.8903	-2.5819
second Difference with Constant	.88	**-39.6772**	-3.4993	-2.8915	-2.5826

*MacKinnon critical values for rejection of hypothesis of a unit root

Southern Pine Sawtimber Stumpage Price Equations

Below are the statistics for the equation used in determining breakpoints for the entire data series. The coefficient of the single variable (the price lagged a single year) is statistically significant, the coefficient of the constant is probably statistically significant, the combination of both is statistically significant (as indicated by the F-statistic and the R^2 is strong at .89.

Equation used in Chow's breakpoint test
LS // Dependent Variable is HTRGSOPINE96
Date: 08/27/97 Time: 10:38
Sample(adjusted): 1891 1996
Included observations: 102
Excluded observations: 4 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	10.68582	5.471711	1.952921	0.0536
HTRGSOPINE96(-1)	0.939683	0.033123	28.36915	0.0000
R-squared	0.889479	Mean dependent var		140.8190
Adjusted R-squared	0.888374	S.D. dependent var		90.16928
S.E. of regression	30.12597	Akaike info criterion		6.830188
Sum squared resid	90757.38	Schwarz criterion		6.881658
Log likelihood	-491.0713	F-statistic		804.8084
Durbin-Watson stat	2.003193	Prob(F-statistic)		0.000000

The equation below uses an intercept, two lagged prices. This equation is not as strong as the first equation. While the constant (C) is more likely statistically significant, the second lagged variable is not statistically significant. This makes the significance of the entire equation weaker (F-statistic = 372) and the R^2s are lower .

Alternative Equation #1
LS // Dependent Variable is HTRGSOPINE96
Date: 08/27/97 Time: 10:42
Sample(adjusted): 1892 1996
Included observations: 100
Excluded observations: 5 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	11.45423	5.757769	1.989353	0.0495
HTRGSOPINE96(-1)	0.937920	0.102295	9.168759	0.0000
HTRGSOPINE96(-2)	-0.002148	0.102604	-0.020935	0.9833
R-squared	0.884546	Mean dependent var		143.5275
Adjusted R-squared	0.882166	S.D. dependent var		88.97636
S.E. of regression	30.54293	Akaike info criterion		6.867807
Sum squared resid	90488.46	Schwarz criterion		6.945963
Log likelihood	-482.2842	F-statistic		371.5810
Durbin-Watson stat	2.004091	Prob(F-statistic)		0.000000

The equation below uses a lagged variable and no intercept term. While this model is not as strong as the first model using an intercept (based on the slightly lower R^2s), it is significant in most statistics. An interesting point is that it implies a downward trend in prices—each price is equal to 99 percent of the previous price.

Alternative Equation #2
LS // Dependent Variable is HTRGSOPINE96
Date: 08/26/97 Time: 17:05
Sample(adjusted): 1891 1996
Included observations: 102
Excluded observations: 4 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
HTRGSOPINE96(-1)	0.993913	0.018307	54.29107	0.0000
R-squared	0.885264	Mean dependent var		140.8190
Adjusted R-squared	0.885264	S.D. dependent var		90.16928
S.E. of regression	30.54274	Akaike info criterion		6.848010
Sum squared resid	94218.77	Schwarz criterion		6.873745
Log likelihood	-492.9802	Durbin-Watson stat		2.035971

Southern Pine Sawtimber Stumpage Price Chow Breakpoint Tests

There are a number of breakpoints that seem to apply to the southern pine prices. As with the Douglas-fir prices, the series can be broken down into a large number of short-term trends: 1941-1946 (five years), 1946-1952 (six years), 1952-1963 (eleven years), 1963-1973 (ten years), 1973-1979 (six years), 1979-1987 (eight years), 1987-1991 (four years) and 1991-1995 (four years).

Note that both 1951 and 1952 are statistically significant breakpoints. 1951 is slightly stronger as a stand alone breakpoint, but 1952 seems to be the better (stronger) choice when used with multiple breakpoints.

Chow Breakpoint Test: 1946

F-statistic	6.683056	Probability	0.001902
Log likelihood ratio	13.04127	Probability	0.001473

Chow Breakpoint Test: 1919

F-statistic	0.849678	Probability	0.430678
Log likelihood ratio	1.753557	Probability	0.416121

Chow Breakpoint Test: 1919 1941

F-statistic	4.543483	Probability	0.002101
Log likelihood ratio	17.68423	Probability	0.001422

Chow Breakpoint Test: 1919 1941 1946

F-statistic	4.855332	Probability	0.000232
Log likelihood ratio	27.53613	Probability	0.000115

Chow Breakpoint Test: 1941 1946

F-statistic	5.420945	Probability	0.000560
Log likelihood ratio	20.77261	Probability	0.000351

Chow Breakpoint Test: 1919 1941 1946 1951

F-statistic	4.277031	Probability	0.000211
Log likelihood ratio	32.25323	Probability	0.000084

Chow Breakpoint Test: 1919 1941 1946 1952

F-statistic	4.579135	Probability	0.000101
Log likelihood ratio	34.18789	Probability	0.000038

Chow Breakpoint Test: 1919 1941 1946 1952 1963

F-statistic	3.794770	Probability	0.000271
Log likelihood ratio	35.88481	Probability	0.000088

Chow Breakpoint Test: 1919 1941 1946 1952 1963 1973 1979 1987 1991

F-statistic	2.764072	Probability	0.000954
Log likelihood ratio	48.36962	Probability	0.000133

Chow Breakpoint Test: 1919 1941 1952 1975

F-statistic	2.733659	Probability	0.009455
Log likelihood ratio	21.75277	Probability	0.005395

Chow Breakpoint Test: 1919 1941 1946 1952 1973

F-statistic	3.627744	Probability	0.000435
Log likelihood ratio	34.54451	Probability	0.000149

Chow Breakpoint Test: 1946 1952

F-statistic	4.853623	Probability	0.001313
Log likelihood ratio	18.78654	Probability	0.000866

Chow Breakpoint Test: 1919 1946 1952

F-statistic	4.843484	Probability	0.000238
Log likelihood ratio	27.47723	Probability	0.000118

Chow Breakpoint Test: 1951

F-statistic	5.759408	Probability	0.004316
Log likelihood ratio	11.33515	Probability	0.003456

Chow Breakpoint Test: 1952

F-statistic	5.186208	Probability	0.007229
Log likelihood ratio	10.26182	Probability	0.005911

Southern Pine Sawtimber Stumpage Price Series—Stationarity of Current Trend

Table E10 presents the autocorrelation functions for the southern pine prices since 1952. Both the full and partial functions indicate stationarity for the level series. For the full function, $\rho \to 0$ after $k=6$, while only one value exceeds the limit of $\pm 2n^{-1/2}$ in the partial function. Both the full and partial functions indicate stationarity for the first differenced southern pine prices. For the full function, $\rho \to 0$ after $k=3$, while only two values exceed the limit of $\pm 2n^{-1/2}$ in the partial function. The full function indicates stationarity for the second differenced series because $\rho \to 0$ after $k=3$. The partial function is weaker than the level and first differenced series because three values exceed $\pm 2n^{-1/2}$.

Table E11 presents the results of ADF unit root tests on the series. The test indicates the level series has a unit root, but the differenced series do not.

Table E12 presents the results of the Phillips-Perron unit root test. Again, the level series seems to have a unit root, while the first differenced series does not.

Table E10—Autocorrelation functions for the southern pine sawtimber price series since 1952

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.6510	**0.6510**	-0.0060	-0.0060	-0.3180	**-0.3180**
2	0.3050	-0.2070	-0.3020	**-0.3020**	-0.1930	**-0.3270**
3	0.1740	0.1250	**-0.1950**	-0.2200	**-0.0890**	**-0.3420**
4	0.1820	0.0960	0.0310	-0.0890	0.0560	-0.2700
5	0.1640	-0.0180	0.1590	0.0330	0.1230	-0.1140
6	**0.0560**	-0.1020	0.0610	0.0210	-0.0360	-0.1080
7	-0.0940	-0.1340	0.0130	0.0840	0.0350	0.0360
8	-0.2580	-0.2190	-0.1270	-0.0590	-0.0370	0.0580
9	-0.3350	-0.1050	-0.1610	-0.1430	-0.1410	-0.1290
10	-0.2900	-0.0020	0.0900	0.0230	0.1800	0.0770
11	-0.3090	-0.1930	-0.0340	-0.1870	-0.0390	-0.0160
12	-0.3050	0.0350	-0.1060	-0.1970	-0.1410	-0.2340
13	-0.2400	0.0530	0.1020	0.0540	0.1670	0.0210
14	-0.2500	-0.1860	0.0000	-0.0880	-0.0300	-0.0310
15	-0.2640	-0.0510	-0.0890	-0.1130	-0.0580	-0.1260
16	-0.2210	-0.0430	-0.0040	0.0250	-0.0630	-0.1270
17	-0.1740	-0.1690	0.1260	0.0750	0.2350	0.1960
18	-0.2350	-0.2900	-0.1530	-0.2610	-0.1270	-0.0420
19	-0.1760	0.0850	-0.1170	-0.1260	-0.0290	0.0850
20	-0.0360	-0.0500	-0.0880	**-0.3390**	-0.1400	-0.1990
21	0.1580	0.2370	0.2070	-0.0490	0.1480	-0.1310
22	0.1990	-0.0460	0.0990	-0.0670	0.0490	-0.0420
23	0.1790	0.0010	0.0070	-0.0400	0.0480	0.0420
24	0.1510	-0.0460	-0.0600	-0.0200	-0.1020	-0.0800
25	0.1730	-0.0360	-0.0270	0.1260	-0.0450	0.0870
26	0.2190	-0.1840	0.0830	0.0210	0.0420	0.1150
27	0.2050	-0.1380	0.0410	-0.1340	0.0170	-0.0820
28	0.1480	0.0160	0.0300	-0.0070	0.0230	0.0310
29	0.0930	-0.0790	0.0280	-0.0760	-0.0130	0.0300
30	0.0170	-0.0420	-0.0250	-0.1270	0.0060	-0.0520
31	-0.0360	0.0260	-0.0320	-0.0620	-0.0380	-0.0190
32	-0.0650	-0.0330	-0.0100	-0.0090	0.0270	0.0140
33	-0.0810	-0.0840	-0.0220	0.0040	-0.0100	0.0100
34	-0.0710	-0.0630	-0.0120	-0.0410	-0.0150	-0.0270
35	-0.0530	-0.0160	0.0030	-0.0110	-0.0160	-0.0120
36	-0.0340	-0.0890	0.0260	-0.0640	0.0460	-0.1140
n		45		45		45
limit		0.2981		0.2981		0.2981

Table E11—Results of ADF unit root tests on the southern pine sawtimber stumpage price series since 1952

	R^2	ADF Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.21	**-3.3838**	-3.5814	-2.9271	-2.6013
first Difference with Constant	.54	**-6.3182**	-3.5814	-2.9271	-2.6013
second Difference with Constant	.91	**-14.8715**	-3.5814	-2.9271	-2.6013
Level with Constant and Trend	.22	**-3.3478**	-4.1728	-3.5112	-3.1854
first Difference with Constant and Trend	.54	**-6.2479**	-4.1728	-3.5112	-3.1854
second Difference with Constant and Trend	.92	**-14.7253**	-4.1728	-3.5112	-3.1854
Level with no Constant or Trend	.01	-0.5626	-2.6143	-1.9481	-1.6196
first Difference with no Constant or Trend	.54	-6.4027	-2.6143	-1.9481	-1.6196
second Difference with no Constant or Trend	.92	-15.0265	-2.6143	-1.9481	-1.6196

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E12—Results of Phillips-Perron unit root test on the southern pine sawtimber stumpage price series since 1952

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.01	-0.4361	-2.6143	-1.9481	-1.6196
first Difference with Constant	.49	-6.6544	-3.5814	-2.9271	-2.6013
second Difference with Constant	.86	-20.2730	-3.5814	-2.9271	-2.6013

*MacKinnon critical values for rejection of hypothesis of a unit root

USFS PNW Westside Douglas-fir Stumpage Cut Price Series

USFS PNW Westside Douglas-fir Stumpage Cut Price Series—Stationarity of Full Series

Table E13 presents the autocorrelation functions for the USFS PNW Westside Douglas-fir stumpage cut price series. For the level series, the full autocorrelation function indicates stationarity, but not strongly so: $\rho \rightarrow 0$ after k=29. The partial autocorrelation function does indicate stationarity as only two values exceed the limit. Both the full and partial functions indicate stationarity for the first differenced series: $\rho \rightarrow 0$ after k=3 and only one partial function value exceeds the limit. The full function indicates stationarity for the second differenced series as $\rho \rightarrow 0$ after k=2. The partial function has four values which exceed the limit.

Table E14 presents the results of the ADF unit root tests. As with the previous series, the level series is not indicated as stationary. The first and second differenced series are indicated as stationary for all confidence levels.

Table E15 shows the results of the Phillips-Perron test. Here, the level series is indicated as having a unit root while the first and second differenced series do not.

Table E13—Autocorrelation functions for the USFS PNW Westside Douglas-fir stumpage cut price series

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.9220	**0.9220**	0.1490	0.1490	-0.4130	**-0.4130**
2	0.8360	-0.0890	0.0040	-0.0180	**-0.0930**	**-0.3180**
3	0.7390	-0.1200	**0.0150**	0.0180	0.0380	-0.1920
4	0.6390	-0.0790	-0.0550	-0.0610	-0.1110	**-0.2880**
5	0.5840	**0.2590**	0.0760	0.0970	0.2420	0.0550
6	0.5310	-0.0430	-0.2020	**-0.2390**	-0.2380	-0.1960
7	0.4940	0.0190	-0.0750	0.0040	0.1180	-0.0200
8	0.4620	-0.0200	-0.1490	-0.1680	-0.1040	-0.2080
9	0.4420	0.1350	-0.0500	0.0300	-0.0150	-0.1830
10	0.4390	0.0770	0.0760	0.0330	0.2470	0.0610
11	0.4360	0.0070	-0.2170	-0.2100	-0.3020	-0.1890
12	0.4490	0.0950	0.0080	0.0330	0.2260	0.0490
13	0.4550	0.0030	-0.1550	-0.2040	-0.1430	-0.1110
14	0.4670	0.1000	-0.0780	-0.0600	-0.0720	**-0.2270**
15	0.4920	0.1230	0.1320	0.0890	0.1490	-0.2030
16	0.4820	-0.1800	0.0840	0.1050	-0.0780	-0.1300
17	0.4560	-0.1250	0.1700	0.0500	0.1980	0.0280
18	0.4020	-0.1090	-0.0840	-0.1110	-0.1730	0.0420
19	0.3480	0.1190	-0.0480	-0.1350	-0.0800	-0.1910
20	0.3020	-0.0380	0.1220	0.0980	0.1320	-0.1470
21	0.2600	-0.0410	0.0660	0.0730	-0.0110	-0.0380
22	0.2350	-0.0310	0.0360	-0.0300	0.0370	-0.1470
23	0.2040	-0.0100	-0.0590	0.0810	-0.1670	-0.1550
24	0.1780	-0.0130	0.1310	0.1040	0.1070	-0.1020
25	0.1440	-0.1320	0.1350	0.0520	0.1540	0.1310
26	0.1090	-0.0590	-0.1190	-0.1810	-0.2620	-0.2150
27	0.0820	-0.0490	0.0760	0.1690	0.1840	-0.0950
28	0.0370	-0.1150	-0.0480	0.0550	-0.0720	-0.0340
29	**0.0020**	-0.0330	-0.0490	-0.0040	0.0140	0.0430
30	-0.0220	0.0110	-0.0720	-0.0850	-0.0020	-0.0560
31	-0.0440	-0.0320	-0.0940	0.0120	-0.0720	0.0010
32	-0.0550	-0.0210	0.0100	-0.0470	0.0930	-0.0580
33	-0.0640	0.0830	-0.0450	0.0140	-0.0600	-0.0570
34	-0.0710	0.0230	0.0030	0.0160	0.0520	-0.1060
35	-0.0800	-0.0320	-0.0380	0.0700	-0.0420	-0.0610
36	-0.0900	-0.0490	-0.0070	0.0200	-0.0450	0.0330
n		87		86		85
limit		0.2144		0.2157		0.2169

Table E14—Results of ADF unit root tests on the USFS PNW Westside Douglas-fir stumpage cut price series

	R^2	ADF Test Statistic	Critical Value*		
lagged differences = 4 for all			1%	5%	10%
Level with Constant	.00	0.1344	-3.5111	-2.8967	-2.5853
first Difference with Constant	.44	**-3.2220**	-3.5121	-2.8972	-2.5855
second Difference with Constant	.93	**-9.7625**	-3.5142	-2.8981	-2.5860
Level with Constant and Trend	.13	-2.6353	-4.0727	-3.4645	-3.1585
first Difference with Constant and Trend	.45	**-3.4289**	-4.0742	-3.4652	-3.1589
second Difference with Constant and Trend	.93	**-9.6859**	-4.0771	-3.4666	-3.1597
Level with no Constant or Trend	.02	1.1301	-2.5912	-1.9442	-1.6178
first Difference with no Constant or Trend	.43	**-2.9625**	-2.5915	-1.9442	-1.6178
second Difference with no Constant or Trend	.93	**-9.8301**	-2.5922	-1.9443	-1.6179

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E15—Results of Phillips-Perron unit root test on the USFS PNW Westside Douglas-fir stumpage cut price series

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	-.00	1.3285	-2.5899	-1.9439	-1.6177
first Difference with Constant	.43	**-7.8232**	-3.5082	-2.8955	-2.5846
second Difference with Constant	.88	**-25.7785**	-3.5101	-2.8963	-2.5851

*MacKinnon critical values for rejection of hypothesis of a unit root

USFS PNW Westside Douglas-fir Stumpage Cut Price Series Equations

Below are the statistics for the equation used in calculating breakpoints for the series. It consists of a single lagged price variable and has the highest adjusted R^2 of this group of models. Note that the coefficient suggests that each price will be slightly higher than the preceding price.

Equation used in Chow's breakpoint test
LS // Dependent Variable is USFSCUT96
Date: 10/01/97 Time: 09:19
Sample(adjusted): 1911 1996
Included observations: 86 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
USFSCUT96(-1)	1.027868	0.018287	56.20897	0.0000
R-squared	0.942228	Mean dependent var		105.4799
Adjusted R-squared	0.942228	S.D. dependent var		96.64619
S.E. of regression	23.22978	Akaike info criterion	6.302430	
Sum squared resid	45867.92	Schwarz criterion		6.330969
Log likelihood	-392.0332	Durbin-Watson stat		1.742460

The second equation has two lagged price variables and no intercept. The adjusted-R^2 is high, however, the second lagged price variable is not statistically significant at high levels.

Alternate equation #1
LS // Dependent Variable is USFSCUT96
Date: 10/01/97 Time: 09:19
Sample(adjusted): 1912 1996
Included observations: 85 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
USFSCUT96(-1)	1.156648	0.108823	10.62868	0.0000
USFSCUT96(-2)	-0.136256	0.113500	-1.200490	0.2334
R-squared	0.942643	Mean dependent var		106.5201
Adjusted R-squared	0.941952	S.D. dependent var		96.73425
S.E. of regression	23.30633	Akaike info criterion	6.320698	
Sum squared resid	45084.36	Schwarz criterion		6.378172
Log likelihood	-387.2394	F-statistic	1364.078	
Durbin-Watson stat	1.989643	Prob(F-statistic)		0.000000

The next equation consists of an intercept, a single lagged variable. This equation is stronger than the equation above (based on the adjusted R^2 and F-statistic), but the intercept is not statistically significant.

Alternate equation #2
LS // Dependent Variable is USFSCUT96
Date: 10/01/97 Time: 09:19
Sample(adjusted): 1911 1996
Included observations: 86 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	2.834029	3.733805	0.759019	0.4500
USFSCUT96(-1)	1.012557	0.027258	37.14772	0.0000

R-squared	0.942621	Mean dependent var	105.4799
Adjusted R-squared	0.941938	S.D. dependent var	96.64619
S.E. of regression	23.28792	Akaike info criterion	6.318851
Sum squared resid	45555.48	Schwarz criterion	6.375928
Log likelihood	-391.7393	F-statistic	1379.953
Durbin-Watson stat	1.727678	Prob(F-statistic)	0.000000

The fourth equation uses two lagged price variables with no intercept. It has the lowest adjusted R^2 and F-statistic of any of the models in this group and the intercept and second lagged price value are not statistically significant at high levels of confidence.

Alternate equation #3
LS // Dependent Variable is USFSCUT96
Date: 10/01/97 Time: 09:19
Sample(adjusted): 1912 1996
Included observations: 85 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3.433738	3.802365	0.903053	0.3691
USFSCUT96(-1)	1.148451	0.109322	10.50522	0.0000
USFSCUT96(-2)	-0.147176	0.114268	-1.287988	0.2014

R-squared	0.943208	Mean dependent var	106.5201
Adjusted R-squared	0.941823	S.D. dependent var	96.73425
S.E. of regression	23.33228	Akaike info criterion	6.334332
Sum squared resid	44640.40	Schwarz criterion	6.420543
Log likelihood	-386.8189	F-statistic	680.9308
Durbin-Watson stat	1.992268	Prob(F-statistic)	0.000000

USFS PNW Westside Douglas-fir Stumpage Cut Price Series Chow Breakpoint Tests

The first equation was used determine breakpoints. The results below show no single breakpoint is statistically significant, but a combination of 1946, 1969, 1978, and 1985 is. The second strongest test used seven breakpoints between and including 1946 and 1993.

Chow Breakpoint Test: 1946

F-statistic	0.000115	Probability	0.991453
Log likelihood ratio	0.000118	Probability	0.991326

Chow Breakpoint Test: 1956

F-statistic	0.039709	Probability	0.842532
Log likelihood ratio	0.040645	Probability	0.840225

Chow Breakpoint Test: 1963

F-statistic	0.070671	Probability	0.791014
Log likelihood ratio	0.072323	Probability	0.787984

Chow Breakpoint Test: 1969

F-statistic	0.019117	Probability	0.890363
Log likelihood ratio	0.019570	Probability	0.888746

Chow Breakpoint Test: 1978

F-statistic	1.515408	Probability	0.221751
Log likelihood ratio	1.537660	Probability	0.214966

Chow Breakpoint Test: 1980

F-statistic	0.978236	Probability	0.325475
Log likelihood ratio	0.995741	Probability	0.318343

Chow Breakpoint Test: 1982

F-statistic	0.491689	Probability	0.485113
Log likelihood ratio	0.501928	Probability	0.478654

Chow Breakpoint Test: 1985

F-statistic	3.087584	Probability	0.082536
Log likelihood ratio	3.104388	Probability	0.078082

Chow Breakpoint Test: 1946 1956

F-statistic	0.025761	Probability	0.974575
Log likelihood ratio	0.053368	Probability	0.973669

Chow Breakpoint Test: 1946 1969 1978 1985

F-statistic	3.387950	Probability	0.012937
Log likelihood ratio	13.30409	Probability	0.009882

Chow Breakpoint Test: 1946 1956 1963 1978 1982 1985 1993			
F-statistic	1.959844	Probability	0.062899
Log likelihood ratio	15.93871	Probability	0.043266

Chow Breakpoint Test: 1946 1956 1963 1969 1978 1985 1993			
F-statistic	2.038891	Probability	0.060470
Log likelihood ratio	14.45096	Probability	0.043718

Both 1978 and 1985 are analyzed as breakpoints below. 1985 may be slightly more significant, but leaves only twelve data points for analysis.

USFS PNW Westside Douglas-fir Stumpage Cut Price Series—Stationarity of Trend Since 1978

Table E16 presents the autocorrelation functions for the series since 1978. The full function for the level series indicates stationarity as $\rho \to 0$ after k=4. The partial function also indicates stationarity as only one value exceeds the limit. The full function for the first differenced series indicates the series is probably stationary as $\rho \to 0$ after k=5. The partial function indicates stationarity, as no value exceeds the limit. Both the full and partial function indicate stationarity for the second differenced series as $\rho \to 0$ after k=2 and no values of the partial function exceed the limit.

Table E17 presents the results of the ADF unit root tests. They indicate the level series has a unit root. The first differenced series does not have unit root at lower confidence levels, but this is less certain at higher critical values. The second differenced series does not have a unit root.

Table E18 shows the results of the Phillips-Perron test. The level series is indicated as having a unit root, the first differenced series is indicated as probably not having a unit root, while the second differenced series is indicates as not having a unit root.

Table E16—Autocorrelation functions for the USFS PNW Westside Douglas-fir stumpage cut price series since 1978

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.8170	0.8170	0.1850	0.1850	-0.3790	-0.3790
2	0.6010	-0.1980	0.0270	-0.0070	-0.0900	-0.2730
3	0.3620	-0.2020	0.0570	0.0550	0.0270	-0.1510
4	0.1080	-0.2190	0.0140	-0.0070	-0.0930	-0.2160
5	-0.0120	0.2340	0.1910	0.1970	0.2070	0.0840
6	-0.1640	-0.3160	-0.0840	-0.1710	-0.1230	-0.0350
7	-0.2860	-0.1150	-0.1210	-0.0760	0.0240	0.0240
8	-0.3730	-0.1340	-0.1840	-0.1870	-0.1230	-0.1680
9	-0.4160	0.1430	-0.0810	0.0110	-0.0290	-0.1870
10	-0.4070	-0.1940	0.0660	0.0510	0.3310	0.2070
11	-0.4080	-0.1810	-0.3590	-0.3590	-0.3500	-0.1860
12	-0.3200	0.2030	-0.1760	-0.0170	0.0810	-0.0880
13	-0.2120	0.0990	-0.1240	-0.0750	-0.0420	-0.1460
14	-0.0840	-0.0600	-0.0140	0.0540	-0.0130	-0.1160
15	0.0670	-0.0600	0.1130	0.0320	0.0620	-0.2000
16	0.0900	-0.1940	0.0050	0.1160	0.0370	0.0550
17	0.0870	-0.0130	-0.0170	-0.0850	-0.0130	-0.0260
n		19		19		19
limit		0.4588		0.4588		0.4588

Table E17—Results of ADF unit root tests on the USFS PNW Westside Douglas-fir stumpage cut price series since 1978

	R^2	ADF Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.08	-0.8809	.-3.8304	-3.0294	-2.6552
first Difference with Constant	.41	**-2.7151**	.-3.8304	-3.0294	-2.6552
second Difference with Constant	.91	**-8.3537**	.-3.8304	-3.0294	-2.6552
Level with Constant and Trend	.27	-1.5520	-4.5348	-3.6746	-3.2762
first Difference with Constant and Trend	.48	-3.1635	-4.5348	-3.6746	-3.2762
second Difference with Constant and Trend	.91	**-8.1283**	-4.5348	-3.6746	-3.2762
Level with no Constant or Trend	.03	0.0803	-2.6968	-1.9602	-1.6251
first Difference with no Constant or Trend	.41	**-2.7807**	-2.6968	-1.9602	-1.6251
second Difference with no Constant or Trend	.91	**-8.6341**	-2.6968	-1.9602	-1.6251

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E18—Results of Phillips-Perron unit root test on the USFS PNW Westside Douglas-fir stumpage cut price series since 1978

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	-.01	0.2138	-2.6968	-1.9602	-1.6251
first Difference with Constant	.41	**-3.4532**	-3.8304	-3.0294	-2.6552
second Difference with Constant	.86	**-9.7354**	-3.8304	-3.0294	-2.6552

*MacKinnon critical values for rejection of hypothesis of a unit root

USFS PNW Westside Douglas-fir Stumpage Cut Price Series—Stationarity of Current Trend.

Table E19 presents the autocorrelation functions for the series since 1985. The full function indicates stationarity for the level series as $\rho \rightarrow 0$ after k=3. The partial function also indicates stationarity as only one value exceeds the limit. The full function indicates the first differenced series is probably stationary as $\rho \rightarrow 0$ after k=3. The partial function indicates stationarity, as no value exceeds the limit. Both the full and partial function indicate stationarity for the second differenced series as $\rho \rightarrow 0$ after k=4 and no values of the partial function exceed the limit.

Table E20 presents the results of the ADF unit root tests. They indicate the level series has a unit root. The first differenced series does not have unit root at lower confidence levels, but this is less certain at higher critical values. The second differenced series does not have a unit root.

Table E21 shows the results of the Phillips-Perron test. The level series is indicated as having a unit root, the first differenced series is indicated as probably not having a unit root, while the second differenced series is indicates as not having a unit root.

Table E19—Autocorrelation functions for the USFS PNW Westside Douglas-fir stumpage cut price series since 1985

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.7590	**0.7590**	-0.0190	-0.0190	-0.0190	-0.0190
2	0.4990	-0.1800	-0.3420	-0.3420	-0.3420	-0.3420
3	**0.2350**	-0.1820	**-0.1890**	-0.2320	-0.1890	-0.2320
4	-0.0080	-0.1610	0.0060	-0.1650	**0.0060**	-0.1650
5	-0.1200	0.0900	0.2150	0.0630	0.2150	0.0630
6	-0.2530	-0.2420	-0.0080	-0.0880	-0.0080	-0.0880
7	-0.3760	-0.2010	-0.1090	-0.0520	-0.1090	-0.0520
8	-0.4650	-0.1560	-0.2340	-0.2790	-0.2340	-0.2790
9	-0.3800	0.3020	0.0630	-0.0520	0.0630	-0.0520
10	-0.2520	-0.0540	0.0970	-0.1770	0.0970	-0.1770
n		12		12		12
limit		0.5774		0.5774		0.5774

Table E20—Results of ADF unit root tests on the USFS PNW Westside Douglas-fir stumpage cut price series since 1985

	R^2	ADF Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.03	-0.5228	-4.1366	-3.1483	-2.7180
first Difference with Constant	.56	**-3.0413**	-4.1366	-3.1483	-2.7180
second Difference with Constant	.92	**-7.2788**	-4.1366	-3.1483	-2.7180
Level with Constant and Trend	.54	-3.0489	-4.9893	-3.8730	-3.3820
first Difference with Constant and Trend	.59	-3.0122	-4.9893	-3.8730	-3.3820
second Difference with Constant and Trend	.93	**-7.2855**	-4.9893	-3.8730	-3.3820
Level with no Constant or Trend	-.08	1.0046	-2.7989	-1.9725	-1.6307
first Difference with no Constant or Trend	.40	**-2.2189**	-2.7989	-1.9725	-1.6307
second Difference with no Constant or Trend	.92	**-7.6838**	-2.7989	-1.9725	-1.6307

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E21—Results of Phillips-Perron unit root test on the USFS PNW Westside Douglas-fir stumpage cut price series since 1985

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	-.08	1.4811	-2.7989	-1.9725	-1.6307
first Difference with Constant	.49	**-3.1028**	-4.1366	-3.1486	-2.7180
second Difference with Constant	.87	**-8.2874**	-4.1366	-3.1483	-2.7180

*MacKinnon critical values for rejection of hypothesis of a unit root

USFS PNW Westside Douglas-fir Stumpage Sold Price Series

USFS PNW Westside Douglas-fir Stumpage Sold Price Series—Stationarity of Full Series

Table E22 presents the autocorrelation functions for the USFS PNW Westside Douglas-fir stumpage sold price series. As with the previous long-term series, the full autocorrelation function indicates stationarity for the level series, but not strongly so: $\rho \to 0$ after k=28. The partial autocorrelation function probably does indicate stationarity as only three values exceed the limit. The full autocorrelation function indicates stationarity for the first differenced series: $\rho \to 0$ after k=1. The partial autocorrelation function probably does indicate stationarity as only three values exceed the limit. The full function indicates stationarity for the second differenced series as $\rho \to 0$ after k=3. The partial function has seven values which exceed the limit—the highest number of any of the long-term price series.

Table E23 presents the results of the ADF unit root tests. As with the previous series, the level series is not indicated as stationary—only the level series with constant and trend shows any indication that there may not be a unit root, and that is only indicated at low confidence intervals. Both the first and second differenced series are indicated as stationary for all confidence levels.

Table E24 shows the results of the Phillips-Perron test. Here, the level series is indicated as having a unit root while the first and second differenced series do not.

Table E22—Autocorrelation functions for the USFS PNW Westside Douglas-fir stumpage sold price series

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.8790	**0.8790**	**0.0050**	0.0050	-0.4220	**-0.4220**
2	0.7570	-0.0660	-0.1470	-0.1470	-0.0080	**-0.2260**
3	0.6380	-0.0560	-0.2910	**-0.2960**	**-0.2640**	**-0.4660**
4	0.6070	**0.3160**	0.0940	0.0700	0.2160	**-0.2430**
5	0.5650	-0.0920	0.0480	-0.0370	0.0110	-0.1570
6	0.5200	-0.0400	-0.0160	-0.0880	-0.0390	**-0.2500**
7	0.4550	0.0160	-0.0060	0.0480	0.0980	0.0340
8	0.4010	-0.0320	-0.1900	**-0.2340**	-0.1670	-0.1410
9	0.3920	0.1780	-0.0410	-0.0830	0.0400	-0.1890
10	0.3980	0.0320	0.0290	-0.0110	0.0310	-0.0550
11	0.4020	-0.0030	0.0350	-0.1370	0.1220	0.0230
12	0.4050	0.1400	-0.1990	**-0.2510**	-0.2430	**-0.2640**
13	0.4450	0.2080	0.0510	0.0400	0.1150	-0.1170
14	0.4700	-0.0610	0.0710	-0.0730	-0.0050	-0.1410
15	0.4850	0.0180	0.1060	-0.0310	0.0880	-0.1430
16	0.4420	-0.1410	-0.0350	-0.0060	-0.0960	-0.0970
17	0.3880	-0.0980	0.0120	-0.0370	0.0610	-0.0160
18	0.3210	-0.0580	-0.0660	-0.1170	-0.0130	0.0260
19	0.2840	-0.0450	-0.1170	-0.1840	-0.1430	-0.1520
20	0.2770	0.1390	0.1160	-0.0140	0.0860	**-0.2200**
21	0.2580	-0.0330	0.1780	0.0910	0.1500	0.0220
22	0.2040	-0.1570	-0.0540	-0.1420	-0.0920	-0.1100
23	0.1410	0.0110	-0.1080	-0.0160	-0.0760	-0.0960
24	0.1090	0.0080	-0.0120	-0.0180	-0.0390	-0.1900
25	0.1000	-0.0560	0.1630	0.0990	0.1670	-0.0760
26	0.0690	**-0.2190**	0.0070	-0.0010	-0.0170	0.0670
27	0.0370	-0.0130	-0.1130	-0.1460	-0.1330	-0.1850
28	**0.0060**	0.0040	0.0280	0.1110	0.0780	-0.1160
29	-0.0230	-0.1410	0.0130	0.0570	0.0060	0.0820
30	-0.0460	-0.0450	-0.0110	-0.1420	-0.0130	-0.1040
31	-0.0720	0.0360	-0.0090	0.0380	0.0130	-0.0780
32	-0.0930	0.0720	-0.0350	0.0190	-0.0380	-0.1400
33	-0.1050	0.0250	0.0160	0.0920	0.0370	-0.0440
34	-0.1150	-0.1410	-0.0070	0.0030	-0.0360	-0.0100
35	-0.1240	-0.0050	0.0420	-0.0330	0.0820	-0.0280
36	-0.1440	0.0370	-0.0710	-0.0130	-0.0830	-0.1180
87		84		86		85
limit		0.2144		0.2157		0.2169

Table E23—Results of ADF unit root tests on the USFS PNW Westside Douglas-fir stumpage sold price series

	R^2	ADF Test Statistic	Critical Value*		
lagged differences = 4 for all			1%	5%	10%
Level with Constant	.15	-1.2194	-3.5111	-2.8967	-2.5853
first Difference with Constant	.57	**-4.5693**	-3.5121	-2.8972	-2.5895
second Difference with Constant	.93	**-11.6575**	-3.5142	-2.8981	-2.5860
Level with Constant and Trend	.25	**-3.3172**	-4.0727	-3.4645	-3.1585
first Difference with Constant and Trend	.57	**-4.5772**	-4.0742	-3.4652	-3.1589
second Difference with Constant and Trend	.93	**-115766**	-4.0771	-3.4666	-3.1597
Level with no Constant or Trend	.13	-0.2193	-2.5912	-1.9442	-1.6178
first Difference with no Constant or Trend	.57	**-4.4960**	-2.5915	-1.9442	-1.6178
second Difference with no Constant or Trend	.93	**-11.7374**	-2.5922	-1.9443	-1.6179

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E24—Results of Phillips-Perron unit root test on the USFS PNW Westside Douglas-fir stumpage sold price series

	R^2	PP Test Statistic	Critical Value*		
lagged differences = 4 for all			1%	5%	10%
Level with Constant	.01	-0.6279	-2.5899	-1.9439	-1.6177
first Difference with Constant	.50	**-9.2689**	-3.5082	-2.8955	-2.5846
second Difference with Constant	.87	**-31.3996**	-3.5101	-2.8963	-2.5851

*MacKinnon critical values for rejection of hypothesis of a unit root

USFS PNW Westside Douglas-fir Stumpage Sold Price Series Equations

Below are the statistics for the equation used in calculating breakpoints for the series. The equation has two lagged price variables and no intercept.

Equation used in Chow's breakpoint test
LS // Dependent Variable is USFSSOLD96
Date: 08/27/97 Time: 16:35
Sample(adjusted): 1911 1996
Included observations: 86 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	14.74726	8.479538	1.739159	0.0857
USFSSOLD96(-1)	0.908194	0.048870	18.58395	0.0000
R-squared	0.804361	Mean dependent var		124.6093
Adjusted R-squared	0.802032	S.D. dependent var		126.7032
S.E. of regression	56.37475	Akaike info criterion		8.087024
Sum squared resid	266961.4	Schwarz criterion		8.144102
Log likelihood	-467.7707	F-statistic		345.3631
Durbin-Watson stat	1.892010	Prob(F-statistic)		0.000000

The next equation uses a second lagged variable. It is not as strong as the previous equation—the intercept and second lagged variable are not strongly significant.

Alternate equation #1
LS // Dependent Variable is USFSSOLD96
Date: 08/27/97 Time: 16:37
Sample(adjusted): 1912 1996
Included observations: 85 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	15.65921	8.730285	1.793665	0.0766
USFSSOLD96(-1)	0.960640	0.110335	8.706558	0.0000
USFSSOLD96(-2)	-0.060487	0.111665	-0.541686	0.5895
R-squared	0.803602	Mean dependent var		125.8313
Adjusted R-squared	0.798812	S.D. dependent var		126.9443
S.E. of regression	56.93964	Akaike info criterion		8.118640
Sum squared resid	265854.1	Schwarz criterion		8.204851
Log likelihood	-462.6520	F-statistic		167.7596
Durbin-Watson stat	1.985723	Prob(F-statistic)		0.000000

The next equation uses a single lagged variable and no intercept. While the single variable is statistically significant, the model is not quite as strong a predictor.

Alternate equation #2
LS // Dependent Variable is USFSSOLD96
Date: 08/27/97 Time: 16:41
Sample(adjusted): 1911 1996
Included observations: 86 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
USFSSOLD96(-1)	0.967448	0.035450	27.29053	0.0000
R-squared	0.797317	Mean dependent var		124.6093
Adjusted R-squared	0.797317	S.D. dependent var		126.7032
S.E. of regression	57.04221	Akaike info criterion		8.099143
Sum squared resid	276574.2	Schwarz criterion		8.127682
Log likelihood	-469.2919	Durbin-Watson stat		1.937384

The final equation uses two lagged variables and no intercept. The second lagged variable is not strongly significant.

Alternate equation #3
LS // Dependent Variable is USFSSOLD96
Date: 08/27/97 Time: 16:49
Sample(adjusted): 1912 1996
Included observations: 85 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
USFSSOLD96(-1)	0.997965	0.109793	9.089530	0.0000
USFSSOLD96(-2)	-0.032968	0.112073	-0.294168	0.7694
R-squared	0.795896	Mean dependent var		125.8313
Adjusted R-squared	0.793437	S.D. dependent var		126.9443
S.E. of regression	57.69516	Akaike info criterion		8.133595
Sum squared resid	276284.7	Schwarz criterion		8.191069
Log likelihood	-464.2876	F-statistic		323.6558
Durbin-Watson stat	1.990159	Prob(F-statistic)		0.000000

USFS PNW Westside Douglas-fir Stumpage Sold Price Series Chow Breakpoint Tests

1982 and 1985 are indicated as breakpoints, with 1985 the strongest when used in combination with a number of other points. But, as with the cut prices, using these dates would only leave twelve to fifteen points for analysis. The second strongest single breakpoint is 1970.

Chow Breakpoint Test: 1946			
F-statistic	2.441211	Probability	0.093360
Log likelihood ratio	4.973937	Probability	0.083162

Chow Breakpoint Test: 1955			
F-statistic	3.393458	Probability	0.038376
Log likelihood ratio	6.838724	Probability	0.032733

Chow Breakpoint Test: 1970			
F-statistic	5.165752	Probability	0.007709
Log likelihood ratio	10.20529	Probability	0.006081

Chow Breakpoint Test: 1979			
F-statistic	3.993281	Probability	0.022135
Log likelihood ratio	7.992934	Probability	0.018380

Chow Breakpoint Test: 1982			
F-statistic	5.290002	Probability	0.006905
Log likelihood ratio	10.43644	Probability	0.005417

Chow Breakpoint Test: 1985			
F-statistic	3.846894	Probability	0.025299
Log likelihood ratio	7.712674	Probability	0.021145

Chow Breakpoint Test: 1955 1979 1982			
F-statistic	2.996390	Probability	0.010947
Log likelihood ratio	17.83758	Probability	0.006651

Chow Breakpoint Test: 1946 1955 1970 1979 1982 1985			
F-statistic	3.578392	Probability	0.000337
Log likelihood ratio	40.22652	Probability	0.000066

USFS PNW Westside Douglas-fir Stumpage Sold Price Series –Stationarity of Trend Since 1970

Table E25 presents the autocorrelation functions for the USFS PNW Westside Douglas-fir stumpage sold price series since 1970. The full autocorrelation function indicates stationarity for the level series: $\rho \to 0$ after $k=2$. The partial autocorrelation function also indicate stationarity as only one value exceeds the limit. The full autocorrelation function indicates stationarity for the first differenced series: $\rho \to 0$ after $k=1$. The partial autocorrelation function also indicates stationarity no values exceed the limit. The full function indicates stationarity for the second differenced series as $\rho \to 0$ after $k=1$. The partial function has only one value that exceeds the limit.

Table E26 presents the results of the ADF unit root tests. As with the previous series, the level series is indicated as having a unit root. Both the first and second differenced series are indicated as not having unit roots.

Table E27 shows the results of the Phillips-Perron test. Here, the level series is indicated as having a unit root while the first and second differenced series do not.

Table E25—Autocorrelation functions for the USFS PNW Westside Douglas-fir stumpage sold price series since 1970

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.6550	**0.6550**	**0.0280**	0.0280	**-0.4360**	-0.4360
2	**0.2920**	-0.2410	-0.0910	-0.0920	0.0540	-0.1680
3	-0.0360	-0.2160	-0.3410	-0.3380	-0.3120	**-0.4540**
4	-0.1000	0.1730	0.0260	0.0320	0.1940	-0.2630
5	-0.1650	-0.2000	0.0160	-0.0490	-0.0020	-0.1780
6	-0.2420	-0.2010	0.0480	-0.0710	0.0160	-0.2490
7	-0.3720	-0.1740	0.0170	0.0400	0.1190	0.0800
8	-0.4960	-0.3100	-0.2600	-0.3150	-0.2160	-0.1400
9	-0.4390	0.0060	-0.1020	-0.1190	0.0180	-0.2230
10	-0.2960	-0.1050	0.0090	-0.0310	0.0290	-0.0740
11	-0.1550	-0.2290	0.0910	-0.1710	0.1740	0.0290
12	-0.0740	-0.0780	-0.1640	-0.2970	-0.2250	-0.2330
13	0.0940	0.1280	0.0560	-0.0100	0.0830	-0.1090
14	0.2230	-0.1050	0.0590	-0.0810	-0.0330	-0.1010
15	0.3150	-0.0510	0.1460	-0.0360	0.0770	-0.1190
16	0.2690	-0.1370	0.0720	0.0400	-0.0080	0.0270
17	0.1570	-0.2170	0.0030	-0.1000	0.0280	0.0690
18	0.0330	-0.1170	-0.1240	-0.1480	-0.0610	0.0210
19	0.0090	-0.0740	-0.1300	-0.1460	-0.1330	-0.0770
20	0.0800	0.0020	0.1320	-0.0690	0.1210	-0.1010
21	0.0820	-0.0460	0.1480	0.0090	0.1290	0.0850
22	-0.0210	-0.1520	-0.0550	-0.1640	-0.1130	-0.0850
23	-0.1060	0.0310	-0.0700	-0.0010	0.0080	0.0510
24	-0.1310	-0.0890	-0.1040	-0.1170	-0.1270	-0.1130
25	-0.0500	0.0180	0.0920	0.0530	0.1790	0.0300
n		27		27		27
limit		0.3849		0.3849		0.3849

Table E26—Results of ADF unit root tests on the USFS PNW Westside Douglas-fir stumpage sold price series since 1970

	R^2	ADF Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.19	-2.3914	-3.6959	-2.9750	-2.6265
first Difference with Constant	.51	**-3.8656**	-3.6959	-2.9750	-2.6265
second Difference with Constant	.93	**-10.3535**	-3.6959	-2.9750	-2.6265
Level with Constant and Trend	.20	-2.3712	-4.3382	-3.5867	-3.2279
first Difference with Constant and Trend	.51	**-3.7896**	-4.3382	-3.5867	-3.2279
second Difference with Constant and Trend	.93	**-10.1333**	-4.3382	-3.5867	-3.2279
Level with no Constant or Trend	.02	-0.6819	-2.6522	-1.9540	-1.6223
first Difference with no Constant or Trend	.50	**-3.9394**	-2.6522	-1.9540	-1.6223
second Difference with no Constant or Trend	.93	**-10.5606**	-2.6522	-1.9540	-1.6223

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E27—Results of Phillips-Perron unit root test on the USFS PNW Westside Douglas-fir stumpage sold price series since 1970

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.02	-0.7001	-2.6522	-1.9540	-1.6223
first Difference with Constant	.50	**-5.0038**	-3.6959	-2.9750	-2.6265
second Difference with Constant	.86	**-13.1085**	-3.6959	-2.9750	-2.6265

*MacKinnon critical values for rejection of hypothesis of a unit root

USFS PNW Westside Douglas-fir Stumpage Sold Price Series –Stationarity of Current Trend

Table E28 presents the autocorrelation functions for the USFS PNW Westside Douglas-fir stumpage sold price series since 1985. The full autocorrelation function indicates stationarity for the level series: $\rho \rightarrow 0$ after k=2. The partial autocorrelation function also indicate stationarity as no value exceeds the limit. The full autocorrelation function indicates stationarity for the first differenced series: $\rho \rightarrow 0$ after k=3. The partial autocorrelation function also indicates stationarity as only one value exceeds the limit. The full function indicates stationarity for the second differenced series as $\rho \rightarrow 0$ after k=1. The partial function has only two values that exceed the limit.

Table E29 presents the results of the ADF unit root tests. The level series is indicated as not having a unit root when the test includes both a constant and trend. The first differenced series probably does not have a unit root and the second differenced series is indicated as not having a unit root.

Table E30 shows the results of the Phillips-Perron test. Here, the level series is indicated as having a unit root while the first and second differenced series do not.

Table E28—Autocorrelation functions for the USFS PNW Westside Douglas-fir stumpage sold price series since 1985

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.4500	0.4500	-0.3530	-0.3530	**-0.5940**	**-0.5940**
2	0.2060	0.0050	-0.0860	-0.2410	0.2090	-0.2230
3	-0.0890	-0.2300	**-0.3610**	**-0.5870**	-0.3760	**-0.5800**
4	0.0670	0.2490	0.3720	-0.1610	0.4290	-0.2500
5	-0.0140	-0.1160	-0.0570	-0.2480	-0.2000	-0.1450
6	0.0560	0.0280	0.0550	-0.2460	0.0400	-0.3120
7	-0.1850	-0.2170	-0.0310	0.0830	-0.0100	-0.0150
8	-0.3340	-0.2960	-0.0040	0.0090	0.0420	0.0340
9	-0.4100	-0.0820	-0.0880	-0.0210	-0.0560	-0.0330
10	-0.1530	0.0900	0.0510	0.0990	0.0020	0.0800
n		12		12		12
limit		0.5774		0.5774		0.5774

Table E29—Results of ADF unit root tests on the USFS PNW Westside Douglas-fir stumpage sold price series since 1985

	R^2	ADF Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.25	-1.2984	-4.1366	-3.1483	-2.7180
first Difference with Constant	.70	**-3.0155**	-4.1366	-3.1483	-2.7180
second Difference with Constant	.95	**-6.8271**	-4.1366	-3.1483	-2.7180
Level with Constant and Trend	.65	**-3.4537**	-4.9893	-3.8730	-3.3820
first Difference with Constant and Trend	.70	-2.6998	-4.9893	-3.8730	-3.3820
second Difference with Constant and Trend	-.96	**-6.8419**	-4.9893	-3.8730	-3.3820
Level with no Constant or Trend	.06	0.3010	-2.7989	-1.9725	-1.6307
first Difference with no Constant or Trend	.66	**-2.7133**	-2.7989	-1.9725	-1.6307
second Difference with no Constant or Trend	.95	**-7.1807**	-2.7989	-1.9725	-1.6307

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E30—Results of Phillips-Perron unit root test on the USFS PNW Westside Douglas-fir stumpage sold price series since 1985

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	-.04	0.2847	-2.7989	-1.9725	-1.6307
first Difference with Constant	.67	**-4.9797**	-4.1366	-3.1483	-2.7180
second Difference with Constant	.90	**-11.1112**	-4.1366	-3.1483	-2.7180

*MacKinnon critical values for rejection of hypothesis of a unit root

USFS PSW Ponderosa Pine Stumpage Sold Price Series

USFS PSW Ponderosa Pine Stumpage Sold Price Series—Stationarity of Full Series

Table E31 presents the autocorrelation functions for the USFS PSW ponderosa pine stumpage sold price series. The full autocorrelation function probably indicates stationarity for the level series: $\rho \to 0$ after k=10. The partial autocorrelation function also indicates stationarity as only one value exceeds the limit. The full autocorrelation function indicates stationarity for the first differenced series: $\rho \to 0$ after k=3. The partial autocorrelation function also indicates stationarity as only one value exceeds the limit. The full function indicates stationarity for the second differenced series as $\rho \to 0$ after k=3. The partial autocorrelation function also probably indicates stationarity as only three values exceed the limit.

Table E32 presents the results of the ADF unit root tests. The level series may be indicated as stationary—the level series with constant and trend suggests there may not be a unit root, but that is only indicated at low confidence intervals. Both the first and second differenced series are indicated as stationary for all confidence levels.

Table E33 shows the results of the Phillips-Perron test. Here, the level series is indicated as having a unit root while the first and second differenced series do not.

Table E31—Autocorrelation functions for the USFS PSW ponderosa pine stumpage sold price series

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.6550	**0.6550**	-0.1910	-0.1910	-0.4510	**-0.4510**
2	0.4630	0.0600	-0.2310	-0.2770	-0.0760	**-0.3510**
3	0.4020	0.1370	**-0.0620**	-0.1920	**-0.0550**	**-0.3730**
4	0.3490	0.0470	0.0830	-0.0540	0.1250	-0.2130
5	0.2680	-0.0240	-0.0040	-0.0680	-0.0080	-0.1410
6	0.1940	-0.0300	-0.0630	-0.0920	-0.0560	-0.1590
7	0.1630	0.0180	0.0490	0.0030	0.0750	-0.0140
8	0.0820	-0.0950	-0.0780	-0.1230	-0.0430	-0.0150
9	0.0610	0.0360	-0.0630	-0.1400	-0.1010	-0.1880
10	0.0770	0.0490	0.1600	0.0710	0.2780	0.2080
11	-0.0090	-0.1360	-0.2650	**-0.3410**	-0.3440	-0.2220
12	0.0820	0.2380	0.1340	0.0190	0.2300	0.0180
13	0.0830	-0.0650	-0.0160	-0.1540	-0.1140	-0.0800
14	0.0950	0.0710	0.0870	-0.0130	0.0940	-0.0600
15	0.0580	-0.0630	0.0490	0.0900	0.0350	0.1940
16	-0.0370	-0.1800	-0.1170	-0.1210	-0.1210	0.0470
17	-0.0620	-0.0140	0.0160	-0.0350	0.0640	0.0880
18	-0.1110	-0.0850	-0.0670	-0.1280	-0.0510	0.0720
19	-0.1010	0.0110	-0.0410	-0.2580	-0.0650	-0.2430
20	-0.0320	0.1810	0.2020	0.0930	0.1850	-0.0380
21	-0.1200	-0.2010	-0.0310	-0.0140	-0.0630	0.1160
22	-0.1780	-0.0770	-0.0820	-0.1980	-0.0200	-0.1430
23	-0.1770	0.0810	-0.1060	-0.0180	-0.1610	-0.0730
24	-0.0950	-0.0080	0.2400	0.0340	0.2560	0.0420
25	-0.1670	-0.1230	-0.0020	-0.0060	-0.0490	-0.0080
26	-0.2440	-0.1210	-0.1410	0.0100	-0.1160	0.0930
27	-0.2120	-0.0610	0.0480	-0.1070	0.0520	-0.0790
28	-0.2220	0.0240	0.0230	-0.0020	0.0110	-0.0710
29	-0.2200	-0.0270	-0.0010	-0.0120	0.0090	0.0270
30	-0.1950	0.0450	0.0050	-0.0860	0.0250	-0.0820
31	-0.1900	0.0740	-0.0570	0.0540	-0.0280	0.1260
32	-0.1540	-0.0550	-0.0220	-0.0790	-0.0300	0.0670
33	-0.1400	-0.0150	0.0250	-0.0020	0.0340	0.1190
34	-0.1330	-0.0920	0.0040	-0.1060	0.0030	0.0310
35	-0.1250	0.0380	-0.0180	-0.0600	-0.0260	-0.0480
36	-0.1100	-0.0100	0.0140	0.0070	0.0140	-0.0210
n		47		46		45
limit		0.2917		0.2949		0.2981

Table E32—Results of ADF unit root tests on the USFS PSW ponderosa pine stumpage sold price series

	R^2	ADF Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.17	-2.5331	-3.5814	-2.9271	-2.6013
first Difference with Constant	.62	**-6.5707**	-3.5850	-2.9286	-2.6021
second Difference with Constant	.94	**-14.9758**	-3.5930	-2.9320	-2.6039
Level with Constant and Trend	.27	**-3.6124**	-4.1728	-3.5112	-3.1854
first Difference with Constant and Trend	.62	**-6.4889**	-4.1781	-3.5136	-3.1868
second Difference with Constant and Trend	.94	**-14.6925**	-4.1896	-3.5189	-3.1898
Level with no Constant or Trend	.06	-0.9368	-2.6143	-1.9481	-1.6196
first Difference with no Constant or Trend	.62	**-6.6394**	-2.6155	-1.9483	-1.6197
second Difference with no Constant or Trend	.94	**-15.1814**	-2.6182	-1.9488	-1.6199

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E33—Results of Phillips-Perron unit root test on the USFS PSW ponderosa pine stumpage sold price series

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.03	-0.7363	-2.6132	-1.9480	-1.6195
first Difference with Constant	.59	**-8.5605**	-3.5814	-2.9271	-2.6013
second Difference with Constant	.91	**-25.0572**	-3.5889	-2.9303	-2.6030

*MacKinnon critical values for rejection of hypothesis of a unit root

USFS PSW Ponderosa Pine Stumpage Sold Price Series Equations

Below are the statistics for the equation used in calculating breakpoints for the series. The equation has a single lagged price variable and no intercept. The adjusted-R^2 is not very high (42%), but the model has the highest F-statistic of any in the group.

Equation used in Chow's breakpoint test
LS // Dependent Variable is PONDPSW
Date: 08/21/97 Time: 16:20
Sample(adjusted): 1951 1996
Included observations: 46 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	76.03635	27.18244	2.797259	0.0076
PONDPSW(-1)	0.659730	0.112386	5.870192	0.0000
R-squared	0.439199	Mean dependent var		216.5420
Adjusted R-squared	0.426453	S.D. dependent var		115.3779
S.E. of regression	87.37898	Akaike info criterion		8.983014
Sum squared resid	335943.8	Schwarz criterion		9.062520
Log likelihood	-269.8805	F-statistic		34.45916
Durbin-Watson stat	2.002056	Prob(F-statistic)		0.000001

The next equation consists of two lagged variables and no intercept. The equation has two lagged price variables and no intercept. The adjusted-R^2 is lower than the first equation and the second lagged variable is not statistically significant at high levels of confidence.

Alternative Equation #1
LS // Dependent Variable is PONDPSW
Date: 09/05/97 Time: 13:12
Sample(adjusted): 1952 1996
Included observations: 45 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
PONDPSW(-1)	0.776286	0.151870	5.111507	0.0000
PONDPSW(-2)	0.169076	0.152249	1.110526	0.2729
R-squared	0.371613	Mean dependent var		216.8802
Adjusted R-squared	0.356999	S.D. dependent var		116.6585
S.E. of regression	93.54538	Akaike info criterion		9.120320
Sum squared resid	376281.8	Schwarz criterion		9.200616
Log likelihood	-267.0594	F-statistic		25.42914
Durbin-Watson stat	2.050650	Prob(F-statistic)		0.000009

The next equation uses two lagged variables and an intercept. While the adjusted-R^2 is higher than the first equation, the second lagged variable is not statistically significant.

Alternative equation #2
LS // Dependent Variable is PONDPSW
Date: 09/05/97 Time: 13:14
Sample(adjusted): 1952 1996
Included observations: 45 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	70.39537	30.10080	2.338655	0.0242
PONDPSW(-1)	0.640124	0.155829	4.107850	0.0002
PONDPSW(-2)	0.041000	0.154908	0.264674	0.7926
R-squared	0.444014	Mean dependent var		216.8802
Adjusted R-squared	0.417539	S.D. dependent var		116.6585
S.E. of regression	89.03282	Akaike info criterion		9.042351
Sum squared resid	332927.4	Schwarz criterion		9.162795
Log likelihood	-264.3051	F-statistic		16.77074
Durbin-Watson stat	1.970158	Prob(F-statistic)		0.000004

The last equation consists of a single lagged variable with no intercept. The adjusted-R^2 is lower than in the first equation.

Alternative Equation #3
LS // Dependent Variable is PONDPSW
Date: 09/05/97 Time: 13:16
Sample(adjusted): 1951 1996
Included observations: 46 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
PONDPSW(-1)	0.936551	0.057163	16.38386	0.0000
R-squared	0.339470	Mean dependent var		216.5420
Adjusted R-squared	0.339470	S.D. dependent var		115.3779
S.E. of regression	93.77108	Akaike info criterion		9.103212
Sum squared resid	395685.7	Schwarz criterion		9.142965
Log likelihood	-273.6451	Durbin-Watson stat		2.247063

USFS PSW Ponderosa Pine Stumpage Sold Price Series Chow Breakpoint Tests

1968 is indicated as the statistically most significant breakpoint, with 1967 as an alternative. No other year or combination of years are statistically significant, although combinations that include a mid-1980's and mid-1990's point come close to being significant.

Chow Breakpoint Test: 1961			
F-statistic	0.740469	Probability	0.483012
Log likelihood ratio	1.594038	Probability	0.450670
Chow Breakpoint Test: 1967			
F-statistic	3.352763	Probability	0.044575
Log likelihood ratio	6.813653	Probability	0.033146
Chow Breakpoint Test: 1968			
F-statistic	4.087092	Probability	0.023886
Log likelihood ratio	8.180227	Probability	0.016737
Chow Breakpoint Test: 1979			
F-statistic	2.063100	Probability	0.139744
Log likelihood ratio	4.310728	Probability	0.115861
Chow Breakpoint Test: 1981			
F-statistic	2.923556	Probability	0.064754
Log likelihood ratio	5.995692	Probability	0.049894
Chow Breakpoint Test: 1982			
F-statistic	2.967862	Probability	0.062286
Log likelihood ratio	6.080805	Probability	0.047816
Chow Breakpoint Test: 1993			
F-statistic	2.821091	Probability	0.070862
Log likelihood ratio	5.798251	Probability	0.055071
Chow Breakpoint Test: 1961 1968 1979 1982 1993			
F-statistic	1.378389	Probability	0.231721
Log likelihood ratio	15.65509	Probability	0.109941
Chow Breakpoint Test: 1968 1979 1982 1993			
F-statistic	1.767025	Probability	0.116434
Log likelihood ratio	15.23632	Probability	0.054710
Chow Breakpoint Test: 1968 1979 1982			
F-statistic	1.866970	Probability	0.112035
Log likelihood ratio	11.88385	Probability	0.064611

Chow Breakpoint Test: 1961 1979 1982 1993

F-statistic	1.279115	Probability	0.284856
Log likelihood ratio	11.50797	Probability	0.174544

Chow Breakpoint Test: 1967 1981

F-statistic	2.190232	Probability	0.087478
Log likelihood ratio	9.110294	Probability	0.058401

Chow Breakpoint Test: 1967 1981 1994

F-statistic	1.842597	Probability	0.116663
Log likelihood ratio	11.74692	Probability	0.067859

Chow Breakpoint Test: 1967 1981 1992

F-statistic	2.089306	Probability	0.077296
Log likelihood ratio	13.11444	Probability	0.041254

<u>USFS PSW Ponderosa Pine Stumpage Sold Price Series—Stationarity of Current Series</u>

Table E34 presents the autocorrelation functions for the USFS PSW ponderosa pine stumpage sold price series. The full autocorrelation function indicates stationarity for the level series as $\rho \to 0$ after $k=2$. The partial autocorrelation function also indicates stationarity as only one value exceeds the limit. The full autocorrelation function indicates stationarity for the first differenced series as $\rho \to 0$ after $k=3$. The partial autocorrelation function also indicates stationarity as no value exceeds the limit. The full function indicates stationarity for the second differenced series as $\rho \to 0$ after $k=3$. The partial autocorrelation function also indicates stationarity as only two values exceed the limit.

Table E35 presents the results of the ADF unit root tests. The level series may be indicated as stationary—the tests with constant and with constant and trend reject the unit root hypothesis at lower confidence levels. Both the first and second differenced series are indicated as stationary for all confidence levels.

Table E36 shows the results of the Phillips-Perron test. Here, the level series is indicated as having a unit root while the first and second differenced series are not.

Table E34—Autocorrelation functions for the USFS PSW ponderosa pine stumpage sold price series since 1968

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.3810	**0.3810**	-0.1900	-0.1900	-0.4550	**-0.4550**
2	**0.0720**	-0.0850	-0.2380	-0.2850	-0.0750	-0.3550
3	-0.0460	-0.0510	**-0.0680**	-0.2040	**-0.0580**	**-0.3830**
4	-0.0900	-0.0560	0.0830	-0.0660	0.1300	-0.2230
5	-0.1790	-0.1450	-0.0140	-0.0920	-0.0190	-0.1690
6	-0.2160	-0.1180	-0.0550	-0.1020	-0.0480	-0.1860
7	-0.1910	-0.0910	0.0530	-0.0060	0.0660	-0.0560
8	-0.2870	-0.2550	-0.0620	-0.1120	-0.0200	-0.0200
9	-0.2710	-0.1670	-0.0820	-0.1570	-0.1300	-0.2220
10	-0.1310	-0.0740	0.1700	0.0770	0.2840	0.1730
11	-0.1640	-0.2880	-0.2470	-0.3320	-0.3310	-0.2350
12	0.1550	0.2050	0.1450	0.0410	0.2310	0.0000
13	0.2480	-0.0230	-0.0190	-0.1410	-0.1200	-0.0940
14	0.3410	0.1460	0.0860	0.0100	0.0910	-0.0740
15	0.2250	-0.0080	0.0580	0.1210	0.0330	0.1740
16	0.0570	-0.1520	-0.1020	-0.0690	-0.1080	0.0640
17	0.0130	-0.0230	0.0130	0.0230	0.0700	0.1530
18	-0.0760	-0.1110	-0.0990	-0.1220	-0.0800	0.0750
19	-0.0120	0.0320	-0.0090	-0.1540	-0.0610	-0.2140
20	0.0900	0.2290	0.2220	0.1560	0.2140	-0.0370
21	-0.0950	-0.1190	-0.0530	0.0500	-0.0700	0.1220
22	-0.1530	0.0190	-0.1140	-0.1480	-0.0350	-0.1020
23	-0.1340	0.1450	-0.1190	-0.0080	-0.1700	-0.1190
24	0.0270	0.0510	0.2510	0.0830	0.2710	0.0070
25	-0.0810	-0.0630	-0.0250	-0.0030	-0.0650	-0.0570
26	-0.0270	-0.0240	-0.1280	0.0270	-0.0880	0.0470
27	0.0450	-0.1230	0.0350	-0.1010	0.0390	-0.1030
n		29		29		29
limit		0.3714		0.3714		0.3714

Table E35—Results of ADF unit root tests on the USFS PSW ponderosa pine stumpage sold price series since 1968

	R^2	ADF Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.32	**-3.2888**	-3.6752	-2.9665	-2.6220
first Difference with Constant	.62	**-5.2662**	-3.6752	-2.9665	-2.6220
second Difference with Constant	.94	**-12.1442**	-3.6752	-2.9665	-2.6220
Level with Constant and Trend	.34	**-3.2919**	-4.3082	-3.5731	-3.2203
first Difference with Constant and Trend	.63	**-5.2630**	-4.3082	-3.5731	-3.2203
second Difference with Constant and Trend	.94	**-11.8282**	-4.3082	-3.5731	-3.2203
Level with no Constant or Trend	.05	-0.6954	-2.6453	-1.9530	-1.6218
first Difference with no Constant or Trend	.62	**-5.3333**	-2.6453	-1.9530	-1.6218
second Difference with no Constant or Trend	.94	**-12.4002**	-2.6453	-1.9530	-1.6218

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E36—Results of Phillips-Perron unit root test on the USFS PSW ponderosa pine stumpage sold price series since 1968

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.03	-0.5843	-2.6453	-1.9530	-1.6218
first Difference with Constant	.59	**-6.7183**	-3.6752	-2.9665	-2.6220
second Difference with Constant	.91	**-20.4334**	-3.6752	-2.9665	-2.6220

*MacKinnon critical values for rejection of hypothesis of a unit root

Louisiana Southern Pine Pulpwood Stumpage Price Series

Louisiana Southern Pine Pulpwood Stumpage Price Series—Stationarity of Full Series

Table E37 presents the results of the autocorrelation functions for the southern pine pulpwood series. The full autocorrelation function probably indicates stationarity for the level series: $\rho \rightarrow 0$ after k=9. The partial autocorrelation function also indicates stationarity as only two values exceed the limit. The full autocorrelation function indicates stationarity for the first differenced series as $\rho \rightarrow 0$ after k=1. The partial autocorrelation function also indicates stationarity as only two values exceed the limit. The full function indicates stationarity for the second differenced series as $\rho \rightarrow 0$ after k=1. The partial autocorrelation function also probably indicates stationarity as only three values exceed the limit.

Table E38 presents the results of the ADF unit root tests. The level series is indicated as having a unit root. Both the first and second differenced series are indicated as not having unit roots.

Table E39 shows the results of the Phillips-Perron test. Here, the level series is indicated as having a unit root while the first and second differenced series are not.

Table E37—Autocorrelation functions for the Louisiana southern pine pulpwood stumpage price series

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.6670	**0.6670**	**-0.4730**	**-0.4730**	**-0.7290**	**-0.7290**
2	0.6720	**0.4080**	0.2510	0.0350	0.3650	-0.3550
3	0.5040	-0.0730	-0.1030	0.0360	-0.0860	0.0380
4	0.4020	-0.1230	-0.1690	-0.2740	-0.0470	0.0330
5	0.3740	0.1220	-0.0690	**-0.3420**	-0.0760	**-0.3640**
6	0.3380	0.1220	0.1240	0.0490	0.1090	**-0.3640**
7	0.2640	-0.1150	0.0270	0.2280	-0.0430	0.0070
8	0.1940	-0.1470	0.0750	0.0630	-0.0070	0.1260
9	**0.0860**	-0.1070	0.1100	0.0660	0.1110	0.1200
10	-0.0600	-0.2050	-0.1730	-0.0620	-0.1310	-0.1020
11	-0.0720	0.0530	0.1120	0.1300	0.1060	-0.0280
12	-0.2600	-0.2600	-0.1620	0.0450	-0.0900	0.0980
13	-0.2750	-0.1400	0.0030	-0.1200	0.0310	0.0750
14	-0.3470	-0.0030	-0.0490	-0.2310	-0.0180	-0.0450
15	-0.3520	0.0870	0.0040	-0.1760	-0.0060	-0.1730
16	-0.3630	-0.0160	0.0410	0.0170	0.0270	-0.0710
17	-0.3780	-0.0860	-0.0100	-0.0610	-0.0210	0.0220
18	-0.3600	0.0840	0.0390	-0.1340	0.0310	0.0040
19	-0.3700	0.0340	-0.0200	-0.0450	-0.0080	-0.0220
20	-0.3570	-0.0330	-0.0430	0.0290	-0.0140	-0.0670
21	-0.3170	0.0420	-0.0210	0.0870	0.0080	-0.0140
22	-0.2660	-0.0140	-0.0240	-0.0080	-0.0120	0.0390
23	-0.2030	0.0770	0.0010	-0.0250	-0.0080	0.0250
24	-0.1430	-0.0140	0.0420	0.0490	0.0270	0.0300
25	-0.1000	-0.0510	0.0000	0.0460	-0.0250	-0.0220
26	-0.0570	-0.0680	0.0430	0.0280	0.0350	0.0150
27	-0.0440	-0.0670	-0.0050	-0.0460	-0.0040	0.1040
28	-0.0330	-0.0650	-0.0550	-0.1180	-0.0340	0.0150
29	0.0040	-0.0710	0.0460	0.0050	0.0520	-0.0200
30	-0.0020	-0.1030	-0.0740	-0.0250	-0.0400	0.0370
31	0.0320	-0.0320	0.0060	-0.1360	-0.0080	0.0370
32	0.0530	0.0110	0.0330	-0.1230	0.0230	-0.0470
33	0.0540	-0.0140	-0.0040	0.0020	-0.0110	-0.0750
34	0.0580	-0.0580	0.0070	0.0220	-0.0090	-0.0090
35	0.0530	0.0470	0.0320	-0.0320	0.0300	0.0420
36	0.0290	0.0200	-0.0360	-0.0320	-0.0140	0.0140
n		42		41		40
limit		0.3086		0.3123		0.3162

Table E38—Results of ADF unit root tests on the Louisiana southern pine pulpwood stumpage price series

	R^2	ADF Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.28	-1.3654	-3.6019	-2.9358	-2.6059
first Difference with Constant	.74	**-4.9463**	-3.6067	-2.9378	-2.6069
second Difference with Constant	.97	**-17.1424**	-3.6171	-2.9422	-2.6092
Level with Constant and Trend	.32	-1.8762	-4.2023	-3.5247	-3.1931
first Difference with Constant and Trend	.74	**-4.9838**	-4.2092	-3.6279	-3.1949
second Difference with Constant and Trend	.97	**-16.8892**	-4.2242	-3.5348	-3.1988
Level with no Constant or Trend	.24	0.0779	-2.6211	-1.9492	-1.6201
first Difference with no Constant or Trend	.74	**-5.0088**	-2.6227	-1.9495	-1.6202
second Difference with no Constant or Trend	.97	**-17.3891**	-2.6261	-1.9501	-1.6205

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E39—Results of Phillips-Perron unit root test on the Louisiana southern pine stumpage sold price series

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.13	-2.3559	-3.5973	-2.9339	-2.6048
first Difference with Constant	.74	**-10.3257**	-3.6019	-2.9358	-2.6059
second Difference with Constant	.96	**-30.7818**	-3.6117	-2.9399	-2.6080

*MacKinnon critical values for rejection of hypothesis of a unit root

Louisiana Southern Pine Pulpwood Stumpage Price Series Equations

Below are the statistics for the equation used in calculating breakpoints for the series. The equation consists of two lagged variables and no intercept. This model has the highest adjusted-R^2 and F-statistic.

Equation used in Chow's breakpoint test
LS // Dependent Variable is PINESLAP
Date: 09/08/97 Time: 12:22
Sample(adjusted): 1958 1997
Included observations: 40 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
PINESLAP(-1)	0.493589	0.145686	3.388033	0.0017
PINESLAP(-2)	0.507635	0.145798	3.481767	0.0013
R-squared	0.538866	Mean dependent var		22.08975
Adjusted R-squared	0.526731	S.D. dependent var		3.204436
S.E. of regression	2.204476	Akaike info criterion		1.629687
Sum squared resid	184.6692	Schwarz criterion		1.714131
Log likelihood	-87.35128	F-statistic		44.40561
Durbin-Watson stat	1.915835	Prob(F-statistic)		0.000000

The next equation has a single lagged price variable and an intercept. The adjusted-R^2 and F-statistic are slightly lower than for the previous model.

Alternate Equation used in Chow's breakpoint test
LS // Dependent Variable is PINESLAP
Date: 09/08/97 Time: 12:22
Sample(adjusted): 1957 1997
Included observations: 41 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	6.580660	2.660722	2.473261	0.0179
PINESLAP(-1)	0.706301	0.119745	5.898363	0.0000
R-squared	0.471478	Mean dependent var		22.12634
Adjusted R-squared	0.457926	S.D. dependent var		3.172790
S.E. of regression	2.335987	Akaike info criterion		1.744420
Sum squared resid	212.8167	Schwarz criterion		1.828009
Log likelihood	-91.93709	F-statistic		34.79068
Durbin-Watson stat	2.455022	Prob(F-statistic)		0.000001

The next equation consists of a single lagged variable and no intercept. The adjusted-R^2 is not as high as in the prior equations.

Alternative Equation #1
LS // Dependent Variable is PINESLAP
Date: 09/08/97 Time: 12:22
Sample(adjusted): 1957 1997
Included observations: 41 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
PINESLAP(-1)	0.999665	0.017437	57.32934	0.0000

R-squared	0.388581	Mean dependent var	22.12634
Adjusted R-squared	0.388581	S.D. dependent var	3.172790
S.E. of regression	2.480908	Akaike info criterion	1.841337
Sum squared resid	246.1962	Schwarz criterion	1.883132
Log likelihood	-94.92389	Durbin-Watson stat	2.865866

The last equation consists of two lagged variables and an intercept. The intercept is not statistically significant.

Alternate Equation #2
LS // Dependent Variable is PINESLAP
Date: 09/08/97 Time: 12:22
Sample(adjusted): 1958 1997
Included observations: 40 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	3.729185	2.688819	1.386923	0.1738
PINESLAP(-1)	0.410218	0.155995	2.629692	0.0124
PINESLAP(-2)	0.424292	0.156089	2.718272	0.0099

R-squared	0.561655	Mean dependent var	22.08975
Adjusted R-squared	0.537961	S.D. dependent var	3.204436
S.E. of regression	2.178166	Akaike info criterion	1.629005
Sum squared resid	175.5431	Schwarz criterion	1.755671
Log likelihood	-86.33764	F-statistic	23.70420
Durbin-Watson stat	1.862101	Prob(F-statistic)	0.000000

Louisiana Southern Pine Pulpwood Stumpage Price Series Chow Breakpoint Tests

The breakpoint tests using the first equation were inconclusive as no single year or combination of years proved to be statistically significant.

Chow Breakpoint Test: 1972			
F-statistic	0.811321	Probability	0.452228
Log likelihood ratio	1.763485	Probability	0.414061
Chow Breakpoint Test: 1973			
F-statistic	0.921970	Probability	0.406922
Log likelihood ratio	1.998076	Probability	0.368233
Chow Breakpoint Test: 1980			
F-statistic	0.822046	Probability	0.447613
Log likelihood ratio	1.786283	Probability	0.409368
Chow Breakpoint Test: 1986			
F-statistic	0.109603	Probability	0.896488
Log likelihood ratio	0.242823	Probability	0.885669
Chow Breakpoint Test: 1972 1980			
F-statistic	0.436318	Probability	0.781418
Log likelihood ratio	2.002301	Probability	0.735336
Chow Breakpoint Test: 1972 1980 1986			
F-statistic	0.797393	Probability	0.579044
Log likelihood ratio	5.573469	Probability	0.472622
Chow Breakpoint Test: 1973 1980 1986			
F-statistic	0.809970	Probability	0.569938
Log likelihood ratio	5.655444	Probability	0.462872
Chow Breakpoint Test: 1972 1980 1986 1992			
F-statistic	0.880032	Probability	0.544253
Log likelihood ratio	8.432316	Probability	0.392418
Chow Breakpoint Test: 1973 1980 1986 1992			
F-statistic	0.890235	Probability	0.536439
Log likelihood ratio	8.520370	Probability	0.384356

The second equation was then used to determine breakpoints. The test suggests breakpoints in 1972 (or 1973), 1980, 1986 and 1992. 1986 was selected for purposes of further analysis because 1992 would probably provide too few data points to work with.

Chow Breakpoint Test: 1972			
F-statistic	0.792587	Probability	0.460207
Log likelihood ratio	1.719958	Probability	0.423171
Chow Breakpoint Test: 1973			
F-statistic	1.250854	Probability	0.298084
Log likelihood ratio	2.682466	Probability	0.261523
Chow Breakpoint Test: 1980			
F-statistic	7.305049	Probability	0.002119
Log likelihood ratio	13.64478	Probability	0.001089
Chow Breakpoint Test: 1986			
F-statistic	8.516177	Probability	0.000907
Log likelihood ratio	15.52527	Probability	0.000425
Chow Breakpoint Test: 1972 1980			
F-statistic	3.548611	Probability	0.015645
Log likelihood ratio	13.95774	Probability	0.007431
Chow Breakpoint Test: 1973 1980			
F-statistic	3.574899	Probability	0.015137
Log likelihood ratio	14.04528	Probability	0.007152
Chow Breakpoint Test: 1972 1980 1986			
F-statistic	3.358006	Probability	0.010768
Log likelihood ratio	19.53952	Probability	0.003343
Chow Breakpoint Test: 1973 1980 1986			
F-statistic	3.379708	Probability	0.010413
Log likelihood ratio	19.63984	Probability	0.003209
Chow Breakpoint Test: 1972 1980 1986 1992			
F-statistic	3.105777	Probability	0.010787
Log likelihood ratio	24.13319	Probability	0.002177
Chow Breakpoint Test: 1973 1980 1986 1992			
F-statistic	3.124912	Probability	0.010430
Log likelihood ratio	24.24543	Probability	0.002084

Louisiana Southern Pine Pulpwood Stumpage Price Series—Stationarity of Series Since 1980

Table E40 presents the autocorrelation functions for the Louisiana southern pine pulpwood stumpage price series since 1980. The full autocorrelation function indicates stationarity for the full series as $\rho \rightarrow 0$ after $k=2$. The partial autocorrelation function also indicates stationarity as no value exceeds the limit. The full autocorrelation function indicates stationarity for the first differenced series as $\rho \rightarrow 0$ after $k=1$. The partial autocorrelation function also indicates stationarity only one value exceeds the limit. The full function indicates stationarity for the second differenced series as $\rho \rightarrow 0$ after $k=1$. The partial function has only one value that exceeds the limit.

Table E41 presents the results of the ADF unit root tests. As with the previous series, the level series is indicated as having a unit root. The first differenced series may have a unit root as the null hypothesis cannot be rejected at high levels of confidence. The second differenced series is indicated as not having a unit root.

Table E42 shows the results of the Phillips-Perron test. Here, the level series is indicated as having a unit root while the first and second differenced series do not.

Table E40—Autocorrelation functions for the Louisiana southern pine pulpwood stumpage price series since 1980

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.1780	0.1780	**-0.5120**	**-0.5120**	**-0.5120**	**-0.5120**
2	**0.1830**	0.1560	0.2560	-0.0080	0.2560	-0.0080
3	-0.1290	-0.1940	-0.0910	0.0500	-0.0910	0.0500
4	-0.2910	-0.2930	-0.1140	-0.1910	-0.1140	-0.1910
5	-0.1520	-0.0090	-0.1530	-0.4140	-0.1530	-0.4140
6	0.0290	0.1850	0.1210	-0.1390	0.1210	-0.1390
7	0.2210	0.1980	-0.0090	0.1300	-0.0090	0.1300
8	0.1290	-0.0940	0.0580	0.0770	0.0580	0.0770
9	0.0010	-0.2040	0.0840	-0.0130	0.0840	-0.0130
10	-0.1880	-0.1490	-0.0450	-0.0660	-0.0450	-0.0660
11	-0.2100	0.0450	0.0360	0.1030	0.0360	0.1030
12	-0.2840	-0.1270	-0.0960	0.0610	-0.0960	0.0610
13	-0.0700	-0.1000	-0.0140	-0.0700	-0.0140	-0.0700
14	0.0110	-0.0840	-0.0070	-0.0590	-0.0070	-0.0590
15	0.0220	-0.0920	-0.0180	-0.0240	-0.0180	-0.0240
n		17		17		17
limit		0.4851		0.4851		0.4851

Table E41—Results of ADF unit root tests on the Louisiana southern pine pulpwood stumpage price series since 1980

	R^2	ADF Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.44	-2.1111	-3.8877	-3.0521	-2.6672
first Difference with Constant	.76	**-3.2478**	-3.8877	-3.0521	-2.6672
second Difference with Constant	.97	**-11.8658**	-3.8877	-3.0521	-2.6672
Level with Constant and Trend	.45	-1.7093	-4.6193	-3.7119	-3.2964
first Difference with Constant and Trend	.78	**-3.4727**	-4.6193	-3.7119	-3.2964
second Difference with Constant and Trend	.98	**-11.5445**	-4.6193	-3.7119	-3.2964
Level with no Constant or Trend	.26	0.2553	-2.7158	-1.9627	-1.6262
first Difference with no Constant or Trend	.75	**-3.3071**	-2.7158	-1.9627	-1.6262
second Difference with no Constant or Trend	.97	**-12.2449**	-2.7158	-1.9627	-1.6262

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E42—Results of Phillips-Perron unit root test on the Louisiana southern pine pulpwood stumpage price series since 1980

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	-.00	0.0672	-2.7158	-1.9627	-1.6262
first Difference with Constant	.76	**-6.8261**	-3.8877	-3.0521	-2.6672
second Difference with Constant	.97	**-19.9831**	-3.8877	-3.0521	-2.6672

*MacKinnon critical values for rejection of hypothesis of a unit root

Louisiana Southern Pine Pulpwood Stumpage Price Series—Stationarity of Current Series.

Table E43 presents the autocorrelation functions for the Louisiana southern pine pulpwood stumpage price series since 1986. The full autocorrelation function indicates stationarity for the level series as $\rho \rightarrow 0$ after $k=1$. The partial autocorrelation function also indicates stationarity as no value exceeds the limit. The full autocorrelation function indicates stationarity for the first differenced series as $\rho \rightarrow 0$ after $k=2$. The partial autocorrelation function also indicates stationarity as no value exceeds the limit. The full function indicates stationarity for the second differenced series as $\rho \rightarrow 0$ after $k=1$. The partial function has only one value that exceeds the limit.

Table E44 presents the results of the ADF unit root tests. As with the previous series, the level series is indicated as having a unit root. The first differenced series may have a unit root as the null hypothesis cannot be rejected at high levels of confidence. The second differenced series is indicated as not having a unit root.

Table E45 shows the results of the Phillips-Perron test. Here, the level series is indicated as having a unit root while the first and second differenced series do not.

Table E43—Autocorrelation functions for the Louisiana southern pine pulpwood stumpage price series since 1986

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	**0.1620**	0.1620	-0.3850	-0.3850	**-0.6330**	**-0.6330**
2	-0.1190	-0.1490	**-0.0670**	-0.2530	0.1310	-0.4500
3	-0.2450	-0.2090	0.0600	-0.0870	0.1470	-0.0360
4	-0.4170	-0.3940	-0.2020	-0.2850	-0.1070	0.1490
5	-0.2300	-0.2500	-0.1370	-0.4760	-0.1650	-0.2640
6	0.1840	0.0670	0.3060	-0.1390	0.2630	-0.1820
7	0.1560	-0.1150	-0.0160	-0.0330	-0.1440	0.0030
8	0.0760	-0.1920	-0.0650	-0.1430	-0.0920	-0.1260
9	0.0540	-0.1120	0.1310	-0.0560	0.1940	-0.1100
10	-0.1770	-0.2230	-0.2430	-0.2610	-0.1780	-0.2440
n		12		12		12
limit		0.5774		0.5774		0.5774

Table E44—Results of ADF unit root tests on the Louisiana southern pine pulpwood stumpage price series since 1986

	R^2	ADF Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.47	-1.6759	-4.2207	-3.1801	-2.7349
first Difference with Constant	.77	-2.6300	-4.2207	-3.1801	-2.7349
second Difference with Constant	.98	**-9.4138**	-4.2207	-3.1801	-2.7349
Level with Constant and Trend	.47	-1.4164	-5.1152	-3.9271	-3.4104
first Difference with Constant and Trend	.79	-2.5687	-5.1152	-3.9271	-3.4104
second Difference with Constant and Trend	.98	**-8.8551**	-5.1152	-3.9271	-3.4104
Level with no Constant or Trend	.28	-0.1773	-2.8270	-1.9755	-1.6321
first Difference with no Constant or Trend	.78	**-2.7894**	-2.8270	-1.9755	-1.6321
second Difference with no Constant or Trend	.98	**-9.9575**	-2.8270	-1.9755	-1.6321

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E45—Results of Phillips-Perron unit root test on the Louisiana southern pine pulpwood stumpage price series since 1986

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	-.00	-0.1009	-2.8270	-1.9755	-1.6321
first Difference with Constant	.78	**-5.7439**	-4.2207	-3.1801	-2.7349
second Difference with Constant	.97	**-16.2697**	-4.2207	-3.1801	-2.7349

*MacKinnon critical values for rejection of hypothesis of a unit root

Louisiana Southern Pine Sawtimber Stumpage Price Series

Louisiana Southern Pine Sawtimber Stumpage Price Series—Stationarity of Full Series

Table E46 presents the results of the autocorrelation functions for the southern pine sawtimber series. The full autocorrelation function probably indicates stationarity for the level series: $\rho \rightarrow 0$ after k=9. The partial autocorrelation function also indicates stationarity as only one value exceeds the limit. The full autocorrelation function indicates stationarity for the first differenced series as $\rho \rightarrow 0$ after k=1. The partial autocorrelation function also indicates stationarity as only one value exceeds the limit. The full function indicates stationarity for the second differenced series as $\rho \rightarrow 0$ after k=1. The partial autocorrelation function also probably indicates stationarity as only three values exceed the limit.

Table E47 presents the results of the ADF unit root tests. The level series is indicated as having a unit root. Both the first and second differenced series are indicated as not having unit roots.

Table E48 shows the results of the Phillips-Perron test. Here, the level series is indicated as having a unit root while the first and second differenced series are not.

Table E46—Autocorrelation functions for the Louisiana southern pine sawtimber stumpage price series

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.6240	**0.6240**	**-0.4320**	**-0.4320**	**-0.6730**	**-0.6730**
2	0.5630	0.2850	0.0910	-0.1180	0.1940	**-0.4740**
3	0.4110	-0.0320	0.0300	0.0290	0.0410	-0.2020
4	0.2610	-0.1340	-0.1530	-0.1450	-0.1490	-0.2690
5	0.2390	0.0890	0.0910	-0.0470	0.1630	-0.1520
6	0.1810	0.0470	-0.1200	-0.1250	-0.1850	**-0.3300**
7	0.2090	0.1010	0.2010	0.1410	0.1960	-0.2030
8	0.1100	-0.1440	-0.0350	0.1180	-0.0980	-0.1020
9	**0.0320**	-0.1440	0.0070	0.0640	0.0650	0.1470
10	-0.0500	-0.0820	-0.1370	-0.1950	-0.0530	0.2010
11	-0.0420	0.1380	-0.0370	-0.1810	-0.0410	0.1100
12	-0.1580	-0.1760	-0.0130	-0.1290	0.0530	-0.0220
13	-0.1050	0.0340	-0.0160	-0.0410	-0.0090	0.0310
14	-0.0810	0.0590	-0.0130	-0.1400	-0.0050	0.0180
15	-0.0530	0.0950	-0.0090	-0.1650	0.0310	0.0500
16	-0.0170	-0.0030	-0.0590	-0.2400	-0.0600	-0.1310
17	0.0130	0.0680	0.0470	-0.0350	0.0660	-0.1570
18	-0.0040	-0.1070	-0.0140	0.0520	-0.0460	-0.1060
19	-0.0620	-0.0760	-0.0020	0.0340	-0.0070	-0.0310
20	-0.0820	-0.0510	0.0300	-0.0650	0.0180	-0.0540
21	-0.0980	0.0040	0.0210	-0.0160	0.0020	-0.0520
22	-0.1040	-0.0860	0.0010	0.0110	0.0040	-0.0720
23	-0.0810	0.0590	0.0020	0.0570	-0.0160	-0.0260
24	-0.0740	-0.0610	0.0350	-0.0020	0.0190	0.0290
25	-0.0790	0.0030	-0.0010	-0.0880	-0.0220	0.0320
26	-0.0800	0.0260	0.0260	-0.1140	0.0140	-0.0120
27	-0.0880	0.0510	0.0120	-0.0160	0.0030	0.0070
28	-0.1020	-0.0910	0.0100	0.0340	0.0010	0.0890
29	-0.1360	-0.0550	-0.0170	-0.0210	-0.0210	0.0850
30	-0.1470	-0.0670	0.0210	-0.0460	0.0220	0.0290
31	-0.1820	-0.0860	-0.0030	-0.0020	-0.0090	-0.0220
32	-0.1560	0.0050	-0.0080	0.0570	0.0000	-0.0290
33	-0.1610	-0.0140	-0.0080	0.0730	0.0020	-0.0130
34	-0.1590	-0.1040	-0.0140	0.0130	-0.0040	-0.0320
35	-0.1510	0.0090	-0.0050	-0.0430	0.0030	-0.1000
36	-0.1470	0.0630	-0.0100	-0.0170	0.0010	-0.1170
n		43		42		42
limit		0.3050		0.3086		0.3086

Table E47—Results of ADF unit root tests on the Louisiana southern pine sawtimber stumpage price series

	R^2	ADF Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.23	-1.3224	-3.5973	-2.9339	-2.6048
first Difference with Constant	.72	**-5.7814**	-3.6019	-2.9358	-2.6059
second Difference with Constant	.97	**-18.3114**	-3.6117	-2.9399	-2.6080
Level with Constant and Trend	.31	-2.3748	-4.1958	-3.5217	-3.1914
first Difference with Constant and Trend	.72	**-5.7648**	-4.2023	-3.5247	-3.1931
second Difference with Constant and Trend	.97	**-18.0387**	-4.2165	-3.5312	-3.1968
Level with no Constant or Trend	.18	0.3204	-2.6196	-1.9490	-1.6200
first Difference with no Constant or Trend	.71	**-5.7431**	-2.6211	-1.9492	-1.6201
second Difference with no Constant or Trend	.97	**-18.5660**	-2.6243	-1.9498	-1.6204

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E48—Results of Phillips-Perron unit root test on the Louisiana southern pine stumpage sold price series

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	-.01	0.2837	-2.6182	-1.9488	-1.6199
first Difference with Constant	.72	**-10.2717**	-3.5973	-2.9339	-2.6048
second Difference with Constant	.95	**-33.4317**	-3.6067	-2.9378	-2.6069

*MacKinnon critical values for rejection of hypothesis of a unit root

Louisiana Southern Pine Sawtimber Stumpage Price Series Equations

Below are the statistics for the equation used in calculating breakpoints for the series. The equation has two lagged price variables and no intercept. The adjusted-R^2 is not very high (47%), but model has the highest F-statistic than any other model in the group.

Equation used in Chow's breakpoint test
LS // Dependent Variable is PINESLAS
Date: 09/09/97 Time: 09:40
Sample(adjusted): 1957 1997
Included observations: 41 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
PINESLAS(-1)	0.566682	0.146865	3.858524	0.0004
PINESLAS(-2)	0.446154	0.149302	2.988257	0.0048
R-squared	0.470221	Mean dependent var		244.3020
Adjusted R-squared	0.456637	S.D. dependent var		86.03707
S.E. of regression	63.42064	Akaike info criterion		8.347129
Sum squared resid	156864.9	Schwarz criterion		8.430718
Log likelihood	-227.2926	F-statistic		34.61563
Durbin-Watson stat	2.079809	Prob(F-statistic)		0.000001

The next equation has a single lagged price variable and an intercept. The adjusted-R^2 is not as high as in the first equation.

Alternative Equation #1
LS // Dependent Variable is PINESLAS
Date: 09/09/97 Time: 09:39
Sample(adjusted): 1956 1997
Included observations: 42 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	77.29744	31.12560	2.483404	0.0173
PINESLAS(-1)	0.697981	0.124199	5.619864	0.0000
R-squared	0.441207	Mean dependent var		242.9969
Adjusted R-squared	0.427237	S.D. dependent var		85.40120
S.E. of regression	64.63256	Akaike info criterion		8.383884
Sum squared resid	167094.7	Schwarz criterion		8.466631
Log likelihood	-233.6570	F-statistic		31.58287
Durbin-Watson stat	2.386616	Prob(F-statistic)		0.000002

The next equation has two lagged price variables and an intercept. The adjusted-R^2 is higher than in the first equation, but the intercept may not be statistically significant.

Alternative Equation #2
LS // Dependent Variable is PINESLAS
Date: 09/09/97 Time: 09:39
Sample(adjusted): 1957 1997
Included observations: 41 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	49.29938	33.22776	1.483681	0.1461
PINESLAS(-1)	0.472155	0.158063	2.987139	0.0049
PINESLAS(-2)	0.350408	0.160591	2.181985	0.0354
R-squared	0.499230	Mean dependent var		244.3020
Adjusted R-squared	0.472874	S.D. dependent var		86.03707
S.E. of regression	62.46587	Akaike info criterion		8.339596
Sum squared resid	148275.4	Schwarz criterion		8.464980
Log likelihood	-226.1382	F-statistic		18.94160
Durbin-Watson stat	1.993102	Prob(F-statistic)		0.000002

The last equation has a single lagged price variable and no intercept. The adjusted-R^2 is lower than in the first equation.

Alternative Equation #3
LS // Dependent Variable is PINESLAS
Date: 09/09/97 Time: 09:40
Sample(adjusted): 1956 1997
Included observations: 42 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
PINESLAS(-1)	0.990156	0.042228	23.44777	0.0000
R-squared	0.355051	Mean dependent var		242.9969
Adjusted R-squared	0.355051	S.D. dependent var		85.40120
S.E. of regression	68.58460	Akaike info criterion		8.479658
Sum squared resid	192857.8	Schwarz criterion		8.521031
Log likelihood	-236.6682	Durbin-Watson stat		2.795638

Louisiana Southern Pine Sawtimber Stumpage Price Series Chow Breakpoint Tests

There do not appear to be any single statistically significant breakpoints. 1985 has the highest F-statistic of any of the single points tested, but is not significant at the .05 level. However, several combinations of multiple points are significant. For further analysis, 1987 is chosen as the beginning of the current trend. This leaves only eleven data points, which was considered too few points in the analysis of all the previous series, but it appears to be the only statistically viable alternative here.

Chow Breakpoint Test: 1964

F-statistic	0.122539	Probability	0.885029
Log likelihood ratio	0.270677	Probability	0.873420

Chow Breakpoint Test: 1979

F-statistic	0.779957	Probability	0.465817
Log likelihood ratio	1.693108	Probability	0.428890

Chow Breakpoint Test: 1985

F-statistic	2.004757	Probability	0.149062
Log likelihood ratio	4.218334	Probability	0.121339

Chow Breakpoint Test: 1987

F-statistic	0.087139	Probability	0.916738
Log likelihood ratio	0.192665	Probability	0.908162

Chow Breakpoint Test: 1964 1979 1985

F-statistic	0.915118	Probability	0.496444
Log likelihood ratio	6.310282	Probability	0.389345

Chow Breakpoint Test: 1964 1979 1987

F-statistic	0.345966	Probability	0.907149
Log likelihood ratio	2.501153	Probability	0.868339

Chow Breakpoint Test: 1964 1979 1985 1987

F-statistic	4.503050	Probability	0.001045
Log likelihood ratio	31.61385	Probability	0.000109

Chow Breakpoint Test: 1964 1970 1975 1979 1985 1987

F-statistic	2.661657	Probability	0.016909
Log likelihood ratio	32.00792	Probability	0.001380

Chow Breakpoint Test: 1964 1970 1975 1979 1982 1985 1987

F-statistic	2.168429	Probability	0.044287
Log likelihood ratio	32.59277	Probability	0.003297

Louisiana Southern Pine Sawtimber Stumpage Price Series—Stationarity of Current Series

Table E49 presents the autocorrelation functions for the Louisiana southern pine sawtimber stumpage price series since 1987. The full autocorrelation function indicates stationarity for the level series as $\rho \rightarrow 0$ after k=3. The partial autocorrelation function also indicates stationarity as only one value exceeds the limit. The full autocorrelation function indicates stationarity for the first differenced series as $\rho \rightarrow 0$ after k=4. The partial autocorrelation function also indicates stationarity as no value exceeds the limit. The full function indicates stationarity for the second differenced series as $\rho \rightarrow 0$ after k=3. The partial function has no value that exceeds the limit.

Table E50 presents the results of the ADF unit root tests. The level series is probably indicated as having a unit root. Only the test with constant and trend suggests there may not be a unit root. The first differenced series and second differenced series are indicated as not having unit roots.

Table E51 shows the results of the Phillips-Perron test. Here, the level series is indicated as having a unit root while the first and second differenced series do not.

Table E49—Autocorrelation functions for the Louisiana southern pine sawtimber stumpage price series since 1987

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.6870	**0.6870**	0.0010	0.0010	-0.3860	-0.3860
2	0.5220	0.0940	0.0420	0.0420	-0.0100	-0.1860
3	**0.2050**	-0.3530	0.0410	0.0410	**-0.0010**	-0.0940
4	-0.0770	-0.2910	**0.0300**	0.0290	0.0170	-0.0270
5	-0.2790	-0.0820	-0.0480	-0.0520	-0.0140	-0.0210
6	-0.3930	-0.0100	-0.1380	-0.1430	-0.0260	-0.0460
7	-0.4090	-0.0150	-0.1870	-0.1920	-0.0400	-0.0890
8	-0.3520	-0.0310	-0.1390	-0.1400	-0.0490	-0.1370
9	-0.2360	-0.0040	0.1440	0.1770	0.2030	0.1400
n		11		11		11
limit		0.6030		0.6030		0.6030

Table E50—Results of ADF unit root tests on the Louisiana southern pine sawtimber stumpage price series since 1987

	R^2	ADF Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.45	-0.6928	-4.2207	-3.1801	-2.7349
first Difference with Constant	.88	**-4.3179**	-4.2207	-3.1801	-2.7349
second Difference with Constant	.99	**-14.3447**	-4.2207	-3.1801	-2.7349
Level with Constant and Trend	.93	**-4.7627**	-5.1152	-3.9271	-3.4104
first Difference with Constant and Trend	.96	**-7.0831**	-5.1152	-3.9271	-3.4104
second Difference with Constant and Trend	.99	**-14.3289**	-5.1152	-3.9271	-3.4104
Level with no Constant or Trend	.41	0.0538	-2.8270	-1.955	-1.6321
first Difference with no Constant or Trend	.88	**-4.5857**	-2.8270	-1.955	-1.6321
second Difference with no Constant or Trend	.99	**-15.0476**	-2.8270	-1.955	-1.6321

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E51—Results of Phillips-Perron unit root test on the Louisiana southern pine sawtimber stumpage price series since 1987

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.04	-0.6376	-2.8270	-1.9755	-1.6321
first Difference with Constant	.87	**-6.5870**	-4.2207	-3.1801	-2.7349
second Difference with Constant	.98	**-19.6647**	-4.2207	-3.1801	-2.7349

*MacKinnon critical values for rejection of hypothesis of a unit root

New York Hard Maple Sawtimber Stumpage Price Series

New York Hard Maple Sawtimber Stumpage Price Series—Stationarity of Full Series

Table E52 shows the results of the autocorrelation functions for the Hard Maple Sawtimber series. The full autocorrelation function probably indicates stationarity for the level series: $\rho \rightarrow 0$ after k=5. The partial autocorrelation function also indicates stationarity as only one value exceeds the limit. The full autocorrelation function probably indicates stationarity for the first differenced series as $\rho \rightarrow 0$ after k=5. The partial autocorrelation function also indicates stationarity as no value exceeds the limit. The full function probably indicates stationarity for the second differenced series as $\rho \rightarrow 0$ after k=4. The partial autocorrelation function also indicates stationarity as only one value exceeds the limit.

Table E53 presents the results of the ADF unit root tests. The level series is indicated as having a unit root. The first differenced series probably also has a unit root, as the test statistic is lower than the critical value in most cases. The second differenced series is indicated as not having a unit root.

Table E54 shows the results of the Phillips-Perron test. Here, the level series is indicated as having a unit root while the first and second differenced series are not.

Table E52—Autocorrelation functions for the New York Hard Maple Sawtimber stumpage price series

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.7400	**0.7400**	0.1080	0.1080	-0.3730	**-0.3730**
2	0.5810	0.0750	0.1020	0.0920	-0.0880	-0.2640
3	0.4010	-0.1150	0.1620	0.1450	-0.0620	-0.2520
4	0.2060	-0.1720	0.1920	0.1610	**-0.0720**	-0.3100
5	**0.0330**	-0.1230	**0.2820**	0.2450	0.2900	0.0920
6	-0.0640	0.0220	-0.0210	-0.1060	-0.1520	-0.0380
7	-0.1250	0.0150	0.0150	-0.0690	0.0220	0.0270
8	-0.1880	-0.0910	-0.0130	-0.1200	0.0370	0.1230
9	-0.2230	-0.0750	-0.0700	-0.1560	-0.1100	-0.0070
10	-0.2470	-0.0690	0.0820	0.0640	0.1860	0.1390
11	-0.2670	-0.0600	-0.0620	0.0110	-0.1050	0.0750
12	-0.2750	-0.0460	-0.0730	-0.0090	0.0300	0.0720
13	-0.2830	-0.0810	-0.0840	-0.0250	-0.0380	-0.0150
14	-0.2800	-0.0670	-0.1590	-0.1380	-0.0430	-0.0380
15	-0.2300	0.0370	-0.0140	-0.0330	0.0230	-0.1630
16	-0.1940	-0.0390	-0.0010	0.0830	0.0560	-0.0280
17	-0.1760	-0.1010	-0.0680	0.0160	0.0390	0.0260
18	-0.1680	-0.1170	-0.0990	-0.0180	-0.0970	-0.0710
19	-0.1820	-0.1340	-0.1530	-0.0940	-0.0350	-0.0590
20	-0.1470	0.0450	-0.0290	-0.0780	0.0600	0.0080
21	-0.1240	-0.0170	0.0380	0.0450	0.1150	0.1630
22	-0.1150	-0.1180	-0.2120	-0.1880	-0.1970	-0.1230
23	-0.0490	0.0210	-0.0080	0.0860	0.0670	0.0440
24	-0.0600	-0.1840	-0.1640	-0.0910	0.0170	0.0430
25	-0.0110	0.0350	-0.0580	-0.0320	-0.0240	-0.0350
26	-0.0050	-0.0860	0.0010	0.0180	0.0130	-0.1030
27	0.0550	0.0400	-0.0390	0.0660	0.0170	0.0660
28	0.0940	-0.0030	-0.0270	-0.0440	0.0110	0.0050
29	0.0970	-0.1150	-0.1060	-0.0120	-0.0510	-0.0570
30	0.1180	-0.0320	-0.0800	-0.1180	-0.0530	-0.0640
31	0.1280	-0.0290	-0.0290	-0.1190	-0.0120	-0.1980
32	0.1530	0.0290	0.0070	0.0460	0.0360	-0.1210
33	0.1830	0.0520	0.0070	0.0070	0.0580	-0.0800
34	0.1770	-0.0600	-0.0630	0.0340	-0.0860	0.1150
35	0.1680	-0.0400	-0.0410	0.0190	0.0760	0.0890
36	0.1420	-0.0480	0.0620	0.0020	-0.0370	-0.0590
n		42		38		35
Limit		0.3086		0.3244		0.3381

Table E53—Results of ADF unit root tests on the New York hard maple sawtimber stumpage price series

	R^2	ADF Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.02	0.1611	-3.6289	-2.9472	-2.6118
first Difference with Constant	.33	-2.5495	-3.6496	-2.9558	-2.6164
second Difference with Constant	.92	**-10.4549**	-3.6959	-2.9750	-2.6265
Level with Constant and Trend	.13	0.57426	-4.2412	-3.5426	-3.2032
first Difference with Constant and Trend	.40	-3.1166	-4.2712	-3.5562	-3.2109
second Difference with Constant and Trend	.92	**-10.2730**	-4.3382	-3.5867	-3.2279
Level with no Constant or Trend	.02	0.9401	-2.63000	-1.9507	-1.6208
first Difference with no Constant or Trend	.32	**-2.4906**	-2.6369	-1.9517	1.6213
second Difference with no Constant or Trend	.92	**-10.5686**	-2.6522	-1.9540	-1.6223

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E54—Results of Phillips-Perron unit root test on the New York hard maple sawtimber stumpage price series

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.00	0.8281	-2.6243	-1.9498	-1.6204
first Difference with Constant	.36	**-4.3978**	-3.6289	-2.9472	-2.6118
second Difference with Constant	.89	**-16.5958**	-3.6752	-2.9665	-2.6220

*MacKinnon critical values for rejection of hypothesis of a unit root

New York Hard Maple Sawtimber Stumpage Price Series Equations

Below are the statistics for the equation used in calculating breakpoints for the series. The equation has two lagged price variables and no intercept. The adjusted-R^2 is reasonably high (77%), but the second lagged variable is not statistically significant. However, the F-statistic is stronger for the model as a whole than in the next equation.

Equation used in Chow's breakpoint test
LS // Dependent Variable is MAPLEHNYS
Date: 09/09/97 Time: 17:18
Sample(adjusted): 1955 1997
Included observations: 35
Excluded observations: 8 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
MAPLEHNYS(-1)	1.155333	0.198432	5.822323	0.0000
MAPLEHNYS(-2)	-0.133241	0.201437	-0.661452	0.5129
R-squared	0.787966	Mean dependent var		188.1683
Adjusted R-squared	0.781541	S.D. dependent var		55.40791
S.E. of regression	25.89746	Akaike info criterion		6.563735
Sum squared resid	22132.38	Schwarz criterion		6.652612
Log likelihood	-162.5282	F-statistic		122.6354
Durbin-Watson stat	1.760301	Prob(F-statistic)		0.000000

The next equation is similar to the first, but adds an intercept term. The adjusted-R^2 is slightly lower than the first equation, the intercept and the second lagged variable are not statistically significant and the F-statistic is lower for the model as a whole than in the first equation.

Alternative Equation #1
LS // Dependent Variable is MAPLEHNYS
Date: 09/09/97 Time: 17:16
Sample(adjusted): 1955 1997
Included observations: 35
Excluded observations: 8 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.077439	19.16620	0.056216	0.9555
MAPLEHNYS(-1)	1.153732	0.203502	5.669387	0.0000
MAPLEHNYS(-2)	-0.137236	0.216544	-0.633757	0.5307
R-squared	0.787987	Mean dependent var		188.1683
Adjusted R-squared	0.774736	S.D. dependent var		55.40791
S.E. of regression	26.29769	Akaike info criterion		6.620779
Sum squared resid	22130.20	Schwarz criterion		6.754094
Log likelihood	-162.5265	F-statistic		59.46702
Durbin-Watson stat	1.758910	Prob(F-statistic)		0.000000

The next equation consists of an intercept and a single lagged variable. The adjusted-R^2 is slightly lower than the first equation, the intercept is not statistically significant and the F-statistic is lower for the model as a whole than in the first equation.

Alternative Equation #2
LS // Dependent Variable is MAPLEHNYS
Date: 09/09/97 Time: 17:20
Sample(adjusted): 1954 1997
Included observations: 38
Excluded observations: 6 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-1.849503	17.25405	-0.107192	0.9152
MAPLEHNYS(-1)	1.032428	0.090753	11.37622	0.0000
R-squared	0.782370	Mean dependent var		188.7255
Adjusted R-squared	0.776325	S.D. dependent var		53.85327
S.E. of regression	25.46954	Akaike info criterion		6.526163
Sum squared resid	23353.11	Schwarz criterion		6.612351
Log likelihood	-175.9168	F-statistic		129.4184
Durbin-Watson stat	1.604826	Prob(F-statistic)		0.000000

The next equation consists of a single lagged variable. The adjusted-R^2 is slightly higher than the first equation, and might arguably be a better equation than the first.

Alternative Equation #3

LS // Dependent Variable is MAPLEHNYS
Date: 09/09/97 Time: 17:16
Sample(adjusted): 1954 1997
Included observations: 38
Excluded observations: 6 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
MAPLEHNYS(-1)	1.022983	0.021440	47.71431	0.0000
R-squared	0.782301	Mean dependent var		188.7255
Adjusted R-squared	0.782301	S.D. dependent var		53.85327
S.E. of regression	25.12701	Akaike info criterion		6.473850
Sum squared resid	23360.57	Schwarz criterion		6.516944
Log likelihood	-175.9228	Durbin-Watson stat		1.591759

New York Hard Maple Sawtimber Stumpage Price Series Chow Breakpoint Tests

Chow Breakpoint Test: 1961			
F-statistic	0.154391	Probability	0.857592
Log likelihood ratio	0.346900	Probability	0.840759
Chow Breakpoint Test: 1979			
F-statistic	4.175997	Probability	0.024781
Log likelihood ratio	8.349581	Probability	0.015378
Chow Breakpoint Test: 1974			
F-statistic	0.555757	Probability	0.579248
Log likelihood ratio	1.232960	Probability	0.539841
Chow Breakpoint Test: 1991			
F-statistic	7.923021	Probability	0.001662
Log likelihood ratio	14.45078	Probability	0.000728
Chow Breakpoint Test: 1961 1974 1991			
F-statistic	2.853152	Probability	0.027711
Log likelihood ratio	17.18681	Probability	0.008621
Chow Breakpoint Test: 1961 1979 1991			
F-statistic	2.733191	Probability	0.033120
Log likelihood ratio	16.61110	Probability	0.010824
Chow Breakpoint Test: 1961 1974 1979 1991			
F-statistic	2.042390	Probability	0.082444
Log likelihood ratio	17.60267	Probability	0.024411

New York Hard Maple Sawtimber Stumpage Price Series—Stationarity of Current Series

Table E55 presents the autocorrelation functions for the New York hard maple sawtimber stumpage price series since 1991. The full autocorrelation function indicates stationarity for the level series as $\rho \to 0$ after k=2. The partial autocorrelation function also indicates stationarity as no value exceeds the limit. The full autocorrelation function indicates stationarity for the first differenced series as $\rho \to 0$ after k=3. The partial autocorrelation function also indicates stationarity as no value exceeds the limit. The full function indicates stationarity for the second differenced series as $\rho \to 0$ after k=1. The partial function has no value that exceeds the limit.

Table E56 presents the results of the ADF unit root tests. The level and first differenced series are indicated as probably having unit roots. Only the test with constant and trend suggests there may not be a unit root. The second differenced series is indicated as not having a unit root.

Table E57 shows the results of the Phillips-Perron test. Here all three series are indicated as having unit roots.

Table E55—Autocorrelation functions for the New York hard maple sawtimber stumpage price series since 1991

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.4650	0.4650	-0.0350	-0.0350	0.0580	0.0580
2	0.0760	-0.1790	-0.6710	-0.6730	-0.6190	-0.6240
3	-0.0950	-0.0700	-0.1260	-0.3460	-0.2650	-0.2800
4	-0.2250	-0.1740	0.4610	-0.1100	0.3340	-0.0740
5	-0.3830	-0.2750	0.0780	-0.2620	0.0960	-0.3810
n		7		7		7
limit		0.7559		0.7559		0.7559

Table E56—Results of ADF unit root tests on the New York hard maple sawtimber stumpage price series since 1991

	R^2	ADF Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.01	-0.5497	-4.8875	-3.4239	-2.8640
first Difference with Constant	.61	-2.5034	-4.8875	-3.4239	-2.8640
second Difference with Constant	.70	-3.0415	-4.8875	-3.4239	-2.8640
Level with Constant and Trend	.92	-5.5633	-6.1252	-4.3535	-3.6280
first Difference with Constant and Trend	.84	-3.7817	-6.1252	-4.3535	-3.6280
second Difference with Constant and Trend	.70	-2.3910	-6.1252	-4.3535	-3.6280
Level with no Constant or Trend	-.07	1.3719	-3.0507	-1.9962	-1.6415
first Difference with no Constant or Trend	.13	-1.0304	-3.0507	-1.9962	-1.6415
second Difference with no Constant or Trend	.67	-3.2637	-3.0507	-1.9962	-1.6415

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E57—Results of Phillips-Perron unit root test on the New York hard maple sawtimber stumpage price series since 1991

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.00	0.4734	-4.8875	-3.4239	-2.8640
first Difference with Constant	.37	-1.3289	-4.8875	-3.4239	-2.8640
second Difference with Constant	.34	-1.2651	-4.8875	-3.4239	-2.8640

*MacKinnon critical values for rejection of hypothesis of a unit root

New York White Pine Sawtimber Stumpage Price Series

New York White Pine Sawtimber Stumpage Price Series—Stationarity of Full Series

Table E58 shows the results of the autocorrelation functions for the white pine sawtimber series. The full autocorrelation function probably indicates stationarity for the level series as $\rho \rightarrow 0$ after k=15. The partial autocorrelation function also indicates stationarity as only two values exceed the limit. The full autocorrelation function indicates stationarity for the first differenced series as $\rho \rightarrow 0$ after k=4. The partial autocorrelation function also indicates stationarity as no value exceeds the limit. The full function probably indicates stationarity for the second differenced series as $\rho \rightarrow 0$ after k=2. The partial autocorrelation function also indicates stationarity as only one value exceeds the limit.

Table E59 presents the results of the ADF unit root tests. The level series has a unit root, as the test statistic is lower than the critical value in most cases. The first and second differenced series is indicated as not having a unit root.

Table E60 shows the results of the Phillips-Perron test. Here, the level series is indicated as having a unit root while the first and second differenced series are not.

Table E58—Autocorrelation functions for the New York white pine sawtimber stumpage price series

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.6840	**0.6840**	-0.1190	-0.1190	-0.4480	**-0.4480**
2	0.6850	**0.4080**	-0.1180	-0.1350	**-0.0170**	-0.2730
3	0.5950	0.0890	-0.0150	-0.0490	0.0990	-0.0440
4	0.4830	-0.1180	**-0.1970**	-0.2300	-0.2490	-0.2930
5	0.5440	0.2390	0.3610	0.3180	0.2970	0.0780
6	0.4420	-0.0130	-0.0700	-0.0670	-0.1640	-0.0540
7	0.4080	-0.0860	-0.0670	0.0090	0.0300	0.0080
8	0.3320	-0.1140	-0.1270	-0.2100	-0.0720	-0.1910
9	0.2180	-0.1240	-0.1530	-0.0660	-0.0610	-0.1520
10	0.1740	-0.0800	0.1990	-0.0070	0.2840	0.1420
11	0.1000	-0.0460	-0.1900	-0.2200	-0.1680	0.0760
12	0.0140	-0.1430	-0.0800	-0.1590	-0.0170	-0.0590
13	0.0810	0.2230	0.0300	0.0020	0.0900	0.0750
14	0.0070	0.0510	-0.1080	-0.0740	-0.1260	0.0170
15	**0.0090**	-0.0100	0.1820	0.0110	0.1630	0.0600
16	-0.0120	-0.0030	-0.0570	-0.0300	-0.0680	0.0280
17	-0.0720	0.0320	-0.0160	0.0300	-0.0850	-0.0430
18	-0.0060	0.0980	0.0840	0.0280	0.0370	-0.0470
19	-0.0580	-0.0660	-0.0070	0.0320	-0.0130	0.0110
20	-0.0580	-0.1390	0.0710	-0.0910	-0.0320	-0.1990
21	-0.0840	-0.1150	0.1330	0.2420	0.1010	0.0420
22	-0.1770	-0.1820	-0.0290	-0.0390	-0.0630	0.0230
23	-0.1760	-0.1320	-0.0380	-0.0410	-0.0660	-0.1330
24	-0.1820	0.0420	0.0100	0.0060	0.0410	-0.1330
25	-0.2090	0.0360	-0.0410	-0.0140	0.0190	-0.0340
26	-0.2440	-0.1500	-0.0630	-0.1780	-0.1020	-0.2590
27	-0.2850	-0.0160	0.0740	0.1280	0.0890	-0.0510
28	-0.3210	0.0440	0.0180	0.0270	0.0180	0.0010
29	-0.3690	-0.0660	-0.0420	0.0970	-0.0140	0.0700
30	-0.3640	0.0600	-0.0560	-0.0430	-0.0170	-0.0170
31	-0.3720	-0.0120	-0.0420	0.0290	0.0090	-0.0290
32	-0.3440	0.0590	-0.0190	-0.0400	-0.0040	-0.0420
33	-0.3100	0.0610	-0.0360	-0.0460	-0.0470	0.0230
34	-0.2790	0.0190	0.0190	-0.1660		
35	-0.2530	0.0390	-0.0570	0.0030		
36	-0.2560	-0.0200	0.0250	-0.0280		
n		42		38		35
limit		0.3086		0.3244		0.3381

Table E59—Results of ADF unit root tests on the New York white pine sawtimber stumpage price series

	R^2	ADF Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.22	**-2.8830**	-3.6289	-2.9472	-2.6118
first Difference with Constant	.68	**-6.1839**	-3.6496	-2.9558	-2.6164
second Difference with Constant	.94	**-12.4859**	-3.6959	-2.9750	-2.6265
Level with Constant and Trend	.33	**-3.4141**	-4.2412	-3.5426	-3.2032
first Difference with Constant and Trend	.71	**-6.5573**	-4.2712	-3.5562	-3.2109
second Difference with Constant and Trend	.94	**-12.0334**	-4.3382	-3.5867	-3.2279
Level with no Constant or Trend	.02	-1.5673	-2.6300	-1.9507	-1.6208
first Difference with no Constant or Trend	.66	**-5.9309**	-2.6369	-1.9517	1.6213
second Difference with no Constant or Trend	.94	**-12.8062**	-2.6522	-1.9540	-1.6223

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E60—Results of Phillips-Perron unit root test on the New York white pine sawtimber stumpage price series

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.02	-1.0649	-2.6243	-1.9498	-1.6204
first Difference with Constant	.58	**-6.8672**	-3.6289	-2.9472	-2.6118
second Difference with Constant	.92	**-21.8440**	-3.6752	-2.9665	-2.6220

*MacKinnon critical values for rejection of hypothesis of a unit root

New York White Pine Sawtimber Stumpage Price Series Equations

Below are the statistics for the equation used in calculating breakpoints for the series. The equation has one lagged price variable and an intercept. The adjusted-R^2 is reasonably high (77%) and the F-statistic is the strongest of any in the group.

Equation used in Chow's breakpoint test
LS // Dependent Variable is PINEWNYS
Date: 09/12/97 Time: 08:33
Sample(adjusted): 1954 1997
Included observations: 38
Excluded observations: 6 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	14.00674	6.401623	2.187998	0.0352
PINEWNYS(-1)	0.825628	0.074496	11.08290	0.0000
R-squared	0.773344	Mean dependent var		83.66237
Adjusted R-squared	0.767048	S.D. dependent var		15.53791
S.E. of regression	7.499394	Akaike info criterion		4.080840
Sum squared resid	2024.673	Schwarz criterion		4.167029
Log likelihood	-129.4556	F-statistic		122.8307
Durbin-Watson stat	2.064562	Prob(F-statistic)		0.000000

The next equation is similar to the first, but omits the intercept term. The adjusted-R^2 is slightly lower than the first equation.

Alternative Equation #1
LS // Dependent Variable is PINEWNYS
Date: 09/12/97 Time: 08:33
Sample(adjusted): 1954 1997
Included observations: 38
Excluded observations: 6 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
PINEWNYS(-1)	0.985654	0.014864	66.31130	0.0000
R-squared	0.743203	Mean dependent var		83.66237
Adjusted R-squared	0.743203	S.D. dependent var		15.53791
S.E. of regression	7.873865	Akaike info criterion		4.153061
Sum squared resid	2293.917	Schwarz criterion		4.196156
Log likelihood	-131.8278	Durbin-Watson stat		2.149392

The next equation consists of an intercept and two lagged variables. The adjusted-R^2 is slightly lower than the first equation, the second lagged variable is not statistically significant and the F-statistic is lower for the model as a whole than in the first equation.

Alternative Equation #2
LS // Dependent Variable is PINEWNYS
Date: 09/12/97 Time: 08:33
Sample(adjusted): 1955 1997
Included observations: 35
Excluded observations: 8 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	17.60806	6.712061	2.623346	0.0132
PINEWNYS(-1)	0.672657	0.165280	4.069798	0.0003
PINEWNYS(-2)	0.098249	0.150715	0.651884	0.5191
R-squared	0.746262	Mean dependent var		81.69086
Adjusted R-squared	0.730404	S.D. dependent var		13.46541
S.E. of regression	6.991600	Akaike info criterion		3.971235
Sum squared resid	1564.239	Schwarz criterion		4.104551
Log likelihood	-116.1595	F-statistic		47.05721
Durbin-Watson stat	1.787524	Prob(F-statistic)		0.000000

The next equation consists of two lagged variables. The adjusted-R^2 is the lowest of the four equations and the second lagged variable is not statistically significant.

Alternative Equation #3
LS // Dependent Variable is PINEWNYS
Date: 09/12/97 Time: 08:33
Sample(adjusted): 1955 1997
Included observations: 35
Excluded observations: 8 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
PINEWNYS(-1)	0.843182	0.164949	5.111777	0.0000
PINEWNYS(-2)	0.132900	0.162967	0.815504	0.4206
R-squared	0.691693	Mean dependent var		81.69086
Adjusted R-squared	0.682350	S.D. dependent var		13.46541
S.E. of regression	7.589158	Akaike info criterion		4.108887
Sum squared resid	1900.646	Schwarz criterion		4.197764
Log likelihood	-119.5684	F-statistic		74.03621
Durbin-Watson stat	1.806782	Prob(F-statistic)		0.000000

New York White Pine Sawtimber Stumpage Price Series Chow Breakpoint Tests

While no individual year is statistically significant as a breakpoint, the combinations of 1970 and 1979, and 1970, 1979 and 1987 are statistically significant. Visual inspection of Figure 17 suggests the trend since 1979 would be negative, while the trend since 1987 would be flat. 1987 is used in further analysis.

Chow Breakpoint Test: 1960			
F-statistic	1.869139	Probability	0.169764
Log likelihood ratio	3.963947	Probability	0.137797
Chow Breakpoint Test: 1970			
F-statistic	1.676303	Probability	0.202156
Log likelihood ratio	3.573603	Probability	0.167495
Chow Breakpoint Test: 1979			
F-statistic	1.633574	Probability	0.210183
Log likelihood ratio	3.486564	Probability	0.174945
Chow Breakpoint Test: 1987			
F-statistic	0.218771	Probability	0.804628
Log likelihood ratio	0.485899	Probability	0.784311
Chow Breakpoint Test: 1992			
F-statistic	0.051879	Probability	0.949519
Log likelihood ratio	0.115787	Probability	0.943750
Chow Breakpoint Test: 1970 1979			
F-statistic	3.716039	Probability	0.013567
Log likelihood ratio	14.49766	Probability	0.005865
Chow Breakpoint Test: 1970 1979 1987			
F-statistic	2.428805	Probability	0.049355
Log likelihood ratio	15.04523	Probability	0.019908
Chow Breakpoint Test: 1970 1979 1987 1992			
F-statistic	1.907411	Probability	0.098719
Log likelihood ratio	16.53028	Probability	0.035389

New York White Pine Sawtimber Stumpage Price Series—Stationarity of Current Trend

Table E61 presents the autocorrelation functions for the New York white pine sawtimber stumpage price series since 1987. The full autocorrelation function indicates stationarity for the level series as $\rho \rightarrow 0$ after k=2. The partial autocorrelation function also indicates stationarity as no value exceeds the limit. The full autocorrelation function indicates stationarity for the first differenced series as $\rho \rightarrow 0$ after k=4. The partial autocorrelation function also indicates stationarity as no value exceeds the limit. The full function indicates stationarity for the second differenced as $\rho \rightarrow 0$ after k=4. The partial function has no value that exceeds the limit.

Table E62 presents the results of the ADF unit root tests. The level series is indicated as having a unit root. The first differenced series is indicated as probably having a unit root. Only the test with no constant or trend suggests there may not be a unit root. The second differenced series is indicated as not having a unit root.

Table E63 shows the results of the Phillips-Perron test. Here, the level series is indicated as having a unit root, the first differenced series probably has a unit root, and second differenced series does not.

Table E61—Autocorrelation functions for the New York white pine sawtimber stumpage price series since 1987

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.4490	0.4490	-0.0190	-0.0190	-0.3260	-0.3260
2	0.1150	-0.1090	-0.1490	-0.1490	-0.1250	-0.2590
3	-0.2620	-0.3420	-0.3140	-0.3280	-0.1570	-0.3510
4	-0.3710	-0.1490	-0.2020	-0.2900	-0.0790	-0.4410
5	-0.2670	0.0020	0.0670	-0.1080	0.1510	-0.3510
6	-0.1120	-0.0470	0.1180	-0.1030	0.0650	-0.3740
7	-0.0040	-0.0990	0.1450	-0.0260	0.2270	0.0120
8	-0.0270	-0.1650	-0.2550	-0.3740	-0.3860	-0.3690
9	0.0820	0.1160	0.1210	0.0740	0.1040	-0.1870
n		11		11		11
limit		0.6030		0.6030		0.6030

Table E62—Results of ADF unit root tests on the New York white pine sawtimber stumpage price series since 1987

	R^2	ADF Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.24	-1.5941	-4.2207	-3.1801	-2.7349
first Difference with Constant	.54	-2.6921	-4.2207	-3.1801	-2.7349
second Difference with Constant	.91	**-6.2520**	-4.2207	-3.1801	-2.7349
Level with Constant and Trend	.35	-1.8883	-5.1152	-3.9271	-3.4104
first Difference with Constant and Trend	.56	-2.6556	-5.1152	-3.9271	-3.4104
second Difference with Constant and Trend	.91	**-5.8144**	-5.1152	-3.9271	-3.4104
Level with no Constant or Trend	-.01	0.5287	-2.8270	-1.9755	-1.6321
first Difference with no Constant or Trend	.51	**-2.6953**	-2.8270	-1.9755	-1.6321
second Difference with no Constant or Trend	-91	**-6.5774**	-2.8270	-1.9755	-1.6321

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E63—Results of Phillips-Perron unit root test on the New York white pine sawtimber stumpage price series since 1987

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	-.01	0.6165	-2.8270	-1.9755	-1.6321
first Difference with Constant	.50	**-3.0059**	-4.2207	-3.1801	-2.7349
second Difference with Constant	.84	**-7.4120**	-4.2207	-3.1801	-2.7349

*MacKinnon critical values for rejection of hypothesis of a unit root

New York Red Spruce Sawtimber Stumpage Price Series

New York Red Spruce Sawtimber Stumpage Price Series—Stationarity of Full Series

Table E64 shows the results of the autocorrelation functions for the red spruce sawtimber series. The full autocorrelation function for the level series probably indicates stationarity as $\rho \rightarrow 0$ after k=13. The partial autocorrelation function also indicates stationarity as only two values exceed the limit. The full autocorrelation function indicates stationarity for the first differenced series as $\rho \rightarrow 0$ after k=1. The partial autocorrelation function also indicates stationarity as only two values exceed the limit. The full function probably indicates stationarity for the second differenced series as $\rho \rightarrow 0$ after k=1. The partial autocorrelation function also indicates stationarity as three values exceed the limit.

Table E65 presents the results of the ADF unit root tests. The level series is indicated as having a unit root. The first and second differenced series are indicated as not having unit roots.

Table E66 shows the results of the Phillips-Perron test. Here, the level series is indicated as having a unit root while the first and second differenced series are not.

Table E64—Autocorrelation functions for the New York red spruce sawtimber stumpage price series

	Level Series		1[st] Difference		2[nd] Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.6850	**0.6850**	-0.2270	-0.2270	**-0.5680**	**-0.5680**
2	0.7660	**0.5590**	0.0570	0.0060	0.2000	-0.1810
3	0.5900	-0.0690	-0.2330	-0.2300	-0.2590	**-0.3460**
4	0.6030	0.0130	0.1860	0.0940	0.2090	-0.1650
5	0.5320	0.0980	0.0150	0.0860	-0.0750	-0.0620
6	0.4840	-0.0590	0.0820	0.0620	0.1150	0.0710
7	0.3940	-0.1580	-0.0270	0.0710	0.0360	0.3260
8	0.3280	-0.0840	**-0.3220**	**-0.3540**	-0.3130	-0.1870
9	0.2450	-0.0690	0.1240	0.0020	0.3150	0.0780
10	0.1390	-0.2030	-0.2710	**-0.3420**	-0.3610	**-0.3660**
11	0.1330	0.0870	0.3890	0.2270	0.4680	0.0290
12	0.0230	-0.0240	-0.1850	0.0290	-0.2390	0.2430
13	**0.0300**	-0.0080	-0.0810	-0.2490	0.0540	-0.0190
14	-0.0750	-0.0400	-0.1960	0.0210	-0.2240	-0.0280
15	-0.0010	0.2530	0.2240	0.0060	0.2430	-0.0330
16	-0.1040	-0.0440	0.0750	0.0640	-0.0410	-0.0130
17	-0.1050	-0.2230	0.0510	0.1080	0.0380	0.1280
18	-0.1800	-0.0400	-0.0550	-0.1750	-0.0740	-0.2350
19	-0.2080	-0.0810	-0.0430	0.2650	-0.1410	-0.1060
20	-0.2250	-0.1080	0.1930	0.0300	0.1740	-0.0770
21	-0.2700	-0.1020	-0.0480	-0.0360	-0.0980	-0.0950
22	-0.3020	-0.0830	0.0760	-0.0110	0.0880	-0.1420
23	-0.3230	-0.0090	-0.0870	-0.1630	-0.0400	-0.0600
24	-0.3560	-0.0420	-0.1180	-0.0800	-0.0300	-0.0430
25	-0.3780	0.0620	-0.0790	-0.0130	-0.0870	0.0450
26	-0.3470	0.1350	0.1320	-0.0650	0.1280	-0.0710
27	-0.3680	0.0290	0.0210	0.1580	0.0320	-0.0020
28	-0.3690	-0.1360	-0.0880	-0.0770	-0.0450	-0.0270
29	-0.3600	0.0790	-0.1260	-0.0130	-0.0310	-0.0260
30	-0.3240	0.0790	-0.0990	-0.1190	-0.0680	-0.0430
31	-0.2580	0.0040	0.1160	-0.1580	0.1280	0.0430
32	-0.2040	0.0730	0.0060	-0.0370	-0.0130	-0.0320
33	-0.1830	-0.0180	-0.0390	-0.0570	-0.0310	-0.0020
34	-0.1570	-0.1330	-0.0290	-0.0040		
35	-0.1140	-0.0220	-0.0090	0.0530		
36	-0.1090	-0.0280	-0.0020	-0.1290		
n		42		38		35
limit		0.3086		0.3244		0.3381

Table E65—Results of ADF unit root tests on the New York red spruce sawtimber stumpage price series

	R^2	ADF Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.13	-1.5661	-3.6289	-2.9472	-2.6118
first Difference with Constant	.62	**-4.0641**	-3.6496	-2.9558	-2.6164
second Difference with Constant	.96	**-12.1441**	-3.6959	-2.9750	-2.6265
Level with Constant and Trend	.14	-1.58045	-4.2412	-3.5426	-3.2032
first Difference with Constant and Trend	.66	**-4.52839**	-4.2712	-3.5562	-3.2109
second Difference with Constant and Trend	.96	**-11.8670**	-4.3382	-3.5867	-3.2279
Level with no Constant or Trend	.07	-0.6163	-2.6300	-1.9507	-1.6208
first Difference with no Constant or Trend	.61	**-4.0538**	-2.6369	-1.9517	1.6213
second Difference with no Constant or Trend	.96	**-12.3953**	-2.6522	-1.9540	-1.6223

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E66—Results of Phillips-Perron unit root test on the New York red spruce sawtimber stumpage price series

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.01	-0.5103	-2.6243	-1.9498	-1.6204
first Difference with Constant	.64	**-7.7552**	-3.6289	-2.9472	-2.6118
second Difference with Constant	.91	**-21.8440**	-3.6752	-2.9665	-2.6220

*MacKinnon critical values for rejection of hypothesis of a unit root

New York Red Spruce Sawtimber Stumpage Price Series Equations

Below are the statistics for the equation used in calculating breakpoints for the series. The equation has one lagged price variable and an intercept. The adjusted-R^2 is reasonably high and the F-statistic is higher than any other model in the group.

Equation used in Chow's breakpoint test
LS // Dependent Variable is SPRUCERNYS
Date: 09/12/97 Time: 08:33
Sample(adjusted): 1954 1997
Included observations: 38
Excluded observations: 6 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	12.22933	6.009608	2.034964	0.0493
SPRUCERNYS(-1)	0.827269	0.081989	10.09004	0.0000
R-squared	0.738769	Mean dependent var		71.44789
Adjusted R-squared	0.731512	S.D. dependent var		15.37462
S.E. of regression	7.966480	Akaike info criterion		4.201681
Sum squared resid	2284.733	Schwarz criterion		4.287870
Log likelihood	-131.7516	F-statistic		101.8090
Durbin-Watson stat	2.283232	Prob(F-statistic)		0.000000

The next equation is similar to the first, but omits the intercept term. The adjusted-R^2 is slightly lower than the first equation.

Alternative Equation #1
LS // Dependent Variable is SPRUCERNYS
Date: 09/12/97 Time: 08:33
Sample(adjusted): 1954 1997
Included observations: 38
Excluded observations: 6 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
SPRUCERNYS(-1)	0.990210	0.018364	53.92017	0.0000
R-squared	0.708719	Mean dependent var		71.44789
Adjusted R-squared	0.708719	S.D. dependent var		15.37462
S.E. of regression	8.297745	Akaike info criterion		4.257931
Sum squared resid	2547.545	Schwarz criterion		4.301025
Log likelihood	-133.8204	Durbin-Watson stat		2.433157

The next equation consists of two lagged variables. The adjusted-R^2 is slightly lower than the first equation, the second lagged variable is not statistically significant and the F-statistic is lower for the model as a whole than in the first equation.

Alternative Equation #2

LS // Dependent Variable is SPRUCERNYS
Date: 09/12/97 Time: 08:33
Sample(adjusted): 1955 1997
Included observations: 35
Excluded observations: 8 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
SPRUCERNYS(-1)	0.756985	0.160956	4.703061	0.0000
SPRUCERNYS(-2)	0.231471	0.159852	1.448026	0.1570
R-squared	0.725686	Mean dependent var		70.24657
Adjusted R-squared	0.717373	S.D. dependent var		15.04583
S.E. of regression	7.998768	Akaike info criterion		4.214020
Sum squared resid	2111.349	Schwarz criterion		4.302897
Log likelihood	-121.4082	F-statistic		87.29988
Durbin-Watson stat	1.750165	Prob(F-statistic)		0.000000

The next equation consists of two lagged variables and an intercept. This equation has the lowest F-statistic.

Alternative Equation #3

LS // Dependent Variable is SPRUCERNYS
Date: 09/12/97 Time: 08:33
Sample(adjusted): 1955 1997
Included observations: 35
Excluded observations: 8 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
SPRUCERNYS(-1)	0.756985	0.160956	4.703061	0.0000
SPRUCERNYS(-2)	0.231471	0.159852	1.448026	0.1570
R-squared	0.725686	Mean dependent var		70.24657
Adjusted R-squared	0.717373	S.D. dependent var		15.04583
S.E. of regression	7.998768	Akaike info criterion		4.214020
Sum squared resid	2111.349	Schwarz criterion		4.302897
Log likelihood	-121.4082	F-statistic		87.29988
Durbin-Watson stat	1.750165	Prob(F-statistic)		0.000000

<u>**New York Red Spruce Sawtimber Stumpage Price Series Chow Breakpoint Tests**</u>

While no individual year is statistically significant as a breakpoint, the combination of 1962, 1970, 1980 and 1991 is statistically significant. 1991 is used in further analysis.

Chow Breakpoint Test: 1962			
F-statistic	1.555587	Probability	0.225716
Log likelihood ratio	3.327188	Probability	0.189457
Chow Breakpoint Test: 1970			
F-statistic	1.339121	Probability	0.275548
Log likelihood ratio	2.881281	Probability	0.236776
Chow Breakpoint Test: 1972			
F-statistic	0.852811	Probability	0.435130
Log likelihood ratio	1.860010	Probability	0.394552
Chow Breakpoint Test: 1980			
F-statistic	1.077216	Probability	0.351881
Log likelihood ratio	2.334682	Probability	0.311193
Chow Breakpoint Test: 1991			
F-statistic	0.354285	Probability	0.704235
Log likelihood ratio	0.783792	Probability	0.675775
Chow Breakpoint Test: 1972 1991			
F-statistic	0.745142	Probability	0.568446
Log likelihood ratio	3.384160	Probability	0.495709
Chow Breakpoint Test: 1962 1970 1980			
F-statistic	1.855734	Probability	0.121695
Log likelihood ratio	11.99460	Probability	0.062089
Chow Breakpoint Test: 1962 1970 1980 1991			
F-statistic	2.304847	Probability	0.048815
Log likelihood ratio	19.22535	Probability	0.013700
Chow Breakpoint Test: 1962 1972 1980 1991			
F-statistic	2.170480	Probability	0.061909
Log likelihood ratio	18.33541	Probability	0.018848

New York Red Spruce Sawtimber Stumpage Price Series—Stationarity of Current Series

Table E67 presents the autocorrelation functions for the New York red spruce sawtimber stumpage price series since 1991. The full autocorrelation function indicates stationarity for the level series as $\rho \rightarrow 0$ after $k=1$. The partial autocorrelation function also indicates stationarity as no value exceeds the limit. The full autocorrelation function indicates stationarity for the first differenced series as $\rho \rightarrow 0$ after $k=3$ The partial autocorrelation function also indicates stationarity as no value exceeds the limit. The full function indicates stationarity for the second differenced series as $\rho \rightarrow 0$ after $k=2$ The partial function has no value that exceeds the limit.

Table E68 presents the results of the ADF unit root tests. The level series is indicated as having a unit root. The first differenced series is indicated as probably having a unit root. Only the test with no constant or trend suggests there may not be a unit root. The second differenced series is indicated as not having a unit root.

Table E69 shows the results of the Phillips-Perron test. Here, the level series and first differenced series are indicated as having unit roots and second differenced series does not.

Table E67—Autocorrelation functions for the New York red spruce sawtimber stumpage price series since 1991

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.3580	0.3580	-0.0150	-0.0150	-0.1140	-0.1140
2	-0.1900	-0.3650	-0.6290	-0.6290	-0.6020	-0.6230
3	-0.0830	0.1850	-0.0040	-0.0470	0.1440	-0.0640
4	-0.0730	-0.2450	0.1310	-0.4420	0.1030	-0.4230
5	-0.2760	-0.1900	0.0180	-0.0570	-0.0300	-0.0390
n		7		7		7
limit		0.7559		0.7559		0.7559

Table E68—Results of ADF unit root tests on the New York red spruce sawtimber stumpage price series since 1991

	R^2	ADF Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.27	-1.1813	-4.8875	-3.4239	-2.8640
first Difference with Constant	.66	-2.7777	-4.8875	-3.4239	-2.8640
second Difference with Constant	.90	-5.3685	-4.8875	-3.4239	-2.8640
Level with Constant and Trend	.81	-3.5753	-6.1252	-4.3535	-3.6280
first Difference with Constant and Trend	.66	-2.3868	-6.1252	-4.3535	-3.6280
second Difference with Constant and Trend	.91	-4.8929	-6.1252	-4.3535	-3.6280
Level with no Constant or Trend	-.04	0.5976	-3.0507	-1.9962	-1.6415
first Difference with no Constant or Trend	.55	-2.4809	-3.0507	-1.9962	-1.6415
second Difference with no Constant or Trend	.90	-5.9986	-3.0507	-1.9962	-1.6415

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E69—Results of Phillips-Perron unit root test on the New York red spruce sawtimber stumpage price series since 1991

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	-.05	1.0725	-3.0507	-1.9962	-1.6415
first Difference with Constant	.46	-2.0188	-4.8875	-3.4239	-2.8640
second Difference with Constant	.87	-6.4079	-4.8875	-3.4239	-2.8640

*MacKinnon critical values for rejection of hypothesis of a unit root

New York Spruce/Fir Pulpwood Stumpage Price Series

New York Spruce/Fir Pulpwood Stumpage Price Series—Stationarity of Full Series

Table E70 shows the results of the autocorrelation functions for the spruce/fir pulpwood series. The full autocorrelation function for the level probably indicates stationarity as $\rho \rightarrow 0$ after k=13. The partial autocorrelation function also indicates stationarity as only one value exceeds the limit. The full autocorrelation function for the first differenced series indicates stationarity as $\rho \rightarrow 0$ after k=1. The partial autocorrelation function also indicates stationarity as no values exceed the limit. The full function indicates stationarity for the second differenced series as $\rho \rightarrow 0$ after k=1. The partial autocorrelation function indicates stationarity as only one value exceeds the limit.

Table E71 presents the results of the ADF unit root tests. The level series is indicated as probably having a unit root as most test values are smaller than the critical values. The first and second differenced series are indicated as not having unit roots.

Table E72 shows the results of the Phillips-Perron test. Here, the level series is indicated as having a unit root only at the highest critical values while the first and second differenced series are consistently indicated as not having unit roots.

Table E70—Autocorrelation functions for the New York spruce/fir pulpwood stumpage price series

	Level Series		1[st] Difference		2[nd] Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.8420	**0.8420**	0.8420	**0.8420**	**-0.4920**	**-0.4920**
2	0.6950	-0.0470	0.6950	-0.0470	0.1540	-0.1160
3	0.5630	-0.0340	0.5630	-0.0340	-0.1030	-0.1000
4	0.4700	0.0520	0.4700	0.0520	-0.0750	-0.2100
5	0.4760	0.2840	0.4760	0.2840	0.3150	0.2550
6	0.4550	-0.0750	0.4550	-0.0750	-0.1760	0.1460
7	0.4550	0.0950	0.4550	0.0950	-0.1240	-0.2670
8	0.3790	-0.2180	0.3790	-0.2180	-0.0710	-0.3390
9	0.3030	0.0540	0.3030	0.0540	0.0900	-0.0370
10	0.2740	0.0760	0.2740	0.0760	-0.0110	-0.1290
11	0.1870	-0.2240	0.1870	-0.2240	0.0540	-0.0390
12	0.1080	-0.1790	0.1080	-0.1790	-0.1060	0.1290
13	**0.0480**	0.0800	**0.0480**	0.0800	-0.0120	0.0260
14	-0.0260	-0.1220	-0.0260	-0.1220	0.1180	-0.0680
15	-0.0930	-0.1450	-0.0930	-0.1450	-0.0360	-0.0580
16	-0.1390	0.0220	-0.1390	0.0220	0.1140	0.0960
17	-0.1690	-0.0410	-0.1690	-0.0410	-0.0860	0.0590
18	-0.2060	-0.0380	-0.2060	-0.0380	-0.0810	-0.1430
19	-0.2510	-0.0340	-0.2510	-0.0340	0.1990	0.1680
20	-0.2840	-0.0720	-0.2840	-0.0720	-0.2390	-0.1450
21	-0.3030	0.0780	-0.3030	0.0780	0.2700	0.0100
22	-0.3140	0.0660	-0.3140	0.0660	-0.2130	0.0960
23	-0.3090	-0.0750	-0.3090	-0.0750	0.0100	0.0240
24	-0.3050	-0.0030	-0.3050	-0.0030	0.1040	0.0300
25	-0.3250	-0.0010	-0.3250	-0.0010	-0.1570	-0.0590
26	-0.3270	0.0240	-0.3270	0.0240	0.1250	-0.1070
27	-0.3360	-0.0870	-0.3360	-0.0870	-0.1040	-0.1210
28	-0.3220	0.0350	-0.3220	0.0350	0.0570	0.0510
29	-0.2860	0.0440	-0.2860	0.0440	-0.0500	0.0040
30	-0.2620	-0.0230	-0.2620	-0.0230	0.0700	0.0000
31	-0.2270	-0.0280	-0.2270	-0.0280		32
32	-0.2070	0.0140	-0.2070	0.0140		0.3536
33	-0.1790	0.0320	-0.1790	0.0320		
34	-0.1540	-0.0360	-0.1540	-0.0360		
35	-0.1360	-0.0230	-0.1360	-0.0230		
36	-0.1200	-0.0850	-0.1200	-0.0850		
n		38		38		
limit		0.3244		0.3244		

Table E71—Results of ADF unit root tests on the New York spruce/fir pulpwood stumpage price series

	R^2	ADF Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.18	-2.3479	-3.6496	-2.9558	-2.6164
first Difference with Constant	.47	**-2.7581**	-3.6752	-2.9665	-2.6220
second Difference with Constant	.96	**-10.3587**	-3.7204	-2.9850	-2.6318
Level with Constant and Trend	.21	-0.3374	-4.2712	-3.5562	-3.2109
first Difference with Constant and Trend	.57	**-3.7601**	-4.3082	-3.5731	-3.2203
second Difference with Constant and Trend	.97	**-11.1224**	-4.3738	-3.6027	-3.2367
Level with no Constant or Trend	.09	**-1.9753**	-2.6369	-1.9517	-1.6213
first Difference with no Constant or Trend	.46	**-2.67136**	-2.6453	-1.9530	1.6218
second Difference with no Constant or Trend	.96	**-10.5480**	-2.6603	-1.9552	-1.6228

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E72—Results of Phillips-Perron unit root test on the New York spruce/fir pulpwood stumpage price series

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.06	**-2.1435**	-2.6300	-1.9507	-1.6208
first Difference with Constant	.50	**-5.6949**	-3.6496	-2.9558	-2.6164
second Difference with Constant	.95	**-23.5129**	-3.6959	-2.9750	-2.6265

*MacKinnon critical values for rejection of hypothesis of a unit root

New York Spruce/Fir Pulpwood Stumpage Price Series Equations

Below are the statistics for the equation used in calculating breakpoints for the series. The equation has one lagged price variable and an intercept. The adjusted-R^2 is reasonably high, but the intercept is not statistically significant at the .10 level.

Equation used in Chow's breakpoint test
LS // Dependent Variable is SPRUCENYP
Date: 09/12/97 Time: 08:33
Sample(adjusted): 1954 1996
Included observations: 35
Excluded observations: 8 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.023318	0.617446	1.657342	0.1069
SPRUCENYP(-1)	0.910826	0.039247	23.20743	0.0000

R-squared	0.942266	Mean dependent var	14.50771
Adjusted R-squared	0.940516	S.D. dependent var	5.066962
S.E. of regression	1.235796	Akaike info criterion	0.478876
Sum squared resid	50.39733	Schwarz criterion	0.567753
Log likelihood	-56.04317	F-statistic	538.5848
Durbin-Watson stat	2.046521	Prob(F-statistic)	0.000000

The next equation is similar to the first, but with two lagged variables. The adjusted-R^2 is slightly lower than the first equation, the intercept is not statistically significant at high confidence levels, and the second lagged variable is not statistically significant at lower confidence levels.

Alternative Equation #1
LS // Dependent Variable is SPRUCENYP
Date: 09/12/97 Time: 08:33
Sample(adjusted): 1955 1996
Included observations: 32
Excluded observations: 10 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.174583	0.662652	1.772549	0.0868
SPRUCENYP(-1)	0.664536	0.209940	3.165354	0.0036
SPRUCENYP(-2)	0.231856	0.200443	1.156717	0.2568

R-squared	0.936025	Mean dependent var	13.98562
Adjusted R-squared	0.931613	S.D. dependent var	4.683159
S.E. of regression	1.224689	Akaike info criterion	0.494434
Sum squared resid	43.49606	Schwarz criterion	0.631847
Log likelihood	-50.31698	F-statistic	212.1510
Durbin-Watson stat	1.725712	Prob(F-statistic)	0.000000

The next equation consists of a single lagged variable. The adjusted-R^2 is slightly lower than the first equation.

Alternative Equation #2
LS // Dependent Variable is SPRUCENYP
Date: 09/12/97 Time: 08:33
Sample(adjusted): 1954 1996
Included observations: 35
Excluded observations: 8 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
SPRUCENYP(-1)	0.972037	0.013614	71.39719	0.0000
R-squared	0.937460	Mean dependent var		14.50771
Adjusted R-squared	0.937460	S.D. dependent var		5.066962
S.E. of regression	1.267144	Akaike info criterion		0.501686
Sum squared resid	54.59219	Schwarz criterion		0.546124
Log likelihood	-57.44235	Durbin-Watson stat		1.988631

The next equation consists of two lagged variables and an intercept. This equation has the lowest F-statistic.

Alternative Equation #3
LS // Dependent Variable is SPRUCENYP
Date: 09/12/97 Time: 08:33
Sample(adjusted): 1955 1996
Included observations: 32
Excluded observations: 10 after adjusting endpoints

Variable	Coefficient	Std. Error	t-Statistic	Prob.
SPRUCENYP(-1)	0.759097	0.210173	3.611772	0.0011
SPRUCENYP(-2)	0.211134	0.207122	1.019373	0.3162
R-squared	0.929094	Mean dependent var		13.98562
Adjusted R-squared	0.926730	S.D. dependent var		4.683159
S.E. of regression	1.267656	Akaike info criterion		0.534800
Sum squared resid	48.20853	Schwarz criterion		0.626409
Log likelihood	-51.96283	F-statistic		393.0941
Durbin-Watson stat	1.670734	Prob(F-statistic)		0.000000

<u>New York Spruce/Fir Pulpwood Stumpage Price Series Chow Breakpoint Tests</u>

No statistically significant breakpoints were found for this series. However, a visual inspection of Figure 84 suggests a major change in price behavior in 1972. 1972 is used in further analysis.

Chow Breakpoint Test: 1972 1983			
F-statistic	0.515568	Probability	0.724834
Log likelihood ratio	2.404433	Probability	0.661826

Chow Breakpoint Test: 1972			
F-statistic	0.659153	Probability	0.524389
Log likelihood ratio	1.457631	Probability	0.482480

Chow Breakpoint Test: 1983			
F-statistic	0.634919	Probability	0.536730
Log likelihood ratio	1.405101	Probability	0.495320

Chow Breakpoint Test: 1990			
F-statistic	0.353135	Probability	0.705272
Log likelihood ratio	0.788453	Probability	0.674201

Chow Breakpoint Test: 1972 1983			
F-statistic	0.515568	Probability	0.724834
Log likelihood ratio	2.404433	Probability	0.661826

Chow Breakpoint Test: 1972 1983 1990			
F-statistic	0.684813	Probability	0.663393
Log likelihood ratio	4.957972	Probability	0.549215

Chow Breakpoint Test: 1972 1983			
F-statistic	0.515568	Probability	0.724834
Log likelihood ratio	2.404433	Probability	0.661826

New York Spruce/Fir Pulpwood Stumpage Price Series—Stationarity of Current Series

Table E73 presents the autocorrelation functions for the New York spruce/fir pulpwood stumpage price series since 1972. The full autocorrelation function for the level series indicates stationarity as $\rho \rightarrow 0$ after k=2 The partial autocorrelation function also indicates stationarity as only one value exceeds the limit. The full autocorrelation function for the first differenced series indicates stationarity as $\rho \rightarrow 0$ after k=1 The partial autocorrelation function also indicates stationarity as no value exceeds the limit. The full function indicates stationarity for the second differenced series as $\rho \rightarrow 0$ after k=1 The partial function has only two values that exceed the limit.

Table E74 presents the results of the ADF unit root tests. The level series is indicated as having a unit root. The first differenced series is indicated as probably not having a unit root, but only at lower critical values. The second differenced series is indicated as not having a unit root.

Table E75 shows the results of the Phillips-Perron test. Here, the level series is indicated as having a unit root and the first and second differenced series are indicated as not having unit roots.

Table E73—Autocorrelation functions for the New York spruce/fir pulpwood stumpage price series since 1972

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.5200	**0.5200**	**-0.1600**	-0.1600	**-0.6660**	**-0.6660**
2	**0.2050**	-0.0900	0.1680	0.1460	0.2610	-0.3290
3	-0.0160	-0.1170	-0.0760	-0.0310	-0.0190	-0.0140
4	-0.0940	-0.0270	-0.2680	-0.3220	-0.3170	**-0.5130**
5	0.0470	0.1870	0.2980	0.2750	0.3850	-0.3500
6	-0.0310	-0.1880	-0.0570	0.1230	-0.2220	-0.1640
7	-0.0030	0.0630	0.1590	0.0010	0.1960	0.0940
8	-0.1650	-0.2320	-0.1520	-0.2230	-0.1740	-0.2340
9	-0.1140	0.1520	-0.0250	0.1070	0.0920	-0.0470
10	-0.0480	-0.0740	-0.0820	-0.0620	-0.1420	-0.2090
11	-0.0230	0.0440	0.1250	0.1280	0.1650	-0.0240
12	0.0090	-0.1070	0.0660	-0.0310	-0.0680	-0.1530
13	-0.2540	-0.2660	0.0060	0.0560	0.0200	-0.0430
14	-0.2760	-0.0490	-0.0350	-0.1140	0.0090	-0.1970
15	-0.2740	-0.0550	-0.1050	0.0580	-0.0710	-0.0190
16	-0.1520	-0.0250	0.0130	-0.0730	0.0840	-0.0840
17	-0.0680	-0.1250	-0.0290	-0.0090	-0.0600	0.0040
18	-0.0990	-0.0250	0.0170	-0.1290	0.0560	-0.1410
19	-0.1100	-0.1550	-0.0530	0.0320	-0.0190	0.0880
20	-0.1200	0.0640	-0.1110	-0.1620	-0.0020	0.0420
21	0.0000	-0.0880	-0.1310	-0.1150	-0.0290	0.0660
22	0.1600	0.2140	-0.0610	-0.1290		23
23	0.2520	-0.0160		24		0.4170
n		25		0.4082		
limit		0.4000				

Table E74—Results of ADF unit root tests on the New York spruce/fir pulpwood stumpage price series since 1972

	R^2	ADF Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.10	-1.2790	-3.7497	-2.9969	-2.6381
first Difference with Constant	.63	**-2.8181**	-3.7667	-3.0038	-2.6417
second Difference with Constant	.96	**-10.9595**	-3.8067	-3.0199	-2.6502
Level with Constant and Trend	.34	-1.4877	-4.4167	-3.6219	-3.2474
first Difference with Constant and Trend	.68	**-3.4636**	-4.4415	-3.6330	-3.2535
second Difference with Constant and Trend	.96	**-10.6362**	-4.5000	-3.6591	-3.2677
Level with no Constant or Trend	.02	0.2831	-2.6700	-1.9566	-1.6235
first Difference with no Constant or Trend	.61	**-2.8537**	-2.6756	-1.9574	-1.6238
second Difference with no Constant or Trend	.96	**-11.0012**	-2.6889	-1.9592	-1.6246

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E75—Results of Phillips-Perron unit root test on the New York spruce/fir pulpwood stumpage price series since 1972

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	-.00	0.2183	-2.6649	-1.9559	-1.6231
first Difference with Constant	.58	**-5.3375**	-3.7497	-2.9969	-2.6381
second Difference with Constant	.94	**-16.5452**	-3.7856	-3.0114	-2.6457

*MacKinnon critical values for rejection of hypothesis of a unit root

PNW Westside Douglas-fir Sawlog Price Series—Nominal Dollar Prices

All of the previous analysis was carried out in real dollars—inflation was removed before the analysis was conducted. This was done to examine the behavior of timber prices without the impact of inflation. Since the inflation rate has generally been positive over the last century, analyzing nominal prices would have had either of two impacts: any price series exhibiting a negative real trend could exhibit stationarity (constant mean) when inflation was added in, and any price series exhibiting stationarity could exhibit a positive trend when inflation was added in. Below is a brief examination of the PNW Westside Douglas-fir sawlog series in nominal dollars.

PNW Westside Douglas-fir Sawlog Price Series—Nominal Dollar Prices—Stationarity of Full Series

Table E76 shows the results of the autocorrelation functions for the nominal Douglas-fir series. The full autocorrelation function for the level series may indicate stationarity as $\rho \rightarrow 0$ after k=27. Note than in the real dollar series (Table E1), $\rho \rightarrow 0$ only after k=35. The partial autocorrelation function may also indicate stationarity as four values exceed the limit, compared with three values in the real dollar series. The full autocorrelation function indicates stationarity for the first differenced series as $\rho \rightarrow 0$ after k=1. The partial autocorrelation function also indicates stationarity as two values exceed the limit. The full function indicates stationarity for the second differenced series as $\rho \rightarrow 0$ after k=1. The partial autocorrelation function may not indicate stationarity as seven values exceed the limit.

Table E77 presents the results of the ADF unit root tests. The level series is indicated as having a unit root while the first and second differenced series are indicated as not having unit roots.

Table E78 shows the results of the Phillips-Perron test. The level series is indicated as having a unit root while the first and second differenced series are indicated as not having unit roots.

However, the unit root tests more strongly support the stationarity of the first differenced series and the non-stationarity of the level series.

Table E76—Autocorrelation functions for the PNW Westside Douglas-fir sawlog nominal price series

	Level Series		1st Difference		2nd Difference	
k	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function	Autocorrelation function	Partial autocorrelation function
1	0.8790	**0.8790**	**-0.3250**	**-0.3250**	**-0.6940**	**-0.6940**
2	0.8100	0.1630	0.1780	0.0810	0.3440	**-0.2650**
3	0.6800	**-0.2680**	-0.2010	-0.1370	-0.2380	**-0.2490**
4	0.6400	**0.2620**	0.0240	-0.0980	0.0910	**-0.3100**
5	0.5640	-0.0460	0.0200	0.0390	0.0130	-0.1800
6	0.5000	-0.1690	-0.0260	-0.0310	0.0160	-0.0390
7	0.4270	0.0690	-0.1050	-0.1650	-0.0200	-0.0160
8	0.3840	0.0760	-0.1270	**-0.2180**	-0.0680	-0.1730
9	0.3860	0.1820	0.0260	-0.0730	0.0750	-0.1500
10	0.3930	0.0560	-0.0200	-0.0700	-0.1030	**-0.2940**
11	0.4090	0.0290	0.2080	0.1440	0.2400	0.0070
12	0.3980	-0.0060	-0.2010	-0.1300	-0.2560	-0.0420
13	0.4180	0.1150	0.0670	-0.1020	0.1170	**-0.2180**
14	0.4210	-0.0120	0.0300	0.0900	-0.0720	**-0.2460**
15	0.4250	-0.0850	0.1700	0.1680	0.1410	-0.0130
16	0.3610	**-0.2190**	-0.0560	-0.0440	-0.1110	-0.0530
17	0.2890	-0.1140	0.0190	-0.0010	0.0420	-0.1730
18	0.2190	0.0670	-0.0100	0.1380	0.0130	0.0330
19	0.1760	-0.0150	-0.0790	-0.0500	-0.0790	0.0170
20	0.1510	0.0570	0.0610	-0.0350	0.0580	-0.1820
21	0.1240	0.0670	0.0460	0.1750	0.0260	-0.0440
22	0.0900	-0.0780	-0.0410	0.0510	-0.0490	-0.0720
23	0.0560	-0.0730	0.0070	0.0880	0.0340	-0.0170
24	0.0320	-0.1170	-0.0340	0.0430	-0.0450	0.0180
25	0.0260	-0.0130	0.0410	0.0110	0.0410	0.0120
26	0.0180	-0.0040	0.0050	0.0120	0.0010	-0.0280
27	0.0080	-0.0040	-0.0350	0.0530	-0.0330	0.0090
28	-0.0050	0.0240	0.0150	0.0180	0.0250	0.0290
29	-0.0140	0.0200	0.0010	-0.0050	-0.0080	-0.0420
30	-0.0170	0.0580	0.0040	0.0680	0.0050	0.0460
31	-0.0240	0.0520	-0.0050	-0.0200	-0.0020	0.1120
32	-0.0300	0.0310	-0.0100	-0.1040	-0.0100	-0.0650
33	-0.0360	0.0010	0.0110	0.0640	0.0170	-0.0210
34	-0.0370	-0.0350	-0.0120	0.0220	-0.0200	0.0670
35	-0.0360	-0.0420	0.0170	-0.0720	0.0210	0.0410
36	-0.0370	-0.0420	-0.0120	-0.0590	-0.0110	-0.0170
n		104		101		85
limit		0.1961		0.1990		0.2169

Table E77—Results of ADF unit root tests on the PNW Westside Douglas-fir sawlog nominal price series

	R^2	ADF Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	.15	-0.1683	-3.5023	-2.8928	-2.5833
first Difference with Constant	.68	**-4.2820**	-3.5039	-2.8936	-2.5836
second Difference with Constant	.96	**-14.8194**	-3.5039	-2.8936	-2.5836
Level with Constant and Trend	.19	-1.6219	-4.0602	-3.4586	-3.1551
first Difference with Constant and Trend	.69	**-4.4347**	-4.0625	—3.4597	-3.1557
second Difference with Constant and Trend	.96	**-14.7207**	-4.0625	—3.4597	-3.1557
Level with no Constant or Trend	.14	0.3728	-2.5883	-1.9436	-1.6176
first Difference with no Constant or Trend	.68	**-4.1668**	-2.5888	-1.9437	-1.6176
second Difference with no Constant or Trend	.96	**-14.9109**	-2.5888	-1.9437	-1.6176

*MacKinnon critical values for rejection of hypothesis of a unit root

Table E78—Results of Phillips-Perron unit root test on the PNW Westside Douglas-fir sawlog nominal price series

	R^2	PP Test Statistic	Critical Value*		
			1%	5%	10%
Level with Constant	-.00	-0.1494	-2.5862	-1.9432	-1.6174
first Difference with Constant	.66	**-13.9256**	-3.4979	-2.8909	-2.5822
second Difference with Constant	.94	**-44.0613**	-3.5007	-2.8922	-2.5829

*MacKinnon critical values for rejection of hypothesis of a unit root

APPENDIX F

TIMBER PRICE SHOCKS

There is a long list of shocks that are hypothesized to have had an impact on timber prices. There have been technology changes that have created whole new industries or allowed existing industries to move into new regions. There are changes in regions that affect other regions. Sometimes the impact of a shock differs greatly among regions. A comparison of the technology shocks discussed below with the graphs of the price series above does not indicate a clear impact of the technology shocks—no breakpoints in the price series appear to correspond to any of the technology shocks. This suggests the impacts of these "shocks" are not as severe as economic and policy change shocks.

General economic conditions have had significant impacts on timber prices. Wars and recovery from wars have had generally driven timber prices up. Policy changes by the United States Forest Service caused major changes in price structures in the 1940's and the 1990's. Substitution of other materials for wood (steel studs, plastic bags), substitution of one wood-based material for another (corrugated containers) and substitution of wood for another material (paper diapers) can all have an impact on demand and prices for wood.

Technology Shocks

Logging and Transportation Technology

During the 1960's horses and mules virtually disappeared from commercial logging in the eastern and southern United States, replaced by skidders and other logging machinery. This machinery in turn has evolved over time, from tracked vehicles hauling logs by cable to wheeled cable skidders pulling logs to grapple skidders pulling whole trees to forwarders. Transportation methods have evolved through river drives to railroads to trucks and barges.

River drives were common practice in New England from the 1700's until the middle of this century. Since wood had to travel by water, only wood relatively near water was accessible—log sleds and pulpwood racks had to be skidded by horses to the landings. (Of course, there is very little land in New England that is *not* relatively near water.) When river drives were halted in the 1960's—primarily due to environmental concerns—the paper companies began building roads. The result of this road building program is that *all* timber in New England is now accessible for harvesting.

Railroads became important in the New England woods by the early 1900's and were used extensively to log the area that became the White Mountain National Forest. Rivers were less suitable to log drives in the West, so logging railroads were a more important means of log transportation there. Railroads were replaced by trucks in the woods because roads were cheaper and quicker to build—they *can* be narrower and have steeper grades and trucks provide much more flexibility in delivery points once they are out of the woods.

The opening of the Tennessee-Tombigbee Waterway in Alabama and Mississippi in January of 1985 has changed the economics of the wood supply in the mid-South. Wood (usually, but not always, in the form of chips) and wood and paper products are transported by barge on the waterway and its related rivers. It has lowered the cost of wood transportation for wood suppliers and user with access to the waterway.

Improved road building technology and trucks have allowed bigger trucks to haul larger volumes of wood from further distances. Two-axle trucks began in the East by hauling short logs and rack loads of pulpwood. Tractor-trailer rigs were common in the woods by the 1960's. They required better roads (with greater curve radii) than the shorter trucks, but they were able to haul tree-length material.

In the South, the short, "bob-tail" truck hauling pulpwood was still common in the 1980's, but has virtually disappeared by the 1990's. The capital cost of a tractor-trailer rig is higher than for a bob-tail truck, but the delivered cost per cord is less. The South has also developed an elaborate system of outlying woodyards where pulpwood is off-loaded from trucks onto railcars for transportation to pulpmills.

In the Northeast, logging technology has changed considerably since the Second World War. Baldwin and Heermance wrote in 1947 that "[p]ortable power saws are now used extensively for felling and bucking sawlogs. [This passage is accompanied by a photograph of a two-person "motor-driven" chain saw in use.] New types of fairly lightweight power saws for cutting smaller trees are on the market. Tractors have been taking the place of horses... and various mechanical loaders are coming into use....The mechanization of the woods is still in its infancy".[10] Irland (1982) notes "Horse operations on major industrial holdings were common until the 1960's in northern Maine....The skidder came into its own in the Maine woods only in the 1960's."[11]

In the Pacific Northwest, constantly improving technology has allowed roads to replace railroads in the woods and has provided logging equipment that can operate in previously inaccessible places. There have been several generations of cable-based equipment—up through skyline and balloon systems—that allow logs to be retrieved from ever-increasing distances from the log landing. Helicopter logging allows harvest of trees that cannot otherwise be reached from the ground. It is interesting to note regional differences in the United States and Canada. Cable-type systems are nearly unheard of in the eastern half of both countries. Terrain that loggers consider "nearly flat" in the West is considered "too steep" or "inoperable" in the East. It is possible that there is not enough steep land in the East to justify the use of these systems. An alternative explanation is that the per-acre value of timber is much higher in the West than in the East and so allows greater investment in logging equipment

Improvements in logging and transportation technology would have a tendency to lower the cost of getting fiber out of the forest, effectively increasing the supply of wood available at a given prices. Assuming no change in the demand curve, this would cause timber prices to fall.

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[10] Baldwin and Heermance, 1949, p. 68
[11] Irland, 1982, p. 32

Pulp Species

Over the long time horizon, species used in producing pulp have changed. As ways were developed to pulp "new" species, the changes have included the development of entire industries in new regions and improvements in the ability to manage forests for higher quality species and products.

From the late 1800's until about the 1930's, spruce was the only wood species that could be pulped. Research and improvements in technology have since allowed southern pines and a variety of northern and southern hardwoods to be used in making pulp.

This had a tremendous impact on southern forests. Small southern pines which had no commercial value were suddenly worth something. There are parts of the South—particularly southern Georgia and northern Florida—where the forest products industry is described as a pulpwood economy. Commercial thinning has become fairly common in southern pine plantations, in part because the small logs removed can be sold to pulpmills. The trees remaining can produce sawlogs in a shorter time than if the thinning had not taken place.

The ability to pulp new species is usually developed in response to tight supplies of currently utilized species. Northern New England pulpmills were primarily spruce/fir consumers a couple of decades ago. As spruce supplies have become tighter, most have developed the capability to use pines and hardwoods to some extent in the pulping process. The demand for hardwood pulpwood has allowed foresters to remove low quality stems from the forests in New England. This is an outlet the region desperately needs after three and a half centuries of high-grading. While there is not enough demand to allow the all forests to be "cleaned up" quickly, the general quality of the hardwood forests are slowly being improved.

Sometimes the "new" species is only new to a region. For example, aspen is used extensively by pulpmills in Wisconsin, but it is used very little in Maine. In this case, the requirements and processes for pulping aspen are known in Maine, but extensive changes to equipment and procedures would be necessary to utilize the species. These changes could be made if the area of aspen forest type in Maine expands and other species become scarcer.

The ability to pulp new species will have the effect reducing demand and price for currently used species—if spruce were still the only pulpable species in the world, prices for spruce would be much higher or the paperless society would have become a reality. Pulpwood demand (and prices) can allow improvements in the quality of the standing forest as low quality logs and species have a commercial outlet.

<u>Chip N Saw/Studwood Logs</u>

Beginning in the 1960's, a "new" category of log evolved. The Chip N Saw (primarily southern) or studwood (primarily northeastern) log was a borderline large pulpwood log/small sawlog. This type of log was processed in special (new) equipment that chipped the slabs from around the lumber pieces (hence the name "Chip N Saw", rather than sawing off the slabs and then chipping them. The intent was to extract higher value out of the large pulpwood log by producing at least one 2x4 (lumber/stud—hence the name "studwood") instead of chipping the whole log. It was quickly recognized that the smallest sawlogs could be processed more efficiently though this equipment, rather than by processing them through conventional sawmill equipment This created a whole new price category of logs.

This new technology should have caused an increase in the average price of sawlogs due purely to arithmetic. The new class of logs would have drawn the bulk of its volume from the pulpwood class, but it is likely that most of the smallest sawlogs suddenly became Chip N Saw material. With all of the smallest (and probably lowest-prices) sawlogs suddenly "disappearing", the *average* price for sawlogs should have increased even if the actual price paid for any sawlogs did not change.

To illustrate, suppose we have three log sizes and prices as shown in Table F1. When the smallest sawlog class is removed, the average price of the logs increases.

Table F1—Change in sawlog average values due to Chip N Saw

	Price ($/MBF)	
Log Size (Diameter Class)	Before CNS*	After CNS
14"	$ 150	$ 150
10"	$ 100	$ 100
6"	$ 50	
Average (assume equal volumes)	$ 100	$ 125

*CNS = Chip N Saw

It is possible that the introduction and spread of this technology was slow enough that no clear breakpoint will be discernible.

It is likely that the average size of Chip N Saw logs has decreased over time as equipment has been improved to process smaller and smaller logs—logs that were formerly pulpwood logs. Increasing demand for Chip N Saw logs, which would cause a price increase, should have been offset by the increasing supply of Chip N Saw logs (smaller logs).

Irland (1982) states "Chip N Saw and other systems capable of making framing lumber from small trees have significantly increased the stumpage value of spruce and fir"[12].

In Maine, the supply of spruce has become tight, and the studwood mills are competing for material that would recently have been classified as pulpwood and the pulpmills are trying to obtain material that could be used by the studmills. This should be having the impact of driving the price of spruce studwood and pulpwood up, as the two industry segments compete for the same wood.

[12] Irland, 1982, p. 33

Plywood Species

The volume of structural plywood produced from western species soared between 1950 and 1965. Southern pine plywood was introduced in the mid-1960's. Western production dropped slightly through 1985, while production of southern pine structural plywood soared.

The introduction of southern pine plywood would have created a new class of log prices. This should have caused a decrease in the average price of sawlogs due purely to arithmetic, just the opposite to the creation of the Chip N Saw log class, but for the same reason. The best and largest sawlogs would have "disappeared" from the sawlog category as they were transferred to the veneer log category. With the best, largest and most costly logs gone, the average sawlog price should have dipped.

The price series developed by the Hancock Timber Resource Group (Figure 6) does not support this theory very well. Real southern pine sawtimber prices dropped erratically but steadily between 1950 and 1965 after a huge increase between 1945 and 1950. Price rose for several years after 1965. So prices dropped before the veneer class was created and rose immediately after—the opposite of what was expected.

Here is a possible explanation for this unexpected behavior. The price rise from 1945 to 1950 was likely driven by the surge in housing starts after World War II. The decline in prices between 1950 and 1965 could be caused by the relatively fulfilled demand for housing and an adjustment of prices to "normal" levels, all of which overwhelmed the introduction of the veneer log class.

Old Growth Liquidation

In the 1890's, most timber harvesting was in old-growth stands. By the 1990's, most timber harvesting was in second- or third-growth stands. The "Spotted Owl Crisis" (see below) caused an abrupt end to almost all old-growth harvest in the Pacific Northwest. Log Lines™ and The Pacific Rim Wood Market Report™ consistently report higher prices for old-growth than for second growth logs.

The average value of western stumpage should have fallen over time as less and less of that stumpage is made up of old-growth timber and more and more is second-growth. Unfortunately, data is not available to test this hypothesis. It can probably be safely assumed that most timber sales before 1945 were in old-growth, and it is likely that a substantial portion of the timber harvested before the 1970's was old-growth, but some of it must have been second-growth.

The almost total removal of old-growth timber from the timber supply would have resulted in much higher timber prices without changes in technology. Second growth logs (<16-24") are generally much smaller than old-growth logs (24-36+"). Sawmills designed to process large (old-growth) logs are not efficient processors of small (second-growth) logs. If smaller logs cannot be used, prices paid for the few remaining old-growth logs would be astronomical.

However, as second growth forests have matured, sawmills specifically designed to handle these smaller logs have been built and old-growth mills have closed. This has had two effects—prices for smaller logs have increased as mills compete for them, and prices for larger logs have not increased as much as they otherwise would have because there are fewer mills competing for them.

Engineered Wood Products

Beginning in the 1980's, significant volumes of engineered wood products: OSB and Particleboard Panels, Laminated-Veneer Lumber (LVL), and other composite/reconstituted products have been increasing in importance.

During the 1980's the dramatic increase in production of OSB panels created a whole new market for wood fiber. This was driven by two factors: the high prices of peeler logs (very high quality/price) for traditional plywood, and the search for an outlet for low quality species and logs. There has been a tremendous increase in OSB production in the last decade, with a substantial portion of this volume replacing plywood. The OSB industry is mostly located in the Northeast and South

The increase in OSB production should ease the demand for softwood veneer logs. Veneer logs are generally the most expensive logs on the market. The old-growth forests of the Pacific Northwest were a primary source of western softwood veneer logs. With the halt in timber harvesting on the National Forests and the rapidly dwindling amount of old-growth on private lands, there is tremendous upward pressure on veneer log prices in the region. This upward pressure is offset by southern pine plywood and OSB from the Northeast and South. The volume of western plywood production has dropped steadily since the mid-1960's (Sinclair 1992). While it is unlikely that the price of PNW veneer logs will fall, the substitution of other products for western plywood will keep prices from rising as fast as they otherwise would have.

OSB should also ease demand for pine veneer logs in the South.

As with new pulp species, the utilization of poor quality logs in the production of engineered wood products should have a long-term impact on forest management and, therefore, timber and timberland values. As low quality wood is removed from the forest via thinnings or other operations, higher quality trees and species will be left behind. It will take many years of removing low quality wood from the forests of the Northeast before prices for this material can be expected to increase—the supply of low quality material far exceeds demand.

LVL has a mixed impact on wood markets. It does not require the large, unblemished sheets of veneer used in producing plywood, but it requires better quality wood than that used in producing reconstituted panels. The volume of LVL production is currently small enough that its impact is minimal.

To summarize, the growth in production of reconstituted wood products should ease the demand for high quality softwood sawlogs in the West and South, and provide a market for low quality trees and species in the Northeast and South.

Energy Chips

After the energy price shocks resulting from the OPEC embargoes and price increases of the 1970's, utilities in the Northeast became involved in programs to burn wood chips to produce electricity.

Activity varied by state, but by the 1980's wood-burning plants contributed observable amounts of power in some places. Seven states surveyed in the Northeast and Lake States had 56 major wood-fired energy plants with a capacity of nearly 900 megawatts consuming over ten million green tons of wood annually in 1990 (Lutz and Irland 1990).

Ten percent of New Hampshire's electricity was generated by independent wood burning plants. Many forest products facility produced steam, heat or some electricity by burning wood. New Hampshire's program suffered a serious blow in the late 1980's when the State's primary utility—Public Service Company of New Hampshire bought most of the independent plants out and closed them down. This buyout program was driven by the relatively high cost of the energy from these plants (priced by law at Public Service's avoided cost) and the relatively low cost of other energy sources.

Most of the wood supplied to these plants arrived in the form of whole tree chips, produced in the woods by portable chippers. The forestry community in the state generally looked on the program favorably as it provided an outlet for low quality hardwoods. These hardwoods could normally have been sold only as pulpwood, and the supply of hardwood pulpwood in the State substantially exceeds the demand.

Has the use of wood for energy provided another shock to the pulpwood price trends?

Over the long-term, the wood energy program would have allowed an outlet for low quality wood in the region and gradually improve the quality and value of the hardwood forests. With the general collapse in interest in wood fired power plants, the impact of the remaining plants will be minimal.

Wood/Corrugated Packaging

Until the 1950's the wood box/barrel industry consumed significant quantities of solid wood. Since then, corrugated boxes have virtually replaced wood containers in all but the heaviest applications.

The box industry had been a major consumer of large but poor quality white pine logs. This was a much needed outlet for white pine forests. Much of the higher quality white pine had been logged out over the centuries—Thoreau reported seeing no large pines south of Mt Katahdin in Maine during his travels there in the 1840's and 1850's.

The accidental introduction of the white pine weevil had a serious impact on the overall quality of the white pine supply. The weevil kills the leader on the tree and one of the side branches will take over as leader. This results in a crook in the log. Because appearance is unimportant is wood packaging, these crooked logs were readily useable in manufacturing wood boxed.

The loss of the box industry has left no outlet for large volumes of low quality white pine sawlogs.

Paper/Plastic Bags

The change from kraft paper to plastic shopping/grocery bags began in earnest the mid-1980's and was virtually complete by the mid-1990's. This would appear to have been an important event and should have had some impact on certain paper mills and, therefore, it should have had an impact on timber prices.

However, there do not appear to be any kraft paper mills that have closed as a result of this transformation. Either the mills have found some other use for their product, or they have managed to convert to producing another paper grade.

In any event, kraft bag producers were/are consumers of pulpwood—generally low quality wood. Since the supply of low quality wood generally exceeds the demand for it across the continent, the impact of this substitution of a non-wood product for a wood-based product should have had a minimal impact on timber prices.

Policy Shocks

Post-War Policy Change

Sohngen and Haynes (1994) report a major shift in Forest Service policy at the end of the Second World War. Before that time, National Forest timber sales had occurred as local mills asked the Forest Service for timber. After the war, the Forest Service became "...an active part of the timber supply"[13] and produced increasing amounts of timber into the 1960's. The result of this policy can be seen in Figure 5, Figure 6Figure 7 and Figure 8, as price volatility increases sharply in the mid-1940's.

This change in policy coincided with the end of the war, when war-related price controls were removed and five years of pent-up consumer demand for housing (and consumer goods shipped in wood boxes) could finally begin to be met. This surge in demand for wood products lasted well into the 1950's.

Note that southern pine sawtimber stumpage prices (Figure 6) do not show this increase in volatility, but do increase sharply at this time. Without the change in Forest Service, would Douglas-fir prices have been less volatile, but have risen more sharply?

Is a new era developing in Douglas-fir prices? Pre-1940's prices are from a period where the National Forests were not major contributors to the nation's timber supply. Since 1993, the National Forests have again become only minor contributors to the timber supply. Figure F1 shows the changes in timber harvest volumes sold and cut from Pacific Northwest Westside National Forests.

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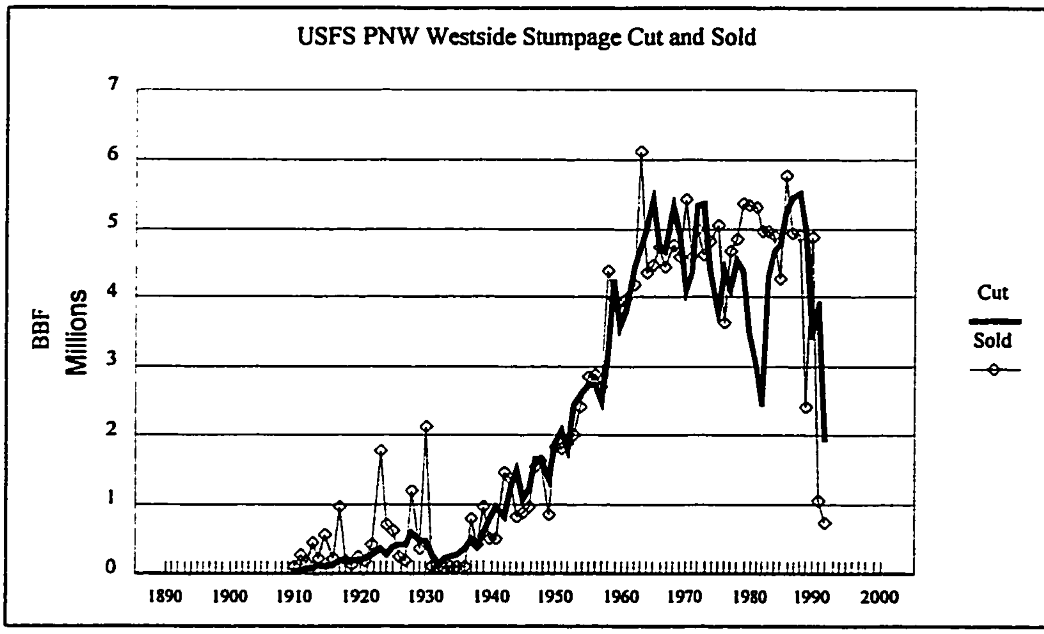
[13] Sohngen and Haynes, 1994, p. 11

Figure F1—National Forest Timber Harvests



Douglas-fir sawlog prices since 1993 have not shown the low volatility of the pre-1940's period, but perhaps prices will become less volatile over time?

This is *probably* unlikely as other factors affecting Douglas-fir prices have certainly changed since 1946. Among those factors are the method of establishing prices for National Forest stumpage.

Finally, if Douglas-fir prices *do* become less volatile, will the other series also become less volatile?

USFS Timber Sale Crisis

PNW Westside timber prices rose sharply after 1972. Douglas-fir stumpage prices jumped $100/MBF in 1973 and 1974—probably as a result of OPEC actions and energy shortages. There was a brief respite in 1975 and 1976 as the world adjusted to new price levels for energy, then timber prices rose even more sharply, up more than

$250/MBF between 1976 and 1980. This steady increase in stumpage prices continued in the face of falling lumber prices.

The stumpage buyers and the US Forest Service were quite aware that the prices being paid for stumpage were much higher than justifiable given lumber prices at that time, but both groups assumed lumber prices would rebound and cover the high stumpage costs. But this did not happen.

By 1982, prices had fallen over $300/MBF. The Forest Service allowed stumpage contract holders to extend contracts up to two years as long as interest payments were made. By the end of 1982, many of these extended contracts were beginning to expire. Given lumber prices and conversion costs at the time, the maximum that could be paid for stumpage was $60/MBF, but most of the contracts called for payments near $300/MBF.

The lumber industry asked Congress to nullify the overpriced contracts. President Reagan authorized five-year extensions in 1983, and Congress passed the Federal Timber Contract Modifications Act of 1984, which became law in October of that year. The Act allowed companies to buyout a maximum of 55 percent or 200 MMBF of contracts purchased before 1982, with the "buyout fee" depending upon the solvency of the company.

Mattey (1990) suggests two causes for this crisis: a change in macroeconomic conditions and a perceived timber shortage in the region. In 1979, the Federal Reserve Bank changed emphasis from controlling the short-tern Federal Funds rate to controlling growth in the money supply. "The tight-money, loose-fiscal-policy mix had a disinflationary effect. The GNP deflator slowed to about a 3-1/2 percent annual rate of increase in the last quarter of 1982, after beginning the decade at an 8-3/4 percent pace."[14] This caused a significant economic downturn, reducing demand for forest products.

On the stumpage side, there was a perception that timber in the Westside was running out. The supply of mature timber from private lands was believed to be becoming scarce and Forest Service volumes had leveled off in 1969. Mill owners got into a bidding war to keep their mills running.

The result of all this is a sharp boom and bust cycle in PNW Westside Douglas-fir prices that affected prices between 1975 and 1982.

Spotted Owl Crisis

In the late 1980's, there was increasing debate on the fate of old-growth forests on federal ownership in the West. This debate took on many forms—below-cost timber sales, the long-term contracts on the Tongass National Forest in Alaska, biodiversity, sustainability,, and finally, the northern spotted owl.

As the debate continued, stumpage prices on PNW National Forests rose. When National Forest sales were virtually halted in 1992/1993, lumber prices shot up and affected lumber prices as well. Between 1985 and 1994, sold stumpage prices rose from around $100/MBF to nearly $500/MBF and cut prices went from $125/MBF to

[14] Mattey, 1990, p. 13

$400/MBF. This forest policy effectively removed about 25 percent of the United States' wood supply.

While prices have moderated somewhat since their highs in 1994, Figure 5, Figure 6 Figure 7 and Figure 8 show prices for Douglas-fir from Westside National Forests are still higher (and more volatile) than prices before 1972.

And, while current real prices are higher than those before 1972, the "spotted owl crisis" did not send prices as high as the "timber sale crisis" of the previous decade. Why did an event that physically removed a quarter of the nation's timber supply not cause prices to rise as high as a "perceived" timber shortage. There may be a number of reasons why this may be the case.

The shock may have been anticipated by some. The judicial order shutting down timber sales was "sudden", but a number of industry players may have anticipated such a decision and assembled a private timber supply. These firms would not have been dependent upon public timber and would not have helped drive bid prices up higher.

Some companies may have been less dependent on old-growth. After the timber sale crisis, some firms would have built new mills designed to process second growth timber. These facilities would have been less dependent on old-growth timber from public forests and would not have helped drive up prices.

Some timber buyers were able to turn to other regions of the world for their wood supply. Large volumes of logs from the Pacific Northwest are exported to Pacific Rim countries like Japan, Taiwan and Korea. (National Forest and state timber is prohibited by law from the export markets, but industry would export their own logs and replace them in their mills with public timber.) As prices for logs from the US rose, the Pacific Rim countries looked for other sources of supply. The great radiata pine plantations of New Zealand and Chile were coming on line at this time. Korea is perhaps the most startling example of a country that found other sources—the western hemlock/radiata pine import relationship was 90 percent hemlock/10 percent pine in 1980, and has reversed to 10 percent hemlock/90 percent pine in 1996 (Davidson 1996).

It is also likely that substitution of other wood products and non-wood products helped moderate price increases. This shock occurred as OSB production was exploding (see above). The reduction in supply of peeler logs for producing western plywood occurred as OSB was putting price pressures on western plywood. With plywood prices under pressure, higher prices could not be paid for these logs.

Assembling private timber sources, international species substitution, and product substitution may have combined to keep the spotted-owl-crisis-real-prices of the 1990's below the timber-sale-crisis-real-prices of the 1980's.

Other Shocks

The Hurricane of 1938

This hurricane blew down about 2.5 billion board feet of timber, with the majority of the loss in white pine (Irland 1982). Irland notes that this was about equal to ten years of lumber production at that time. In order to avoid glutting the market, the federal government bought up much of this wood through the New England Timber Salvage Administration and released it slowly into the market up through the Second World War. This is a rare case of a supply shock being mitigated by a government agency instead of being caused by a policy change.

OPEC and the Energy Crisis

Howard and Chase (1995) studied stumpage price in Maine from 1963 to 1990 and reviewed other studies in the region. They found evidence of impact on timber prices from the OPEC oil embargo. In particular, they noted that Remington and Davis (1986) found a sharp rise in prices for all timber species and products beginning with the oil crisis between 1972 and 1974. Howard and Chase found that post-oil-crisis sawlog and veneer prices grew at higher nominal rates than pre-crisis prices. However, boltwood prices grew at a slower rate, which they attribute to a decline in the wood-turning industry in Maine. Sohngen and Haynes note a price increase in western National Forest stumpage prices at the time of the energy crisis, but found that prices fell quickly again due to a drop in GNP and housing starts.

The energy crisis is also the underlying cause of the growth in energy chip markets.

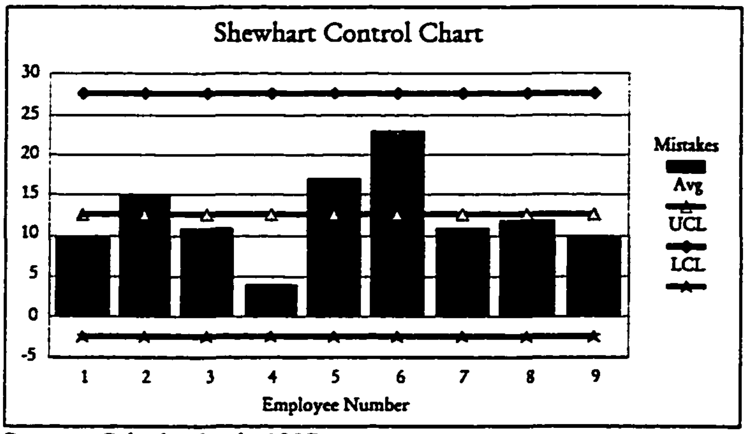
APPENDIX G

PROCESS CONTROL CHARTS

Introduction

Process control charts have been used by engineers for years. They have been particularly popular in Japan, where their use was promoted by W. Edwards Deming (Scherkenbach 1987). Typical control charts compare samples to a mean or expected value and to upper and lower control lines. In the chart below (Figure G1), production mistakes for a month for nine production workers are charted against a mean (Avg), upper control line (UCL) and lower control line (LCL). In this particular example, the UCL is calculated as the mean plus three standard deviations (σ) and the LCL is the mean minus three standard deviations. (The LCL is meaningless in this example because it is a negative number and no employee could make "negative" mistakes.) While employee #6 made the most mistakes at 24, this number of mistakes is considered as still within the system, because it lies within the UCL.

Figure G1—Shewhart Control Chart



Source: Scherkenbach, 1987

The above example compares mistakes made in a month by nine employees, but could just as easily measure the mistakes made over nine months by a single employee, or the measurement of a hole or thickness in a part being manufactured.

Setting Control Lines

Standard Deviations

A fundamental assumption in the use of control charts is that almost all points generated by the process lie within $\pm 3\sigma$ of the mean. This is true of a normally distributed population: nearly 100% of all observations in the sample lie within $\pm 3\sigma$ of the mean (Table G1).

Table G1—Observations included within $\pm k$ standard deviations under a normal curve

k	Area	Percent of Observations Inside the Area
0.674	$\mu \pm 0.674\sigma$	50.00%
1.000	$\mu \pm 1.000\sigma$	68.26%
1.960	$\mu \pm 1.960\sigma$	95.00%
2.000	$\mu \pm 2.000\sigma$	95.44%
2.576	$\mu \pm 2.576\sigma$	99.00%
3.000	$\mu \pm 3.000\sigma$	99.73%

Source: Sokal and Rohlf, 1981

If a population is not normally distributed, control charts can still be used with some degree of certainty. Scherkenbach (1987) notes even if a population is not normally distributed, but has a mode that equals the mean and observations continuously decline on both sides of mode, the probability of being within $\pm k\sigma$ is:

$$p = 1 - \frac{1}{(2.25 \times k^2)}$$

If $k = 3$, then the probability of being within $\pm 3\sigma$ is 95.1 percent.

Chebyshev's inequality (Hogg and Tanis 1983) says that, no matter what the distribution, the probability of being within $\pm k\sigma$ is:

$$p = 1 - \frac{1}{(k^2)}$$

If $k = 3$, then the probability of being within $\pm 3\sigma$ is 88.9 percent.

Alternatives to Standard Deviations

Over time, engineers have developed a number of alternatives to using the standard deviation in setting control lines (ANSI/ASQC 1978). Many of these alternatives are short-cut ways of estimating the standard deviation when slide rules are available but calculators and computers are not. Scherkenbach (1987) estimated the standard deviation for one example by simply taking the square root of the average of the observations. In this case, the actual standard deviation of the sample observations was 5.3, while Scherkenbach's estimated standard deviation was 3.5. This would result in control lines closer to the mean than if the true standard deviation was used.

Nelson (1982) discussed control line calculations for individual measurements. He recommended using the average of the moving range (MR) and estimating the standard deviation by dividing the average MR by the factor of ranges for two (1.128 from ANSI/ASQC Standard A1-1978). The UCL and LCL are calculated as follows:

$$\bar{X} \pm 3\sigma$$

$$\bar{X} \pm 3(\overline{MR}/1.128)$$

$$X \pm 2.660(\overline{MR})$$

where ***X-bar*** is the mean of the observations. The moving range is calculated by taking the absolute values of the differences between observations—the absolute value of the first difference. Nelson states the use of the moving range of two "...minimizes inflationary effects on the variability which are caused by trends and oscillations that may be present. It measures variations from point to point irrespective of their average level."[15]

Ishikawa (1976) provides a table of factors based on the size of the sample groups (Table G2). The upper control line is calculated as:

$$\bar{X} \pm A_1 \bar{R}$$

[15] Nelson, 1982, p. 172

where ***X-bar*** is the average of the observations and ***R-bar*** is the range of the sample set—the difference between the highest and lowest observation. If each sample subset contains three data points, the upper and lower control lines would be calculated as:

$$\bar{X} \pm 1.023\,\bar{R}$$

Table G2—Coefficients for Ishikawa mean and range control charts

n	A_1	A_2	A_3
2	1.880	3.267	n.a.
3	1.023	2.575	n.a.
4	0.729	2.282	n.a.
5	0.577	2.115	n.a.
6	0.483	2.004	n.a.
7	0.419	1.924	0.076

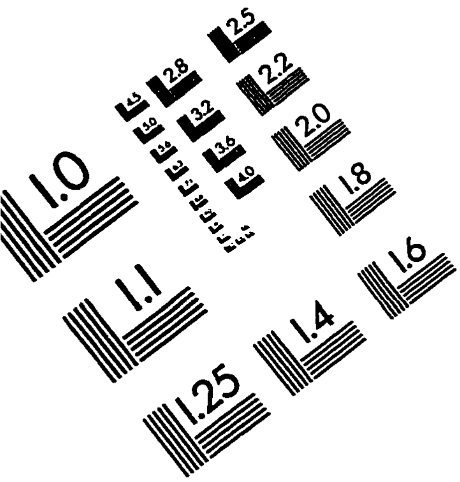
Ishikawa also constructs a control chart for the range or *variability*. The equations for the UCL and LCL are:

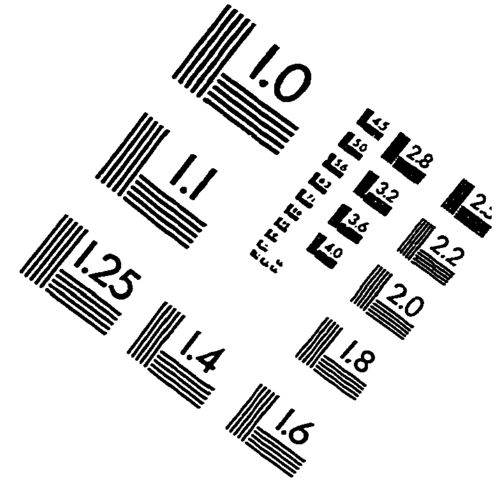
$$UCL = A_2\,\bar{R}$$

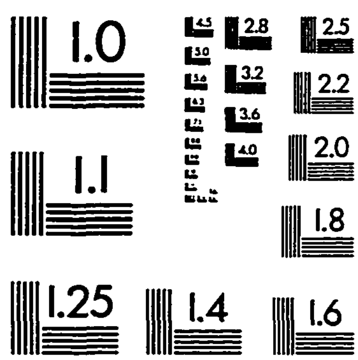
$$LCL = A_3\,\bar{R}$$

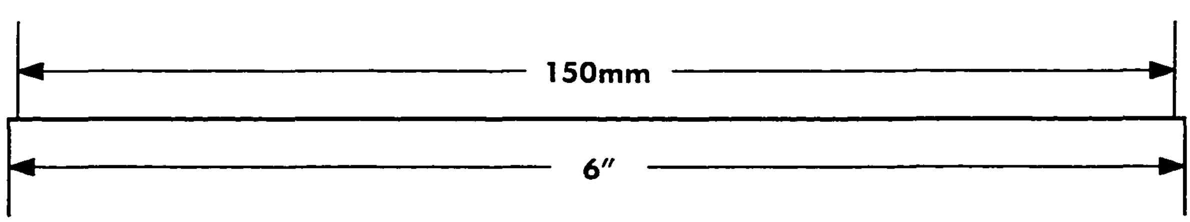
Note that the LCL is only calculated for subgroups of seven observations.

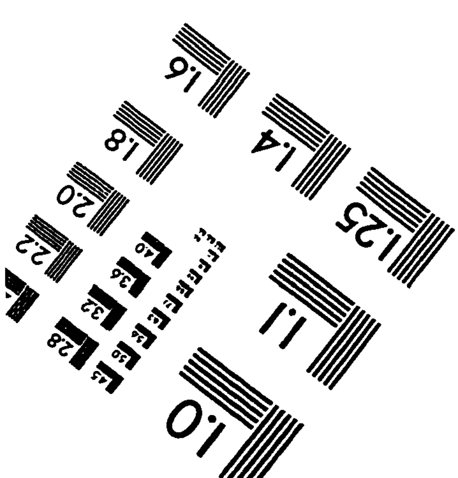
IMAGE EVALUATION TEST TARGET (QA-3)

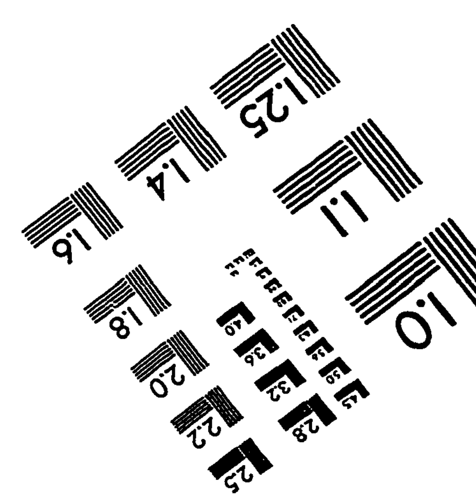












APPLIED IMAGE, Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989