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Statistical Process Control Adapted to Surveillance of Cash Cattle Markets

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Introduction

A number of public and private entities have a need to monitor or to perform market surveillance to reduce undesirable impacts upon firms, sectors, or society as a whole. Public regulatory agencies have a legal obligation to perform market surveillance whereas private entities have a need to monitor individuals' conduct to prevent behavior that could have undesirable impacts upon the firm. A number of examples of breakdowns can be pointed out; such as, the savings and loan industry problems. These problems could be seen as a breakdown of effective market surveillance and regulation both from the perspective of some individual firms and from the public regulatory agencies with the responsibility to regulate this industry.

Market surveillance is a multifaceted problem which can be approached at several different levels. One of the initial problems encountered at the first level of market surveillance is the need for a systematic procedure to distinguish "regular" from "irregular" market behavior. The procedure(s) used to identify irregular market conditions should be timely, low cost, and efficient. We describe the development of a systematic method to identify regular and irregular behavior in selected fed cattle markets. The approach merges time series modeling with traditional quality control techniques [1].

Structural changes in the cattle industry have resulted in increased packer concentration and raises the possibility of manipulation in the cash markets and, therefore, the need to identify irregular market behavior. Buyers may move reported prices in their favor at times by selective price reporting, misreporting, or using supply and demand conditions to alter price levels and reported prices. While this paper uses the fed cattle markets as an example, the methodology could be applied to any set of related markets.

Quality control methods are most frequently associated with monitoring repetitive manufacturing processes. The application monitors a process to see if the output of the manufacturing process is falling within some acceptable standard of quality, as specified by the user.

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Deviations outside of these standards indicate that the process is out of control and action should be taken to identify and correct the causes. Quality control methods are used to indicate if corrective actions are required based upon user-established performance standards.

In this paper, selected fed cattle prices, expressed as price ratios, are filtered through time series models to remove the systematic patterns to allow for the analysis of the generated residuals. The greater the amount of systematic patterns within the price ratio series explained by the model, the smaller the unexplained residual remaining. Standard quality control methods using control-chart procedures are applied to the generated residual series to determine if the process is in a state of statistical control. Monitoring the price ratios within a time series model provides a methodology to quickly compare price relationships between the cash cattle markets and identify any irregular price behavior among the cattle markets.

Data Sources

Weekly observations were selected for the surveillance activities. Daily cash prices were rejected because they require too many resources, presented problems for handling 2- or 3-day per week markets and had trading day differences. Monthly, quarterly, or annual observations were also rejected because they were too infrequent and irregular price variations were likely masked due to the averaging process. Weekly observations provide sufficient detail for irregular price behavior to be identified by the surveillance activities.

Weekly average prices for Choice Steers 1/, 900 to 1000 pound Yield Grade 2-4 published in the Livestock, Meat, and Wool Market News [6] were assembled from January 4, 1974 through December 30, 1988. Texas, California, Colorado, Nebraska, and Iowa were selected for the development phase of this project so that each major fed cattle production area was represented. The total data set contains 783 weekly observations for each market. 2/

Weekly cattle prices appear to follow an irregular seasonal pattern (Figure 1). No regular seasonal price patterns were identified that could be modeled. Prices held in the upper-$30's per hundred weight to low-$50's from 1974 through 1977. Prices trended sharply higher during 1978 to peak near $80 in early 1979. After peak levels in early 1979, Choice steer prices fluctuated in a fairly broad band of the low-$60's to low-$70's, except for a brief period in 1985.

Cattle prices for the five markets were highly correlated (Figure 2). The lowest correlation coefficient between any of the markets was 0.9868 for the Iowa and California cattle markets. While Figure 2 demonstrates that price changes and price movements between the five markets were very similar, closer examination shows that differences do exist. For example, from October 31, 1980 through March 27, 1981, the California cattle market prices were consistently greater than the other four markets; California prices exceeded the Texas, Colorado, Nebraska, and the Iowa markets on the average by $2.66, $3.86, $4.93, and $5.29 per hundred weight,

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1/ California, Texas, and Colorado are direct markets, and Omaha, Nebraska and Sioux City, Iowa are terminal markets. The direct markets typically are quoted with a 4 percent shrink from feedlot weight, whereas terminal market price quotes are for actual scale weights.

2/ A few weekly observations were unquoted and values were estimated based upon price relationships among markets before and after unquoted weeks.

Figure 1: Weekly Live Cash Cattle Prices - 900/1000
1974 - 1988, $/cwt

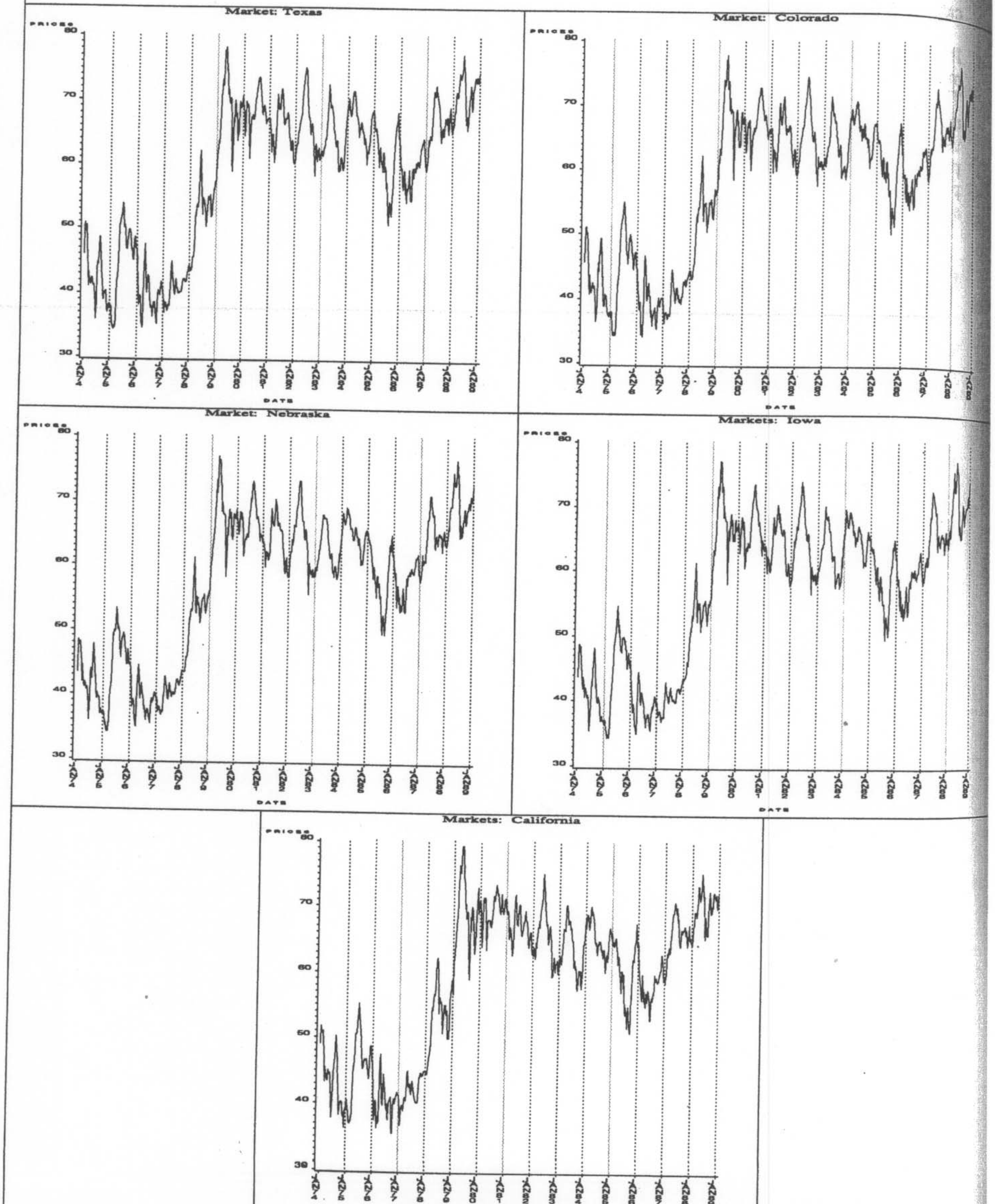
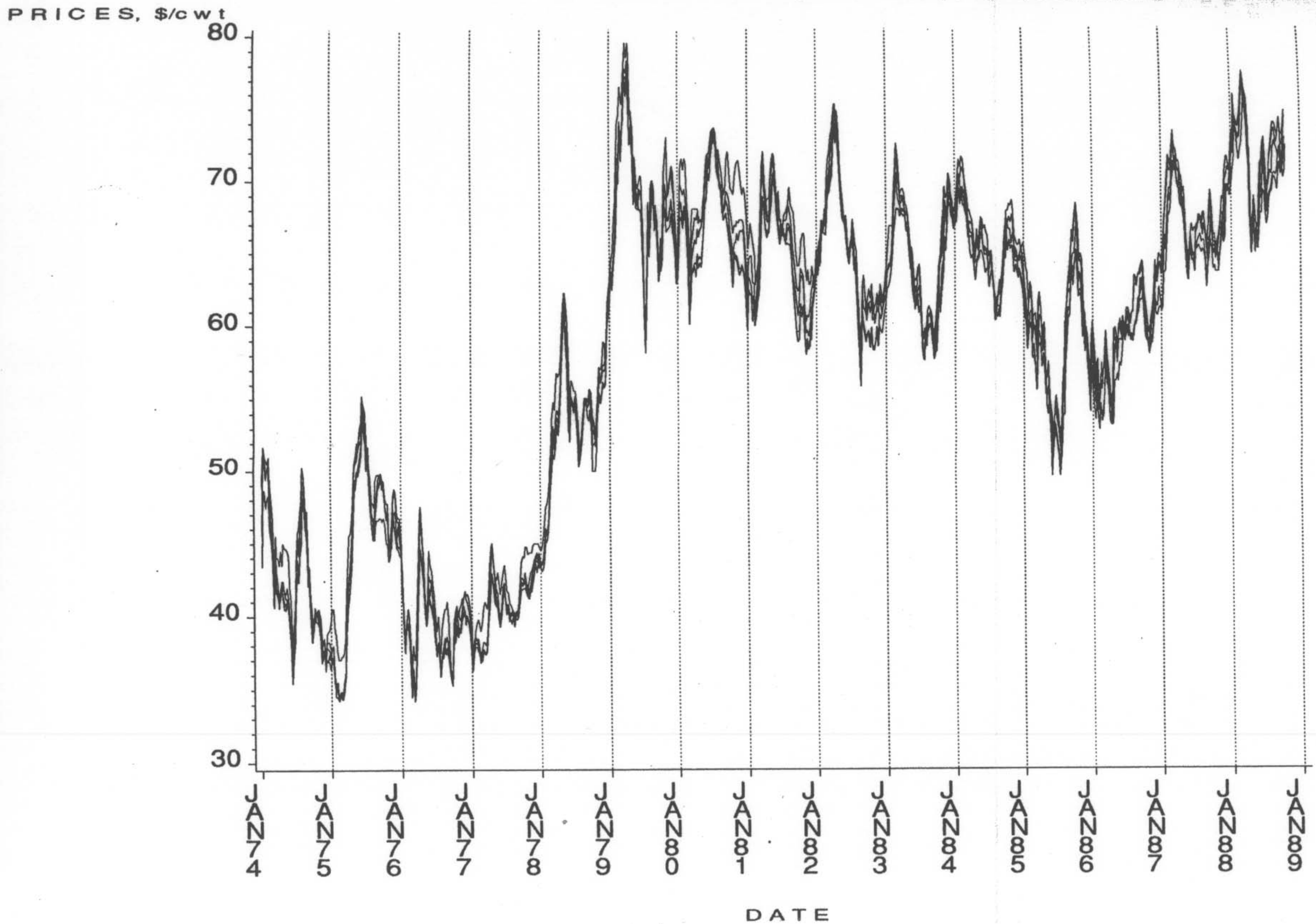


Figure 2: Weekly Live Cash Cattle Prices - 900/1000
Markets: Texas, Colorado, Nebraska, Iowa, California
1974 -1988



respectively. For the entire period, these differences averaged $0.14 for Texas, $0.55 for Colorado, $1.47 for Nebraska, and $1.25 for Iowa.

The direct surveillance of nominal cash cattle prices for an individual market was not seen as a good alternative. Nominal prices for an individual cash market can be modeled and the residuals of the actual prices from the forecasted prices can be analyzed for irregular price behavior using a statistical control chart procedure. But, there is no direct linkage to compare that individual market price to other cattle markets. Whereas, a modeling approach which uses a price ratio, directly links comparisons between the two market prices used by the ratio.

Price Ratio

A ratio of an individual market's price to some reference price series provides a mechanism for comparing that market's price relative to the reference price. Rather than selecting a major market as the reference series, an unweighted simple average of 5 major markets prices was used. Given that the price levels and price movements were highly correlated among the markets, a price ratio provided a quick, simple way of analyzing each individual market's price behavior in relation to what was happening in the other markets represented by the reference series.

A price ratio for a market equal to 1.0 means the market price is the same as the reference price. The Texas market's price ratio deviated around 1.0 before 1979, but after 1979 the price ratio has generally been greater than 1.0 (Figure 3). Before 1983, Colorado's price ratio deviated around 1.0 but after 1983, the ratio has generally been above 1.0. Nebraska's price ratio generally was less than 1.0 for the entire period. The Iowa market's price ratio also was generally less than 1.0, but the price ratio shows a number of high peaks. California's price ratio shows the greatest variation among the five markets. From 1974 to 1982, California's price ratio was generally greater than 1.0, but since 1982 the price has deviated more closely around 1.0.

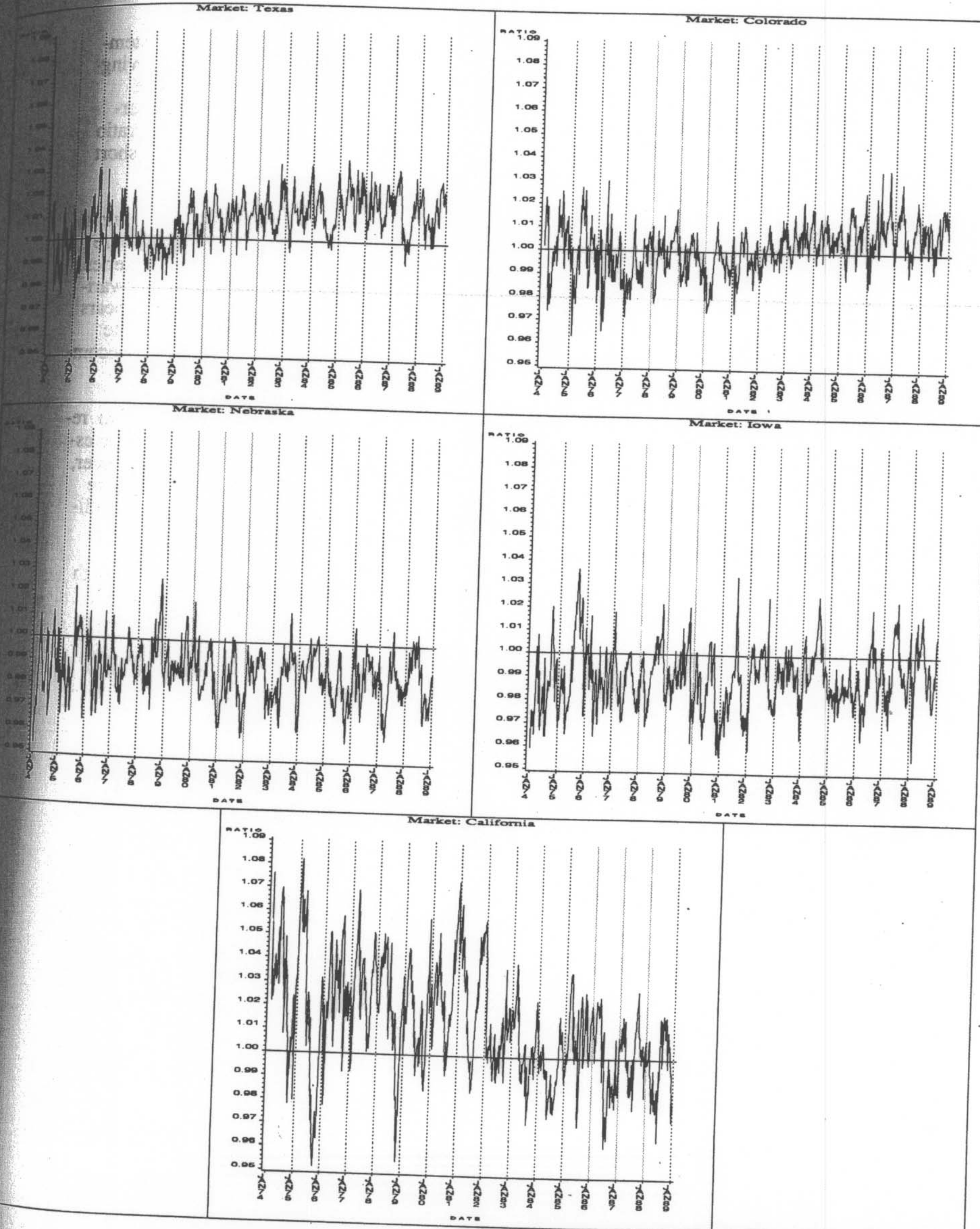
Adapting a Statistical Control Procedure for Market Surveillance

In this market surveillance example, identifying the presence of irregular price behavior quickly was desirable so that further follow-up investigations could be started in a timely fashion. A state of statistical control was identified with a random process: a process that generates independent and random observations. Departures from a state of statistical control were typically reflected in extreme individual observations (outliers) or aberrant sequences of observations (runs above or below a level or runs up and down) [8,9].

Departures from a state of statistical control are usually identified by plotting and viewing control charts. In practice, to identify a state of statistical control or departures from one is difficult due to the presence of systematic nonrandom patterns. The presence of systematic nonrandom patterns throughout the data makes it hard to distinguish between nonrandom causes (common or assignable causes) or other departures from statistical control (special causes). Special causes, a term suggested by Deming [5], refers to a random departure from statistical control which may be explained by some specific local conditions such as weather, mud on cattle, labor problems, price manipulation, or other causes.

Systematic nonrandom patterns or assignable causes in an economic time series are such things as trends, cycles and seasonal components. The plot of the weekly cattle price ratios of the five markets to the reference price series illustrates the presence of systematic nonrandom pat-

Figure 3: Ratio of Weekly Cattle Prices to Average Price
1974 -1988



terns which are clearly not independent nor random. The application of standard control-chart procedures to the unfiltered ratio series can be seriously misleading if used to identify irregular price behavior.

Different forms of time-series models were tested as filtering mechanisms to remove systematic nonrandom patterns from the price ratio series. The autoregressive-integrated-moving-average (ARIMA) class of time series models fits a wide variety of data series and can provide accurate short-term forecasts. These models make forecasts based on past performance of data series and are of greatest use when the factors which effect the cattle price ratio series are expected to behave in the future much the same way as the past [2,4,7]. In the short term, this is often a reasonable assumption.

Models were estimated for each of the selected cattle markets to remove the systematic nonrandom components present in the fed cattle price series. The best fitting models estimated were ARIMA(2,0,0) models. The ARIMA time series models are designed for stationary time series [2,4,7]. Weak stationarity of a time series is achieved when the means, variances and covariances remain constant over time. By making a ratio of the cattle price data, the series appears to meet the conditions of weak stationarity. This can be observed by viewing the plot of the ratio series, Figure 3. By fitting the price ratios with the ARIMA model, the series was decomposed into random and nonrandom components.

A sliding 5-year sample period was used to allow the parameter estimates of the models to reflect the most recent data. This results in 260-262 observations per 5-year period used to estimate each model. Models could have been developed across the entire time series. However, after comparing the estimates using a sliding 5-year period with the estimates for the entire period, the 5-year sample period was selected due to the stability of the coefficients. In addition, the adoption of the sliding 5-year sample period eases the task for adding markets.

The Texas market is presented for illustrative purposes for each 5-year period, starting with the 1974-1978 time period (Table 1). The coefficients of the models have been fairly stable over the 14 year period using 5-year intervals. The standard deviations show the total variation in the 5-year ratio series while the standard error of the projection indicates the random variation or the variation of the residual series after the model has been fitted. The latter statistic shows the amount of variation that is explained by the models. The other models had similar results.

Detection of Irregular Price Behavior

Once the time-series models were properly fitted to the data, the residuals that were left should be randomly distributed around a mean of 0. The practical emphasis then shifted to analyzing the residuals. In other words, the systematic nonrandom patterns (common causes) were modeled and what was left was the unexplained, random residuals (special causes). The residual series were then examined for departures from a state of statistical control.

In our example, quality control techniques were used to identify irregular price behavior. A standard control chart for residuals was used in traditional ways to detect special causes, without the risk of confounding special causes with common causes.

Since a 5-year sliding sample was used in modeling, the residuals were generated by using the most recent 5-year period to estimate the model coefficients and then these estimates were used to estimate the predicted price ratio. The residual was calculated by subtracting the

Table 1: AR(2) Parameter Estimates for the Ratio of Weekly Texas Cattle prices to the Average Price

Year	Number of Observations	Mean	a	b	c	Standard Deviation	Standard Error of Projection
1974-1978	261	0.999	0.2644	0.6498 (0.062)	0.0858 (0.062)	0.0105	0.0074
1975-1979	261	1.002	0.2484	0.6364 (0.062)	0.1157 (0.062)	0.0101	0.0070
1976-1980	261	1.003	0.2506	0.6524 (0.061)	0.0977 (0.062)	0.0094	0.0065
1977-1981	260	1.005	0.1820	0.6919 (0.062)	0.1269 (0.062)	0.0091	0.0055
1978-1982	261	1.007	0.1713	0.6890 (0.061)	0.1411 (0.062)	0.0092	0.0055
1979-1983	261	1.011	0.2334	0.6849 (0.062)	0.0842 (0.063)	0.0080	0.0054
1980-1984	261	1.012	0.2059	0.7808 (0.062)	0.0157 (0.063)	0.0078	0.0049
1981-1985	261	1.014	0.2041	0.7484 (0.062)	0.0502 (0.062)	0.0083	0.0051
1982-1986	261	1.014	0.2191	0.6840 (0.062)	0.1001 (0.062)	0.0082	0.0054
1983-1987	260	1.014	0.1827	0.7200 (0.062)	0.0998 (0.062)	0.0089	0.0053
1984-1988	261	1.014	0.1856	0.706 (0.062)	0.1110 (0.061)	0.0087	0.00522

* Numbers in parenthesis are the Standard Errors of Estimates

actual observed price ratio from the predicted. At the end of a calendar year, the most distant year was dropped and the most recent year was added and the model was re-estimated for the next year.

Control charts of the residuals for the five fed cattle markets are shown in Figure 4. We set control limits on the chart as plus or minus 1.5 and 2 times the standard error from the model and referred to them as tolerance and action limits, respectively. Residuals outside these limits could be used to signal if the process was out of control or irregular and further follow-up investigation was warranted. 95 percent of the residuals are expected to be within plus or minus 2 times the standard error if the residuals are normally distributed with a mean of zero. Therefore, 5 percent of the residuals may fall outside the action limits by chance.

Control limits change each year due to the re-estimation of the model. The control limits have been set based on the total number of outliers. These limits can be increased or decreased based on the surveillance personnel's experience and the amount of resources that could be devoted to surveillance activities.

A list by date of the observations which fall outside of the plus or minus 1.5 standard deviation limits for the Texas cattle market from 1979 through 1988 is given in Table 2. Out of a total of 522 observations, 56 fell outside the tolerance limits and 22 fell outside the action limits.

Identification of Runs in the Residual Series

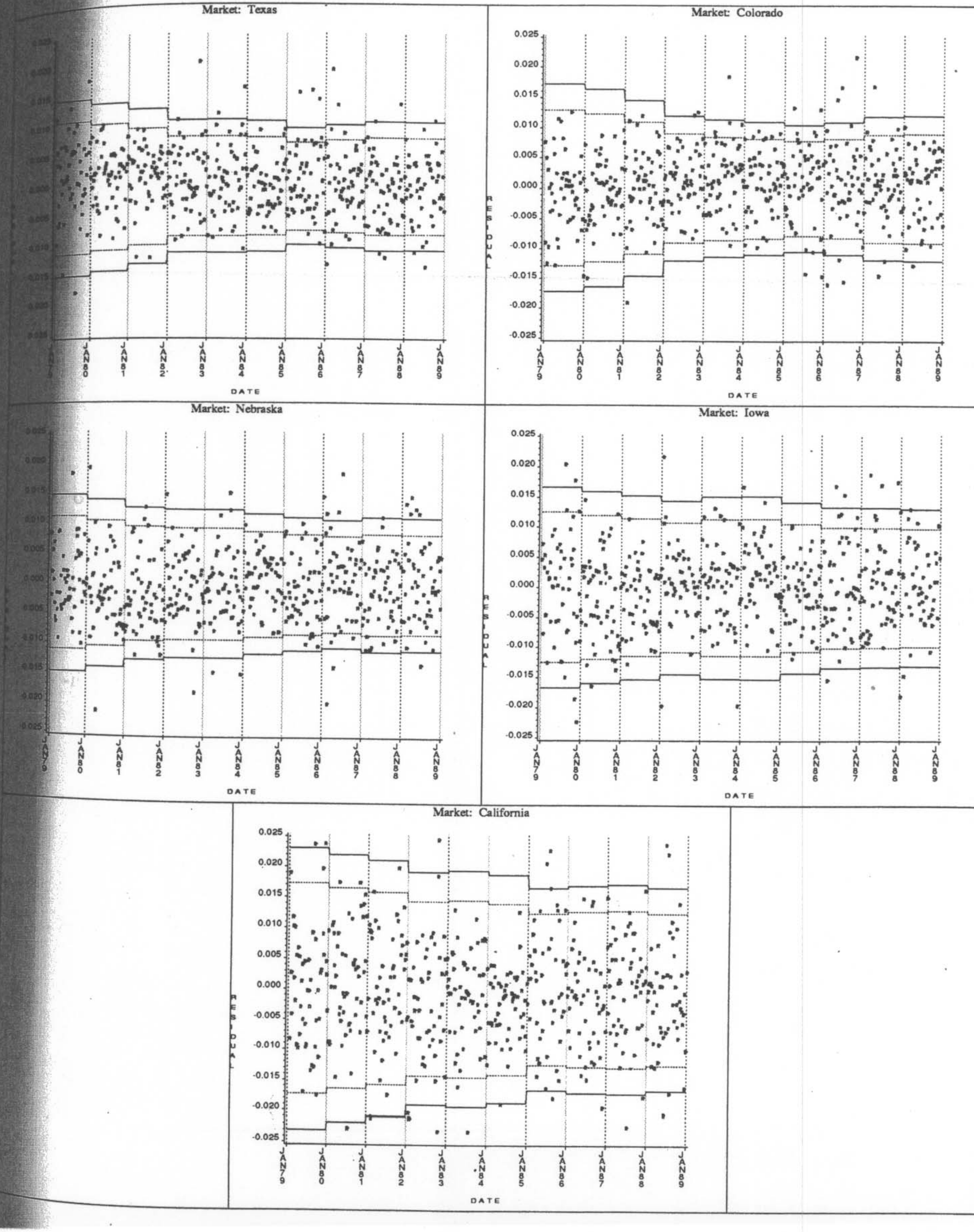
One of the crucial assumptions concerning the residuals in a regression framework is that they are randomly distributed. If systematic patterns exist within the residuals, they may not be detected by analyzing the residuals for single weekly observations using statistical control chart procedures. A runs test has been developed for testing the randomness assumption.

The runs test applied to the nominal weekly cash price series suggests the process was nearly continually out of control, with frequent positive or negative runs. Therefore, the runs test is applied to the residuals series, instead. The probability of getting 6 consecutive positive or negative values is 3.125 percent. A run of 6 consecutive points has been selected as the value where further follow up actions should be initiated to examine the nature of the run of residuals. The control chart plot for Texas reveals a number of intervals for which run counts would suggest some suspicion of lack of control. Since the residuals are expected to be randomly distributed around the mean of zero, a process with a number of consecutive positive or negative residuals, a downward or upward trend, or a cyclical pattern is an indication of the lack of stability or control. A number of tests could be devised to test the randomness of the distribution of the residuals. [10]

Examining the pattern of the residuals for the Texas market, 10 positive runs of 6 or more consecutive weeks were found. Two of the runs had 9 positive values, one had 8 values, three had 7 values, and four had 6 values. Most of the runs occurred in 1979 through 1982. There have been no significant runs in the Texas market over the most recent 3 years (1986-1988).

Another form of the runs test is being investigated which may be a stronger test than the runs test for the fed cattle example. This statistic is intended to highlight unusual trends in the residuals where residuals are accumulated and the larger residuals receive more weight. This technique is commonly called the cumulative sum (CUSUM) chart [3]. The CUSUM chart is in reality a type of sequential analysis, since it relies upon past data for monitoring statistical control.

Figure 4: Control Limits for Weekly Cattle Prices
1974 - 1988



The test statistic takes the following form:

$$C = \sum_{i=1}^{4} (WSR_4 - WASR_4)$$

where

C = Test Statistic
WSR_4 = 4 Week Sum of Residuals
$WASR_4$ = Average of 4 week Sum of Residuals
i = week 1 to 4

The control limits, based on 1.5 and 2.0 times the standard error (assuming independent, normally distributed random observations) were applied to the Texas cattle market (Figure 5.) The upper and lower limits show the total amount of drifting from zero, as the last term ($WASR_4$) is close to zero. But, the calculation of the variance is actually more complex due to the violation of the assumption of independence between observations. It is also important to know how long it takes to reach such a limit. Further investigation is needed to develop techniques that use a V-shaped mask to make a test after each new observation arises [3].

Areas for Further Investigation

Market surveillance activities could be improved by extending the surveillance coverage to additional related markets within the cattle subsector such as wholesale beef, retail beef, feeder cattle, live cattle futures, and option markets.

Various time-series models such as the Kalman filter should be explored to see if further improvements could be made to the models that are used to filter the systematic nonrandom patterns.

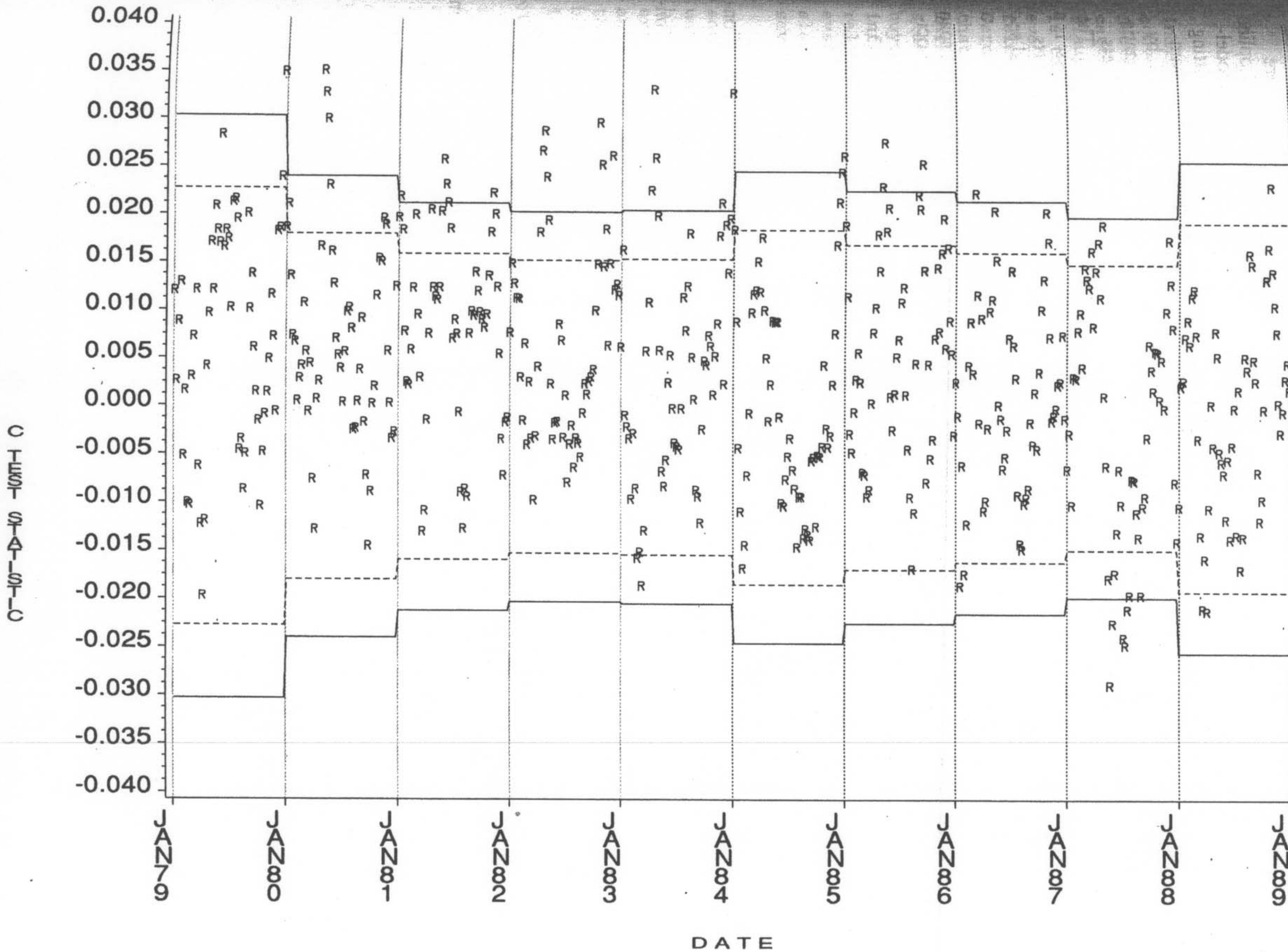
Further investigation is needed to develop the cumulative sum chart (CUSUM) for evaluating runs and trends within the residuals.

Once irregular price behavior is identified, further research is needed to develop techniques to explain and quantify these causes.

Conclusions

This paper investigates tools and techniques to aid in surveillance of livestock and meat markets using cash fed cattle markets as an illustration. An initial level of market surveillance,

Figure 5: Control Limits for 4-week Accumulation of Residuals
Market: Texas



the ability to distinguish "regular" from "irregular" market behavior in a systematic, timely, efficient, and low cost manner was investigated by adapting statistical control chart methodology. Weekly Choice steer prices from January 4, 1974 through December 30, 1988 were collected in five selected markets. Control chart procedures could not meaningfully be applied directly to the nominal prices so a price ratio approach was developed with time series modeling approaches applied as a filtering device. ARIMA(2,0,0) models provided the best fitting filtering device tested, and models were developed for 260-262 weeks per 5-year sliding sampling periods to forecast the weeks one year outside the sample. Residuals were calculated by subtracting the actual weekly price ratio from the model predicted price ratio. Standard statistical control chart approaches were directly applied to the weekly residual series by markets and assume that the residuals are independent, normally distributed with a mean of zero. The ability to distinguish runs or trends in the weekly residuals using control chart approaches is a more complex problem. The simple runs test for randomness and cumulative sum charts (CUSUM) were two approaches used to identify trends, cycles, and patterns in the residual series.

Once "irregular" market behavior has been identified, either for individual weeks or for a span of weeks, market analysis tools should be developed to explain and quantify the factors associated with these special causes.

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