RURAL ECONOMY

PROJECT REPORT

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An Econometric Analysis of the Relationship Between Alberta and United States Livestock Markets

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Abstract

This study uses Vector Autoregressions to investigate and measure the relationship between Alberta slaughter steer prices, United States - Canada exchange rates, Texas slaughter steer prices, nearby live cattle futures prices and live animal exports to the United States (in dollars). The general conclusions are that the exchange rate has a relatively smaller impact on Alberta slaughter steer prices than do U.S. steer markets. Shocks to the exchange rate result in a smaller change to Alberta prices than equally likely shocks to the U.S. futures price. Typically over 1 month periods the U.S.-Canada exchange rate does not play a big role in changing Alberta prices. This may be due to the relative stability of the exchange rate over shorter time periods relative to U.S. cattle prices. Live animal exports are more sensitive to changes in other variables not included in our model than to U.S steer prices, Alberta steer prices or exchange rates. These results have possible implications for Alberta cattle feeder investors. The stronger influence of the futures prices on Alberta prices suggest that Alberta investors first look at the futures market for the price information that most strongly influences the Alberta market. The close relationship of the Alberta market and the futures market implies that the futures market can be used by Alberta cattle investors for risk management. There still exist local Alberta factors that contribute to price risk but the U.S cattle market is the major source of price risk.

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Introduction

The cattle feeding industry is a major sector in the agricultural industry in Alberta. One large source of risk in this industry is slaughter price risk. This price risk affects the success of individual cattle feeder investment programs and the success of different government policies on the cattle feeding industry. Potential sources of Alberta slaughter cattle price instability include U.S. cattle market prices, U.S.-Canada exchange rates and local Alberta factors. These sources of risk must be identified and compared before policy makers can develop effective stabilization policies. Individual cattle investors must also identify the sources of price risk and the relative impact of each source of risk on local prices before they can develop effective individual risk management strategies. This study examines and compares several different sources of risk that affect Alberta slaughter steer prices.

The market for cattle and hogs in North America is relatively free of restrictions. This allows for exports and imports of livestock between Canada and the United States. The law of one price, such as discussed by Carter et al. (1990), should mean that Alberta slaughter steer prices differ from U.S. cattle markets only by the transactions costs of moving from the Alberta market to the U.S. market. The large size of the U.S. cattle and hog market relative to the Canadian market also suggests that North American livestock prices are set in the U.S.. Canadian production and prices have little long run impact on these markets. Carter et al. (1990) concluded in their study on exchange rate pass through, Canada-U.S. exchange rate changes have little impact on relative slaughter cattle prices between the two countries.

Vector Autoregression (VAR) is one statistical tool used in the past decade to measure the relationship between macroeconomic variables and agricultural variables (Mount (1989), Todd (1989)). Orden and Fackler (1989), Taylor and Spriggs (1989), Adamowicz et al. (1991), Bessler (1984) and Robertson and Orden (1990) investigated the interaction of general macroeconomic variables such as money supply and exchange rates on general agricultural price levels using VAR. Canadian studies by Jennings et al. (1990) and Higginson et al. (1988) and a United States study by Bessler and Babula (1987) used VAR to investigate the impact of macroeconomic variables on specific commodities.

This study uses VAR to investigate and measure the relationship between Alberta slaughter steer prices, United States - Canada exchange rates, Texas slaughter steer prices, nearby live cattle futures prices and live animal exports to the United States (in dollars). Policy is often concerned with stabilizing income or reducing the variability of farm producer income. An understanding of the sources of livestock price variation on a particular sector of the agricultural industry and some measurement of the impact these sources have on agricultural prices will help in policy formulation and analysis. This study tries to determine if the conclusions of Adamowicz et al. (1991) and Taylor and Spriggs (1989) that exchange rates have a large impact on general agricultural price levels, carries through to the specific commodity of slaughter cattle. Also this research investigates whether the United States slaughter cattle price or live cattle futures price has a major impact on the Alberta slaughter prices. These results have implications for determining future research directions on risk management for Canadian cattle investors. The more closely the Alberta market is tied to the United States market, the more usable the risk management alternatives available in the United States are to Alberta cattle feeders.

The remainder of the study is organized as follows. The data sources and the selection of the particular variables are discussed first. A five variable VAR model incorporating U.S.-Canada exchange rates (U.S. dollars to buy one Canadian dollar) (EX), Alberta slaughter steer prices (ASP), Texas slaughter steer prices (TSP), Chicago Mercantile Exchange live cattle nearby futures prices (FSP) and live animal exports in dollars to the U.S. (EA) is then estimated. The final VAR model provides information on the relationship between the Alberta slaughter steer price and the different variables in the VAR model. The major model results are analyzed and the conclusions are presented in the final sections of the report. The Appendix contains the technical details of the methodology, model development, model estimation and the detailed results.

Data Description

The monthly data collected covers the time period of March 1976 to June 1992. All prices were collected in nominal dollars of the home currency. The data originally consisted of the Alberta live cattle slaughter steer price (ASP), the Texas live cattle steer price (TSP), the Chicago Mercantile Exchange nearby live cattle futures contract (FSP), the dollar value of live animal exports to the United States (EA), the United States - Canada exchange rate (EX, number of U.S. dollars to buy one Canadian dollar), the Canadian T-Bill interest rate and the United States T-Bill interest rate. All cattle prices are in dollars per hundredweight. The reasons for choosing these particular variables are discussed next.

This study investigates the relationship between the Alberta and United States slaughter steer markets. Alberta is currently Canada's major cattle feeding area and is also a major cattle feeding area in the North American cattle feeding industry. The Alberta steer price is a good proxy for the Western Canadian feeding area. The Texas slaughter steer price represents the price received by cattle feeders in one of the most important cattle feeding areas in North America. Including this variable lets us explore the relationship between two cattle feeding markets. The nearby futures price should represent cattle feeding prices (and investor information) from all parts of North America, not just the Texas or Alberta feeding areas. It is possible that the Alberta price is more closely related to the futures price than the Texas price. Also, the futures market is one possible tool for risk management by the Alberta cattle feeder. More information on the relationship between Alberta's local price versus the futures price is useful in determining the role of the futures market in risk management. The exchange rate, a major macro economic variable, is included since the Alberta cattle market is in a different country than the major United States market and changing exchange rates are expected to change local Alberta slaughter prices. The live animal exports in dollars should be related to the relative difference between the prices in the two countries. A major portion of dollar value of live animal exports includes slaughter cattle exports. Changing cattle prices and changing exchange rates should change the level of live animal exports.

The interest rates (T-Bills) from the United States and Canada were originally included as a second macro economic variable strongly related to the exchange rate. The simple interest rate parity theorem suggests that the local spot exchange rate is proportional to the ratio of interest rates[1]. This ratio of interest rates was subsequently dropped from the model to reduce the number of parameters and improve the model adequacy[2]. Further exploration using this variable may be worthwhile to pursue given a longer data series and different study objectives.

The Alberta cattle prices were obtained from the Alberta provincial government. The futures prices are from the Chicago Mercantile Exchange. The remaining variables were obtained from Statistics Canada, CANSIM data base. The livestock prices and exports, ASP, TSP, FSP and EA, were logged to linearize exponential growth in these variables. The exchange rate, EX, was not logged since it is a non trending data series. The EA was scaled down by 1,000,000.

The ordering of the data, when generating output from the VAR models, the Impulse Response Function graphs and the Variance Decomposition graphs, is important because of the identification restrictions used in VAR models[3]. A brief description of the Impulse Response Function and the Variance Decomposition is provided in the next section. The EX (exchange rate) is ordered first followed by FSP (futures steer price), TSP (Texas steer price), ASP (Alberta steer price) and EA (animal exports). This implies that at time 0 when a single positive non recurring independent one standard deviation shock is administered to the EX equation, all other variables are contemporaneously affected. A single non recurring independent shock to the FSP contemporaneously affects TSP, ASP and EA. A single non recurring independent shock to TSP contemporaneously affects ASP and EA but not EX at time 0 and so on. The effect of the single period shock to a lower order variable can filter back up to other variables **after** time 0 but not at time zero. The reasoning behind this ordering of the data is as follows. The EX is the major macroeconomic variable and should not be contemporaneously affected by the other variables. Results in Adamowicz et al. (1991) suggest that Canadian agricultural prices have little impact on exchange rates. The FSP and TSP are assumed to be more important in setting North American livestock prices than the much smaller Canadian livestock sector. This ordering assumes the futures market has an immediate impact on the Texas market. It is assumed that prices in either the United States or Canada affect live animal exports. Essentially, exports are assumed to be a function of livestock prices in the two countries and exchange rates. These data are used in the VAR model estimated in this study. A brief explanation of VAR modelling and selected model results is presented next.

Results

Vector Autoregression (VAR) models are multiple time series models and VARs jointly estimate a time series equation for each variable. The two main uses for VARs are for forecasting future values and for exploring the dynamic interrelationship between variables. This study focuses on the dynamic aspects of VAR modelling. The estimated VAR model captures the dynamic interrelationships between the model variables without initially imposing a particular structure on the model. To estimate this model, the five variables, Alberta slaughter prices (ASP), nearby live cattle futures (FSP), Texas slaughter prices (TSP), U.S.-Canada exchange rates (EX) and live animal exports to the U.S. (EA) are placed in the five equation model. Historical observations (lagged values) of each of the variables are included in all five equations used in the model. These historical (time series) values are used to capture the dynamic interactions between the variables. The mathematical details behind this description are contained in Appendix A.

The estimated VAR model is used to test the strength of the relationship between the Alberta livestock market and the U.S. market (referred to as Granger causality tests in Appendix A) and to measure the dynamic relationships through Impulse Response Functions and Variance Decompositions. The method and steps for developing the VAR model are in Appendix B.

The VAR model test results on the strength of the relationship between the Alberta steer price, the futures price and the Texas steer price suggest a closer relationship between the Alberta price and the United States nearby live cattle futures price than between the Alberta price and the Texas price[4]. Alberta cattle investors should first look to the futures market for price information that will have the most immediate impact on the Alberta market.

VAR models, after estimation of the parameters, are also used to describe the dynamic interactions between the variables over time. This requires further restrictions on the model to derive these interactions. The particular restrictions used in this study are discussed above in the *Data Description* section. Two sets of dynamic interactions are derived and graphed.

The Impulse Response Function (IRF) describes the effect a single positive one standard deviation shock to one variable has on the forecast values of itself and the other four variables in the system. Since the IRF is only interested in variable changes, all variables in the model are assumed to be at zero before the shock occurs. For example, refer to the IRF for ASP (Figure 4, this section). At time 0, a shock occurs to logged Alberta slaughter steer prices. This shock represents about a .035 change in logged price from the natural log(1)[5] or about a 3.6% increase in Alberta prices. No further shocks occur to any variables after time 0. By the estimation restrictions discussed in the *Data Description* section, ASP can only affect animal exports (EA) at time 0. Figure 4 shows EA dropping at time 0 by -0.014 from the natural log(1) and this forecast represents about a 1.4% drop in export value in response to the shock to Alberta prices. One interpretation of the graph is that a local increase in Alberta slaughter steer prices initially decreases live animal exports but over time the Alberta price adjusts relative to the U.S.

market and live animal exports return to previous levels. None of the other variables respond at time 0. However, the shock to Alberta prices filters through to the other variables in the system after one month (time period 1) and at later time periods.[6]

The VAR model can be decomposed into the forecast error variance[7] (VDC). The VDC measures the percentage source of forecast error variance for each variable. It shows how much of the total forecast variance around a specific variable point forecast is contributed by time 0 shocks (innovations) from **each** variable. We use this to determine which variables contribute the most to the variance of a variable when all variables receive a positive shock at time 0. The size of the shocks to each variable are not of an equal total size but represent shocks that are equally likely to occur in each of the five variables[8]. For example, Figure 9 (this section) is the VDC for ASP. The graph shows that FSP contributes about 60% of the total forecast variance around an h-time periods ahead point forecast of ASP. Here, h time periods might represent a 4 month forecast for ASP and at this point, the graph shows that shocks to FSP represent over 60% of the forecast variance around the ASP forecast. Shocks to ASP contribute about 30% of the total forecast error variance. The conclusion is that ASP forecasts are quite sensitive to time 0 shocks in the variable FSP but not very sensitive to time 0 shocks in TSP, EA or EX. In other words, the U.S. market (mainly the futures market) potentially contributes more to the variability of Alberta prices than exchange rates or live animal exports. The next biggest source of variability to Alberta prices is Alberta prices or in other words, local changes in the Alberta market are the second biggest influence on Alberta price variability. The Texas steer price is the third biggest source of variability in Alberta prices. Exchange rates are only the fourth biggest source of variability in Alberta prices. The influence of the FSP on the forecast variance of the h step ahead ASP forecast does not substantially decrease over time. The Variance Decomposition (VDC) along with the IRFs provide information on the dynamics of the variables in the model. The VDCs depend on the same restrictions discussed above for the IRF. More detailed discussion on the IRF and on the VDC are presented next.

The IRF for the variable ordering EX, FSP, TSP, ASP, and EA are reported in a series of graphs in Figures 1 to 5. Recall that this ordering imposes the constraints that EX, exchange rates, can contemporaneously affect all the other variables at time 0. ASP, Alberta steer prices, can only contemporaneously affect EA at time 0. Figures 1 to 5 trace out the impact of a positive one standard deviation shock to the indicated variable. The model imposes the constraint that this time 0 shock to the variable is independent of the other variables. In other words, this shock directly affects the one variable and the IRF then shows how this shock to the one variable is forecast to affect the other variables in the system over time. The VDC traces out the percentage source of forecast variance in the indicated variable if all variables were shocked at time 0. The analysis of the VDC is in Figures 6 to 10. Figures 1 to 5 show that FSP (Figure 2) has the largest IRF effect on ASP, followed by TSP (Figure 3) and then EX (Figure 1). Positive shocks to either the futures price or the Texas price positively increase the Alberta price. For example the positive shock to the futures price results in about a 4.6% increase in futures prices at time 0 and this immediately translates into a forecast increase in Alberta prices of about 2.5%. The Alberta price rises by 4% by period 3 and then drops steadily with the futures price. A positive shock in the exchange rate (the Canadian dollar becomes more valuable relative to the U.S. dollar) increases the rate by about $0.009/Cdn$[9] and results in a negative price change in Alberta steer prices of about 0.3% at time 0, decreasing to 0.7% by time period 4 . The VDC on ASP (Figure 9) also shows that the FSP is the most influential variable on ASP forecasts explaining 35% of the forecast error variance in month 1 and increasing to 60% by month 3[10]. The TSP provides about 10 % of the forecast error variance in the ASP and the exchange rate has little influence on the variance of ASP forecasts despite being ordered first in the IRF modelling.

The greatest impact of exchange shocks on ASP occurs in the fourth month which may be related to the one quarter delay reported on exchange rate pass through by Carter et al. (1990). The results here agree with Carter et al. (1990) that exchange rates are not as important in explaining the relationship between Canadian and U.S. prices as the actual prices themselves. Our results indicate that exchange rates change Alberta slaughter steer prices but U.S. slaughter cattle market prices are much more influential on Alberta prices. Changes in U.S. prices cause larger dollar value changes in Alberta prices than equally likely changes in exchange rates. The VDC for Alberta prices shows that of equally likely shocks in all variables, the U.S. steer market has the most influence on Alberta price variability. A question that is not answered in this present study is whether the relationship between Alberta prices and U.S. prices has changed as cattle exports have increased from Alberta to the U.S. This is a question of some importance and should be explored in further studies. Other results from the IRF and VDC are summarized next.

Shocks to EA, animal exports, (Figure 5), have little effect in the forecasts for ASP and the ASP forecast error variance (Figure 9). This is similar to the results from Adamowicz et al. (1991). The EX, exchange rate, VDC (Figure 6) is affected little by the other four variables in the model from month 0 to month 30. This is expected since Adamowicz et al. (1991) results show that interest rates or the exchange rate itself are the biggest factors that influence EX forecast variance. This conclusion appears to hold even if a different ordering on the IRF is used (see Appendix). The FSP, nearby futures price, VDC (Figure 7) is affected little by the other four variables and accounts for about 85% of its own forecast error variance after month 6. This would be the expected result considering the original conjecture that prices are set in the United States and FSP is placed before TSP in this ordering. This conclusion changes if the ordering of the IRF changes (see the Appendix for a different ordering).

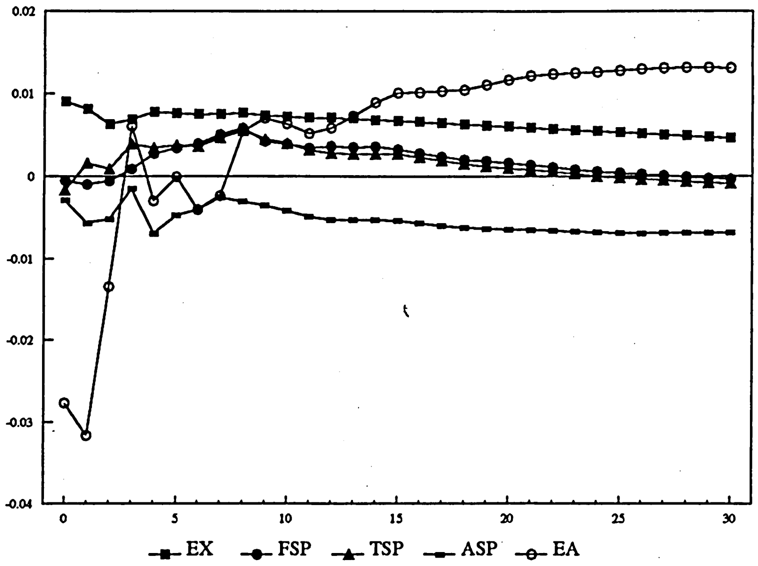
The EA's VDC (Figure 10) shows that after 6 months EA, live animal exports, contributes 80%, FSP contributes 10% and ASP contributes about 3% to EA's forecast error variance. EX has almost no impact on the forecast error variance of EA. The results from our recursive model here show prices and exchange rates are not important in explaining the forecast error variance of future exports in cattle. However, Figures 1, 2, 3 and 4 show that shocks to cattle prices or exchange rates affect the live animal exports for short periods of time. These results on live animal exports are interpreted as follows. The dollar value of live animal exports to the U.S. decrease for a short period of time if Alberta prices independently increase. The value of live animal exports gradually return to their previous level as Alberta prices adjust relative to the U.S. market. Live animal exports permanently increase if there is an independent increase to United States steer prices. Increases in the exchange rate decrease EA for a short period of time and then EA returns to prior levels within three months. Likely, Alberta prices decrease because of the change in exchange rates and this returns export values to their prior level. The VDC show that if all variables are shocked at time 0 with an equally likely shock, that shocks to the EA contribute the most to the future variance of live animal exports. This suggests factors not included in our VAR model have much greater influences on the variability of live animal exports than Alberta prices, U.S. prices or exchange rates.

Specifically, the $.009 shock to exchange rates (Figure 1) results in an immediate 2.8% drop in live animal export values at time 0, increasing to 3% and then gradually returning to the original value. A shock to futures prices of about 4.6% (Figure 2) increases the value of live animal exports by 4.9% at time 0, increasing to 6.9% in period 2 and then drops to a permanent 4% change. A positive shock to Alberta steer prices of about 3.6% (Figure 4) decreases the value of live animal exports initially by 1.3%, decreasing further to 3.9% by period 1, then gradually increasing again as Alberta prices adjust downward.

The general conclusions are that the exchange rate has a relatively smaller impact on Alberta slaughter steer prices than U.S. steer markets have on the Alberta market. The Alberta slaughter price is much more sensitive to U.S. price shocks than equally likely exchange rate shocks. Unidentified Alberta factors also have a larger impact on Alberta price variability than exchange rates. Changing livestock prices in Alberta or the U.S. affects the value of live animal exports. The impact of these price changes on the forecast error variance of animal exports is relatively small which implies that live animal exports are more sensitive to changes in other variables not included in our model. Changing the ordering of the variables when estimating the IRF does not change many of these conclusions significantly. The results for a different ordering are in the Appendix.

Several caveats exist on these conclusions. One of the original purposes of the VAR methodology in economics was to examine equilibrium relationships between variables without imposing a strong structure in the data. The model estimated here, is at best a partial equilibrium type model, since some macro variables were dropped, input prices or supply are not included and no other U.S. variables for the livestock market equilibrium are included[11]. Therefore, these dynamic relationships should be interpreted relative to the variables included in the model while also recognizing that these interpretations could change if different variables are added. The model specification tests and the individual equation tests in the Appendix suggest that this VAR model meets most but not all the theoretical criteria for a VAR. The robustness of the model to these mis-specifications is unknown. Strong identification assumptions are required in the model to derive the IRF and VDC and changing the ordering does change the conclusions somewhat.

Figure 1
IRF - One Std. Dev. Shock to Variable EX

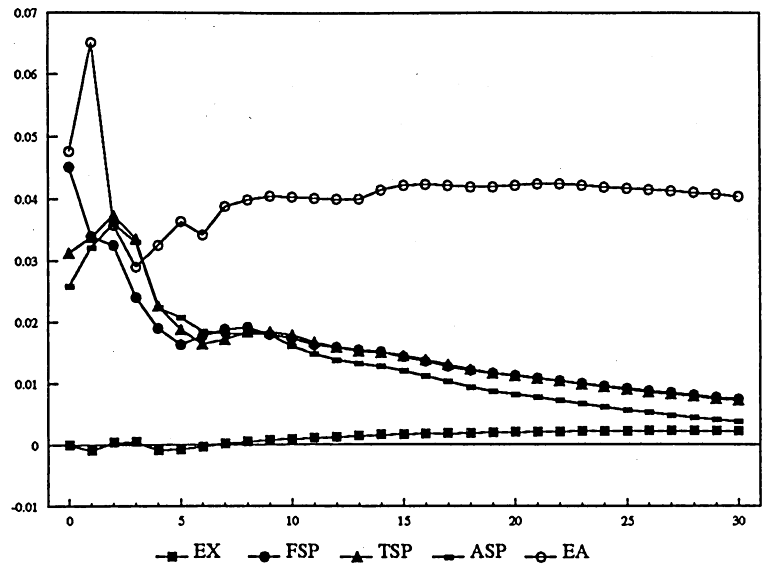


Time Periods

Legend:
EX=U.S./Cdn $ exchange rates
FSP=Nearby Futures Live Cattle Futures Price in U.S. $ (logged)
TSP=Texas Slaughter Steer Price in U.S. $ (logged)
ASP=Alberta Slaughter Steer Price in Canadian $ (logged)
EA=Live Animal Exports from Canada in Canadian $ (logged)

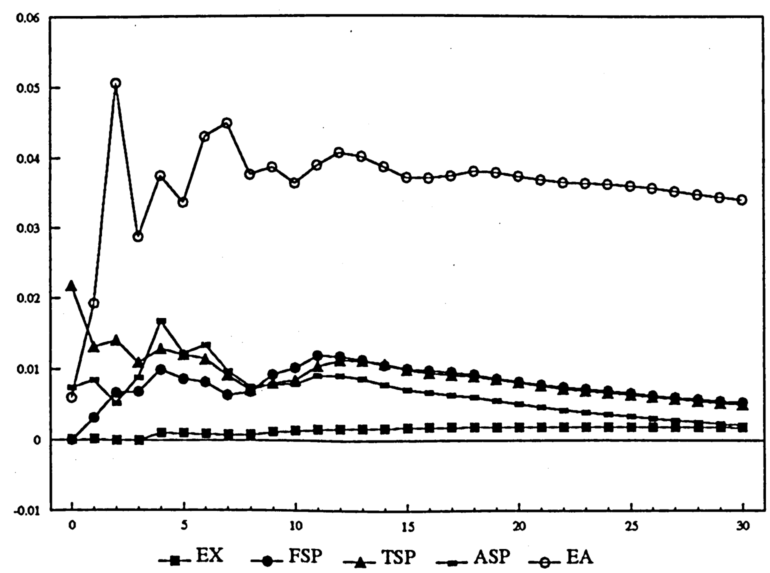
Since the graphs are reported in logged numbers (base e) for cattle prices and live animal exports, the exact percentage changes can be calculated by unlogging the numbers in the graph, subtracting 1 and multiplying by 100. The IRF assumes all variables in the model start from 0. This implies all cattle price variables and animal exports start from the value of 1 if unlogged. For example the time 0 value of ASP from Figure 4 is .035 or in percentage terms it is (exp(.035)-1)*100=(1.0356-1)*100=3.56%. The exp(.) is the natural number base e. As an approximation, the vertical scaling for the IRF graphs can be viewed as the percentage change (after multiplying by 100) in the variables ASP, FSP, TSP, and EA. The vertical scale represents U.S cents per Canadian dollar for the exchange rate, EX.

Figure 2
IRF - One Std. Dev. Shock to Variable FSP



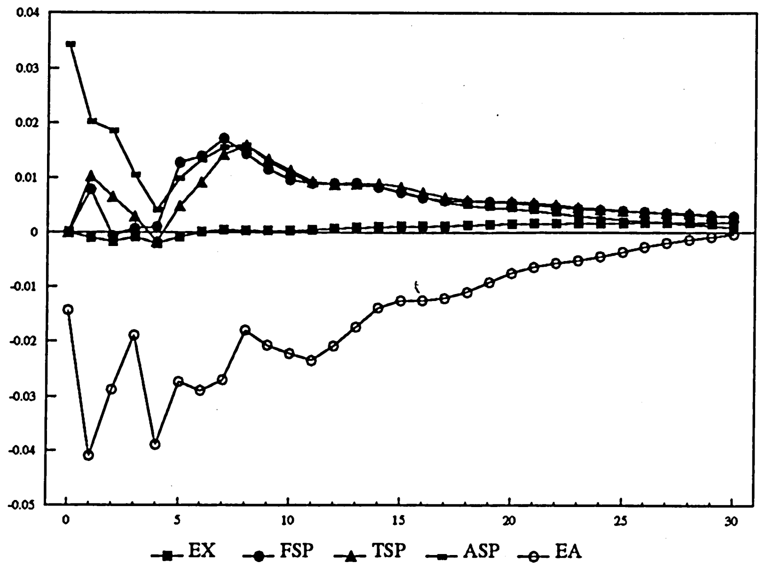
Time Periods

Figure 3
IRF - One Std. Dev. Shock to Variable TSP



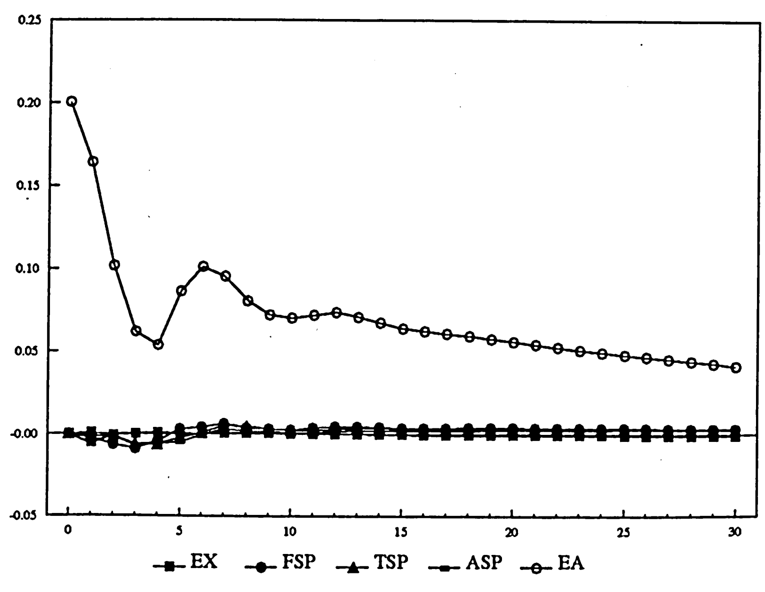
Time Periods

Figure 4
IRF - One Std. Dev. Shock to Variable ASP



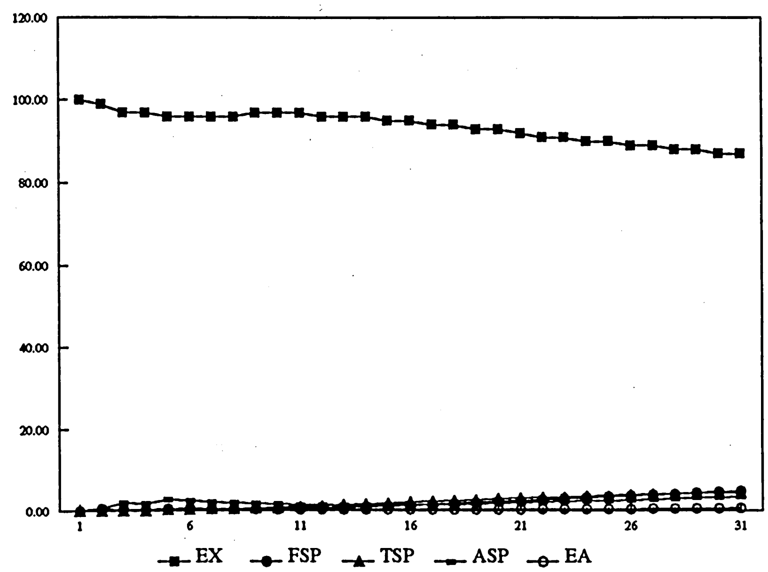
Time Periods

Figure 5
IRF - One Std. Dev. Shock to Variable EA



Time Periods

Figure 6
VDC - Percentage Sources of Forecast Error Variance in EX

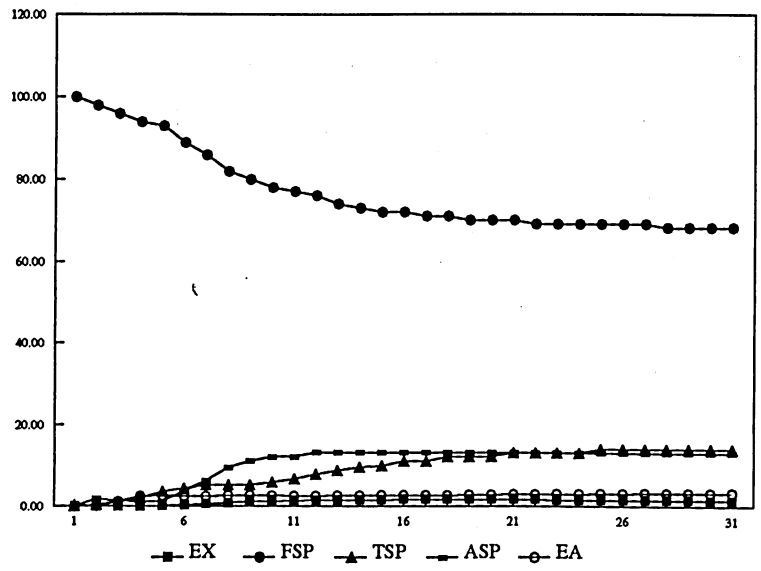


Time Periods

Legend:

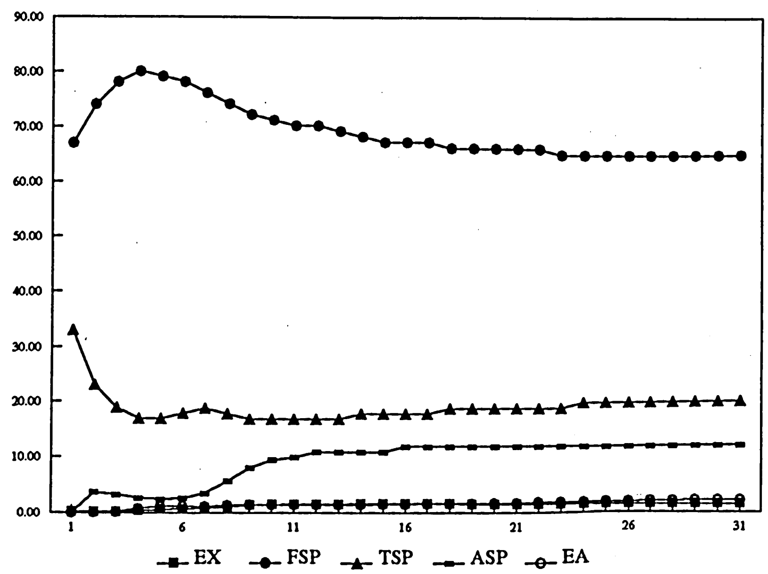
EX=U.S./Cdn $ exchange rates
FSP=Nearby Futures Live Cattle Futures Price in U.S. $ (logged)
TSP=Texas Slaughter Steer Price in U.S. $ (logged)
ASP=Alberta Slaughter Steer Price in Canadian $ (logged)
EA=Live Animal Exports from Canada in Canadian $ (logged)

Figure 7
VDC - Percentage Sources of Forecast Error Variance in FSP



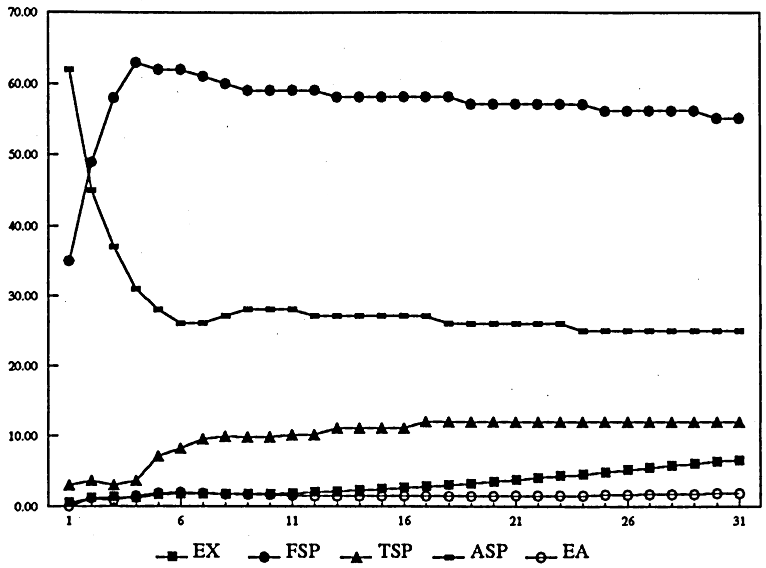
Time Periods

Figure 8
VDC - Percentage Sources of Forecast Error Variance in TSP



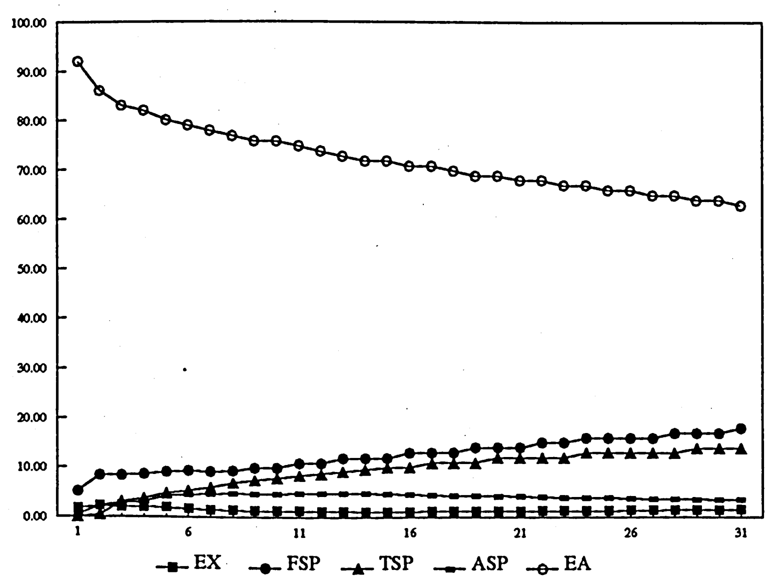
Time Periods

Figure 9
VDC - Percentage Sources of Forecast Error Variance in ASP



Time Periods

Figure 10
VDC - Percentage Sources of Forecast Error Variance in EA



Time Periods

Conclusion

A five variable Vector Autoregression model using U.S.-Canada exchange rates, Canadian live animal exports in dollars, Chicago Mercantile nearby live cattle futures prices, Texas slaughter steer prices and Alberta slaughter steer prices was estimated to investigate the dynamic interactions of these variables with the Alberta slaughter steer price. Our results suggest that the United States cattle price, in particular the futures price, has the biggest impact on Alberta slaughter prices, accounting for up to 60% of the forecast error variance in Canadian prices. That is, Alberta prices are relatively less sensitive to exchange rate shocks and much more sensitive to U.S. slaughter steer price shocks. Forecasts of Alberta prices are quite sensitive to changes in United States cattle prices. A shock to the exchange rate also results in a smaller change to Alberta prices than an equally likely shock to the U.S. futures price. Any policy regarding income stabilization for Canadian cattle feeders must recognize that the greatest source of the price instability comes from the United States cattle market. The second greatest source of price instability comes from factors within the Alberta market. The U.S.-Canada exchange rate was a relatively smaller source of risk in Alberta slaughter steer prices from 1976 to 1992.

Unexpected shocks to Alberta prices or U.S. prices change the total value of live animal exports to the U.S.. An independent positive shock to Alberta slaughter steer prices initially decreases export values but export values gradually return to their prior levels as the Alberta steer price adjusts. An independent positive shock to U.S. steer prices immediately increases live animal export values to the U.S. and this increase in export values does not revert back to its original level. Our study shows animal exports change with shocks to steer prices but animal export variability is more sensitive to shocks in unidentified variables not included in our model.

These results have possible implications for Alberta cattle feeder investors. The stronger influence of the futures prices on the model suggest that Alberta investors first look at the futures market for the price information that most strongly influences the Alberta market. The close relationship of the Alberta market and the futures market implies that the futures market can be used by Alberta cattle investors for risk management. There still exist local Alberta factors that contribute to price risk but the U.S cattle market is the major source of price risk. Typically over 1 month periods the U.S.-Canada exchange rate does not play a big role in changing Alberta prices. This may be due to the relative stability of the exchange rate over shorter time periods relative to U.S. cattle prices.

This paper estimated a five equation Vector Autoregression. Similar models could be extended to Canadian feeder cattle, pork and the grains industry. Including feeder cattle in this model would explore the interactions between the slaughter market and the feeder cattle market and examine the impact of programs such as National Tripartite Stabilization on feeder cattle prices.

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Appendix

This appendix gives a technical description of the work done comparing Alberta slaughter steer prices to United States slaughter steer prices. This includes a description of the Vector Autoregression Model (VAR), the VAR model selection process and the detailed results. The methods of VAR estimation are first explained. The data is tested for unit roots and for co-integration as part of the VAR model development and using various tests a VAR(5) model is developed. A recursive VAR estimation model is used for the impulse response function and the variance decomposition. An alternative ordering of the VAR model is also presented to check for model robustness. The final subsection in the Appendix is a bibliography of referenced literature.

Appendix A - Explanation Of Vector Autoregression

A VAR is a dynamic simultaneous equation model (SEM) made up of endogenous variables and lagged endogenous variables (Judge et al. 1988). Lutkepohl (1991) provides an excellent description of VAR multiple time series models. Exogenous variables can be included if required. The VAR model and some issues in VAR modelling are described in this section.

Vector Autoregression models are a system of time series equations that do not impose strong restrictions on the data during the estimation of the reduced form parameters. These models exploit the autocorrelation exhibited by most economic time series data. This contrasts with the traditional econometric simultaneous equation model (SEM) where strong identification restrictions (referred to as incredible by Sims (1980)) are required on the parameters before estimation. These SEM restrictions usually take the form of zero restrictions on some of the structural parameters so that unique estimates of the structural parameters can be derived from the reduced form parameters. Sims (1980) suggested the use of VAR as an alternative to building structural SEMs. The estimation of the structural coefficients is not of primary concern in VAR models. The two main uses for VARs are for forecasting and for exploring the dynamic interdependence between variables. This study uses a VAR model to explore the interdependence between the Alberta slaughter steer price and the United States slaughter steer price. Forecasting is not an objective of this study and consequently this study places more emphasis on model adequacy in the model development described later in this study. VAR models also imposed strong identification restrictions to measure the relationship between the variables and these restrictions enter the model after estimation of the reduced form parameters.

Economic theory plays a loose role in determining which variables to include in the VAR model. Economic theory does not impose any structure on the VAR model and the data is allowed to drive the model and the selection of lag length. However theory and prior knowledge have a role in determining the restrictions required to derive the Impulse Response Functions and the Variance Decompositions. These are explained further below.

VAR uses lags of all the endogenous variables to estimate the equation system and measure the relationship between variables. A general form of a K equation model at time t is[12]:

$$Y(t)A = \sum_{s=1}^{\infty} Y(t-s)A(s) + Z(t)C + V(t)B \qquad (1)$$

where Y(t) and V(t) are (1xK) random vectors at time t, A, A(s)'s and B are (KxK) matrices of coefficients and Z(t) is a (1xq) vector of exogenous variables. The V(t) are assumed to be serially uncorrelated, have an expected value of 0 and a diagonal covariance matrix of Ω. The diagonal covariance (assumed to have unit variance in this paper) allows the modeler to apply one standard deviation shocks to one equation at a time in the system model and map out the response of the system to this single shock. The V(t) are the independent sources of variation in the model.

The system is assumed to be stationary (although estimation can still be consistent if the endogenous variables are not stationary). This allows both an autoregressive (AR) and moving average (MA) representation of the model. Economists use the fact that MA representations can be approximated by an AR(p) of lag length p to estimate (1). Estimation of an AR model is simpler than a MA model. The AR model is derived from (1) by post multiplying by A^{-1}:

$$Y(t) = \sum_{s=1}^{\infty} Y(t-s)A(s)^{*} + Z(t)C^{*} + U(t) \qquad (2)$$

where $A(s)^{*}=A(s)A^{-1}$, $C^{*}=CA^{-1}$ and $U(t)=V(t)BA^{-1}$. The U(t) are serially uncorrelated step ahead forecast errors with mean 0 and $\text{cov}(U(t))=A^{-T}B'\Omega BA^{-1}$.

Equation (2) is the reduced form SEM and the stationarity assumption implies that after choosing a suitable lag length, p, the effect of prior periods (s>p) is zero. This model is estimated using Ordinary Least Squares (OLS) if all the right hand side variables in each individual equation are the same or with Seemingly Unrelated Regression if the right sides differ (Judge et al. (1988)). It is of course impossible at this point, to derive the original coefficient matrices in (1) from reduced form coefficients in (2). The VAR methodology inverts the estimated reduced AR system (2) to get a MA model:

$$Y(t) = \sum_{s=0}^{\infty} Z(t)C^{*}M(s) + \sum_{s=0}^{\infty} U(t-s)M(s)) \qquad (3)$$

where the M's are the moving average coefficients and M(0) equals the (KxK) identity matrix I. The M(s) are recursively calculated from:

$$M(s) = \sum_{i=1}^{s} A(i)^{*}M(s-i) \qquad (4)$$

The VAR method used in this paper examines the behavior of independent shocks V(t) on the variables Y(t). This analysis of the shocks or innovations to the system is one important use of VARs. The measurement of one independent shock at time t to one equation in the system and the response over time of all n variables in Y to this single shock is called the Impulse Response Function (IRF) and from U(t-s)M(s)=V(t)BA^{-1}M(s) we get the IRF, BA^{-1}M(s). To isolate the impact of one orthogonal shock in one of the equations in Y(t) on all K endogenous variables using the IRF, modelers impose identification restrictions on A^{-1} and B to estimate the B and A^{-1} and isolate V(t) from the IRF. This paper assumes that B=I[13] and focuses on estimating A^{-1}. This requires K(K-1)/2 further restrictions on A^{-1}. The restricted A^{-1} is estimated from the estimated covariance of U(t-s). The cov(U(s)) is estimated using the residuals from each equation in (2).

Essentially VAR modelers place identification restrictions on the contemporaneous interactions between the K variables. Two methods of identification restrictions and estimation of A^{-1} are described here. The most common identification restriction has been to assume the A^{-1} is triangular and estimate cov(U(s))=$A^{-T}A^{-1}$ using the Cholesky decomposition[14]. This provides the required number of restrictions on A^{-1}. This implies a recursive model structure with equations at the top of the ordering contemporaneously affecting equations below but not vice versa (Adamowicz et al. 1991). Therefore the solution to A^{-1} using the Cholesky decomposition is not unique in that different orderings of variables change the solution to A^{-1} and imply different contemporaneous relationships between the variables. Theory and knowledge of the situation are required to choose the ordering of the variables. This recursive estimate of A^{-1} to get the IRF is the estimation procedure used in this paper[15].

Other identification methods that do not result in recursive structures in A^{-1} have been described (Fackler (1988a), Fackler (1988b)) and used (Adamowicz et al. (1991), Orden and Fackler (1989)). Structural identification restrictions are placed on A^{-1} and maximum likelihood estimation procedures are used to find the most likely A^{-1}. Solutions to the problem are not guaranteed using this structural model and this method is not used in this study.

The moving average representation in (3) and (4) can be decomposed into the forecast error variance. This is a relative strength measure of the total contribution all variables have on one variable's forecast variance over a forecast period (Judge et al. (1988)). The Variance Decomposition (VDC) along with the IRFs provide information on the dynamics of the variables in the model. The VDC and IRF are the main outputs of VAR models when used in policy analysis. VAR models are used for testing causality between variables and this is discussed next.

Lutkepohl (1991, pp.35-43) discusses Granger causality and instantaneous causality. Granger causality can be interpreted as follows. A variable X Granger causes variable Z, if information about variable X improves forecasts about variable Z but information about variable Z does not improve forecasts about variable X. A restrictive form of Granger causality can be tested using VAR models where the information set is restricted to historical information. These tests are interpreted cautiously and provide indications of possible relationships between variables. Furthermore, results showing variable X does not Granger cause variable Z using monthly data, does not provide information on causality for daily or quarterly data. Granger causality tests are done on the final selected VAR model by testing the significance of the coefficients of the lagged X variables in the equation where Z is the dependent variable and by testing the significance of the lagged Z variables where X is the dependent variable. If the coefficients on the lagged X variables are significantly different from 0 and the coefficients on the lagged Z variables are not significantly different from 0, then a tentative conclusion is that variable X Granger causes variable Z. These results should be viewed with the above mentioned caveats kept in mind. The zero instantaneous causality concept can be interpreted as zero correlations between variable X and variable Y. No interpretation of causality can be made when using the instantaneous causality concept.

Other issues in VAR estimation include the choice of lag length (the order of the VAR) in the model and stationarity in the data. Some VAR models are estimated in levels and others are estimated using differenced data and impose any cointegration relationships on the model. Engle and Granger (1987) and Engle and Yoo (1987) explain the relationship of this issue to unit roots, stationarity, co-integration, VAR error correction models and missspecification. Even with non stationary endogenous variables, a VAR model estimated in levels (non differenced data) using Least Squares provides consistent estimates although a model that imposes the cointegration restrictions on the model may be preferable in small samples (Engle and Yoo (1987), Lutkepohl (1991) pp.368-370). This study uses the simpler estimation with variables in levels although further work imposing the cointegration relationships may provide more reliable conclusions.

Another major issue in estimating VAR models is the determination of lag lengths or the order of the VAR(p) where p refers to the order of the VAR[16]. Various criteria are used to determine the order of the VAR however these criteria provide conflicting conclusions. This paper uses a combination of SIC, AIC (Judge et al. p. 761 (1988)), likelihood ratio tests, Portmanteau tests for autocorrelation and a normality test on the residuals to determine lag length. The AIC criteria may tend to include too many lags (the order of the VAR) versus the SIC but in small samples the AIC may well have better properties than the SIC (Lutkepohl (1991) pp.132-134) in determining the VAR order. The likelihood ratio test uses a sequence of tests to compare a VAR(p+1) to a VAR(p) model. The generalized Portmanteau test described by Lutkepohl (1991, pp.150-152 equation 4.4.2.1) tests for overall significance of the residual autocorrelation in a VAR(p) model. This test is of interest in determining whether the VAR residuals are white noise, whether the model provides "better' statistical tests and whether the model is extracting all available information from the historical data. The test for nonnormality using the third and fourth moments of the normal distribution (Lutkepohl (1991) pp.152-158, equations 4.5.4, 4.5.5 and 4.5.8) also determines the reliability of the statistical tests on the model in smaller samples. The final order of the chosen model takes into account the results from these tests and the study's objective to investigate the relationships between Alberta slaughter steer prices and U.S. prices. The portmanteau tests and the nonnormality tests strongly influence the final VAR order chosen and the endogenous variables included in the model.

Appendix B - VAR Model Development

The VAR model is developed in steps. The first step tests all the data for stationarity using unit root tests. Since unit roots are found in the data, tests for co-integration are performed. Co-integration, if detected in the data, implies a close relationship between variables in the system and could also suggest using differenced data with error correction terms (Engle and Granger (1987), Engle and Yoo (1987)) or using a cointegrated VAR model estimated directly following Johansen (1988, 1991)[17]. At least one co-integrating relationship is detected using the tests proposed by Engle and Yoo. However to simplify the study, a VAR model using variables in levels is still estimated starting with maximum lag length 8 on each endogenous variable to determine the appropriate order. Test statistics on individual equations are also reported that have a bearing in choosing the lag length and interpretations of Granger causality.

The MA representation is estimated from the final reduced form VAR estimates to give the IRFs and the VDCs. More detailed explanations of these steps and selected test results used in the VAR model building are reported in this section.

B.1 - Unit Root Tests

The data is tested for stationarity by testing for unit roots. Non stationary data may also lead to co-integrating relationships. Therefore the data is tested for unit roots as the first step to determine whether there are cointegrating relationships between the variables included in the VAR model.

Augmented Dickey-Fuller (ADF) unit root tests are used. The test statistic is the usual t ratio but different tables are required to interpret the tests (Davidson and MacKinnon 1993, p.708). The Augmented Dickey-Fuller (ADF(p)) with p lags and with a constant is:

$$\Delta X(t) = \alpha + \beta X(t-1) + \sum_{i=1}^{p} \Delta X(t-i) \tag{6}$$

where Δ refers to the first difference of the variable X. The test is do not reject a unit root if β=0. This test is implemented as reject if the t-ratio is less than the critical value. The ADF test can also include a trend term. The test statistics are in Table 1. The results from ADF tests reject the hypothesis of unit roots in logged prices (ASP, TSP, FSP) at the 10% level of significance. This implies the variable means and variances are constant. However, tests over different subperiods suggest the presence of unit roots in these variables. This indicates that co-integrating vectors may exit among these variables. The data is next tested for co-integration.

Table 1
ADF Unit Root Tests

Variable[1]	ADF Constant[2]	ADF Constant & Trend[3]
EX	-2.66	-2.66
FSP	-3.41	-3.58
TSP	-3.54	-3.67
ASP	-4.81	-4.93
EA	-0.89	-3.01

1. EX=U.S./CDN$, FSP=Nearby live cattle futures, TSP=Logged Texas Steer Price, ASP=logged Alberta Steer Price, EA=logged live animal exports.
2. The asymptotic test statistics critical values with constant at the 1%, 5% and 10% levels of significance are -3.43, -2.86 and --2.57 respectively.
3. The asymptotic test statistics critical values with constant and trend at the 1%, 5% and 10% levels of significance are -3.96, -3.41 and -3.13 respectively.

B.2 - Co-Integration Tests

Co-integration tests whether different variables move together. Two variables may be nonstationary, but a linear combination of the two series may be stationary (Engle and Granger (1987), Engle and Yoo (1987)). Cointegration tests show if a group of variables move together over time. If variables are cointegrated then this can be loosely interpreted as meaning the variables are "stationary" relative to each other even though the individual variables are not stationary. We expect that the Alberta steer price should be cointegrated with the steer prices in the United States and the results in this section support this hypothesis. However work by Goodwin and Schroeder (1991) and Bessler and Covey (1991) found no or low evidence of co-integration between different U.S. cattle markets. A brief discussion of one simple cointegration test and selected co-integration results involving the ASP, FSP, TSP and EX follow. A second cointegration test using Maximum Likelihood estimates on a VAR(5) model suggesting two cointegrating relationships in the variables is also presented.

One way tests using ADF(p) for co-integration were done (Engle and Granger (1987), Engle and Yoo (1987)). The first step is to regress one variable on a single variable or a combination of several variables as follows:

$$y(t) = \alpha + \beta x(t) + u \qquad (7)$$

The estimated residuals from (7) are used in ADF(p) (equation 6) to calculate the same statistics used in the unit root tests. Equation 7 may include a constant and a trend term. The ADF(p) used for this test has no constant and no trend term. Critical values from Davidson and MacKinnon (1993, p.722) are used to evaluate these tests. The null hypotheses, no co-integration, is not rejected if the ADF tests show the residuals from (7) have a unit root. The co-integrating relationships tested and the different test results are in Table 2. The ASP was used as the dependent variable and some combination of U.S. steer prices and exchange rates were used as the independent variables in equation 7.

The representative tests results in Table 2 do not reject the hypothesis of no co-integration between Alberta steer prices and United States steer prices. Unit roots are not detected in the residuals from equation 7. At least one cointegrating relationship exists in the data. The Alberta steer price is cointegrated with the U.S. market. These prices move together over time. A popular VAR model when there is only one cointegrating relationship is a two step estimation procedure (Engle and Yoo (1987), Lutkepohl (1991, pp.370-372)) that incorporates an error correction (cointegrating vector) into the VAR model. A second

Table 2
Co-Integration Tests

Variables[1]	ADF(p)[2] Constant	ADF(p) Constant & Trend[3]
ASP TSP EX	-3.30	-3.66
ASP FSP EX	-3.54	-3.67

1. The first variable is the endogenous (left hand side) variable in equation (7). ASP=logged Alberta Steer Price, TSP=Logged Texas Steer Price, and EX=U.S./CDN $.
2. The asymptotic test statistics critical values with constant at the 1%, 5% and 10% levels of significance are -4.29, -3.74 and -3.45 respectively.
3. The asymptotic test statistics critical values with constant and trend at the 1%, 5% and 10% levels of significance are -4.66, -4.12 and -3.84 respectively.

cointegrating test based on Johansen (1988) suggests there are two cointegrating relationships in this data set[18]. This result rules out the use of the two step procedure. Unfortunately, the Johansen method, while testing for the number of cointegrating vectors does not allow the vectors to be uniquely estimated unless further restrictions are imposed. An alternative estimation procedure based on Johansen can be used to estimate the VAR model and include the cointegrating restrictions, however this method is more difficult than estimating the VAR model in levels using Least Squares.

The study proceeds to estimate the model using Least Squares on a VAR model with variables in levels. The 5x5 Variance-Covariance matrix estimated by Least Squares or estimated by the Maximum Likelihood described by Lutkepohl (1991) give very similar results. Least Squares is consistent even if the cointegrating relationships are not imposed on the model. The determination of the lag length, the estimation of the reduced form of the VAR in levels and the Granger causality are covered next.

B.3 - Selection of Lag Length and Granger Causality Tests

A critical step in the estimation of VAR models is the determination of the number of lags to include in the model. Typically, the literature uses a criteria such as AIC or likelihood ratio tests. These tests are reported in this paper along with the SIC criteria. Portmanteau[19] tests for autocorrelation and nonnormality tests are also used. The following section details the tests to determine lag length and reports selected test statistics.

The VAR model equation (2) is estimated with the variables EX, FSP, TSP, ASP, EA and a constant. The reduced form VAR is estimated with 8 lags, VAR(8), on all endogenous variables in all five equations, then with 7 lags, VAR(7), and so on down to 1 lag, VAR(1).

The AIC, SIC and Likelihood Ratio (LR) test are reported in Table 3 for lag length. The LR tests compare VAR(p+1) to VAR(p) and sequentially test down in lag length. The SIC and AIC criteria are to choose the order which gives the smallest value.

Table 3
VAR Lag Length Statistics

Lag Length	SIC	AIC	LR	LR d.f.
8	-28.41	-31.86	38	25
7	-28.90	-31.92	50*	25
6	-29.34	-31.93	42	25
5	-29.81	-31.97	42	25
4	-30.28	-32.28	66*	25
3	-30.92	-31.93	76*	25
2	-30.92	-31.78	32	25
1	-31.45	-31.88	--	-

* significant at the 1% level.

Table 3 shows a conflict between the criteria for picking the lag length. The AIC is at a minimum at VAR(4) with -32.28, the SIC is at a minimum at VAR(1) with -31.45 and the LR sequential test would pick VAR(7) or VAR(4) at the 1% level as the lowest lag length. Initially we interpret these results as suggesting a VAR order of p>=4 since we place more emphasis on the LR and AIC criteria. The nonnormality check and the autocorrelation check on VAR(4) through VAR(8) are used to finalized the VAR order.

Table 4
Asymptotic Autocorrelation and Nonnormality Tests

VAR MODEL	Skewness[1]	Kurtosis[2]	Joint Normality Test[3]	Portmanteau 25 Lags[4]
VAR(4)	21.3	7.8	17.6	639 (525, 0.0005)
VAR(5)	12.0	3.3	15.3	568 (500, 0.019)
VAR(6)	13.8	2.9	16.7	536 (475, 0.027)
VAR(7)	11.0	2.9	13.9	503 (450, 0.042)
VAR(8)	9.8	12.4	22.2	462 (425, 0.10)

1. Skewness is a Chi-Squared test with 5 degrees of freedom. 1% level of significance is 15.1.
2. Kurtosis is a Chi-Squared test with 5 degrees of freedom.
3. Joint normality test is Chi-Squared with 10 degrees of freedom. A 1% level of significance is 23.2.
4. The Portmanteau tests for autocorrelation on the VAR residuals. This shows the test statistic with 25 lags included in the test. The numbers in brackets give the degrees of freedom and the p-value respectively. The VAR(8) showed the lowest level of autocorrelation at all lags tested.

Table 4 shows evidence of skewness in the residuals in VAR(4). VAR(5) does not reject tests for skewness, kurtosis or joint tests on skewness and kurtosis at the 1% level of significance. The VAR(4) Portmanteau rejects no autocorrelation in the residuals at the 1% level. VAR(5) does not reject no autocorrelation. The Portmanteau test may not be reliable in this model because of the non stationarity of the model. Based on the possible lower level of serial autocorrelation and the normality of the residuals, a VAR(5), was chosen on which to do further testing and develop the impulse response function and the variance decomposition. Therefore each of the five equations in VAR(5) has 26 variables when a constant term is included.

The VAR(5) reduced form is estimated (equation 2) using OLS and this model is used to test for Granger causality. Further checks on model adequacy are provided based on each individual equation in the model. Then the model is converted to a moving average representation and the IRF and the VDC calculated using a routine provided by Fackler. The mathematics are described in Fackler (1988a and 1988b). The IRF gives a general indication of stationarity in the model since a stationary model IRF graph should not continually increase. The recursive ordering is EX, FSP, TSP, ASP and EA. One test of the robustness of the results is to estimate the model with a different variable ordering. This is done with a second ordering of ASP, TSP, FSP, EX, and EA. This alternative ordering implies that EX has no contemporaneous impact on the other variables at time 0. These alternative ordering results are at the end of the Appendix. The results of the IRF and VDC are reported and analyzed in the *Results* section.

Table 5 reports diagnostic statistics on the individual equations in the VAR(5) model. None of the equations reject normality, reject homoskedasticity, or reject no serial autocorrelation at the 1% level of significance. Only the ASP equation rejects linearity in the model. These results combined with the earlier tests suggest the VAR(5) model is adequately specified and further tests using the model may provide some valid results.

The results of the Granger causality tests are reported in Table 6. These provide an indication of relationships between variables. One relationship of interest is whether the U.S. futures market has more impact on the Alberta price than the Texas steer price. The reader is reminded that the data used here is monthly and may not be able to pick up the direction of causality if reactions occur in a matter of days versus one or two months. Some of the results are summarized next and further interpretation of these results is given afterwards. The test results indicate that at the 1% significance level ASP (Alberta Steer Price) causes FSP (Futures Steer Price) and FSP causes ASP (Group 1 in Table 6). This is referred to as a feed

Table 5
Individual Equation Checks on VAR(5) Model

Equation	Normality Jarque-Bera[1]	Heteroske-dasticity B-P-G[2]	Linearity Test[3] RESET 2, 3, 4	Serial Autocorrelation[4] Number of Significant Serial Auto. in First 12 Lags
EX	1.6 (2)	35.8	1.4, 0.8, 1.2	0
FSP	2.5 (2)	37.2	1.9, 1.7, 1.5	0
TSP	1.5 (2)	23.5	1.4, 0.7, 1.0	0
ASP	4.2 (2)	36.2	12.5, 6.2, 4.2	0
EA	3.7 (2)	27.4	3.6, 3.0, 3.3	0

ASP=logged Alberta Steer prices, FSP=logged Nearby Live Cattle Futures prices, TSP=logged Texas Steer prices, EX=U.S./Cdn $ exchange rate, and EA=logged live animal exports in dollars to U.S.

1. Jarque-Bera is a test for normality using the third and fourth moments of the normal distribution. It is Chi-Squared with 2 degrees of freedom.
2. The B-P-G is a Chi-Squared test for heteroskedasticity with 30 degrees of freedom.
3. RESET is an F test for model linearity. The numbers in the column represent RESET 2, 3, and 4 respectively with degrees of freedom (1, 159), (2, 158), and (3, 157) respectively.
4. The number of significant residual autocorrelations (using a t-ratio) at the first 12 lags at the 1% level are reported. Not shown in the table are joint test results for an LM test for no serial autocorrelation to lag 23. The LM results do not reject no autocorrelation at the 10% significance level for each of the five equations.

back system. Further results (Group 2) suggest that TSP (Texas Steer Price) does not cause ASP but ASP does cause TSP. Group 3 results suggest ASP does not cause EX (Exchange Rate) nor does EX cause ASP. Group 4 results suggest that TSP does not cause FSP and FSP does not cause TSP (which indirectly support the results of Goodwin and Schroeder (1991) and Bessler and Covey (1991) of no or low evidence of co-integration between different U.S. cattle markets). Group 5 results suggest a feed back system between ASP and FSP combined with EX.

These Granger causality tests should not be interpreted literally. For example, it is unlikely that the Alberta slaughter steer market has more impact on the nearby futures (Group 1 test) price than the Texas slaughter steer market (Group 4 test). However if we accepted the tests literally this would be our conclusion. Instead we use these tests to indicate some relationships between the Alberta market and the U.S. market. The results from the Group 1 and Group 2 tests may suggest a closer relationship between the Alberta price and the United States nearby live cattle futures price than between the Alberta price and the Texas price. This conclusion has two immediate implications. Alberta cattle investors should first look to the futures market for price information that will have the most immediate impact on the Alberta market. A close relationship between the Alberta market and the futures market supports the use of the futures market for risk management strategies for Alberta cattle investors. The results from the Group 3 tests indicate the exchange rates have less impact on Alberta prices than the futures market. Alberta cattle investors first price concern should be with U.S. futures prices before concerning themselves with exchange rate moves.

Table 6
Granger Causality Tests and Direction of Tests

Direction of Test[1]	Wald Chi-Square Statistic[2]	P-Value
Group 1		
ASP cause FSP	32.073299 (5)	0.00001
FSP cause ASP	17.857031 (5)	0.00313
Group 2		
ASP cause TSP	25.218948 (5)	0.00013
TSP cause ASP	12.508364 (5)	0.02845
Group 3		
EX cause ASP	12.241976 (5)	0.03162
ASP cause EX	12.449396 (5)	0.02912
Group 4		
TSP cause FSP	8.5639658 (5)	0.12777
FSP cause TSP	8.7017908 (5)	0.12157
Group 5		
ASP cause FSP & EX	44.778568 (10)	0.00000
FSP & EX cause ASP	33.953381 (10)	0.00019
Group 6		
ASP cause TSP & EX	38.156769 (10)	0.00004
TSP & EX cause ASP	23.564592 (10)	0.00884

1. The Granger tests are a two way test. The direction of cause is first tested in one direction and then in the opposite direction. The two tests representing these two directions are grouped together in the table. ASP=logged Alberta Steer prices, FSP=logged Nearby Live Cattle Futures prices, TSP=logged Texas Steer prices, EX=U.S./Cdn $ exchange rate.
2. Numbers in brackets are the degrees of freedom.

Table 7 reports the VAR(5) correlations between the five equations. Table 7 uses unrestricted least squares estimates and Maximum Likelihood estimates with cointegrating constraints imposed. The results when the cointegration constraints are imposed are very similar to the Least Squares estimates. The highest correlation is between futures price and the Texas price. The correlation between the Alberta slaughter steer price and the exchange rate is negative (the expected sign), but insignificant. Constraints are place on the VAR(5) model to next derive the Impulse Response Forecast and the Variance Decomposition presented in the main body of the study. An alternative variable ordering for the IRF and the VDC follows in the next subsection.

Table 7
VAR(5) Correlation Matrix By Unconstrained Least Squares Estimates

	ASP	TSP	FSP	EA	EX
ASP	1.000	0.585*	0.593*	0.095	-0.065
TSP		1.000	0.819*	0.209*	-0.044
FSP			1.000	0.230*	-0.011
EA				1.000	-0.133
EX					1.000

VAR(5) Correlation Matrix By Maximum Likelihood Estimates
Two Cointegrating Vector Constraints Imposed

	ASP	TSP	FSP	EA	EX
ASP	1.000	0.596*	0.608*	0.094	-0.097
TSP		1.000	0.824*	0.210*	-0.066
FSP			1.000	0.230*	-0.044
EA				1.000	-0.143**
EX					1.000

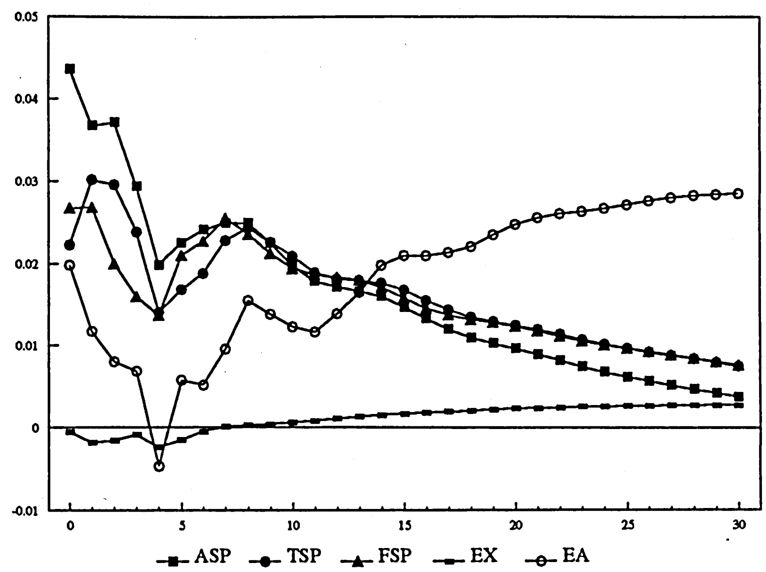
ASP=logged Alberta Steer prices, FSP=logged Nearby Live Cattle Futures prices, TSP=logged Texas Steer prices, EX=U.S./Cdn $ exchange rate, and EA=logged live animal exports in dollars to U.S. A "*" or "**" indicates significantly different from 0 at the 1% or 5% level respectively.

Appendix C - Alternative Ordering Of VAR Recursive Model

An alternative ordering of the variables for identification of the A^{-1} using the Cholesky decomposition is presented here. This practice is used in the literature to gauge the robustness of the conclusions to a different ordering of the variables. The ordering used was ASP, TSP FSP, EX and EA. This ordering implies that ASP has a contemporaneous impact on all variables at t=0 but the other variables do not impact on ASP. Changing the ordering does not substantially change the conclusions in the main body of the paper. The IRFs in Figures 11 to 15 are similar to Figures 1 to 5. The VDC show differences in that ASP now provides up to 60% of the forecast error variability in FSP (Figure 18), FSP accounts for very little of the forecast error variability in ASP (Figure 16) and TSP has a bigger impact on EA (Figure 20) and ASP (Figure

16) forecast error variance. The increased impact of ASP is expected given the ordering used in this VAR model and the generally close correlation exhibited between Canadian, U.S. futures prices and Texas cash prices.

Figure 11
IRF - Alternative Order, One Std. Dev. Shock to Variable ASP

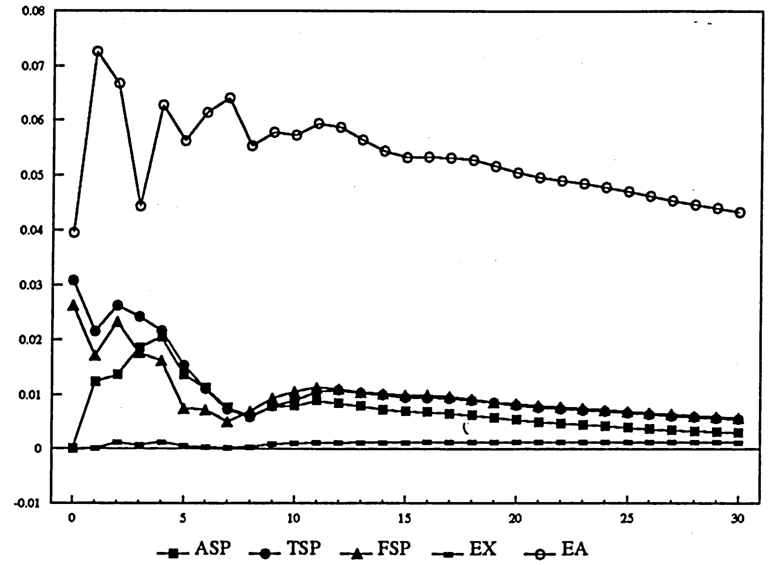


Time Periods

Legend:
EX=U.S./Cdn $ exchange rates
FSP=Nearby Futures Live Cattle Futures Price in U.S. $ (logged)
TSP=Texas Slaughter Steer Price in U.S. $ (logged)
ASP=Alberta Slaughter Steer Price in Canadian $ (logged)
EA=Live Animal Exports from Canada in Canadian $ (logged)

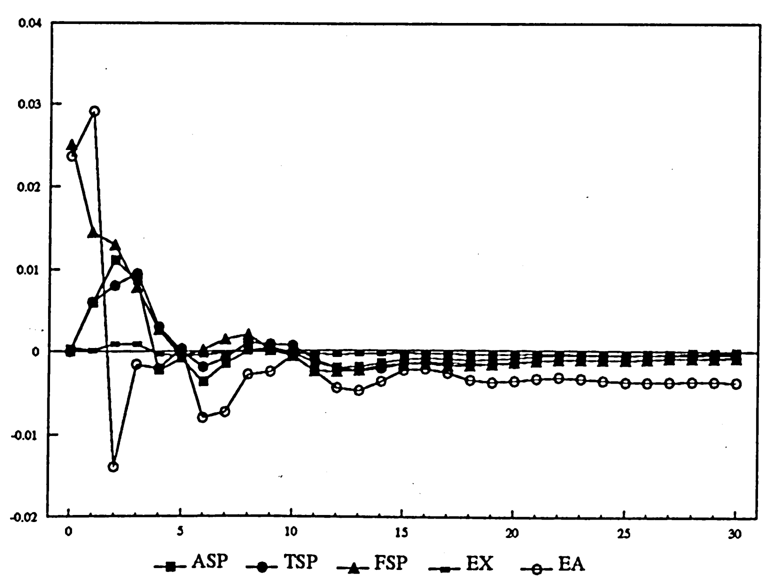
Since the graphs are reported in logged numbers (base e) for cattle prices and live animal exports, the exact percentage changes can be calculated by unlogging the numbers in the graph, subtracting 1 and multiplying by 100. The IRF assumes all variables in the model start from 0. This implies all cattle price variables and animal exports start from the value of 1 if unlogged. For example the time 0 value of ASP from Figure 4 is .035 or in percentage terms it is (exp(.035)-1)*100=(1.0356-1)*100=3.56%. The exp(.) is the natural number base e. As an approximation, the vertical scaling for the IRF graphs can be viewed as the percentage change (after multiplying by 100) in the variables ASP, FSP, TSP, and EA. The vertical scale represents U.S cents per Canadian dollar for the exchange rate, EX.

Figure 12
IRF - Alternative Order, One Std. Dev. Shock to Variable TSP



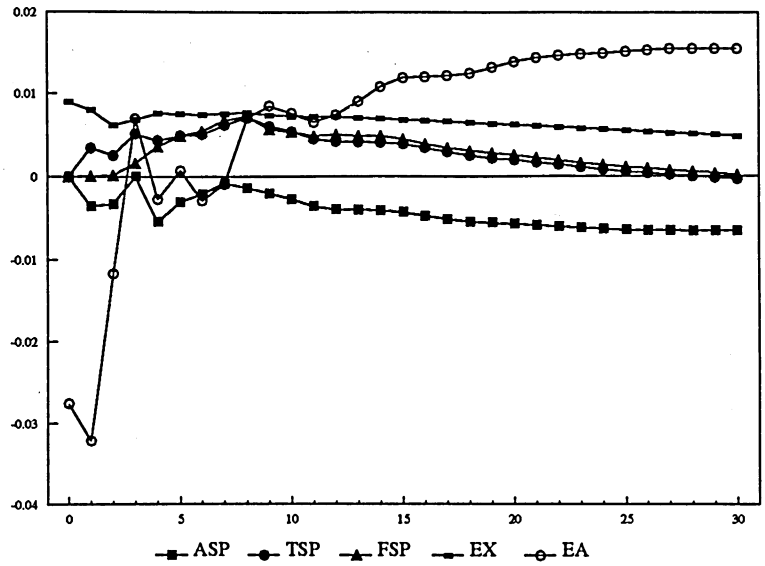
Time Periods

Figure 13
IRF - Alternative Order, One Std. Dev. Shock to Variable FSP



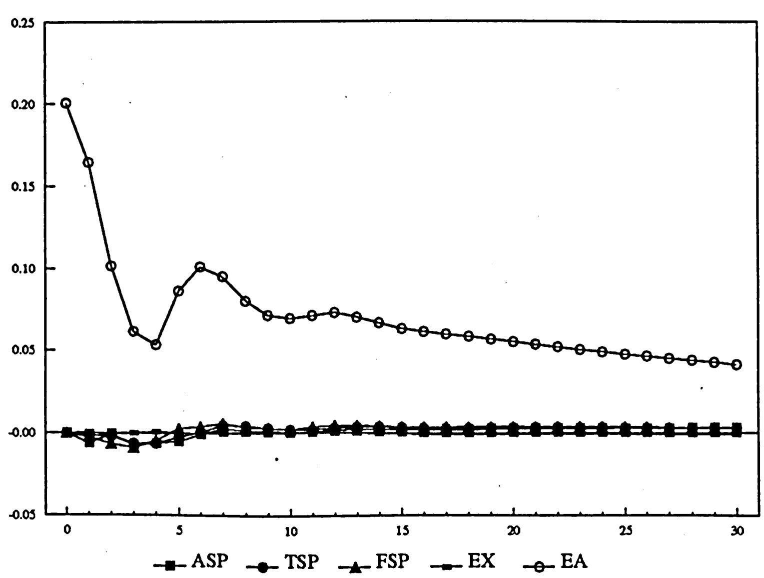
Time Periods

Figure 14
IRF - Alternative Order, One Std. Dev. Shock to Variable EX



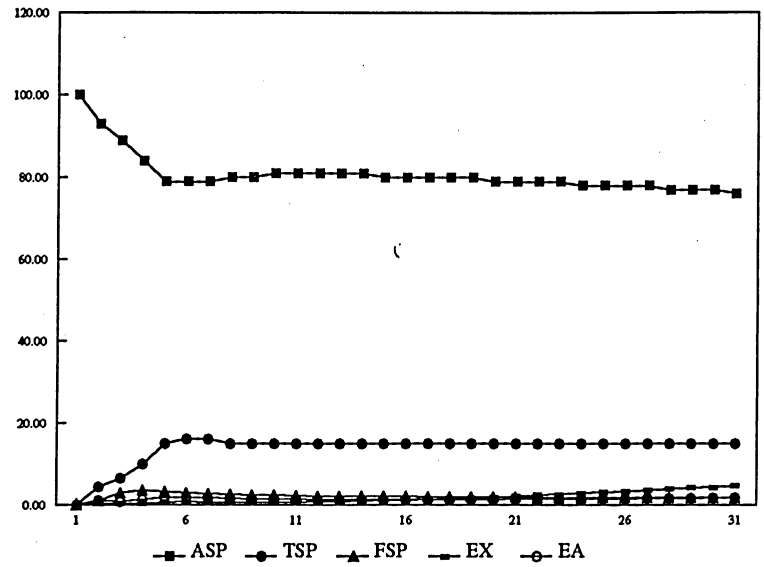
Time Periods

Figure 15
IRF - Alternative Order, One Std. Dev. Shock to Variable EA



Time Periods

Figure 16
VDC - Percentage Sources of Forecast Error Variance in ASP

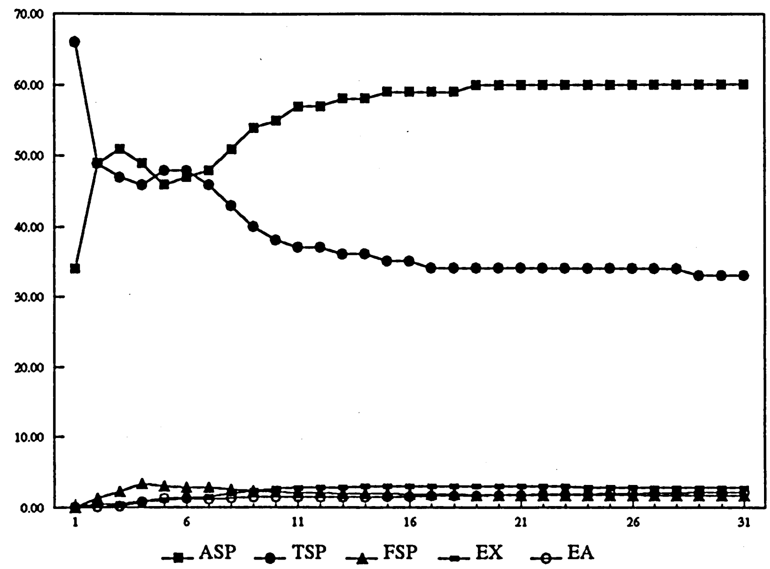


Time Periods

Legend:

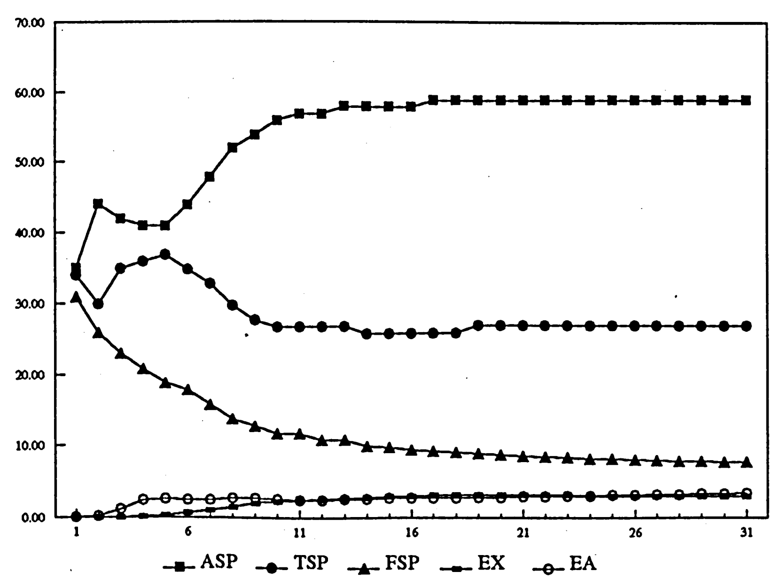
EX=U.S./Cdn $ exchange rates
FSP=Nearby Futures Live Cattle Futures Price in U.S. $ (logged)
TSP=Texas Slaughter Steer Price in U.S. $ (logged)
ASP=Alberta Slaughter Steer Price in Canadian $ (logged)
EA=Live Animal Exports from Canada in Canadian $ (logged)

Figure 17
VDC - Percentage Sources of Forecast Error Variance in TSP



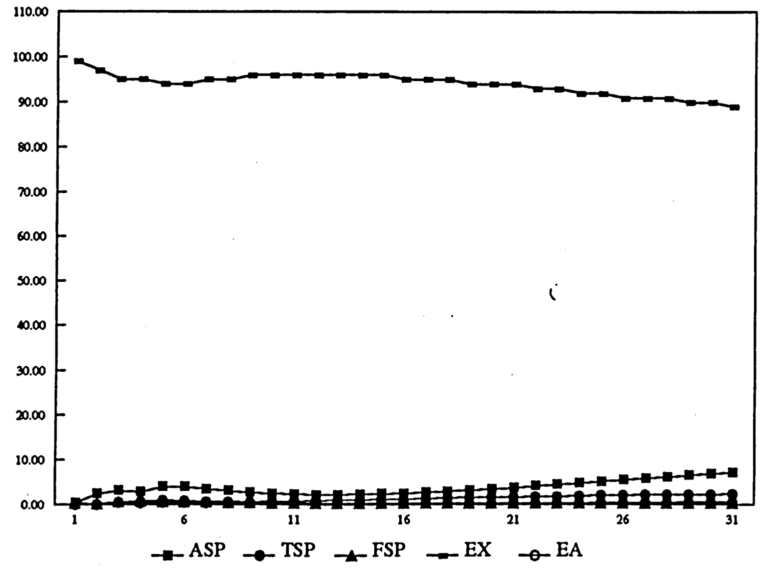
Time Periods

Figure 18
VDC - Percentage Sources of Forecast Error Variance in FSP



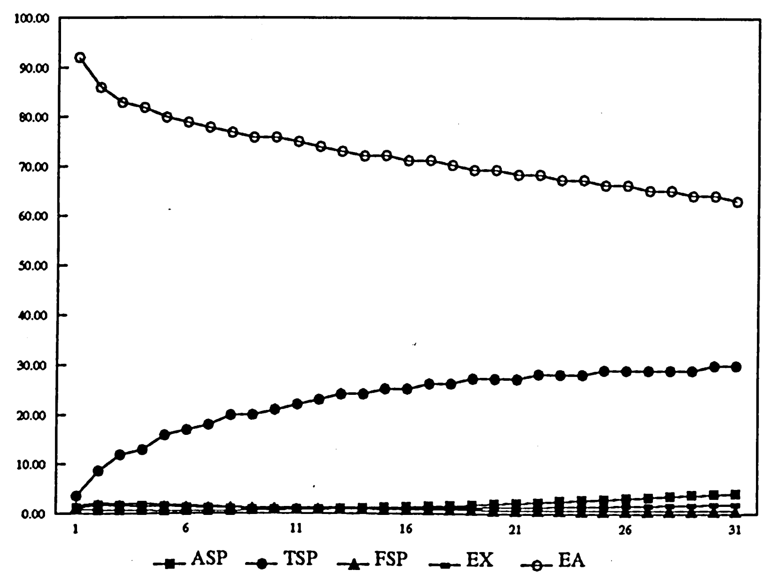
Time Periods

Figure 19
VDC - Percentage Sources of Forecast Error Variance in EX



Time Periods

Figure 20
VDC - Percentage Sources of Forecast Error Variance in EA



Time Periods

Endnotes

1. The interest parity theorem states that the spot exchange rate, EX(t), is related to the Forward exchange rate, FX(t), and the interest rates in the two countries (CR, USR). That is EX(t)=[(1+CR)/(1+USR)]FX(t). As a first approximation, if the forward rate is an unbiased forecast of the future spot rate (E[EX(t+1)]=FX(t)), then including the lagged values of the ratio [(1+CR)/(1+USR)] as well as lagged values of the exchange rate should have predictive power in the model.

2. The individual interest rate equation in the VAR strongly rejected normality of the residuals at the orders of VAR suggested by the other model tests such as the AIC criteria or the likelihood ratio tests.

3. The ordering is not an issue for the initial tests on model adequacy or the simple Granger causality tests explored in this study.

4. A description of the Granger causality test results (Table 6) are in the Appendix in the *VAR Model* subsection.

5. Recall that the natural log(1)=0.

6. The reader is reminded that all cattle prices and export values in the model are logged. The shocks in the IRF for ASP, FSP, TSP, and EA represent shocks to the logged values and the graphs show the forecast changes in the logged values. The direction of the changes is interpreted in the same way as if the values were not logged. Refer to the Legend with Figure 1 for an explanation on how the percentages reported above are calculated. Further discussion and interpretation of the IRF results are delayed until after Variance Decomposition is explained.

7. Another term for this forecast error variance is the Mean Square Error.

8. This is a very loose interpretation of the relationship between shocks to each variable. These one standard deviation shocks represent changes in the variables that occur at the same relative distance (in a statistical sense) from the mean of each variable in the VAR model. Technically, the probability of a price shock occurring anywhere between the mean and one positive standard deviation from the mean is equal between each variable.

9. For example, if ASP=$90/cwt a .009$ increase in Cnd. $ will decrease ASP by $.63/cwt by quarter 4. An equally likely increase in FSP would be expected to change ASP by $3.6/cwt.

10. If the ordering of the IRF is change to ASP, TSP, FSP, EX and EA, then the TSP contributes the most to the variance of the ASP. We can still reasonably conclude that the prices in the U.S. contribute much more to the future variance of Alberta prices than the exchange rate.

11. Carter et al. (1990) concluded using single regression equations that partial equilibrium analysis was appropriate given the large exchange rate pass through and other results of their study.

12. This section uses the notation and description from Fackler (1988a) and Fackler (1988b) for VAR models.

13. This restriction, B=I, is not required but total restrictions needed are $(3K^2-K)/2$ on A^{-1} and B (Fackler (1988b)). Normalization reduces this to $3(K^2-K)/2$. Setting B=I gives K^2 restrictions.

14. Recall that $B=\Omega=I$ by assumption in cov(U(s)).

15. The estimation procedure used for this is from Fackler and it is written for the GAUSS statistical package.

16. Lutkepohl (1991) gives an excellent summary of these issues in chapter 4.

17. More accessible descriptions of the Johansen methodology are given in Lutkepohl (1991, pp.355-368) or in Davidson and MacKinnon (1993, pp.726-730).

18. The exact testing procedure for determining the number of cointegrating relationships followed Lutkepohl (1991) proposition 11.1 (pp.356-357). The eigenvalues derived from this procedure are used in a series of sequential Likelihood Ratio type tests given by Lutkepohl equation 11.4.3 (pp.384-387). The test statistics for 0 cointegrating vectors (CV) versus 1 CV, 2 CV vs 1 CV, 3 CV versus 2 CV, 4 CV versus 3 CV and 5 CV versus 4 CV are 49, 34, 17.5, 4.7 and 1.5 respectively. Special tables show that 49 and 34 are significant at the 1 % level. This strongly suggests 2 cointegrating relationships in the variables. A VAR(5) model was used based on selection criteria results presented later in the study.

19. The Portmanteau test may not be valid when the VAR model is non stationary such as the model we are now planning to estimate. (Lutkepohl (1991, p.384).