University of Alberta

Effects of Age, Time and Location on Agricultural Asset Values

by

James R. Unterschultz ©

A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of
DOCTOR OF PHILOSOPHY
in
FINANCE

Faculty of Business
Edmonton, Alberta
Fall 1996.

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ISBN 0-612-18122-7

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Name of Author: James Ryan Unterschultz.

Title of Thesis: Effects of Age, Time and Location on Agricultural Asset Values.

Degree: Doctor of Philosophy.

Year this Degree Granted: 1996.

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled *Effects of Age, Time and Location on Agricultural Asset Values* submitted by James Ryan Unterschultz in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Finance.

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Abstract

The effects of age, time and location on agricultural asset values are investigated. Secondary asset market data for combines and tractors are used to estimate economic depreciation, technological change and time value change. Combines and tractors generally exhibit constant geometric economic depreciation and vary by manufacturer. There is a predictable time component to machine value. Investment risk over longer planning horizons may be lower when both depreciation coefficients and time component estimates are employed. Risk premia in terminal combine values are consistent with a risk premium ranging from 5.5% to 8.3%. For tractors the risk premium range is 2.4% to 3.6%.

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. An equally likely shock to the exchange rate results in a much smaller change to Alberta prices than an equally likely shock to the U.S. futures price. The second greatest source of price instability after futures prices is from unidentified Alberta sources, basis risk. The third-ranking source of risk comes from United States cash prices. The U.S.-Canada exchange rate was a negligible source of risk in Alberta slaughter steer prices.

The age component was incorporated directly into four different futures price models for non-storable commodities such as cattle. Spot feeder animal prices rather than spot slaughter price were specifically included in the models. Two derived models are very similar to the simple arbitrage futures pricing models in the literature and show how the current feeder value is tied to the relevant futures price. A third model incorporates an unspecified stochastic convenience yield into the model. The final model includes a stochastic feed cost which would have a strong bearing on the price of cattle over longer feeding periods. The validity of these models is an empirical question.

TABLE OF CONTENTS

List of Tables

List of Figures

Chapter 1: Research Objectives and Thesis Overview

Introduction

An agricultural business often represents a large portion of an investor's investment portfolio. This portfolio is not easily diversified and this increases the importance of risk management for an individual investor. The unifying thesis theme is the examination of risk and finance with applications to agriculture business and agriculture investment.

Age, time and/or location are important factors impacting on risk in agriculture investments. This group of papers measures farm machinery investment risk based on asset age and time, measures sources of risk in Western Canadian cattle prices based on location risk and finally examines the theoretical relationship between futures and non-storable commodities based on asset age and time.

Research Objectives

Chapter 2 explores risk and forecasting issues in farm machinery depreciation and examines ways to reduce the forecast risk surrounding machinery investment. Farm machinery is a major component in many farm balance sheets and it may be the major asset held by custom operators. Uncertainty surrounding the future value of farm machinery may therefore contribute significantly to risk exposure in these enterprises.

The standard practice when forecasting terminal asset value is to base the forecast on economic depreciation estimates. These estimates are then used in the machinery purchase investment analysis. Improved terminal asset value forecasts reduce the investment risk surrounding the machinery investment. Investment risk is defined in Chapter 2 as the deviation of the actual value from the forecast value.

Secondary market transactions on combines and tractors from 1972 to 1992 are used to obtain time-independent economic depreciation estimates by manufacturer (an age effect) and in this respect updates the literature. The model used to estimate the age component additionally separates the asset value change into a time component and a technology component. The time component is analyzed for ways to improve terminal asset value forecasts. Information contained in the time component is combined with economic depreciation estimates to improve the terminal asset value forecast and to reduce the machinery investment risk.

Chapter 3 extends the results from Chapter 2 and estimates risk adjusted discount rates for combines and tractors by assuming that machinery portfolios are non-diversified. Conceptually machinery assets can be replaced by financial assets such as stocks or bonds. Machine discount rates are derived by creating a financial portfolio with total risk equivalent to a farm machine asset. The risk premium is derived from this equivalent financial portfolio and this risk premium can be used in farm machinery investment analysis.

Chapter 4 examines and compares the sources of price risk in the cattle feeding industry in Western Canada. Cattle investments are often held in non-diversified portfolios. More accurate analysis of the risk sources and the relative impact of each risk on local prices can be used by individual cattle investors to improve risk management strategies. These strategies include identifying the sources of price risk, hedging using existing derivative securities or changing the scale of the cattle investment. Vector autoregression and intervention analysis are applied to price data from Alberta and the United States to examine long term price relationships between two different cattle feeding locations, determine the historical relative sources of price risk and provide guidance as to future relative price risk relationships. The results will help investors located in Western Canada choose the appropriate risk management strategy and indicate if research on creating domestic based risk markets is justified.

The Chapter 4 study encompasses the time period from 1976 to 1994. Initial analysis covers the entire time period. This gives an historical overview of the sources of price risk. The relative contribution of each potential source of risk may have changed during this time period and this study also investigates possible changes in these sources of risk.

Chapter 5 introduces theoretical models for pricing futures contracts that explicitly include the non-storability component, an age factor. Many agricultural investments such as live cattle are non-storable commodities. Futures markets for several non-storable commodities exist for pricing and transferring risk between different investors. The literature describing futures prices generally ignores the impact of non-storability in the theoretical models. Incorporating non-storability, the age factor, into the theory could improve the efficiency tests on these markets and improve the applied use of these contracts for managing risk.

This Chapter 5 paper derives closed-form solutions relating futures slaughter prices to spot feeder prices. These solutions are extended analytically or numerically to include either stochastic convenience yields or stochastic feed costs. Conceptually these models are useful when analyzing markets and will be useful in future empirical work on non-storable commodities markets.

Conclusion

The remaining chapters present the research on each of the subjects discussed above. Each chapter introduces the research question of interest, discusses the relevant literature and then presents the empirical or theoretical results. Where applicable each chapter is self contained with its own footnotes, tables, figures and bibliography. Extra information pertaining to Chapters 2 and 5 are included in two appendices.

Chapters 2 and 3 explore farm machinery investment and ways to improve terminal asset value forecasts and machinery investment decisions. Chapter 4 uses Vector Autoregression to analyze the relationship between the sources of price risk in

Western Canadian cattle markets. Chapter 5 examines non-storability and the theory of storage in commodity futures prices and how futures pricing models for such commodities as cattle can be improved. Chapter 6 concludes the thesis.

Chapter 2: Risk And Forecasting Issues In Tractor And Combine Depreciation

Introduction

Forecasts of terminal value are very important in the farm machinery investment decision (Reid and Bradford 1983). Terminal asset values[1] are normally forecast with economic depreciation estimates. Improved terminal asset value forecasts reduce the risk surrounding the machinery investment.

This paper improves the terminal asset value forecasts for North American tractors and combines. It accounts for the estimation problems inherent in time-series, cross-sectional machinery price data and improves upon the statistical methods existing in the literature. It introduces the concept of price reversion common in the finance literature to additionally refine the terminal asset value forecast. It also analyses depreciation differences by manufacturer and by type of technology (in combines). Finally it observes seasonality in depreciation rates..

Secondary market transaction records on combines and tractors from 1972 to 1992 are used to obtain time-independent economic depreciation estimates by manufacturer by half year (an age effect). In this respect the paper updates the tractor literature (Perry, Bayaner and Nixon, 1990; Hansen and Lee, 1991; McNeill,1979) and provides an alternative to the Cross and Perry (1995) study which includes 1984-1993 data on tractors, combines and other farm machinery. The Perry, Bayaner and Nixon (1990) results indicated that depreciation rates varied by manufacturer; however their data set only spanned three years while Hansen and Lee ignored the manufacturer effect. Knowledge of a 3% difference in depreciation rates between manufacturers is useful information for farms which may have several hundred thousand dollars or more invested in machinery.

The model used to estimate the effect of age on machine value also identifies time and technology effects. Other studies investigate the effect of individual machine usage (accumulated hours) and size (horsepower) on expected value change (Perry, Bayaner and Nixon, 1990; McNeill, 1979; Cross and Perry, 1995) or use the time component to construct historical machinery price indices (Hansen and Lee,1991; Lee,1978). Here, the time component is analysed for ways to improve terminal value forecasts. Information related to the time the forecast is made is combined with economic depreciation estimates to improve the terminal value forecast and thereby reduce the machinery investment risk

This chapter is organized in the following manner. The next section reviews previous work on depreciation estimates. The data is then described and the estimation methods and results follow. Applications to forecasting terminal asset values are then discussed.

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[1] Terminal asset value is also referred to as the salvage value or the remaining value.

Previous Work And The Hall Model

Asset value changes over time include economic depreciation (an age effect), quality changes (a technology effect) and demand changes (a time effect) (Hall, 1968, 1971). The economic depreciation, defined as the rate of change of asset prices with age, is assumed to be independent of time and independent of the individual manager. The quality changes and demand changes are time-dependent but are also independent of the individual manager. Estimation methods must differentiate between these different effects on used asset prices. These different effects are described below when the Hall model is explained.

Two main models have been used to estimate depreciation. One method, the Box-Cox transformation, transforms the variables allowing a flexible functional form for estimation. A second estimation method is based on the work by Hall and this model is explained later. The Box-Cox transformation is useful when there are many different asset categories, a small sample size and the data does not have any zero observations. Box-Cox estimation problems and biases caused by heteroskedasticity, by autocorrelation and by data scaling (Zarembka 1974; Savin and White 1978; Seaks and Layson 1983; Spitzer 1982) have not been adequately addressed when estimating depreciation. These Box-Cox estimation problems discussed by Spitzer and others can seriously bias the transformation variable and invalidate the statistical tests.

Hulten and Wykoff (1981) were among the first to apply the Box-Cox transformation to estimate depreciation. Perry, Bayaner and Nixon (1990), and Cross and Perry (1995), following Hulten and Wykoff (1981), use the Box-Cox transformation to estimate farm machinery depreciation using auction market data. The Perry, Bayaner and Nixon (1990) data only spans 1985-1988 which is too brief a time period to reliably estimate any time effect. The Cross and Perry (1995) study still only covers ten years, 1984-1993. Neither of these studies on farm machinery address the concerns raised above about the Box-Cox methodology.

Problems with estimating the Box-Cox transformation are avoided by using the model developed by Hall (1968, 1971) in which asset values are viewed as the present value of the future benefits (economic rents) expected from the use of the asset. Hall (1971) utilising this discounted stream of benefits idea, formalized the empirical work done by Cagan (1965) to derive the model

$$p_{t,\tau,v} = P_t^* D_\tau B_v \tag{2.1}$$

The model states that the observed price $p_{t,\tau,v}$ of the used asset is the underlying constant quality price index P_t^* at time t, adjusted for vintage (v) or embodied technology by the index B_V and adjusted for economic depreciation by asset age τ by the index D_τ. P_t^* is affected by disembodied technological changes (general improvements in the use of existing technology) and by such factors as changes in expected equipment demand or in industry manufacturing capacity. D_τ measures the pure age effect of economic depreciation. B_V captures quality differences, including the effects of different asset sizes. Equation (2.1) can be applied to machinery in general or to test whether depreciation varies between manufacturers.

The Hall model requires restrictions to separate embodied technology and machine age. Hall (1971) and Lee (1978) surmounted this problem by placing restrictions on technology change over time. Hansen and Lee (1991) use a normalization similar to Cagan (1965) and use the year a model is first manufactured to denote its technology. In the present paper, the embodied technology term, B_V, denotes the manufacturer's model series number (e.g. John Deere 6600 combine) rather than the year of model introduction on the assumption that manufacturers signal new technology by introducing new models. This normalization on model number distinguishes technology and depreciation effects by manufacturer even when competing machinery model series numbers have been introduced in the same year. For example, it separates value effects of "rotary" versus "conventional" combines from depreciation differences between manufacturers.

Following Hansen and Lee (1991) the model is presented as:

$$\ln(p_{t,\tau,v}) = \sum_t \ln(P_t^*)T_t + \sum_m \sum_\tau \ln(D_{\tau,m})G_{\tau,m} + \sum_v \ln(B_v)V_v + u \tag{2.2}$$

where T, G and V are vectors of zero/one dummy variables that identify the observation year, age manufacturer's series. Subscripts on each vector T, G, and V represent the elements associated with each vector. There are spring and fall observations for both age and time. For example, the combine equation has times of $T_{1972}, T_{1972.5}, \ldots T_{1992}$, ages of $G_1, G_{1.5}, \ldots G_{8.5}$ and models from $V_1, \ldots V_{20}$. The five manufacturers are designated by the subscript *m*. The first summation on the right hand side of equation (2.2) captures the time effect. The time effect is constrained to be the same for all manufacturers. Economic depreciation by manufacturer is captured by the double summation. The final summation compares the embodied technology between assets. There are 130 coefficients in the combine model and 234 coefficients in the tractor model after normalizations[2]. The data are described next.

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[2] Estimation of equation (2) requires the normalization of the embodied technology of one combine (tractor) model, $ln(B_V)$, to be 0 and this provides the technology comparison for each model. The age τ=1 depreciation index $ln(D)$ (spring and fall) is normalized to be zero for each manufacturer. Thus all depreciation factors, D_τ are measured relative to one year old assets by manufacturer. This normalization forces depreciation for assets aged 1 (spring) and 1.5 (fall) to be the same and gives them a depreciation index of 1.

Data

Used combine and tractor prices were collected for the period of spring 1972 to spring 1992. The prices are averaged-as-is dealer selling prices from across North America reported in spring and fall issues of the *Official Guide: Tractors and Farm Equipment*. Perry, Bayaner and Nixon (1990) discussed the limitations of this data source; however it is the best time series source of secondary market asset prices for tractors and combines. Data for actual initial (time zero) selling prices are not included in the *Official Guide*. Studies such as Perry, Bayaner and Nixon (1990) and Cross and Perry (1995) use list prices for initial prices, but list prices are not observed transaction prices and confound depreciation estimates with the manufacturer's marketing methods.

Asset prices on 20 combine series-numbers representing small to medium sized combines with either conventional or rotary technology from 5 different manufacturers were collected from asset age 1 (spring) to 8.5 (fall). There are 2265 observations on 170 cohorts on the combine data. Asset prices on 34 two wheel drive tractor series-numbers in the 100 to 150 horsepower range from 8 manufacturers were collected from asset age 1 (spring) to 11.5 (fall). There are 174 cohorts with 3202 total observations. Additional data on older equipment were available but were omitted out of concern for the censoring problem described by Hulten and Wykoff (1981).

All prices from the Official Guide are in nominal United States dollars. The CPI (Bureau of Labour and Statistics, 1982-1984=100) for the United States is used to deflate the used asset prices. Use of the CPI is consistent with the general concept that investment is an exchange of consumption opportunities across time.

Method and Results

Not surprisingly, considering the time series and cross sectional nature of the data, preliminary ordinary least squares (OLS) estimates revealed first order autocorrelation and heteroskedasticity. The autocorrelations were assumed to be related to each manufacturer. Estimation of serial correlations between manufacturers was not attempted. The OLS residuals were used to estimate a sample autocorrelation coefficient in each cohort. Following Kmenta (1986 p.816) the coefficient was constrained to be between -1 and 1 and a simple mean of these autocorrelation coefficients for the cohorts in each manufacturer group was taken. This provided a consistent AR(1) estimate for each manufacturer. A Prais-Winsten transformation (retaining all observations) using these manufacturer autocorrelations was performed on the data, cohort by cohort. OLS was used on this transformed data. White's heteroskedasticity consistent estimator for the variance-covariance matrix was used to overcome the heteroskedasticity problem. The model still exhibited some non-normality in the residuals after these adjustments. The coefficient and variance estimates are still consistent with non-normal residuals but may no longer be efficient. The student-t test and the F test still have asymptotic justification (Judge et al. p. 824).

Observations about the equation (2.2) results for P_t, B_v and D_τ follow below. Due to the large number of coefficients estimated, only a representative set of model estimates are selected for presentation. All test conclusions reported are significant at the 5% level and detailed results are available from the author.

The constant quality asset value, P_t, represents the value of a combine or tractor of constant quality over the time period 1972 to 1992. Figure 2.1 illustrates this time component and shows a sharp increases in asset values in the 1970's with subsequent value decline. For example, the constant quality combine value increased by 18% during the spring of 1976 and decreased by 10% during the spring of 1979. These value changes are time specific, relatively large, statistically significant and add to investment risk. Statistically significant value changes each time period implies that the returns to holding the constant quality asset are not a random walk[3] and this invites attempts to forecast the time component.

Tables 2.1 and 2.2 are the remaining value coefficient estimates, D_τ, and can be used to estimate terminal values or annual depreciation. All depreciation is measured from a beginning point of one year old assets. All combine manufacturers and six of the eight tractor manufacturers exhibit constant yearly spring-to-spring geometric depreciation rates by manufacturer and as such is similar to the results reported by Hansen and Lee (1991) for their tractor data set. John Deere and Allis Chalmer tractors are the manufacturers not exhibiting constant annual spring-to-spring depreciation.

The remaining value results for tractors and combines (Tables 2.1 and 2.2) exhibit a seasonal economic depreciation effect and this seasonal effect has not been noted or tested in other studies. The greatest depreciation (loss in value) occurs during the fall-to-spring time period. These spring versus fall differences are significant for John Deere, Massey Ferguson and New Holland combines and for Allis Chalmers, Case, John Deere and IH tractor manufacturers. This seasonal effect is likely related to the seasonal nature of North American grain farming. Furthermore manufacturers have significantly different depreciation rates. This supports the conclusions of Perry Bayaner and Nixon (1990) that asset value changes vary by manufacturer.

Figure 2.2 illustrates the difference in annual spring to spring depreciation rates between two manufacturers. New Holland combines hover around 9% annual depreciation rates while John Deere combines vary between 6% and 8%. John Deere tractor depreciation rates vary between 3% and 6%. Case tractor depreciation rates vary between 6.5% and 7.5%. Results for other manufacturers show similar patterns.

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[3] If the returns, r, to owning the constant quality asset are a random walk then $\ln(P_t) = r + \ln(P_{t-1})$. The random walk model, often used in market efficiency tests, is not consistent with a reversion model.

The combine and tractor quality comparisons, B_V, generally showed larger capacity, newer models are valued more highly. This technology component picks up the differences in size. Technology is represented in the Hall model by manufacturer series-number and does not enter the manager's forecast once the asset is purchased because the technology is constant across the forecast period. Figures 2.3 and 2.4 show the economic value of the technology of the tractor and combine models relative to a base technology. Relevant comparison are between machines of similar capacities. In general newer models have a higher technology value or component. This supports the conclusions of improving technology over the time period.

Figure 2.5 presents a special comparison between two competing combine technologies, rotary versus conventional. The two technologies are significantly different and the market placed a slight premium on the rotary technology in the used asset market. Asset values may still decrease more rapidly for rotary combines than for conventional combines because of differences in the manufacturer specific depreciation.

Improving Time Forecasts

The prior results provide historical time-independent, manufacturer-specific depreciation indexes. Managers can use these manufacturer-specific estimates to forecast the future terminal value of the asset assuming no change in the constant quality asset value P_t. The two other value-influencing components besides age in the Hall model are technology and time. Technology is represented in the model by manufacturer series-number and does not enter the manager's forecast because it is constant across the forecast period. This leaves the effect of time as a possible source for improving terminal value forecast. In this section a simulation exercise measures the risk reduction obtained by adding the forecastable part of the time component to the depreciation estimates.

Hansen and Lee (1991) suggested long-run changes in tractor prices are supply-determined with competition between manufacturers tending to drive new equipment prices to long-run average total manufacturing cost. However, in the short run, manufacturing capacity is rigid. Unpredictable demand shocks, probably emanating from agricultural commodity markets, can induce capacity surplus or shortage and correspondingly change short-term pricing of new equipment. Eventually, however, capacity responds to the short-term price signals and long-run equilibrium prices for new equipment are restored. This reversion to long-run price is also expected in used equipment since used equipment is a substitute for new and the supply of used equipment is fixed. Figure 2.1 indicates the time effect on machinery prices. The rapid rise in real commodity prices during the 1970s is a plausible example of a demand shock affecting the machinery price series.

Demand shocks are not predictable. The reversion of prices to some long-run trend after the shock is predictable. Managers can potentially use this reversion in prices to improve terminal asset value forecasts. Fama and French (1988), Poterba and Summers (1988) or Cutler, Poterba and Summers (1991) have used mean reverting models to test the market efficiency (random walk) hypothesis in financial markets. The hypothesis of reversion to long-run average costs suggests the use of similar reverting models for machinery. Results discussed in the prior section rejected the random walk hypothesis for returns to holding constant quality machines. This result is compatible with a model that includes a reversion component.

The Hansen and Lee (1991) results indicated a downward trend in the long-run average manufacturing costs for sixty horsepower tractors. A model that incorporates a constant geometric trend in manufacturing costs and a reversion to trend during one period is:

$$P_t^{**} = P_{t-1}^{**} e^{\delta} + \beta \left(C_0 e^{\{\delta (t-1)\}} - P_{t-1}^{**} \right) + \varepsilon_t \tag{2.3}$$

where the P_t^{**} are the actual constant quality asset coefficient estimates from equation (2), δ is the trend in manufacturing costs, β is the rate of reversion in one time period and C_0 is the long-run manufacturing costs at time t=0. The β is expected to be positive in sign. The manufacturing trend term, δ is expected to be small and this makes it difficult to distinguish this model from alternative forms. A negative δ indicates declining manufacturing costs.

Estimation and testing of this model presents several problems. Results from equation (2.2) estimates are used to eliminate the errors-in-variables estimation problem[4] in (2.3). The model is non-linear in δ and a grid search is used to estimate δ. Finally, knowledge of the manufacturing costs are required at time t=0. Using information from Hansen and Lee (1991), the first observation P_1 (spring 1972) is chosen equal to $C_0 e^{\delta}$ to coincide with a period of relative price stability. The constant quality coefficient estimates from equation (2) were first converted to an index with 1982=100 before estimation.

Results from equation (2.3) are in Table 2.3. The reversion parameter β 's of 0.075 for tractors and 0.035 for combines are not significant but they are of the expected sign. Lack of significance is not surprising considering the long nature of these time trends and the only twenty year span of the data. These are still the best estimates of the reversion parameters and can be used to improve forecasts thereby reducing risk. The tractor reversion of 0.075 per six months implies that if the tractor price index were 20 % above its trend value, prices would revert down by about 3% over the next year. This reversion would be independent of and additive to economic depreciation.

Long-run trend estimates in manufacturing cost δ's are -0.27% and 0.51% for tractors and combines respectively over a six month period. The tractor δ agrees with the Hansen and Lee (1991) data that costs are declining. The combine δ suggests prices were increasing over this period. The difference between tractors and combines could, in addition to differences in manufacturing technology, result from

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[4] Details on the correction used are in Appendix A1.

increased concentration and declining competition in combine manufacturing during the period.

In practical applications, a manager might use manufacturer and age specific economic depreciation estimates from the Hall model (e.g. Tables 2.1 and 2.2). Forecasts are refined by determining the current value of the constant quality asset using equation (2.2) and then using the coefficient estimates from equation (2.3) to estimate the amount of value reversion over the expected machinery holding period.

A simple test, while in-sample, provides supporting evidence on investment error reduction by adding time-reversion estimates to depreciation estimates. Error is measured as the deviation of the actual value from the forecast value. One set of forecast asset values is generated with manufacture-specific depreciation estimates only. A second set of forecasts is enhanced with time-reversion estimates. Root Mean Square Errors[5] (RMSE) measure the forecast errors, in dollars.

The RMSE for forecasts made when the tractors and combines are one year old are shown in Figure 6. RMSE for forecasts based on other ages are similar. Absolute forecast errors or risk exceeds \$8,000 for combines and \$3000 for tractors when the investment holding period is over four years. This dollar error as a percentage of the mean value of five year old machines is 28% and 17% for combines and tractors respectively[6]. Errors are greater on combine investments than tractor investments.

Including time reversion decreases the investment error for both combines and tractors but the error reduction is much greater for tractors. This is emphasized in Table 2.4 where error reduction through the addition of time reversion can approach 50% for tractors and only 20% for combines. The benefits of including time-reversion increase as the intended holding period (forecast horizon) increases.

Profiles of RMSE for one, three, five and eight year holding periods are exhibited in Figures 2.7, 2.8, 2.9, and 2.10. Asset age at the start of the forecast periods varies in these figures. Error for one year holding periods (Figure 2.7) are much lower than for three, five or eight year holding periods (Figures 2.8, 2.9 and 2.10). Comparing Figures 2.7 through 2.10 show investment error initially increases with the intended holding period but it may decrease for investment horizons over 5 years as machinery values become relatively small. Adding time reversion has almost no impact on one year holding period error (Figure 2.7). The benefits of including time reversion appear for holding periods of three years or more. The percentage decrease in error improves with longer intended holding periods and with the age of the machine (Table 2.4). These results are not tested for significance but are likely

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[5] RMSE is defined as RMSE= $\sqrt{\sum_i (ActualValue_i - ForecastValue_i)^2 / n}$ where n is the number of forecasts.

[6] Mean one year old tractor and combine values are \$24,180 and \$41,098 respectively and five year old tractor and combine mean values are \$17,673 and \$28,774 when measured in constant dollars.

economically significant. Slow reversion of asset prices favours the use of time forecasts over longer intended holding periods.

These test results suggest that machinery investors can reduce risk by including time reversion forecasts with depreciation forecasts. This technique may be especially relevant after major demand shocks from the commodity market.

Conclusions

Secondary asset market data for combines and tractors are used to estimate and separate out historical economic depreciation, embodied technological change and time value change. Combines and tractors generally exhibit constant geometric economic depreciation on a year to year basis which supports the findings of Hansen and Lee (1991). Depreciation rates vary by manufacturer as suggested by Perry Bayaner and Nixon (1990). Farm investors can use these manufacturer specific depreciation rates reported here to estimate terminal asset values. The study found significant seasonal differences in machinery depreciation rates. The model used for estimating farm machinery depreciation could be used on other assets where secondary markets exist.

A major source of error in forecasting terminal asset values comes from changes related to time. There is a predictable time component to the constant quality asset index that has not been investigated in previous studies. Unanticipated shocks to demand should be followed by price reversion to long-run average manufacturing costs as industry capacity adjusts to demand. This reversion component is predicable. A forecasting trial using root mean square error measures supports this hypothesis. Investment risk over longer planning horizons may be lower when both depreciation coefficients and time component estimates are employed.

Table 2.1: Combine Remaining Value Factors Based On Age 1 Combines By Manufacturer

Age[1]	Gleaner	John Deere	Case-I.H.	M.F.	N.H.
2.0	91.9%	93.1%	91.6%	92.3%	91.3%
2.5	90.6%	93.1%	90.6%	92.1%	89.8%
3.0	84.3%	86.9%	83.5%	85.2%	82.6%
3.5	82.1%	86.4%	82.8%	84.4%	80.7%
4.0	77.3%	80.6%	76.4%	78.8%	74.9%
4.5	73.7%	79.8%	75.8%	78.3%	72.3%
5.0	69.0%	74.4%	69.6%	73.3%	67.9%
5.5	65.3%	73.4%	68.6%	72.0%	65.1%
6.0	61.7%	69.4%	63.6%	67.7%	61.7%
6.5	58.1%	67.9%	61.7%	65.6%	58.8%
7.0	55.1%	64.6%	57.3%	61.9%	56.1%
7.5	52.1%	62.8%	55.7%	59.5%	52.9%
8.0	49.7%	60.2%	52.4%	56.3%	51.0%
8.5	46.9%	58.3%	49.9%	53.8%	47.9%

1. An age 2.5 Gleaner combine has 0.906 the value of a one year old combine. Ages ending in a half (2.5 or 3.5 etc.) are fall values. Ages ending in a 0 are spring values.

Table 2.2: Tractor Remaining Value Factors Based On Age 1 Tractors By Tractor Manufacturer

Age[1]	Allis	Case	John Deere	Deutz	Ford	I.H.	M.F.	White
2.0	92.8%	92.2%	94.8%	91.2%	95.3%	94.7%	94.2%	93.9%
2.5	92.8%	92.9%	96.6%	90.3%	95.0%	90.8%	92.9%	93.6%
3.0	87.9%	85.7%	91.7%	83.2%	90.4%	87.4%	87.4%	88.9%
3.5	87.5%	86.3%	92.8%	81.9%	90.7%	83.5%	85.6%	88.7%
4.0	82.9%	80.0%	88.5%	77.1%	84.7%	81.7%	80.9%	83.8%
4.5	82.6%	80.6%	89.4%	76.1%	85.8%	76.8%	79.0%	83.3%
5.0	78.6%	74.7%	86.5%	72.0%	80.2%	76.3%	73.1%	77.6%
5.5	77.1%	74.9%	87.2%	70.6%	80.7%	71.2%	71.2%	76.9%
6.0	72.8%	69.3%	84.0%	66.0%	76.9%	69.0%	66.3%	71.0%
6.5	71.3%	69.1%	83.9%	64.7%	77.1%	65.5%	64.0%	69.1%
7.0	65.9%	64.4%	80.4%	60.6%	74.1%	63.7%	60.1%	63.9%
7.5	63.3%	64.1%	79.5%	59.2%	74.3%	60.6%	58.2%	62.0%
8.0	58.2%	60.1%	76.2%	55.5%	70.7%	58.5%	55.3%	57.8%
8.5	55.8%	59.6%	75.5%	53.9%	69.9%	55.7%	53.5%	56.6%
9.0	52.0%	56.0%	72.2%	50.4%	66.3%	52.9%	50.8%	52.8%
9.5	49.2%	55.5%	71.4%	48.8%	65.8%	51.2%	49.2%	51.5%
10.0	45.1%	52.4%	68.6%	45.8%	62.3%	48.4%	46.5%	48.0%
10.5	44.2%	51.6%	68.4%	44.5%	62.1%	47.6%	44.9%	46.7%
11.0	40.6%	48.7%	66.4%	41.8%	58.2%	44.5%	42.2%	43.8%
11.5	40.1%	47.6%	66.4%	40.9%	58.1%	44.1%	41.0%	42.8%

1. An age 6.0 Allis Tractor has 0.728 the value of a one year old tractor. Ages ending in a half (2.5 or 3.5 etc.) are fall values. Ages ending in a 0 are spring values.

Table 2.3: Constant Quality Asset Index (P_t) Reverting Model Parameter Estimates

(Quality Index 1982=100)

Coefficient	Tractors	Combines
δ	-0.0027	.0051
β	0.075(.061)	0.035(.038)
$C_0e^\delta = P_1$	95.01	65.91

These are the estimates for equation 2.3, the reversion to trend model for the constant quality asset time component. The coefficient for the rate of reversion for a half year, β is estimated by using linear least squares adjusted to remove the errors-in-variables inconsistency. The long-run trend in manufacturing costs, δ is estimated by using a grid search that minimizes the least squares. The P_1 is the first data point in the index (spring 1972) and it is assumed that price equals manufacturing cost at this time. The numbers in brackets are standard deviations conditional on P_1 and δ. Neither β estimate is significant using a conventional t test.

Table 2.4: Relative Decrease in RMSE For Different Machinery Investment Holding Periods when Time Reversion is Added to Depreciation Estimates

Age of Asset at time of Forecast	1 Year Holding Period Tract.	1 Year Holding Period Comb.	3 Year Holding Period Tract.	3 Year Holding Period Comb.	5 Year Holding Period Tract.	5 Year Holding Period Comb.	8 Year Holding Period Tract.	8 Year Holding Period Comb.
1	2.9%	0.5%	13.4%	10.3%	28.4%	8.7%	42.0%	na
1.5	3.5%	0.5%	13.4%	10.3%	27.5%	8.0%	43.7%	
2	3.5%	0.5%	15.2%	11.6%	32.3%	9.6%	48.6%	
2.5	3.8%	0.5%	15.4%	11.8%	32.5%	9.0%	48.0%	
3	4.1%	0.6%	19.0%	14.6%	36.7%	10.8%	54.6%	
3.5	4.7%	0.6%	19.0%	14.5%	37.6%	10.4%	54.0%	
4	4.5%	0.6%	20.8%	15.9%	41.5%			
4.5	5.3%	0.6%	21.1%	16.2%	42.7%			
5	5.9%	0.7%	22.7%	17.4%	47.4%			
5.5	6.8%	0.8%	25.1%	19.2%	49.9%			
6	6.9%	0.9%	26.9%		55.6%			
6.5	8.0%	1.0%	30.6%		57.8%			
7	7.8%	1.1%	31.2%					
7.5	9.4%	1.2%	36.4%					
8	8.4%		34.1%					
8.5	10.3%		40.2%					
9	9.4%							
9.5	10.8%							
10	10.9%							
10.5	12.7%							

Figure 2.1: Constant Quality Tractor and Combine

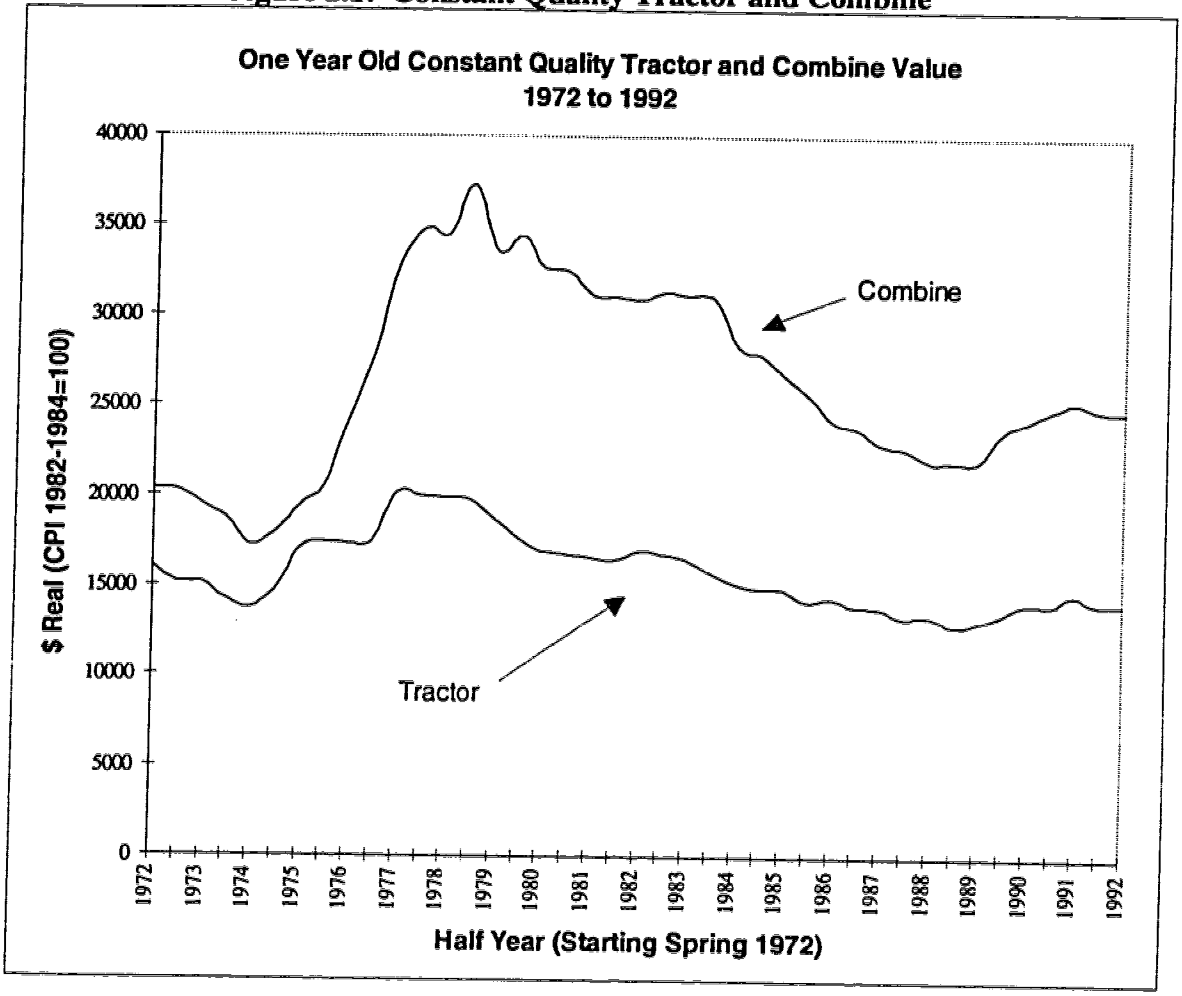
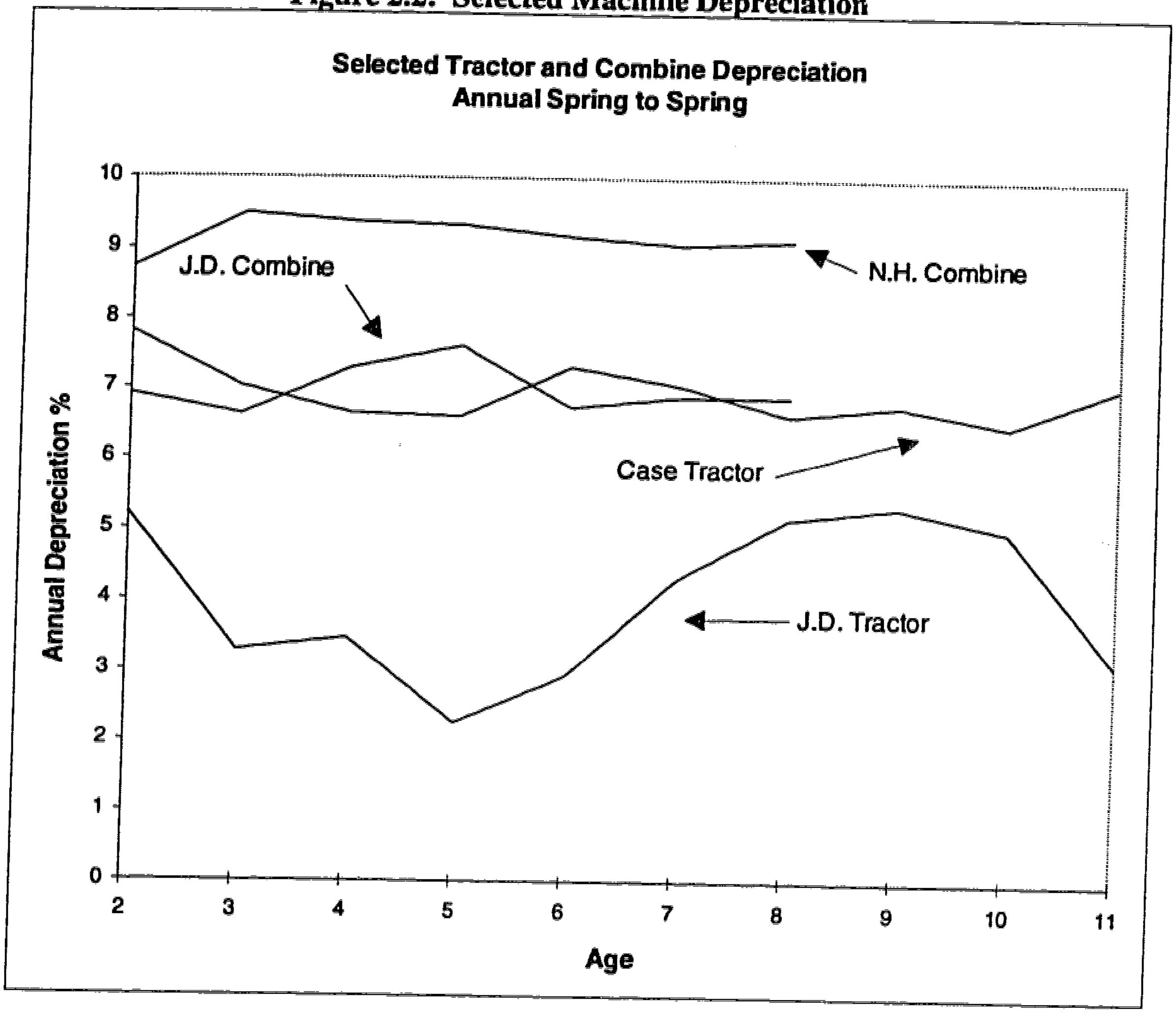


Figure 2.2: Selected Machine Depreciation



Manufacturers were selected to represent commonly available equipment in the secondary market.

Figure 2.3: Tractor Technology

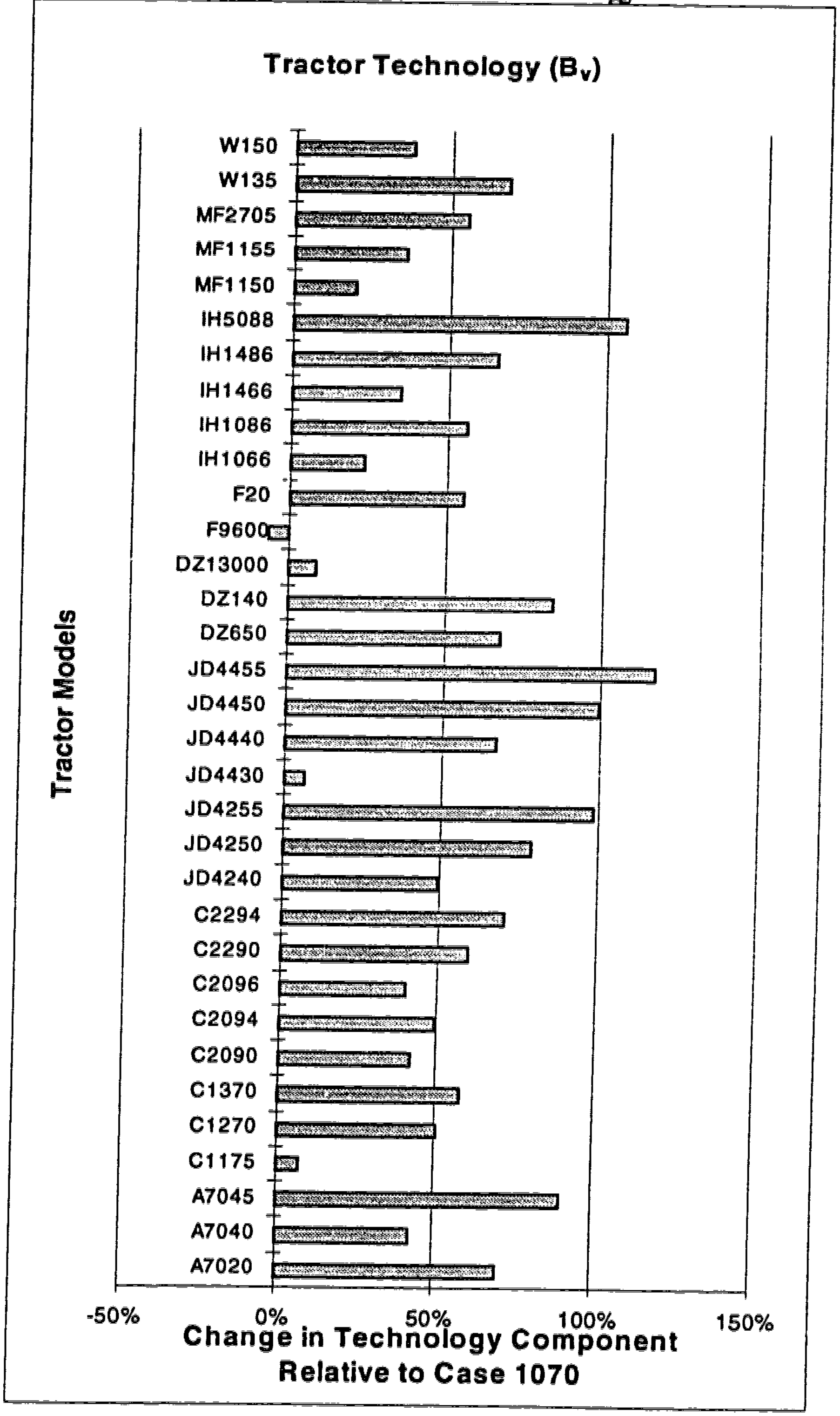


Figure 2.4: Combine Technology

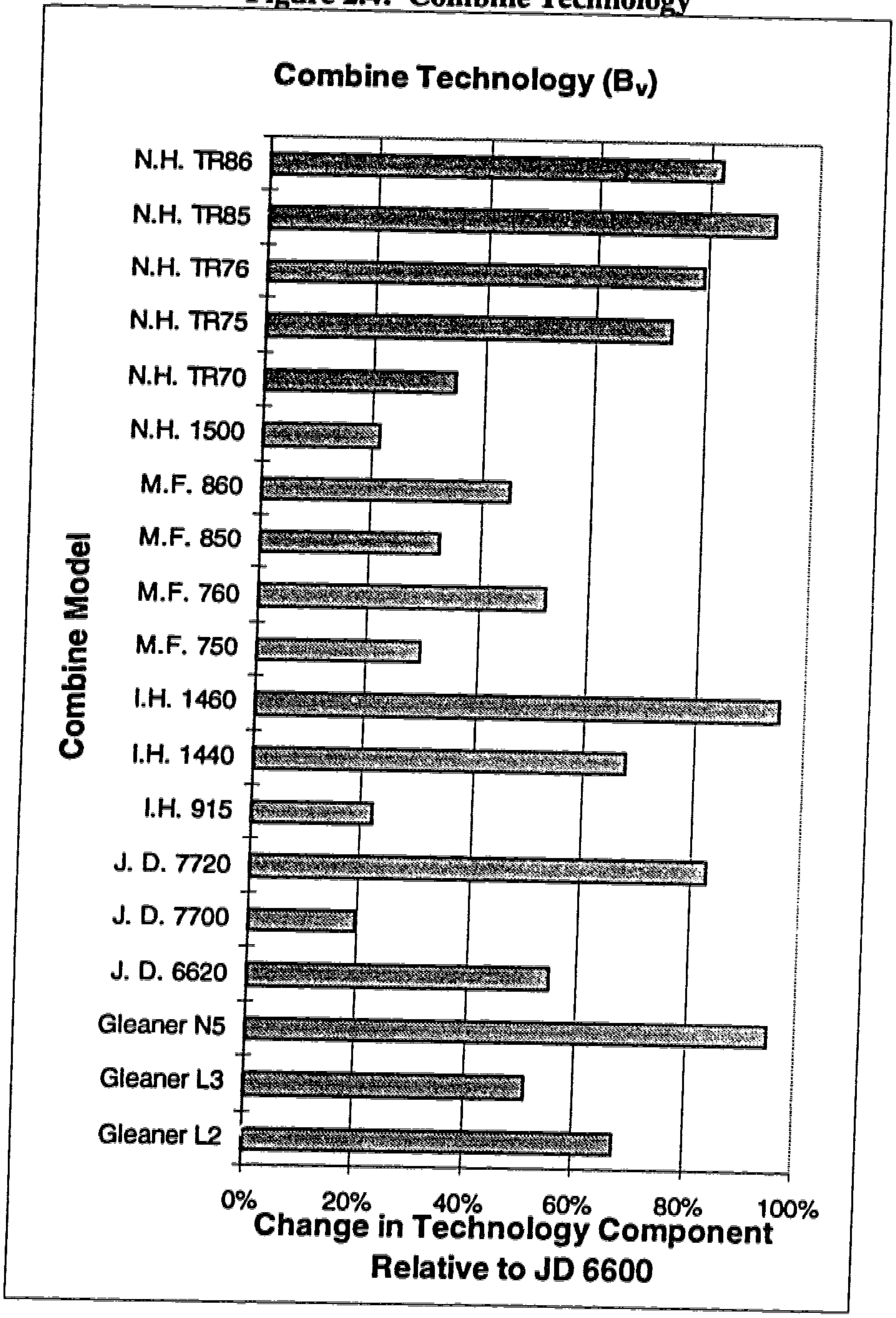


Figure 2.5: Conventional Versus Rotary Combine Technology

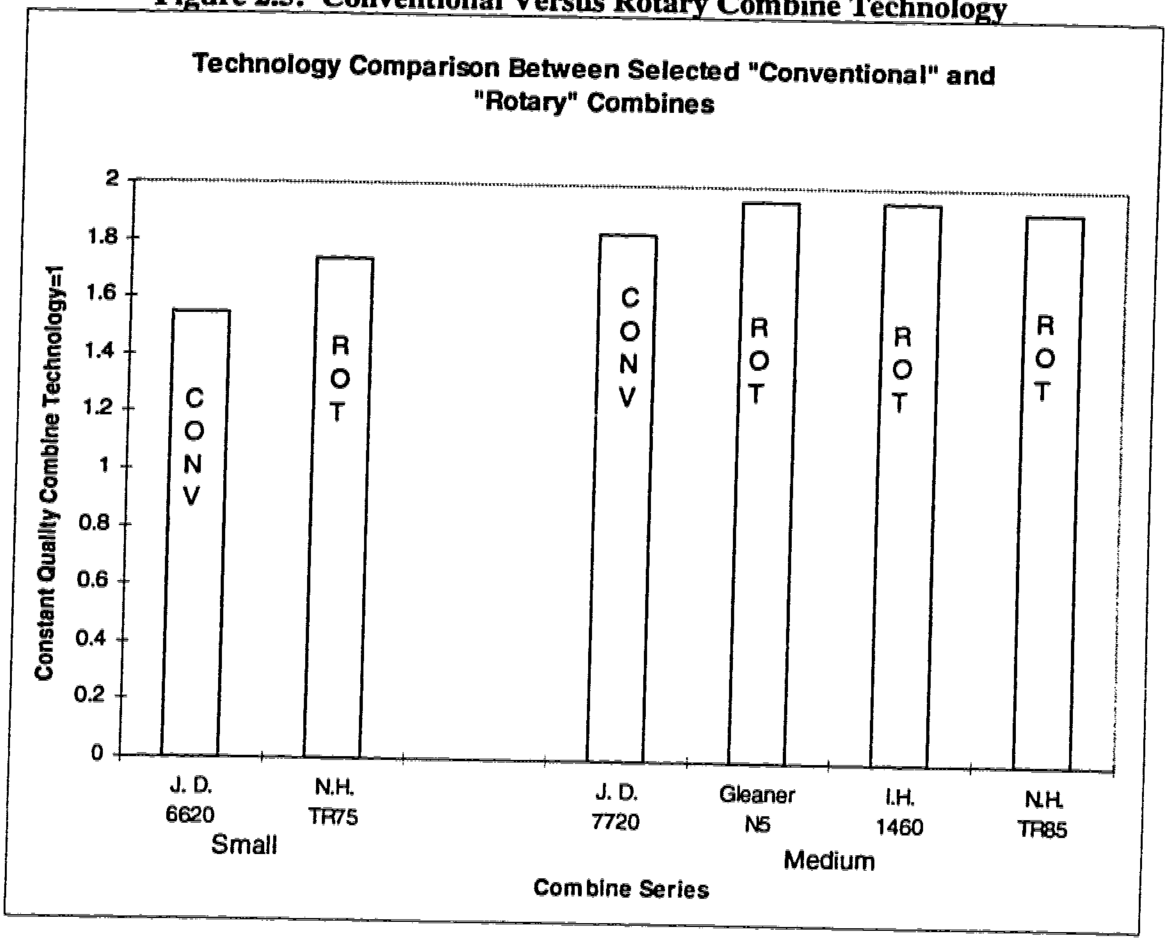


Figure 2.6: RMSE Forecasts

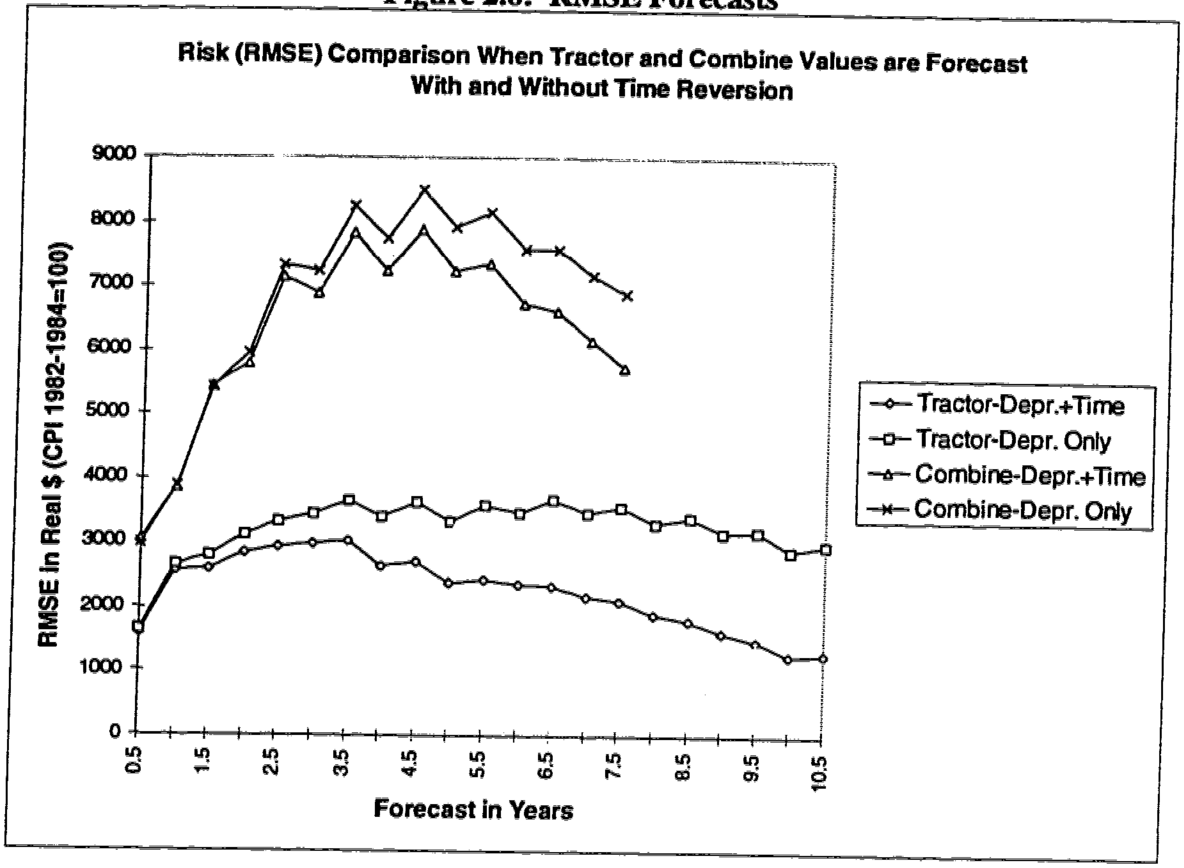


Figure 2.7: RMSE 1 Year Ahead Forecasts

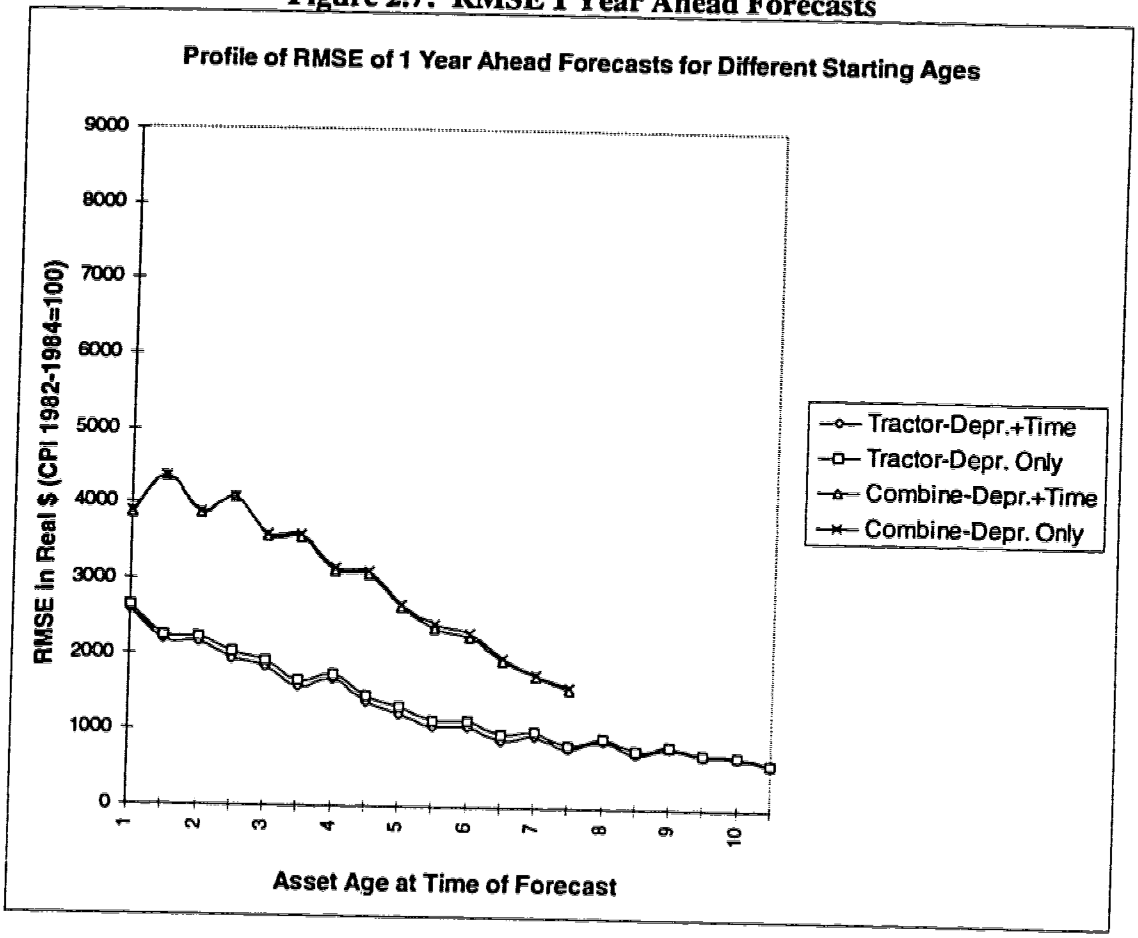


Figure 2.8: RMSE 3 Year Ahead Forecasts

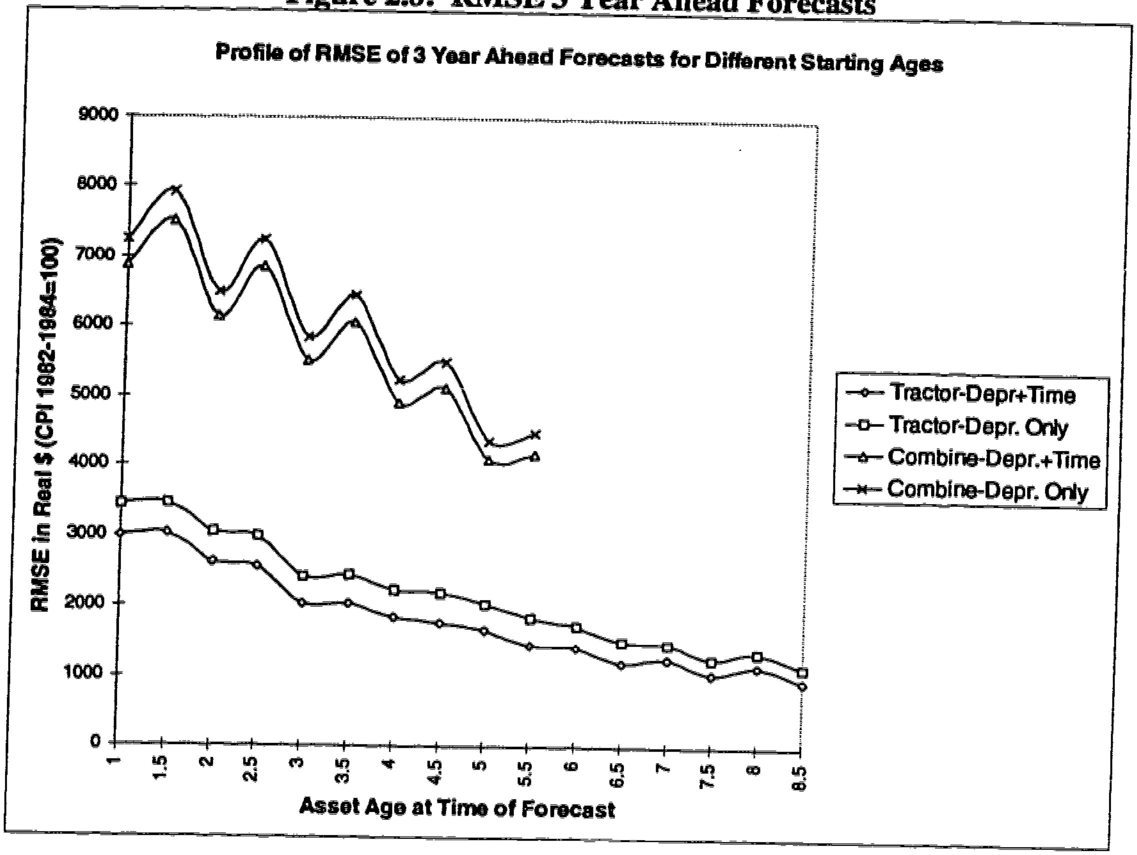


Figure 2.9: RMSE 5 Year Ahead Forecasts

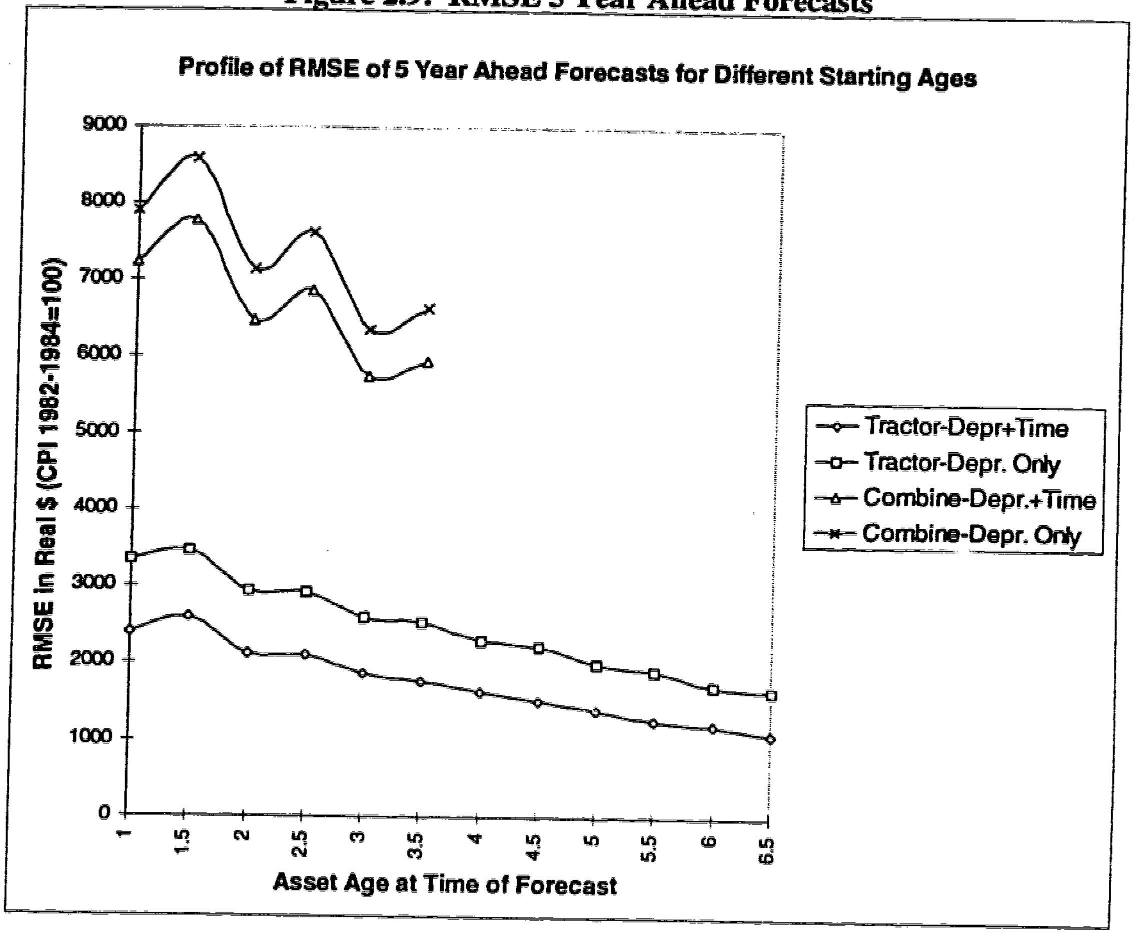
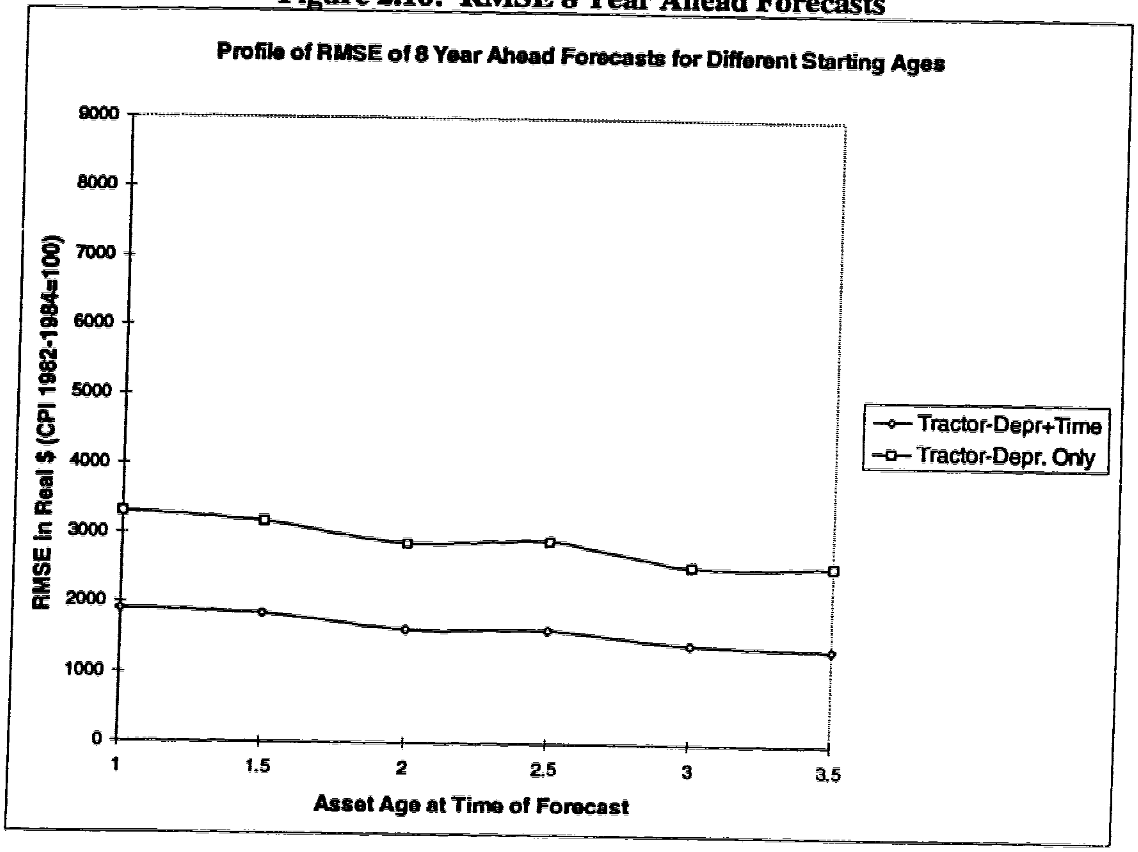


Figure 2.10: RMSE 8 Year Ahead Forecasts



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Chapter 3: Risk Premia in Tractor and Combine Investments

Introduction

Farm machinery is a major investment for most farmers and it may be the dominant asset held by some. A farmer wishing to use Net Present Value (NPV) analysis on machinery requires estimates of operating benefits over time, an estimate of terminal or salvage values and a risk-adjusted discount rate. This paper addresses the risk-adjusted discount rate appropriate for valuing the terminal value.

Studies on optimal replacement of farm machinery assets such as by Reid and Bradford (1987, 1983) that are theoretically consistent with the NPV criteria have ignored the issue of determining the discount rate. Reid and Bradford (1987) did acknowledge that a tangible asset such as a tractor can be replaced with a financial alternative such as a risk free bond or a stock portfolio. Conceptually, the appropriate discount rate is that obtainable from a financial market opportunity with risk exposure equal to farm machinery risk. The task ahead is to quantify the risk on farm machinery and identify the rate of return on a financial investment which replicates this risk.

A discount rate may be separated into a riskless base rate and a risk premium. A riskless rate is customarily identified as the rate of return on a default-free government security. The riskless rate rises and falls with changes in capital supply and demand and inflationary expectations. The risk is the market reward for risk bearing, the difference between the rate-of-return and the riskless rate. This paper will identify an appropriate risk premium for farm machinery, which can be added to the prevailing riskless rate to establish the discount rate.

The risk premium for non-diversified portfolios efficiently obtainable in the capital market is often described as a linear function of the investment standard deviation, and may be called the Capital Market Line (CML) premium. The CML risk premium is described in introductory finance texts as

$$RP_p = \frac{RP_{smp}}{\sigma_{smp}} \sigma_p \tag{3.1}$$

where RP_p is the returns risk premium for the portfolio of interest, RP_{smp} is the stock market portfolio returns risk premium, σ_{smp} is the stock market returns standard deviation and σ_p is the non-diversified portfolio returns standard deviation. Movement along the linear function is enabled by constructing portfolios which are a blend of the market portfolio and the riskless security. Empirical estimates for 1946 to 1990 (Siegel 1992) of the inflation adjusted relevant parameters are RP_{smp}=6.9% over long government bonds and σ_{smp}=15.6%, resulting in a CML risk premium of about 0.44% for every 1% of standard deviation around expected asset return. Siegel's estimates are used later in the study.

The extension of CML risk premium determination to farm machinery is complicated by two elements. First, the CML risk premium equation cited above is based on single period information, while farm machinery is a multi-period investment. Second, risk on machinery must be measured in a way logically comparable to an investment standard deviation.

Measuring Risk in Farm Machinery Terminal Value

The approached used here to assess risk on terminal value is through measurement of deviations from forecast value. This is closely related to the empirical basis for investment standard deviation, a deviation of the actual rate of return from the historic mean. If historic mean is presumed to characterize historic forecasts of investment rate-of-return, investment standard deviation is a statistic based on proportionate deviations from putative forecasts.

Several studies have estimated farm machinery depreciation rates and thereby, terminal value. The more recent of these include Perry, Bayaner and Nixon (1990), Hansen and Lee (1991), Cross and Perry (1995) and Unterschultz (Chapter 2, this document). In the prior chapter, a Root Mean Square Error (RMSE) statistic is developed from forecast errors to measure the risk attendant to terminal value projections. RMSE is defined as

$$\text{RMSE}=\sqrt{\sum_i (ActualValue_i - ForecastValue_i)^2 / n} \tag{3.2}$$

where i=1…n and n is the number of forecasts.

Depreciation rates from Cross and Perry (1995), Hansen and Lee (1991), and Chapter 2 are used to develop four separate terminal value forecasts for tractors and three forecasts for combines. These different forecasts provide a range of forecast errors. Both the Cross and Perry (1995) and the Hansen and Lee (1991) estimates come from different data sets. Chapter 2 results generate two different in-sample forecasts using a combine and tractor data set from the *Official Guide: Tractors and Farm Equipment*. This data set spans the spring of 1972 to the spring of 1992. One forecast uses depreciation estimates only. A second forecast adjusts the depreciation forecasts for different time effects related to changing demand and supply conditions. Both in sample forecasts are described in Chapter 2. RMSEs measure forecast errors on the remaining total value of the machinery portfolio. Forecast errors are divided by the beginning asset value to allow comparisons between different machine assets.

Consider an example forecast error calculation using a four year investment horizon. Assume a one year old Massey Ferguson "750" combine is worth $40,000. The Chapter 2 terminal value estimate for this machine when it is five years old is 73.3% of the year one value or $29,320. If the actual value in year five is $22,000 then one term in the RMSE calculation is

$$RMSE = \sqrt{\left(\ldots+\left({(22{,}000-29{,}320)}\big/{40{,}000}\right)^2+\ldots\right)\Big/n} \tag{3.3}$$

where n is the number of four year forecasts generated on one year old combines. Different RMSEs are calculated for different investment holding periods and for different asset ages at the start of the investment period. Selected data from these calculations are subsequently presented in Figures 3.1 and 3.2 and these data are used later to derive the machinery risk premia via the CML.

The logic of the CML equation can be extended to the development of a financial market portfolio with variance identical to the forecast farm machine values described above . The rate of return on this equivalent terminal risk portfolio (ETRP) is an appropriate benchmark for setting the farm machinery discount rate. Construction of this portfolio is described next.

Consider two separate security market investments at time t. The first is risk free long bonds with exactly the same life span, (T-t), as the projected machinery investment horizon. There is some initial investment in bonds, B_t, that will grow to have exactly the same value as the expected terminal machine value ($E_t(TMV_T)$).

The second security market investment is in a broadly diversified stock portfolio such as a cross-section of the New York stock exchange. All income is reinvested in the portfolio. Choose an initial investment in this stock portfolio, S_t, such that the expected future stock value is equal to the expected terminal machine value (i.e.. $E_t(S_T) = E_t(TMV_T)$). This portfolio is risky and the final value of the portfolio may differ from the terminal value forecast.

By design any linear combination of portfolio weights equal to 1 invested in the bond portfolio and the stock portfolio have a future expected value equal to the terminal machine value (i.e. $E_t((1-x)B_T + xS_T) = E_t(TMV_T)$). Construct the ETRP by adjusting the weight, x, on the stock portfolio until the forecast standard deviation surrounding the expected ETRP value equals the terminal machine value RMSE.

The ETRP and the machine terminal value now have the same risk. Under the standard assumption that the stock index is log-normally distributed, (Hull, 1989) the ETRP forecast standard deviations (stddev) are calculated by

$$(3.[illegible]) \qquad Stddev(E_t(xS_T)) = \{(xS_t)^2 e^{2\mu(T-t)}[e^{\sigma^2_{smp}(T-t)} - 1]\}^{1/2}$$

where $E_t(S_T) = E_t(TMV_T)$, S_t is the initial portfolio investment, μ is the expected single period return on the stock portfolio and σ_{smp} is the portfolio returns standard deviation. The proportion invested in the stock portfolio, x, is varied such that $Stddev(E_t(xS_T)) = RMSE$ to derive the ETRP. The solution for x is simply the ratio, $RMSE / Stddev(E_t(S_T))$. The machine risk premium is calculated from equation (3.1) by setting $\sigma_p = x\sigma_{smp}$.

Chapter 2 results indicate an approximate geometric 5% depreciation rate for tractors and 10% depreciation rate for combines in their data set. Assuming an initial machine value normalized to 100 which corresponds to the RMSE calculations described above, these depreciation estimates provide forecasts of the terminal machine value to use in ETRP. Siegel's (1992) historical geometric stock market real return estimate is 6.2% for 1946 to 1990 and can be used to estimated the initial stock portfolio investment required.

The relationship of machine risk to stock market risk is illustrated by comparing machine RMSE to the stock market forecast standard deviations derived using (3.4) above when the portfolio is composed only of stocks. Forecast standard deviations, $Stddev(E_t(S_T))$ and age 1 machinery RMSE results over different investment horizons are displayed in Figures 3.1 and 3.2 for tractors and combines respectively. Similar results are obtained using assets of different ages and are not reported here. Tractor investment risk first increases then decreases but at all times remains below the stock market risk. Combine risk increases and even exceeds the stock market risk over different investment horizons. Tractor investments exhibit lower total risk than the combine investment.

The Cross and Perry (1995) depreciation has the lowest risk on short term tractor forecasts. The Chapter 2 in-sample time-adjusted forecast is superior in the later time periods. The Hansen and Lee (1991) forecast only outperforms the Cross and Perry (1995) forecast in the last time period. This inaccuracy is not surprising since Hansen and Lee's depreciation rates were estimated from small 2-wheel drive tractors and are now being tested against large 2-wheel drive tractors. Cross and Perry's depreciation estimates may be the most appropriate for measuring risk since these estimates represent an ex ante out of sample forecast of the terminal asset value.

Using the procedure outlined above to derive the portfolio weight, x, in the ETRP, profiles of machinery risk premiums over different investment horizons are calculated and presented in Table 3.1 based on stock market returns, risk premia and standard deviations from Siegel. Tractor risk premia range from 3.6% to 2.3% for the Cross and Perry estimates. The mean risk premium is 2.7%. The Cross and Perry combine risk premia range from 8.3% to 5.5% with a mean of 7.4%. Table 3.1 provides a range of risk premia that can be used for NPV investment analysis for tractors and combines. The level of risk premium depends on the source of the forecast.

These machinery risk premium estimates are relatively insensitive to changes in the stock portfolio expected return but are quite sensitive to changes in the stock portfolio standard deviation of returns. For example if the standard deviation of stock returns is 21.12% and the risk premium is 7.3% (Patterson, 1995 p.113) then the tractor and combine risk premium ranges are 2.7%-1.6% and 6.1%-4.2% respectively. Machinery risk premiums for tractors and combines are higher than those in Table 3.1 if stock market risk premiums derived from short term risk free bonds are used.

The machinery risk premiums presented above are valid if machinery is the sole asset in the farm portfolio. Where other assets such as land constitute a significant proportion of the portfolio, the machine risk premiums are more difficult to evaluate and this question remains for further investigation.

Conclusion

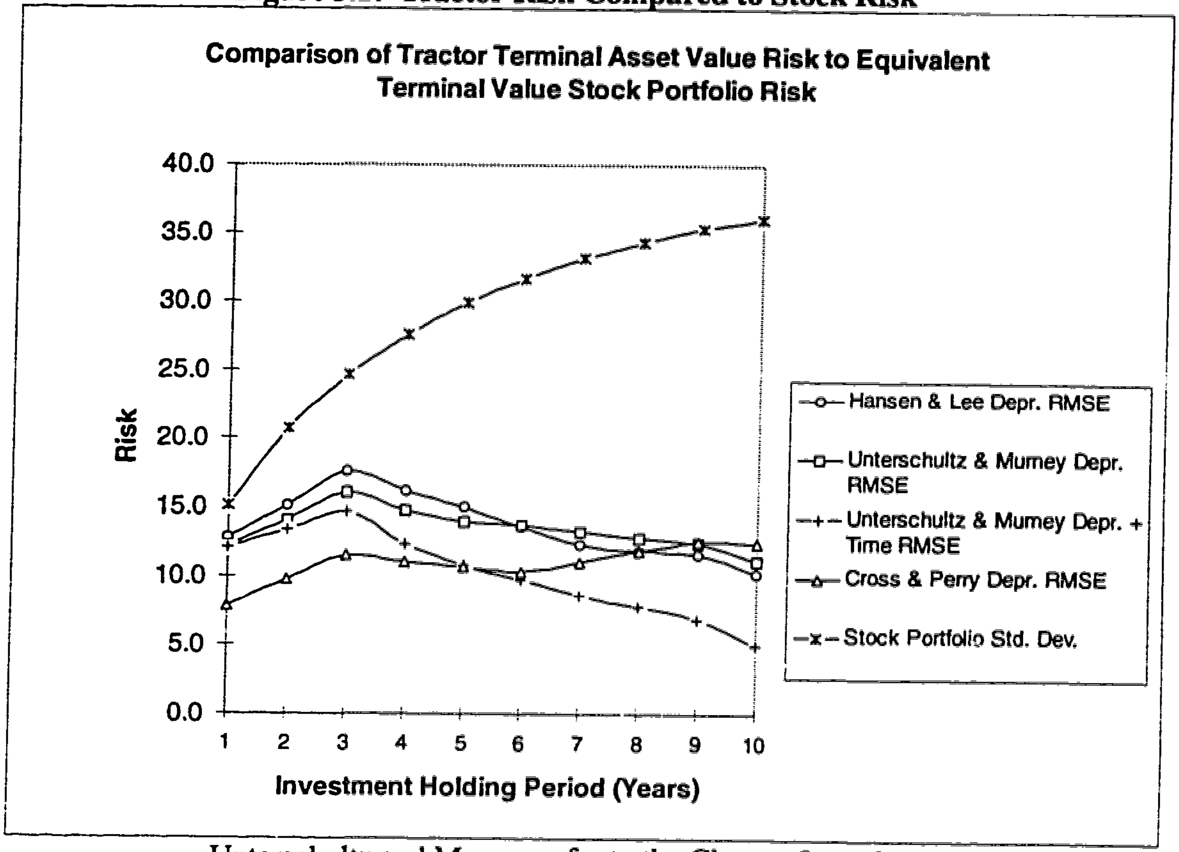
The machinery risk premium estimated varies with the intended holding period or investment horizon. Risk premia in terminal combine values are consistent with a risk premium ranging from 5.5% to 8.3%. For tractors the risk premium range is 2.4% to 3.6% with the greatest risk over the shorter investment horizons. These risk premia can be added to the risk free rate in comparable maturity long term bonds to derive an appropriate discount rate for NPV analysis.

Table 3.1: Tractor and Combine Risk Premium Profile Estimates Using the Capital Market Line and an Equivalent-Terminal-Risk Market Portfolio

	Tractor[1]				Combine		
Investment Horizon (years)	H&L	U&M	U&M+Time	C&P	U&M	U&M+Time	C&P
1	5.9%	5.6%	5.5%	3.6%	5.4%	5.3%	5.5%
2	5.0%	4.7%	4.5%	3.3%	6.9%	6.7%	7.2%
3	4.9%	4.5%	4.1%	3.2%	7.8%	7.4%	8.2%
4	4.1%	3.7%	3.1%	2.8%	8.0%	7.4%	8.3%
5	3.5%	3.2%	2.5%	2.5%	7.7%	7.0%	8.2%
6	3.0%	3.0%	2.1%	2.3%	7.1%	6.3%	7.6%
7	2.6%	2.7%	1.8%	2.3%	6.6%	5.6%	7.0%
8	2.4%	2.6%	1.6%	2.4%			
9	2.3%	2.4%	1.3%	2.4%			
10	2.0%	2.1%	1.0%	2.4%			
mean	3.6%	3.5%	2.7%	2.7%	7.1%	6.5%	7.4%

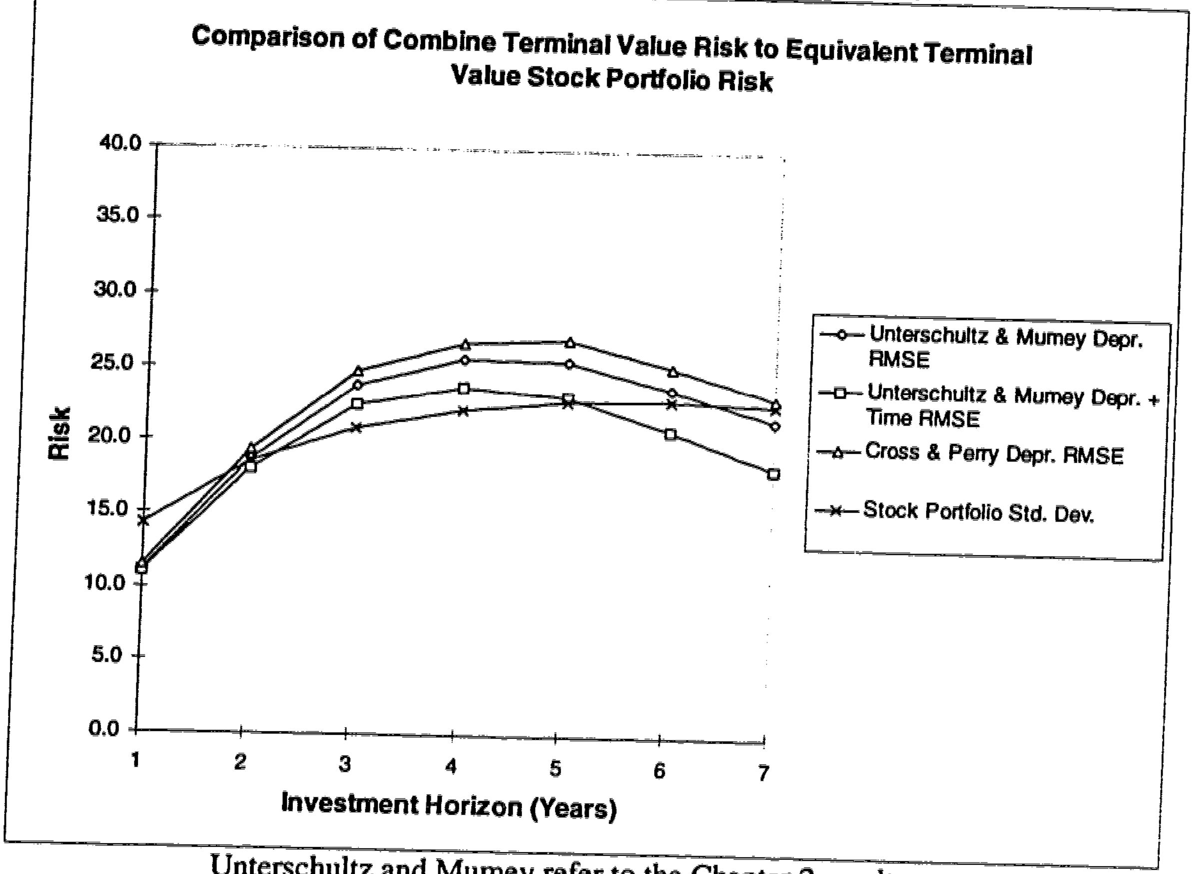
1. H&L=Hansen and Lee depreciation estimates, U&M=Chapter 2 depreciation estimates, U&M+Time=Chapter 2 depreciation estimates with a time adjustment and C&P=Cross and Perry depreciation estimates. The results are based on the planned purchase of a one year old machine asset.

Figure 3.1: Tractor Risk Compared to Stock Risk



Unterschultz and Mumey refer to the Chapter 2 results

Figure 3.2: Combine Risk Compared to Stock Risk



Unterschultz and Mumey refer to the Chapter 2 results

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Chapter 4: Slaughter Cattle Price Relationships Between Western Canada and The United States

Introduction

Cattle investments are often held in non-diversified portfolios. More accurate analysis of the risk sources and the relative impact of each risk on local prices can be used by individual cattle investors to improve risk management strategies. These strategies include identifying the sources of cattle price risk, hedging using existing derivative securities or changing the scale of the cattle investment. Vector autoregression and intervention analysis are applied to cattle price data from Alberta and the United States to examine long term price relationships, determine the historical relative sources of price risk and provide some guide as to future relative price risk relationships. The results will help Western Canadian investors choose the appropriate risk management strategy and indicate if future research on creating domestic based risk markets is justified.

The North American cattle market is relatively free of restrictions and slaughter cattle are easily exported or imported between Canada and the United States. U.S. beef cattle markets dominate cattle price formation in Canada. (Canadian International Trade Tribunal, p.99). For example Statistics Canada estimated the 1994 Canadian beef cow herd inventory at 4.4 million cows. This is 12% of the U.S. beef herd and approximately 13% of the Mexican beef herd.

Alberta is now Canada's major beef supplier with 43% of Canada's beef cows in 1994 and feeding 64% of Canada's slaughter beef cattle in 1993. This study examines the price relationships between the Alberta and United States cattle markets and identifies which risk management strategies are most useful to Alberta investors.

Potential sources of Alberta slaughter cattle price risk include U.S. cattle market price changes, U.S.-Canada exchange rate changes and changes in local supply-demand relationships. Investors can manage this risk by limiting the size of the investment or by using risk markets. By limiting the scale of cattle investment the Alberta investor may maintain adequate equity or borrowing reserves to survive adverse short term price moves. By using risk markets the investor may maintain a higher investment level in the cattle portfolio and transfer part of the risk to more risk tolerant portfolios.

There are no Canadian based public risk markets[7] for cattle although some forward contracts and other risk transfer instruments are privately offered. The Chicago Mercantile Exchange (CME) and the International Money Market (IMM) are

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[7] An exchange adjusted put option was introduced to the cattle market in late 1994. It trades over the counter through the offices of the Farm Credit Corporation in Canada and the BT Bank is acting as the market maker.

two foreign based derivative securities markets accessible to Alberta cattle investors. The CME offers live cattle futures contracts and the IMM offers currency futures on the Canadian dollar. If U.S. cattle prices are a major source of local price risk, then the CME live cattle futures contract should be an effective risk management tool. If Canada-United States exchange rates are a major source of price risk then the IMM currency futures should be an effective risk management tool. If basis[8] is a major risk source then there may be net benefits from the creation of a local cattle based risk market.

The relative contribution of local basis risk to slaughter cash price may have decreased during the study period. Exports of live cattle and beef from Alberta to the United States increased in the latter half of the 1980's and into the 1990's[9]. The Canadian International Trade Tribunal (1993) surmised that favorable climate and structural changes in the cattle feeding industry such as improved production skills, better technology and low feed prices reduced the production costs in Alberta relative to the United States and Eastern Canada[10]. Cattle production was also subsidized through the National Tripartite Stabilization Program (NTSP) from 1986 to 1993[11].

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[8] Basis is defined as the difference between the futures price and the local cash price (Cash price - Futures price). The futures price would be adjusted by an exchange rate when calculating an Alberta basis..

[9] Canadian exports of live slaughter steers and heifers to the United States averaged 62,300 head for 1982-1986, then generally increased with exports of 109,400 head in 1987, 226,900 in 1988, 202,100 in 1989, 252,400 in 1990, 251,900 in 1991 and 460,100 in 1992. (Canadian International Trade Tribunal, 1993, p.61)

[10] Exports of feeder animals to the United States increased from 44,600 in 1981 to 292,600 in 1992. Approximately 87% of these animals were feeder cattle with the remainder being feeder calves. Offsetting this increase in feeder animal exports to the U.S. was a decrease in interprovincial exports of feeder animals to Eastern Canada from 501,000 in 1981 to 192,500 in 1992 (Canadian International Trade Tribunal, 1993).

[11] The federal and provincial governments intervened in the risk markets and offered the National Tripartite Stabilization Program (NTSP) from July 1986 to December 1993. The NTSP's program objective was to reduce cattle feeding risk and it also included a subsidy component. Cattle producers contributed one-third of the premium and the Federal/provincial governments contributed the other two-thirds of the premium for each slaughter animal enrolled in the program. Pay outs were triggered when the gross margin (cash price minus production costs) on cattle sales dropped below a five year rolling average. The NTSP may have accelerated changes in cattle feeding in Alberta. Total production may have increased in response to the decreased risk and the subsidy component of NTSP. Under the law of one price, Alberta slaughter prices would not directly be changed by the NTSP. Indirectly, the NTSP may have contributed to Alberta moving into a net export position of cattle to

Consequently cattle feeding expanded in Alberta leading to increased exports. Local Alberta slaughter basis movement (basis risk from local supply-demand conditions) should be bounded close to the costs of exporting to U.S. markets and the costs of importing live cattle from the U.S. Movement of the Alberta slaughter cattle market into a net export position each period should move local prices to the lower basis bound. This would decrease the impact of local factors on risk and increase the importance of United States prices as a risk source[12].

The study encompasses the time period from January 1976 to July 1994 and compares different sources of risk on Alberta slaughter steer prices using Vector Autoregression (VAR). Initial analysis covers the entire time period. This gives an historical overview of the sources of price risk. The relative contribution of each potential source of risk may have changed during this time period and this study investigates possible changes in these sources of risk. Based on the discussion above, the study investigates and/or asks the following questions.

1) Starting in about 1986 when NTSP was introduced, was there a fundamental shift (structural change) in the relationship between the two cattle markets? If a structural change occurred then analysis can be done to explore recent sources of risk on Alberta prices. The relative importance of local factors on risk is expected to have declined.
2) Do U.S. live cattle prices cause changes in Alberta live cattle prices, is there simultaneity in the price formation or are the two markets unrelated? This question is explored using Granger causality tests on monthly data and provides an initial measure of the usefulness of U.S. based risk markets. Risk markets must be related to the local market for any risk management programs to be successful. Simultaneity in the markets provides initial support for using risk-based markets in the U.S. If no causation in either direction is found between the cattle markets then the

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the United States which could change the basis relationship. The NTSP may have contributed to an expansion of feedlot capacity in Western Canada.

[12] Local Alberta price differences from the United States not accounted for in the law of one price (such as discussed by Carter et al. (1990)) could persist due to capacity constraints in the distribution channels to markets such as in the United States. Unless there were perfect elasticity in distribution services, local price deviations from the law of one price may be sensitive to production volume. The supply of distributions services such as trucking, inspection or slaughter plant capacity in the United States would tend to be inelastic in the short-run. Long-run supply responses in the distribution capacity would increase long-run elasticity. These responses could include developing facilities with greater flexibility for handling volume variation and thereby also increase short run elasticity. However perfect elasticity may be unattainable, thus short term Alberta basis risk could still persist though at a smaller level.

risk markets in the U.S. will not be useful to Alberta investors. If only one-way causation is found between the markets, there may be exploitable arbitrage opportunities. The law of one price suggests that there should be simultaneity in the cattle prices between Alberta and the U.S., or at least as much simultaneity between Alberta and U.S. aggregate prices as between U.S. regions and U.S. aggregate prices.

3) Is there a long term equilibrium relationships between United States cattle prices and Alberta prices? This question is explored using cointegration tests with the VAR model.
4) What is the impact of independent shocks to U.S. prices, Alberta prices or exchange rates on each other? These results are explored using impulse response functions and variance decomposition analysis. These are used to measure the relative contribution of U.S. prices, exchange rates and local basis to Alberta slaughter price risk.

Alternative methodologies from historical simulation to GARCH (Generalized Autoregressive Conditional Heteroskedasticity) have been used to investigate the sources of risk and the effectiveness of United States based risk markets for Canadian cattle feeders. A recent study by Novak and Unterschultz (1996) investigated commodity and currency hedging using price forecasts, local basis forecasts and mean square error risk measures. Kroner et al.(1993) used GARCH models to estimate optimal cattle commodity and currency hedges. Both studies found that Alberta prices have a relatively stable relationship with the CME live cattle futures prices and exchange rates have relatively little impact on local slaughter price risk. Using a different approach, 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) provides a different perspective on the problem by measuring the relationship between different price and exchange rate variables. The VAR model can map out the impact of independent shocks on each price variable on the rest of the price variables in the system. These shocks and multiplier effects were not investigated in the above studies. VAR is one statistical tool used in the past decade to measure the relationship between macroeconomic variables and agricultural variables and used in policy analysis (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. For example Adamowicz et al. (1991) and Taylor and Spriggs (1989) concluded that exchange rates have a large impact on general agricultural price levels.

Information on the impact of exchange rates on specific commodity prices have not in general been investigated. Canadian studies by Jennings et al. (1990), 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.

Larue and Babula (1994) examine dynamic relationships between money supply and food-based prices in Canada and the United States. Macroeconomic variables have an impact on commodity prices.

The questions posed above are explored using VAR models and intervention analysis. Variables included in the analysis are Alberta slaughter steer prices, two U.S. slaughter steer prices, live animal exports and U.S/Canada. exchange rates.

The remainder of the paper is organized as follows. The VAR methodology is explained. The initial data sources are described and the selection of the particular variables discussed. The data is tested for unit roots and for cointegration as part of the VAR model development and an initial exploration of the relationship between the Alberta slaughter market and the United States slaughter cattle market is conducted. A five variable VAR model incorporating U.S.-Canada exchange rates (U.S. dollars to buy one Canadian dollar), Alberta slaughter steer prices, Texas slaughter steer prices , Chicago Mercantile Exchange live cattle nearby futures prices and live animal exports in dollars to the U.S. is estimated. The VAR model is tested for structural breaks during the time period of the study and Impulse Response Function (IRF) and Variance Decomposition (VDC) analysis is conducted on the separate time periods. Finally the conclusions are presented.

Vector Autoregression Explanation

VAR is a dynamic simultaneous equation model (SEM) made up of endogenous variables and lagged endogenous variables (Judge et al., 1988). Lutkepohl (1993) 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 modeling 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 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. Price forecasting is not an objective of this study and consequently the model development focuses on model adequacy. VAR models also require strong identification restrictions to measure the relationship between the variables and these restrictions are imposed after estimation of the reduced form parameters.

Economic theory plays an important role in determining which variables are included 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 determine 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[13]:

$$Y(t)A = \sum_{s=1}^{\infty} Y(t-s)A(s) + Z(t)C + V(t)B \tag{4.1}$$

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 that may include a constant. The C is a (qxK) coefficient matrix. 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 researcher 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 (4.1). The AR model is derived from (4.1) by post multiplying by A^{-1}:

$$Y(t) = \sum_{s=1}^{\infty} Y(t-s)A(s)^{*} + Z(t)C^{*} + U(t) \tag{4.2}$$

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 (4.2) 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), using Seemingly Unrelated Regression (SUR) (Judge et al., 1988) or using Maximum Likelihood (ML). It is of course impossible at this point, to derive the original coefficient matrices in (4.1) from reduced form coefficients in (4.2). The VAR methodology inverts the estimated reduced AR system (4.2) to get a MA model:

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

$$Y(t)=\sum_{s=0}^{\infty} Z(t)C^{*}M(s)+\sum_{s=0}^{\infty} U(t-s)M(s) \tag{4.3}$$

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:

$$M(s)=\sum_{i=1}^{s} A(i)^{*}M(s-i) \tag{4.4}$$

The VAR method used here examines the behaviour 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 K variables in Y to this single shock is called the Impulse Response Function (IRF). To isolate the impact of one orthogonal shock in one of the equations in Y(t) on all K endogenous variables using the IRF, researchers impose identification restrictions on A^{-1} and B. This paper assumes that B=I[14] where I is the identity matrix. 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 covariance of U(t-s). The cov(U(s)) is estimated using the residuals from each equation in (4.2).

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[15]. This

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[14] Setting B=I gives K^2 restrictions

[15] Recall that B=Ω=I by assumption in cov(U(s)). Possibly a simpler view comes from Lutkepohl (1993, chapter 2). Assume there are no exogenous variables then $Y(t)=\sum_{s=0}^{\infty} U(t-s)M(s)$ is the MA representation and the U(t) represent the shocks or innovations to the system at time zero. Since the elements in U(t) are not independent, a shock to one element in U(t) may also imply there are simultaneous shocks in the other variables. This makes it difficult to interpret the outcome on the forecast Y. The procedure is to transform the equation Y(t) such that the shocks are orthogonal (independent if normally distributed). This gives $Y(t)=\sum_{s=0}^{\infty} U(t-s)P^{-1}PM(s)$. By definition there always exists a $P^{T}P= A^{-T}B'\Omega BA^{-1}$ since the cov(U(s)) is positive definite. Then define the new shock as $W(t)=U(t)P^{-1}$ and the new moving average component as Θ(s)=PM(s). The cov(W(t))=$P^{-T}A^{-T}B'\Omega BA^{-1}P^{-1}=I_K$. The transformed shocks are now orthogonal, have unit variance and by implication of the assumptions already made, $P^{-T}=A^{T}$. P is not unique and the Cholesky decomposition is one-way to calculate P. By further implication, the system can now be shocked by setting one of the elements of W(t) equal to 1 and all other elements equal to 0. The elements of Θ(t-s) are the responses

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.

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 (4.3) and (4.4) 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 (1993, pp.35-43) discusses Granger causality and instantaneous causality. A restricted version of Granger causality applicable to VAR models can be interpreted as follows. A variable X Granger causes variable Z, if past values of variable X improve forecasts of variable Z but past values of variable Z do not improve forecasts of variable X. 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 evidence 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 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 Z. No interpretation of causality can be made when using the instantaneous causality concept.

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of the system to the innovations. The elements of $\Theta(t-s)$ are also used to derive the Variance Decomposition (Lutkepohl, 1993, section 2.3.3).

Data stationarity is another issue in VAR estimation. Some VAR models are estimated in levels and others are estimated using differenced data and impose cointegration relationships on the model. Engle and Granger (1987) and Engle and Yoo (1987) explain the relationship between unit roots, stationarity, cointegration, VAR error correction models and miss-specification. 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, 1993 pp.368-370). This study uses both OLS estimation and ML estimation with cointegration constraints imposed.

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 often give conflicting results. A combination of SIC, AIC (Judge et al., 1988 p. 761), likelihood ratio (LR) tests, Portmanteau tests for autocorrelation and a normality test on the residuals are used to determine lag length. The AIC criteria may tend to include too many lags versus the SIC but in small samples the AIC may well have better properties than the SIC (Lutkepohl, 1993 pp.132-134) in determining the VAR order. The likelihood ratio test uses a sequence of tests to compare a VAR(p) to a VAR(p+1) model. The generalized Portmanteau test described by Lutkepohl (1993, 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 normality using the third and fourth moments of the normal distribution (Lutkepohl, 1993 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 portmanteau tests and the normality tests strongly influence the final VAR order chosen.

Investigating the structural change in the cattle markets and the relationship between the U.S. cattle markets and the Alberta cattle markets requires a different VAR approach. Prediction tests for structural change (Lutkepohl, 1993 pp. 387-388) identify possible dates when changes occur[17]. These prediction tests do not identify the source of the change. The VAR model can then be developed in a manner analogous to that described above for the different time periods. However now the model has time varying parameters where

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[16] Lutkepohl (1993) gives an excellent summary of these issues in chapter 4.

[17] The Crow Benefit Offset Program, a feed subsidy for the Alberta livestock industry, and the NTSP commenced in September 1985 and January 1986 respectively. Discussions regarding both programs started well before the commencement date of these programs. Possible structural breaks may have occurred around the commencement of these programs.

$$
(4.5)\qquad
\begin{aligned}
Y(t)A_1 &= \sum_{s=1}^{\infty} Y(t-s)A(s)_1 + Z(t)C_1 + V(t)B_1,\ t \le T_1 \\
Y(t)A_2 &= \sum_{s=1}^{\infty} Y(t-s)A(s)_2 + Z(t)C_2 + V(t)B_2,\ t > T_1
\end{aligned}
$$

The T_1+1 represents the time period where the change in the economic system is hypothesized to have occurred. Several possible results are nested in equation (4.5). The intercept term may vary, other coefficients on exogenous variables may vary, coefficients on the lagged variables may vary or the variance may change between the two periods. Therefore several possible interpretations of the results may plausibly hold depending on which parameters actually change between time periods.

Two types of intervention are plausible for the above problem (Lutkepohl, 1993 p.408). An intervention described by equation (4.5) implies a slower adjustment of the system to the change. This is the likely situation for structural change in the Alberta cattle industry. Cattle production capacity adjusts slowly to changing prices or costs. An alternative intervention specification has the system react abruptly to changes. The mathematics of the abrupt change in a VAR model requires that the system be modeled in mean adjusted form. This second form of modeling is not used in this study since the first form is more plausible for the questions being asked.

Data Description

The monthly data collected covers the time period from January 1976 to July 1994. All prices were collected in nominal dollars of the home currency. All cattle prices are in dollars per hundredweight. The data consists of

1) EX - the United States - Canada exchange rate (number of U.S. dollars to buy one CDN. dollar) from the Wednesday of the third week of the month.
2) FSP - the Chicago Mercantile Exchange nearby live cattle futures contract for slaughter cattle in U.S. $ from the Wednesday close of the third week of the month.
3) TSP - the Texas live cattle slaughter steer price in U.S. $ averaged over the third week of the month.
4) ASP - the Alberta live cattle slaughter steer price in CDN. $ averaged over the third week of the month.
5) EA - the dollar value of live animal exports to the United States in CDN $ for that month.

The Alberta steer prices are from the Alberta provincial government agriculture department. The futures prices are from the Chicago Mercantile Exchange. The exchange rate and live animal exports are from Statistics Canada, CANSIM data base and U.S. Texas prices are from the USDA publications "Livestock Meat Wool Market News Weekly Summary and Statistics".

Exchange rates are included since the Alberta cattle market is in a different country than the dominant United States market and exchange rate fluctuations are expected to change local Alberta slaughter prices. The nearby futures price should represent cattle feeding prices (and investor information) from all parts of North America, not just Texas or Alberta. It is therefore 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. Therefore interest centers on the amount of Alberta slaughter price risk measured relative to the futures market. More information on the relationship between Alberta's local steer price versus the futures price is useful in determining the role of the futures market in risk management.

The Texas steer price represents the price received by cattle feeders in one of the most important cattle feeding areas in North America. For example, Texas with 2.7 million head had 21% of the total U.S. cattle-on-feed for the first quarter 1994 (USDA Agriculture Statistics 1994)[18].The relationship between two cattle feeding markets can be examined. The Texas market is used to proxy the aggregate U.S. cash market and detect residual price risk coming from the United States market that is not measured by the futures market.

Alberta is currently Canada's major cattle feeding area and it 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 market price. The live animal exports in dollars should be related to the relative difference between the prices between the two countries. A major portion of the dollar value of live animal exports includes slaughter cattle exports. Changing cattle prices and changing exchange rates should affect the level of live animal exports.

Livestock prices, exports and exchange rates , EX, FSP, TSP, ASP, and EA, were logged to linearize exponential growth in the price variables. The EA (live animal exports) was scaled down by 1,000,000.

Data order, when generating the Impulse Response Function and the Variance Decomposition is important because of the identification restrictions used in VAR models[19]. 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.

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[18] Alberta inventories for steers one year plus in age, and slaughter heifers was 1.196 million head for July 1, 1995 (CANFAX).

[19] Variable ordering is not an issue for the initial tests on model adequacy or the simple Granger causality tests explored in this study. See also footnote 15.

The reasons for choosing this data order are 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 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. The futures price is also ordered before the Texas price to measure the total risk on Alberta steer prices that can be measured through the futures markets, hence an indirect measure of hedging effectiveness. Then the Texas steer price measures would be the residual United States price risk not accounted for by the futures market. It is assumed that prices in either the United States or Canada impact on 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 described in the next section.

VAR Model Development and Analysis

The VAR model for 1976 to 1994 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 cointegration are performed. Cointegration, if detected in the data, implies a close long run 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 by ML following Johansen (1988, 1991)[20]. At least one cointegrating relationship is detected using the tests proposed by Engle and Yoo. Test statistics reported on individual equations also have a bearing in choosing the lag length. Structural break tests and other related tests are performed on the selected VAR model for the entire time period. Since the evidence supports a structural break starting in 1985, new VAR models for each separate time period are developed. The Granger causality tests are done with these separate time period VAR models. The MA representations are estimated from the final reduced form VAR estimates to give the IRFs and the VDCs for both time periods. More detailed explanations of these steps and selected test results are reported in this section.

Unit Root Tests

Non stationary data may lead to cointegrating relationships. Therefore the data is tested for unit roots as the first step to determine whether there are cointegrating relationships between the variables.

Augmented Dickey-Fuller (ADF) unit root tests, Phillips-Perron unit root tests and standard Box-Jenkins time series techniques are used to evaluate stationarity.

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

The Augmented Dickey-Fuller and the Phillips-Perron test statistics are the usual t ratio but different tables are required to interpret the tests (Davidson and MacKinnon 1993, pp.708-715). The Augmented Dickey-Fuller (ADF(p)) with p lags and with a constant is:

$$\Delta X(t) = \alpha + \beta X(t-1) + \sum_{i=1}^{p} \beta_i \Delta X(t-i) \qquad (4.6)$$

where Δ refers to the first difference of the variable X. ADF tests remove serial correlation and the test is do not reject a unit root if β=0. This test is implemented as reject the unit root hypothesis if the t-ratio is smaller than the critical value. ADF tests can include a trend term. Phillips-Perron tests, a nonparametric test, modifies the Dickey-Fuller unit root regression to account for serial correlation (Davidson and MacKinnon p.712). Box-Jenkins tests various orders of the autocorrelation function on the residuals to determine if the errors are stationary.

Calculated test statistics are in Table 4.1 with critical values at the 2.5%, 5% and 10% level shown. The tests results are mixed but the overall weight of evidence suggests all the series exhibit non-stationarity. Very few tests reject the unit root hypothesis at the 5% or 2.5% level of significance. The results are more difficult to assess at the 10% level of significance. Standard Box-Jenkins analysis indicates all series are non-stationary. Testing over smaller time periods gives similarly mixed results. The study tentatively works under the assumption all variables exhibit non-stationarity. After differencing all series are stationary when tested using the tests described above. The data are next tested for cointegration using the non-stationarity assumption.

Cointegration Tests

Over time two or more variables may wander all over the place but if they are cointegrated they always get pulled back together because their difference has bounded variation. Cointegration tests whether different variables have these rubber band long run relationships. Two variables may be non-stationary, that is wander seemingly randomly, but a linear combination of the two series may be stationary (Engle and Granger, 1987; Engle and Yoo, 1987). If variables are cointegrated then this can be loosely interpreted as meaning the variables are "stationary" relative to each other which implies the difference between the two values fluctuates around a fixed value. Alberta steer prices 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 cointegration between different U.S. cattle markets using relatively short time periods. The difference in cointegration results between those studies and this current study may be related to the span of the data. It is the length of the time period and not the frequency of the data that improves the power to detect cointegrating relationships. A brief discussion of one simple cointegration test and selected cointegration results involving the ASP, FSP, TSP EX and EA follow.

One-way tests using ADF(p) for cointegration 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:

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

Residuals from (4.7) are used in ADF(p) (equation 4.6) to calculate the same statistics used in the unit root tests. Residuals from Equation (4.7) are stationary if the variables are cointegrated. Equation 4.7 may include a constant and a trend term. The ADF(p) and Phillips-Perron tests are reported in Table 4.2. Critical values from Davidson and MacKinnon (1993, p.722) are used to evaluate these tests. The cointegration tests support cointegration if the test statistic is smaller than the critical value. The ASP is the dependent variable and some combination of Texas steer prices, nearby futures prices, exchange rates and live animal exports are the independent variables in equation 4.7. An alternative cointegration test converts the ASP to U.S. prices (ASP*EX) and then tests for cointegration[21].

The representative test results in Table 4.2 reject the hypothesis of no cointegration between Alberta steer prices and United States steer prices combined with exchange rates. Cointegration between Alberta slaughter prices converted to U.S. dollars (ASP*EX) and U.S. slaughter prices is not rejected. At least one cointegrating relationship exists in the data. This group of tests does not identify which of these equations form the cointegrating relationship. The Alberta steer price is cointegrated with the U.S. market and this provides supporting evidence that the two markets are strongly related.

Johansen tests for cointegration are conducted next using a five equation VAR(5) model. The VAR(5) is the final model for the entire time period and derivation of this model is described below. Following Lutkepohl (1993, proposition 11.1 and section 11.4.2) the LR tests for cointegrating rank are calculated and presented in Table 4.3. There are two related tests using the Johansen test. In both cases, the hypothesis regarding the number of cointegrating relationships is tested down sequentially. Test 1 in Table 4.3 suggests two or more cointegrating relationships exist ($r \geq 2$). Test 2 indicates there are two cointegrating relationships ($r=2$).

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. Johansen provides a ML estimation procedure for estimating VAR models that incorporates the cointegrating restrictions.

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[21] When the variables are logged, this imposes a coefficient of -1 on the logged exchange rate in the cointegrating relationship. Cointegration tests imposing a coefficient of -1 on the exchange rate also show evidence of cointegration between the Alberta steer price and the nearby futures price and the Alberta steer price and the Texas steer price.

Least Squares with variables in levels and ML with two cointegration constraints imposed are used to estimate the VAR model for 1976 to 1994. The OLS estimator has the same asymptotic properties as the ML estimator with the cointegrating constraints (Lutkepohl, 1993 proposition 11.3). The variance-covariance matrix estimated by Least Squares or estimated by ML are asymptotically equivalent. The determination of the lag length and the estimation of the reduced form VAR in levels are covered next.

VAR Model Development For 1976-1994

A critical step in the estimation of VAR models is the determination of the number of lags of each variable to include in the model. Typically, the literature uses criteria such as AIC, SIC or likelihood ratio tests. Portmanteau[22] tests for autocorrelation and normality tests are also used. The following section details the tests used to determine lag length and reports selected test statistics.

The VAR model equation (4.2) is estimated by OLS using the variables EX, FSP, TSP, ASP, EA in levels and also includes a constant. No cointegration constraint is imposed. OLS is valid asymptotically however the estimates may not be efficient. The use of OLS simplifies the problem of determining the number of lags to use in ML estimation and provides a comparison to the ML estimates of the VAR(p) model. 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 4.4 for each lag length. The LR (Likelihood Ratio) tests compare VAR(p) to VAR(p+1) and sequentially test up in lag length. The SIC and AIC criteria choose the order which gives the smallest test value.

Table 4.4 shows a conflict between the criteria for picking the lag length. The AIC is at a minimum at VAR(4) with -32.261, the SIC is at a minimum at VAR(1) with -31.74 and the LR sequential test would pick VAR(5) at the 5% level. Initially we interpret these results as suggesting a VAR order of $p \geq 4$ since more emphasis is placed on the LR and AIC criteria. The normality check and the autocorrelation check on VAR(4) through VAR(6) are used to finalized the VAR order.

Table 4.5 shows evidence of skewness in the residuals in VAR(4) and normality of the residuals is rejected at the 1% level of significance. Tests for skewness, kurtosis or joint tests on skewness and kurtosis at the 1% level of significance are not rejected in the VAR(5) model. The VAR(4), VAR(5) and VAR(6) Portmanteau tests do not find evidence of serial correlation in the residuals at the 1% level. The Portmanteau test may not be reliable because of the possible non stationarity of the model. Based on these tests, a VAR(5), was chosen on which to do

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[22] The Portmanteau test may not be valid when the VAR model is non stationary. (Lutkepohl (1993, p.384).

further testing. 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 4.2) by OLS and by ML following the Johansen procedure. Two cointegrating constraints are imposed on the ML estimates. Further diagnostic checks on the model estimated by OLS are conducted on each individual equation and reported in Table 4.6. None of the individual equations reject normality, reject homoskedasticity, or reject no serial autocorrelation at the 1% level of significance. Non-linearities are detected in the equations for ASP, FSP, TSP and EA. These results combined with the earlier tests suggest the VAR(5) model is adequately specified however it does not meet all specification tests presented here.

Table 4.7 reports the VAR(5) correlations between the five equations estimated by unrestricted least squares and restricted ML. The results when the cointegration constraints are imposed are very similar to the least squares results. The highest correlation, 0.82, is between futures price and the Texas steer price. The correlation between the Alberta steer price and the exchange rate, 0.-0.112, is negative (the expected sign), but insignificant. The correlation between Alberta steer price and futures price is 0.596 and between Alberta steer price and Texas steer price is 0.656.

A VAR(5) model for the period 1976 to 1994 was estimated[23]. Since a structural break is hypothesized, the next step is to test for this break. If no structural break is found then analysis may proceed using this VAR(5) model otherwise new models for the separate periods need to be specified. Structural break tests are discussed in the next section.

Structural Change and Intervention Analysis

The VAR(5) presented in the above sections assumes that the data generating process is constant. The analysis in this section investigates whether a structural change occurred in the relationship between the United States cattle market and the Alberta cattle market. Prediction tests for structural change locate possible structural changes in 1984 or 1985 using the VAR(5) model developed above. Intervention analysis is then used to determine if the relationships between Alberta steer prices and United States steer prices changed.

Two structural change tests based on Lutkepohl (1993, 11.4.8 and 11.4.11) identify the period(s) of structural change. The first test compares a single h-step ahead out of sample forecast to the observed values. The second test jointly compares several out of sample 1 to h-step ahead forecasts to observed values. Essentially these prediction tests detect structural change if the forecast errors are large, implying that

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[23] Details on IRF, VDC and Granger causality for the VAR(5) are available on request. Details on VAR(5) IRF, VDC and Granger causality for 1976-1984 and 1985-1994 are also available.

these out of sample observations are not generated by the estimated model. Structural change tests are conducted based on a VAR(5) model estimated by ML with two cointegrating constraints up to January 1982, then January 1983 and so on until January 1992 for a total of eleven different periods. For each time period (Jan. 1982, Jan. 1983 etc.) h=1 to h=24 out of sample forecasts are generated. Since the null hypothesis is no structural change, the alternate hypothesis is tested based on the VAR(5) model identified for the entire time period.

Evidence indicates a structural change occurred after Dec. 1984 although there is weak evidence of structural change in Jan. 1983 or in Jan. 1984. For example, the structural change test results in Table 4.8 use the model estimated over the period 1976 to 1984. The forecasting ability of this VAR(5) model declines significantly after three periods. This provides support for a slow structural change. Some ambiguity in the structural change test is not surprising since one economic regime does not replace another overnight. Further tests using intervention analysis with a break point of Dec. 31, 1984 are next. As discussed earlier, these tests assume a gradual change in the model.

OLS is first used to estimate the VAR(5) models for the two time periods, Jan. 1976 to Dec. 1984 and Jan. 1985 to 1994. Again the VAR(5) model is used since the null hypothesis is that the VAR(5) model for the entire time period is adequate. Any intervention tests conducted on these OLS models are asymptotically valid however they may be less efficient than models estimated using ML with cointegration constraints imposed. Results from these OLS tests provide a starting point for the computationally more intensive intervention/structural change tests using ML.

Four intervention/structural change tests using OLS model estimates are presented comparing the two time periods. (1) An LR test that all coefficients (A^*'s and cov(U(t)) in equation 4.2) are time varying versus all coefficients are time invariant (Lutkepohl 1993, 12.3.12 and 12.3.16). (2) An LR test that there is time invariant white noise (cov(U(t))) versus all coefficients are time varying (Lutkepohl 1993, 12.3.20 and 12.3.12). (3) An LR test that there is time invariant white noise versus all coefficients are time invariant (Lutkepohl 1993, 12.3.20 and 12.3.16. (4) A Wald test that there is time varying white noise only (cov(U(t))) versus all coefficients are time varying (Lutkepohl 1993, 12.3.26 and 12.3.12). The test results are reported in Table 4.9.

All tests reject the hypothesis that the estimated coefficients and white noise are the same in the two time periods and provide general support that (1) a structural change occurred in the data generating process in the mid 1980's, (2) some or all of the A*'s differ between periods and (3) some or all of the cov(U(t)) parameters differ between time periods.

Further tests are conducted using ML estimation of a VAR(5) model in the two separate periods with cointegration constraints imposed. Use of ML should improve the efficiency of the tests. Models for the two separate time periods are asymptotically independent and based on ML properties, Wald statistics for more specific intervention tests can be constructed without resorting to non-linear computationally intensive estimation procedures[24]. Cointegration tests for each period (Table 4.10) indicate two cointegrating vectors in the period 1976-1984 and two or possibly three cointegrating vectors from 1985-1994. ML estimation proceeds under the assumption there are 2 cointegrating vectors in each time period. Three intervention/structural change tests using ML model estimates are presented in Table 4.11 and compare the two time periods. These tests are similar to the tests described above based on the OLS model estimates. Again, all three tests reject the hypothesis that the coefficients and white noise are the same in the two time periods. This confirms the existence of a structural break in the time period. The relationship between the Alberta slaughter steer market and the United States slaughter steer market changed during the time period analyzed by this study.

The data generating process changed starting in about 1985 which is close to the time hypothesized in question one of the introduction. Individual time period/structural break tests used a VAR(5) model. The original VAR(5) model was estimated using the entire time period. A VAR(5) model may be miss specified when each time period is estimated separately. Separate VAR models for each time period are developed next.

VAR Model Development For 1976-1984 and 1985-1994 and Related Tests

Exactly the same steps described above are followed here to develop appropriate VAR(p) models for the two separate time periods, 1976-1984 and 1985-1994. Therefore the discussion on model development is brief.

Prior analysis has already identified that existence of unit roots in each of the two time periods (Table 4.1). Lag length statistics for SIC, AIC and log likelihood statistics (Tables 4.12 and 4.13) agree on VAR(1) models for both 1976-1984 and 1985-1994. Tests results in Table 14 do not show strong evidence for autocorrelation or non-normality in the VAR(1) models. Individual equation checks on the VAR(1) model (Tables 4.15 and 4.16) again do not find strong evidence that would reject the use of a VAR(1) model. Johansen cointegration tests (Table 17) provide strong evidence of three cointegrating vectors in each time period. These cointegration tests along with the earlier tests for the VAR(5) model answer question 3 posed in the introduction and provide proof that long term equilibrium price relationships exist between the United States and Alberta. Therefore a VAR(1) model with three cointegrating vectors is estimated by ML for 1976-1984 and for 1985-1994.

The correlation matrix for the two separate time periods from these VAR(1) ML estimates (Table 18) are similar although the correlation between Alberta prices and Futures prices increases from 0.57 to 0.68 for 1976-1984 and 1985-1994

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[24] It is important to note that the variance-covariance matrix for the A*'s is singular when estimated with cointegration constraints. This places some limits on the extent of testing that can be done using a Wald test.

respectively. There is a similar increase in the correlations between Alberta prices and Texas prices. This may indicate closer relationships between the two markets.

Further questions of interest relate to Granger causality . The Granger causality tests, Table 4.19, differ between the two periods. For 1976-1984 a feedback relationship is indicated between Alberta Steer price and Futures Steer Price (Group 1). Similar feedback situations are indicated between Alberta Steer Prices and Futures Steer Prices-Exchange Rates (Group 4) and between Alberta Steer Prices and Texas Steer Prices-Exchange Rates (Group 5). Exchange Rates alone have a one-way significant effect on Alberta Steer Prices (Group 3). For 1985-1994 the Granger tests indicate one way causation from Futures Steer Price to Alberta Steer Prices (Group 1), from Exchange Rates to Alberta Prices (Group 3), from Futures Prices-Exchange Rates to Alberta Prices (Group 4) and Texas Steer Prices-Exchange Rates to Alberta Prices (Group 5).

Group 6 results suggest that TSP does not cause FSP and FSP causes TSP which indirectly support the results of Goodwin and Schroeder (1991) and Bessler and Covey (1991). They found no or low evidence of cointegration between different U.S. cattle markets.

Based on these tests, futures prices have a stronger individual impact on Alberta steer prices than Texas Steer Prices. The futures steer price and the exchange rate both have a significant impact on the Alberta steer price which partially answers question two posed in the introduction. These tests do not indicate whether futures prices or exchange rates have a bigger impact on Alberta prices. Interestingly, the tests show more one way causation from the other variables to Alberta prices in the later time period (Group 1, Group 4 and Group 5). This may provide evidence of the increased impact of futures prices on Alberta prices in the later time period. Individual IRF and VDC for each period are examined next to further explore the interrelationships between prices.

IRF and VDC Results

The five equation VAR(1) ML model estimated with three cointegrating constraints is converted to a moving average representation based on equation (4.4) and the IRF and the VDC calculated[25]. Each time period was treated separately. The mathematics are described in Judge et al. (1988), Lutkepohl (1993) or Fackler (1988a; 1988b). The recursive ordering, discussed in Data Description above, is EX, FSP, TSP, ASP and EA. Selected IRF and VDC results related to Alberta prices are analyzed in this section to answer question four posed in the introduction. Complete IRF and VDC results for the period 1976-1984 and 1985-1994 on exchange rates, futures prices, Texas steer prices, Alberta steer prices and live animal exports are available from the author.

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[25] The programming and matrix language capabilities of Shazam v7.0 (Shazam 1993) were used to develop the ML estimation programs, IRFs, VDC and other related tests.

The Impulse Response Function (IRF) describes the effect a single orthogonal 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 changes, all variables in the model are assumed to start at zero. The discussion here focuses exclusively on the impacts system variables have on Alberta steer prices.

Figures 4.1-4.5 show the forecast responses in the logged Alberta prices to one standard deviation time zero shocks in each of the variables in the model for 1976-1984 and 1985-1994. Shock size and time zero impact on ASP are reported in Table 4.20. For example, to interpret these results use the IRF for TSP (Figure 4.3). At time 0, a one standard deviation shock occurs to logged Texas steer prices. This shock represents about a 2.67% or 2.49% change in futures prices for 1976-1984 and 1985-1994 respectively (Table 4.20). No further shocks occur to any variables after time 0. Alberta steer prices immediately increase by 1.11% and by 1.49% respectively. Figure 4.3 traces out the forecasted impact of this Texas price shock on Alberta steer prices for a period of twenty-four months.

The sources of the largest time zero changes in Alberta steer prices for 1976-1984 are in decreasing importance: ASP, FSP, TSP, EX and EA (Table 20). The ordering changes slightly for 1985-1994 with the FSP causing the largest change in ASP. Shocks to futures prices and shocks to Alberta prices cause much larger immediate changes in the Alberta steer price than shocks to exchange rates. This in part reflects the greater volatility of live cattle commodity prices versus Canada-U.S. exchange rates

The dynamic impact of these independent shocks over time indicate FSP has the largest impact on ASP (Figure 4.2). For example the positive shock to the 1985-1994 futures price results in about a 4.36% increase in futures prices at time 0 (Table 4.20) and this immediately translates into a forecast increase in Alberta prices of about 2.57% . The Alberta steer price rises to about 3.8% by period 2 and then drops to a permanent change of 3.25%. The initial changes in Alberta prices caused by the exchange rate shock are not as large (Figure 4.1). 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. Changes in U.S. prices cause larger dollar value changes in Alberta prices than equally likely changes in exchange rates.

The IRF changes between the two time periods. Exchange rates (Figure 4.1), initially have a smaller impact on Alberta steer prices in 1985-1994 than 1976-1984. Futures Steer price shocks are similar between the two time periods (Figure 4.2). TSP shocks in 1985-1994 (Figure 4.3) have a bigger initial effect on Alberta steer prices and the impact remains positive. Shocks to Alberta Steer Prices (Figure 4.4) are smaller in 1985-1994 than 1976-1984. While the statistical significance of these IRF results are not tested, these results suggest that more recently Alberta slaughter steer prices are less affected by exchange rate shocks, less affected by independent local shocks and more affected by Texas price shocks.

The VAR models are also decomposed into the forecast error variance or variance decomposition (VDC) (Figures 4.6-4.10) for 1976-1984 and 1985-1994. These graphs show how much of the total forecast variance for 1976-1984 and 1985-1994 for Alberta slaughter steer prices is contributed by time 0 shocks (innovations) from each variable[26]. The size of the shocks to each variable are not of an equal total size but represent shocks of different sizes that are equally likely to occur in each of the five variables (e.g. see Table 4.20).

For example, Figure 4.7 is the VDC for ASP arising from nearby futures prices. The graph shows that FSP contributes about 75% of the total forecast variance around a four-time periods ahead point forecast of ASP in 1985-1994. Shocks to ASP (Figure 4.9) contribute less than 20% of the total forecast error variance after four periods. 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/risk 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. Texas steer price are the third biggest source of variability in Alberta prices and the TSP VDC measures the residual United States price risk not measured by the futures steer price. The combined impact of the nearby futures prices (Figure 4.7) and the Texas prices (Figure 4.8) for 1985-1994 is over 80% and gives a measure of the total price risk coming from the United States markets. Exchange rates (Figure 4.6) are only the fourth biggest source of variability in Alberta prices with an initial time 0 impact of less than 1% rising to 6% by period 10 for 1985-1994.

Two time periods, 1976-1984 and 1985-1994, are depicted in Figures 4.6 to 4.10. Figure 4.6 indicates that EX has not changed in importance as a risk source for Alberta steer prices. FSP, Figure 4.7, increased as a source of Alberta slaughter price risk in 1985-1994. TSP, Figure 4.8, contributes more to the risk in Alberta steer prices in 1985-1994 and is the third largest source of price risk during this time period The unexplained sources of risk contained in Alberta steer prices, Figure 4.9, declined during 1985-1994 supporting the hypothesis posed in question 1 in the introduction. Again the significance of these differences between the two time periods is not tested.

One possible interpretation of these IRF and VDC results follows. Closer ties between the United States cattle markets and the Alberta cattle markets were established during the 1985-1994 time period. Figure 4.9 provides evidence that less Alberta steer price risk is coming from local supply and demand relationships. 1985-1994 was a period of increasing cattle exports to the United States implying closer ties between the two cash markets. Thus, the U.S. futures steer price cash market and the Texas steer price are contributing more to the residual risk in Alberta steer prices. Exchange rate risk is slightly more important during the latter time period.

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[26] Summing the lines for 1976-1984 in Figures 3.6-3.10 would always add up to 100%. A similar result holds for 1985-1994.

Dynamic analysis using IRF and VDC analysis comparing the earlier period to the later period measures the relative sources of risk. The most important sources of price risk in decreasing order were (1) Futures steer prices, (2) unidentified local Alberta factors and (3) U.S. cash steer markets as measured by the Texas steer price series. After 1984 the futures steer price and the Texas steer price increased in importance and the Alberta steer price decreased in importance as sources of risk. Therefore the residual basis risk remaining when an Alberta cattle investor hedges using the CME may have decreased since more of the Alberta price risk comes from the U.S. futures market. NTSP may have indirectly contributed to a decrease in local basis risk by promoting cattle feeding in Alberta. The contribution of exchange rates to Alberta steer price risk was small and remained relatively unchanged over the two time periods.

Several caveats exist regarding 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 are dropped, input prices or supply are not included and no other U.S. variables for the livestock market equilibrium are included. 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 suggest these VAR models meet most but not all the theoretical criteria for a VAR. The robustness of the model to these incorrect specifications is unknown.

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. The model investigated the dynamic interactions of these variables with the Alberta slaughter steer price. Initial analysis encompassed the entire study period of 1976 to 1994. Analysis of the full model indicated a structural break and subsequent analysis split the time period into 1976 to 1984 and 1985 to 1994.

Forecasts of Alberta prices are quite sensitive to changes in United States cattle prices. An equally likely shock to the exchange rate results in a much 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 price instability comes from the United States cattle market. The second greatest source of price instability after futures prices is from unidentified Alberta sources but these unidentified sources of risk have decreased in importance as closer economic ties developed with the U.S. cattle market. The third largest source of risk comes from United States cash prices for risk that is not already measured by the futures price. The U.S.-Canada exchange rate was a relatively small source of risk in Alberta slaughter steer prices over both time periods. Future analysis could incorporate post sample validation.

These results have possible implications for Alberta cattle feeder investors. The strong 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 indicates 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 is due to the relative stability of the exchange rate over shorter time periods relative to U.S. cattle prices.

Alberta investors may find an improvement in the effectiveness of the U.S. futures market for reducing risk in 1985-1994 as opposed to 1976-1984. The U.S. futures price as a source of risk on Alberta steer prices increased over the time period. There was also a slight increase in Texas steer price as a source of Alberta steer price risk. Unidentified local Alberta factors declined in importance. This U.S. cash market analysis measures the risk not accounted for by the futures market. Therefore possible risk management tools in decreasing order of importance that could be used or developed are:

- The CME live cattle futures contract can remove a large proportion of the Alberta steer price risk;
- A local basis contract, if feasible, which captures the difference between the Alberta price and the futures price would remove most of the remaining price risk even if there was residual exchange rate risk remaining. This market might be very thin which would make the costs quite high.

A five equation Vector Autoregression model was estimated to investigate sources of Alberta slaughter cattle price risk. Unfortunately, this analysis uses data that is averaged over different locations and therefore likely underestimates the total risk that an individual cattle investor encounters when idiosyncratic price risk is included. Analysis of individual feedlot data would be useful to extend this risk analysis. Similar VAR models could be extended to Canadian feeder cattle, pork and the grains industry. A review and/or research on the independent sources of risk in the U.S. cash market is warranted by the increased impact of this sector on Alberta steer price risk.

Table 4.1: Unit Root Tests

Variable[1]	ADF Constant[2]	ADF Constant & Trend	Phillips-Perron Constant	Phillips-Perron Trend	Box-Jenkins[3]
EX	-2.85 (-3.12, -2.86, -2.57)	-2.86 (-3.66, -3.41, -3.13)	-1.68 (-3.12, -2.86, -2.57)	-1.63 (-3.66, -3.41, -3.13)	N-S
FSP	-3.63*	-3.77*	-2.83	-3.24	N-S
TSP	-3.56*	-3.47	-2.58	-2.87	N-S
ASP	-4.90*	-4.92*	-2.64	-2.66	N-S
EA	-0.61	-2.66	-2.17	-6.28*	N-S

1. EX=logged U.S./Cdn$, FSP=logged 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 for each column at the 2.5%, 5% and 10% level of significance respectively are in brackets in the first row (Davidson and MacKinnon, 1993, Table 20.1). The unit root hypothesis for the ADF and the Phillips-Perron is rejected when the test statistic is smaller than the critical value. A "*" represents rejection of the unit root hypothesis at the 2.5% level of significance.
3. N-S indicates the series is not-stationary using standard Box-Jenkins analysis.
4. The Dickey-Fuller tests provide strong evidence for unit roots during the two periods Jan. 1976 to Dec. 1984 and Jan. 1985 to 1994 for all variables. The Phillips-Perron tests provide mixed conclusions regarding unit roots in live animal exports during Jan. 1976 to Dec. 1984. The Phillips-Perron tests give mixed results for unit roots for nearby futures, Alberta slaughter prices and live animal exports for Dec. 1985 to 1994. These are at the 10% level of significance.

Table 4.2: Cointegration Tests

Variable[1]	ADF(p)[2] Constant	ADF(p) Constant & Trend	Phillips-Perron & Constant	Phillips-Perron & Trend
ASP, TSP	-1.64 (-3.04)	-1.90 (-3.50)	-4.12 (-3.04)	-4.08 (-3.50)
ASP, FSP	-2.83 (-3.04)	-2.94 (-3.50)	-4.87 (-3.04)	-4.62 (-3.50)
ASP, TSP, EX	-3.44 (-3.45)	-3.74 (-3.84)	-8.4 (-3.45)	-8.78 (-3.84)
ASP, FSP, EX	-3.98 (-3.45)	-4.10 (3.84)	-8.48 (-3.45)	-8.72 (-3.84)
ASP, EA	-3.21 (-3.04)	-3.71 (-3.50)	-3.24 (-3.04)	-2.68 (-3.50)
ASP, FSP, TSP, EX	-3.41 (-3.81)	-3.78 (-4.15)	-8.42 (-3.81)	-8.83 (-4.15)
ASP*EX, FSP[3]	-3.86 (-3.04)	-4.04 (-3.50)	-8.42 (-3.04)	-8.71 (-3.50)
ASP*EX, TSP	-3.31 (-3.04)	-3.70 (-3.50)	-8.07 (-3.04)	-8.62 (-3.50)

1. The first variable is the endogenous (left hand side) variable in equation (3.7). ASP=logged Alberta Steer Price, FSP =logged Nearby Futures Price, TSP=Logged Texas Steer Price, EX=logged U.S./CDN $ and EA=logged animal exports.
2. The asymptotic test statistics critical values are in brackets below each test statistic. These are at the 10% level of significance.
3. The ASP/EX represents the conversion of Alberta slaughter steer prices to United States dollars. ASP/EX=logged Alberta Steer Price-logged exchange rate.

Table 4.3: Tests for the Rank (r) of Cointegration (Johansen Trace Tests) VAR(5): 1976-1994

H_0 Hypothesis	H_1 Hypothesis	Test Statistics[1]	10% Critical Values[2]	5% Critical Values
Test 1				
r=4	r=5	1.75	6.69	8.08
r=3	r≥4	5.39	15.58	17.84
r=2	r≥3	20.23	28.44	31.26
r=1	r≥2	57.2	45.25	48.42
r=0	r≥1	117.72	65.96	69.98
Test 2				
r=4	r=5	1.74	6.69	8.08
r=3	r=4	3.64	12.78	14.60
r=2	r=3	14.84	18.96	21.28
r=1	r=2	36.97	24.92	27.34
r=0	r=1	60.52	30.82	33.26

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[1] The calculated eigenvalues are 0.242408, 0.155985, 6.58E-02, 1.66E-02, 7.98E-03. These are used to calculate the following values used in the test statistics: 60.51892, 36.96946, 14.84403, 3.643618, 1.746149.

[2] Special statistics are required for the two tests. The "r" is the number of cointegrating vectors.

Table 4.4: VAR(p) Lag Length Statistics: 1976-1994

Lag Length	SIC	AIC	Log Likelihood	LR Test Stat.[1]
p=1	-31.74	-32.12	1952.35	48.22
p=2	-31.35	-32.11	1976.46	82.78
p=3	-31.13	-32.259	2017.85	50.76
p=4	-30.75	-32.261	2043.23	37.68
p=5	-30.32	-32.20	2062.07	36.66
p=6	-29.88	-32.14	2080.40	38.92
p=7	-29.45	-32.09	2099.86	41.84
p=8	-29.03	-32.05	2120.78	

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[1] This is the Likelihood Ratio test comparing VAR(p) to VAR(p+1). It has 25 degrees of freedom and the test statistic at the 5% level of significance is 37.65 and at the 1% level it is 44.31.

Table 4.5: Asymptotic Autocorrelation and Normality Tests: 1976-1994

VAR MODEL	Skewness[1]	Kurtosis[2]	Joint Normality Test[3]	Portmanteau 25 Lags[4]
VAR(4)	18.7 (0.002)	7.4 (0.191)	26.1 (0.004)	174.5 (525 1.00)
VAR(5)	12.4 (0.030)	2.5 (0.78)	14.9 (0.14)	169.0 (500 0.98)
VAR(6)	12.8 (.036)	0.89 (0.97)	13.7 (0.19)	131.8 (475 0.97)

1. Skewness is a Chi-Squared test with 5 degrees of freedom. The number in brackets is the probability value (1-CDF).
2. Kurtosis is Chi-Squared test with 5 degrees of freedom.
3. Joint normality test is Chi-Squared with 10 degrees of freedom.
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. A test using 45 lags gives similar results.

Table 4.6: Individual Equation Checks on VAR(5) Model: 1976-1994

Equation	Normality Jarque- Bera[1]	Heteroskedasticity B-P-G[2]	Linearity Test[3] RESET 2 3 4	Serial Autocorrelation[4] Number of Significant Serial Auto. In First 12 Lags
EX	1.5	22.2	1.0, 0.6, 0.9	1
FSP	0.7	35.5	12.7, 6.1, 4.4	0
TSP	0.03	24.5	5.1, 2.7, 2.3	0
ASP	1.8	21.7	12.3, 6.7, 5.4	1
EA	4.9	22.9	5.4, 5.5, 5.3	0

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

1. Jarque-Bera tests for normality using the third and fourth moments of the normal distribution. It is Chi-Squared(2). (Critical at 1% level is 9.2)
2. The B-P-G Heteroskedasticity test is Chi-Squared(25). (Critical value at 1% is 44.3)
3. RESET is an F test for model linearity. The numbers in the column represent RESET 2, 3, and 4 respectively with 1% critical values of 6.63(1, 188), 4.61(2, 187), and 3.78(3, 186) 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 (Q test) for no serial autocorrelation to lag 23. The LM results do not reject no autocorrelation at the 1% significance level for each of the five equations.

Table 4.7: VAR(5) Correlation Matrix By Unconstrained Least Squares Estimates: 1976-1994

	EX	FSP	TSP	ASP	EA
EX	1.000				
FSP	0.062	1.000			
TSP	0.030	0.817*	1.000		
ASP	-0.088	0.586*	0.648*	1.000	
EA	-0.162	0.126	0.105	-0.053	1.000

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

	EX	FSP	TSP	ASP	EA
EX	1.000				
FSP	0.044	1.000			
TSP	0.014	0.821*	1.000		
ASP	-0.112	0.596*	0.656*	1.000	
EA	-0.155	0.120	0.100	-0.059	1.000

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

Table 4.8: Prediction Tests For Structural Change based on VAR(5) Model Estimated From Jan. 1976 to Dec. 1984.

h-Step Ahead Period[1]	Single Period Forecasts (Chi-Squared-(5) test)[2]	Joint Several Step Ahead Forecasts (F-test)	Critical 1% F Values For Joint Test
1	5.81	0.93	3.28
2	12.69	1.51	2.56
3	25.01	2.00	2.28
4	22.64	1.84	2.12
5	14.14	1.87	2.02
6	16.71	1.97	1.95
7	18.09	2.11	1.90
8	21.05	2.08	1.86
9	33.88	2.27	1.83
10	13.70	2.26	1.80
11	9.13	2.14	1.78
12	3.54	2.08	1.76
13	5.97	2.12	1.74
14	16.25	2.26	1.73
15	19.12	2.30	1.71
16	10.19	2.20	1.70
17	8.64	2.15	1.69
18	8.24	2.17	1.68
19	7.72	2.19	1.67
20	6.92	2.12	1.67
21	13.93	2.14	1.66
22	9.38	2.18	1.65
23	10.05	2.12	1.65
24	9.16	2.15	1.64

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1. The is the length of the forecast. For example, the single period test h=5, is a test based on a VAR(5) model estimated to Dec. 1984 and used to forecast May 1985 values, 5-steps into the future. For h=5, the joint several step-ahead test includes the forecasts for h=1 (Jan. 1985), h=2 (Feb. 1986), ..., h=5 (May, 1985) in the test statistic.

The Chi-Squared-(5) 1% critical value is 15.086.

Table 4.9: Intervention Analysis For Structural Change based on VAR(5) Models For Jan. 1976 to Dec. 1984 and Dec. 1985 to July 1994 Using OLS Estimation.

H_0	H_1	Statistic	Degrees of Freedom and P-Value
1. All coefficients time Invariant[1]	All coefficients time varying	254.70	LR test df=145 p=0.00
2. Time invariant white noise only[2]	All coefficients time varying	46.94	LR test df=15 p=0.00
3. All coefficients time invariant	White noise is time invariant only	207.75	LR test df=130 p=0.00
4. Time varying white noise only	All coefficients time varying	245.77	Wald χ^2 df=130 p=0.00

1. All coefficients are the A*'s and cov(U(t)) from equation 3.2.
2. The white noise is cov(U(t)), the variance-covariance between the five equations.

Tests 1, 2, and 3 are based on Lutkepohl Table 12.1 (p. 403) and test 4 is based on Lutkepohl equation 12.3.26.

Table 4.10: Tests for the Rank (r) of Cointegration (Johansen Trace Tests) For VAR(5) Model Estimated For Period Jan. 1976 to Dec. 1984 and For Period Jan. 1985 to July 1994

H_0 Hypotheses	H_1 Hypotheses	1976-1984 Test Statistics	1985-1994 Test Statistics	10% Critical Values[1]	5% Critical Values
Test 1					
r=4	r=5	1.19	0.52	6.69	8.08
r=3	r≥4	8.96	6.11	15.58	17.84
r=2	r≥3	24.01	30.99	28.44	31.26
r=1	r≥2	50.13	63.48	45.25	48.42
r=0	r≥1	95.06	107.38	65.96	69.98
Test 2					
r=4	r=5	1.19	0.52	6.69	8.08
r=3	r=4	7.76	5.58	12.78	14.60
r=2	r=3	15.06	24.88	18.96	21.28
r=1	r=2	26.12	32.49	24.92	27.34
r=0	r=1	44.93	43.90	30.82	33.26

1. Special statistics are required for the two tests. The r indicates the number of cointegration vectors in the test.

Table 4.11: **Intervention Analysis For Structural Change based on VAR(5) Models For Jan. 1976 to Dec. 1984 and Jan. 1985 to July 1994 Using ML Estimation and Wald Tests.**

H_0	H_1	Statistic	Degrees of Freedom and P-Value
1. All coefficients time Invariant[1]	All coefficients time varying	792	Wald[3] χ^2 df=101 p=0.00
2. Time invariant white noise only[2]	All coefficients time varying	33	Wald χ^2 df=15 p=0.004
3. All coefficients time invariant	White noise is time invariant only	NA	NA
4. Time varying white noise only	All coefficients time varying	208	Wald[3] χ^2 df=71 p=0.00

1. All coefficients are the A*'s and cov(U(t)) from equation 3.2. The Wald tests assume the two time period models are independent and uses the ML property of asymptotic independence between the A*'s and the cov(U(t)) to construct the tests (Lutkepohl 1993, proposition 11.2, corollary 11.2.1 and proposition 11.5). Therefore one 290x290 variance-covariance matrix for all the coefficients from both time period models is constructed. Note that the variance-covariance of A* is singular because of the two cointegrating vectors. Tests 1 and 4 are approximated by using a generalized inverse to test the hypothesis (Lutkepohl 1993, p.379).
2. The white noise is cov(U(t)), the variance-covariance between the five equations.
3. Eigenvalues smaller than 0.01 for the estimated distribution of the test were considered equal to zero in calculating the generalized inverse for this test. Different specifications for calculating the generalized inverse change the test value however the null hypothesis is always strongly rejected.

Table 4.12: VAR(p) Lag Length Statistics 1976-1984

Lag Length	SIC	AIC	Log Likelihood	LR Test Stat.[1]
p=1	-31.14	-31.79	905.00	32.17
p=2	-30.31	-31.61	921.09	45.65
p=3	-29.61	-31.57	943.91	37.63
p=4	-28.84	-31.44	962.73	36.81
p=5	-28.06	-31.31	981.13	36.35
p=6	-27.27	-31.18	999.31	48.18
p=7	-26.60	-31.16	1023.40	44.16
p=8	-25.89	-31.10	1045.48	

1. This is the Likelihood Ratio test comparing VAR(p) to VAR(p+1). It has 25 degrees of freedom and the test statistic at the 5% level of significance is 37.65 and at the 1% level it is 44.31.

Table 4.13: VAR(p) Lag Length Statistics 1985-1994

Lag Length	SIC	AIC	Log Likelihood	LR Test Stat.[1]
p=1	-32.42	-33.18	1116.78	34.60
p=2	-31.85	-33.04	1134.08	58.26
p=3	-31.32	-33.11	1163.21	54.92
p=4	-30.77	-33.16	1190.67	39.05
p=5	-30.08	-33.06	1210.20	42.31
p=6	-29.41	-33.00	1231.35	55.53
p=7	-28.87	-33.04	1259.12	42.20
p=8	-28.20	-32.98	1280.22	

1. This is the Likelihood Ratio test comparing VAR(p) to VAR(p+1). It has 25 degrees of freedom and the test statistic at the 5% level of significance is 37.65 and at the 1% level it is 44.31.

Table 4.14: Asymptotic Autocorrelation and Normality Tests: VAR(1)

VAR MODEL	Skewness[1]	Kurtosis[2]	Joint Normality Test[3]	Portmanteau 25 Lags[4]
1976-1984	12.8	2.4	15.2	178.2
	(0.03)	(0.79)	(0.13)	(600, 1.00)
1985-1994	9.3	1.2	10.5	46.5
	(0.1)	0.94	0.40	(600, 1.00)

1. Skewness is a Chi-Squared test with 5 degrees of freedom. The number in brackets is the probability value (1-CDF).
2. Kurtosis is Chi-Squared test with 5 degrees of freedom.
3. Joint normality test is Chi-Squared with 10 degrees of freedom.
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.

Table 4.15: Individual Equation Checks on VAR(1) Model: 1976-1984

Equation	Normality Jarque- Bera[1]	Heteroskedasticity B-P-G[2]	Linearity Test[3] RESET 2 3 4	Serial Autocorrelation[4] Number of Significant Serial Auto. In First 12 Lags
EX	1.04	2.07	0.2, 0.4, 1.3	0
FSP	1.34	3.36	3.8, 4.0, 2.7	0
TSP	2.15	7.71	2.6, 1.7, 1.3	0
ASP	2.19	5.01	19.0, 9.4, 6.7	1
EA	4.02	7.59	6.2, 3.1, 3.1	1

ASP=logged Alberta Steer prices, FSP=logged Nearby Live Cattle Futures prices, TSP=logged Texas Steer prices, EX=logged 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. (Critical at 1% level is 9.2)

2. The B-P-G is a Chi-Squared test for Heteroskedasticity with 5 degrees of freedom. (Critical value at 1% is 15.08)

3. RESET is an F test for model linearity. The numbers in the column represent RESET 2, 3, and 4 respectively with 1% critical values of 6.85(1, 96), 4.79(2, 95), and 3.95(3, 94) 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 (Q test) for no serial autocorrelation to lag 23. The LM results do not reject no autocorrelation at the 1% significance level for each of the five equations.

Table 4.16: Individual Equation Checks on VAR(1) Model: 1985-1994

Equation	Normality Jarque- Bera[1]	Heteroskedasticity B-P-G[2]	Linearity Test[3] RESET 2 3 4	Serial Autocorrelation[4] Number of Significant Serial Auto. In First 12 Lags
EX	5.23	1.00	0.0, 1.3, 1.4	0
FSP	1.35	11.80	2.0, 2.3, 1.6	1
TSP	1.61	15.56	0.7, 0.2, 1.0	0
ASP	0.35	13.04	0.5, 1.4, 1.0	0
EA	2.40	7.95	2.0, 1.6, 1.2	0

ASP=logged Alberta Steer prices, FSP=logged Nearby Live Cattle Futures prices, TSP=logged Texas Steer prices, EX=logged 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. (Critical at 1% level is 9.2)

2. The B-P-G is a Chi-Squared test for Heteroskedasticity with 25 degrees of freedom. (Critical value at 1% is 44.3)

3. RESET is an F test for model linearity. The numbers in the column represent RESET 2, 3, and 4 respectively with 1% critical values of 6.63(1, 188), 4.61(2, 187), and 3.78(3, 186) 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 (Q test) for no serial autocorrelation to lag 23. The LM results do not reject no autocorrelation at the 1% significance level for each of the five equations.

Table 4.17: Tests for the Rank (r) of Cointegration (Johansen Trace Tests) For VAR(1) Model Estimated For Period Jan. 1976 to Dec. 1984 and For Period Jan. 1985 to July 1994

H_0 Hypotheses	H_1 Hypotheses	1976-1984 Test Statistics	1985-1994 Test Statistics	10% Critical Values[1]	5% Critical Values
Test 1					
r=4	r=5	1.0	0.8	6.69	8.08
r=3	r≥4	8.9	12.0	15.58	17.84
r=2	r≥3	42.3	31.9	28.44	31.26
r=1	r≥2	82.9	80.3	45.25	48.42
r=0	r≥1	144.9	155.2	65.96	69.98
Test 2					
r=4	r=5	1.0	0.8	6.69	8.08
r=3	r=4	8.0	11.2	12.78	14.60
r=2	r=3	33.4	19.9	18.96	21.28
r=1	r=2	40.6	48.4	24.92	27.34
r=0	r=1	61.9	74.9	30.82	33.26

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1. Special statistics are required for the two tests. The r indicates the number of cointegration vectors in the test.

Table 4.18: VAR(1) Correlation Matrix by ML Estimates For Period 1976 to 1984

	EX	FSP	TSP	ASP	EA
EX	1.000				
FSP	0.046	1.000			
TSP	-0.038	0.866*	1.000		
ASP	-0.150	0.575*	0.636*	1.000	
EA	-0.045	0.134	0.068	-0.088	1.000

VAR(1) Correlation Matrix By ML Estimates For Period 1985-1994

	EX	FSP	TSP	ASP	EA
EX	1.000				
FSP	-0.012	1.000			
TSP	0.030	0.754*	1.000		
ASP	-0.019	0.680*	0.771*	1.000	
EA	-0.390	0.240	0.237	0.121	1.000

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

Table 4.19: Granger Causality Tests and Direction of Tests based on VAR(1) Models For Jan. 1976 to Dec. 1984 and Jan. 1985 to 1994 Using ML Estimation.

Direction of Test[1]	1976-1984 - ML Wald Chi-Square Statistic[2]	1985-1994 - ML Wald Chi-Square Statistic
Group 1		
ASP cause FSP	10.61* (1)	5.3
FSP cause ASP	20.73* (1)	10.47*
Group 2		
ASP cause TSP	9.43* (1)	6.05
TSP cause ASP	6.25(1)	0.57
Group 3		
ASP cause EX	0.15 (1)	0.08
EX cause ASP	8.06* (1)	11.67*
Group 4		
ASP cause FSP & EX	9.51* (2)	5.37
FSP & EX cause ASP	22.91* (2)	17.75*
Group 5		
ASP cause TSP & EX	9.51* (2)	6.18
TSP & EX cause ASP	13.1* (2)	19.09*
Group 6		
FSP causes TSP	14.81* (2)	10.70*
TSP causes FSP	6.51 (2)	1.23

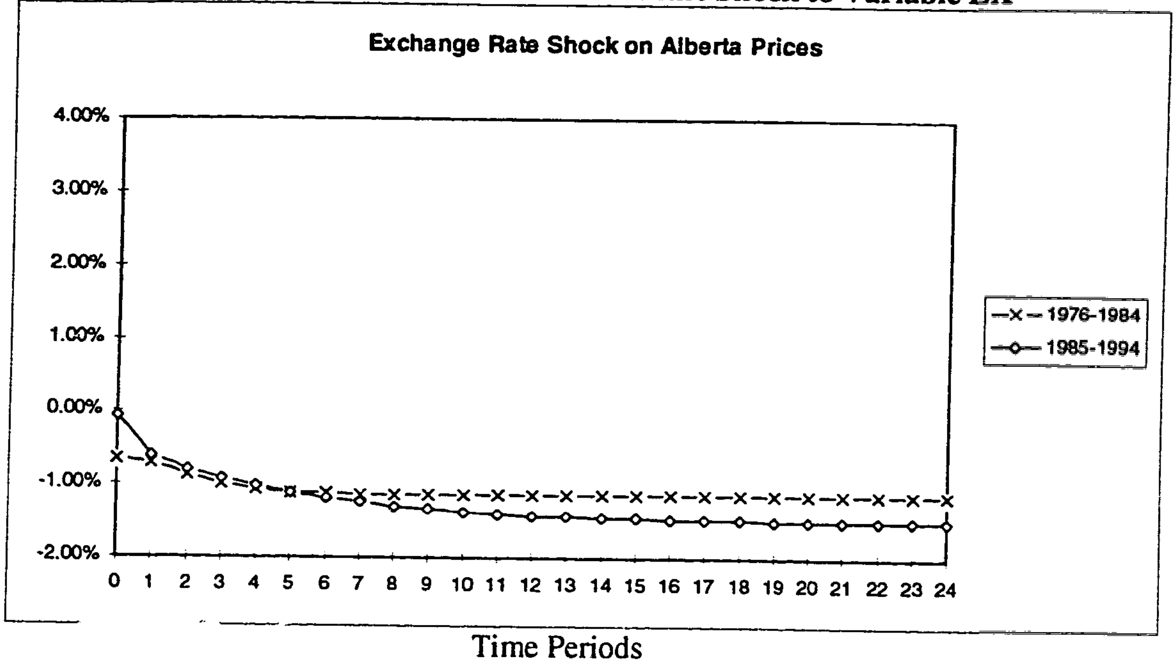
1. The Granger tests are a two way test. The direction of cause is first tested in one direction and then in the opposite direction. The two tests representing these two directions are grouped together in the table. ASP=logged Alberta Steer prices, FSP=logged Nearby Live Cattle Futures prices, TSP=logged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

2. Numbers in brackets are the degrees of freedom. A "*" indicates significant at the 1% level. The ML test has three cointegrating constraints imposed.

Table 4.20: Size of Time 0 IRF Shock on Specified Variable and Immediate Impact on Alberta Prices (ASP).

One Std. Dev. Shock To	1976-1984 Size of Original Shock	Impact on ASP	1985-1994 Size of Original Shock	Impact on ASP
Exchange Rate	1.23%	-0.66%	1.25%	-0.07%
Futures Price	5.96%	2.58%	4.36%	2.57%
Texas Price	2.67%	1.11%	2.49%	1.49%
Alberta Price	3.36%	3.36%	2.33%	2.33%
Live Exports	19.76%	0.0%	16.75%	0.0%

Figure 4.1: IRF - One Std. Dev. One Time Shock to Variable EX



Legend:

EX=U.S./CDN $ exchange rates (logged)

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)

As an approximation, the vertical scaling for the IRF graphs can be viewed as the percentage change in the original unlogged variables.

Figure 4.2: IRF - One Std. Dev. One Time Shock to Variable FSP

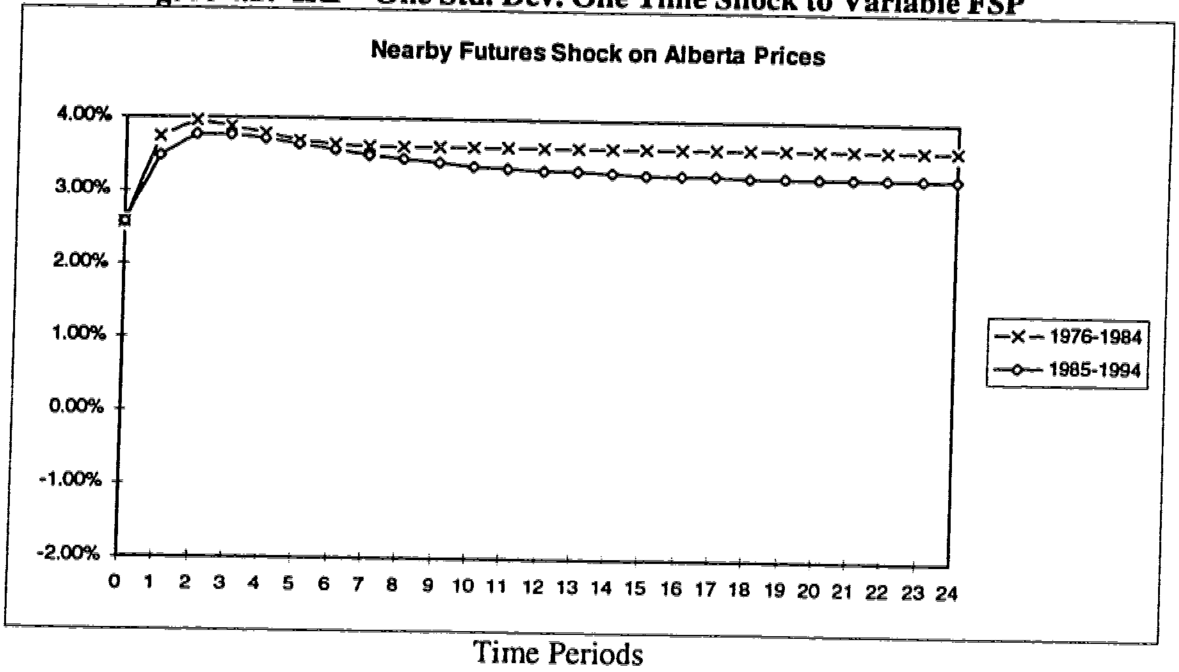


Figure 4.3: IRF - One Std. Dev. One Time Shock to Variable TSP

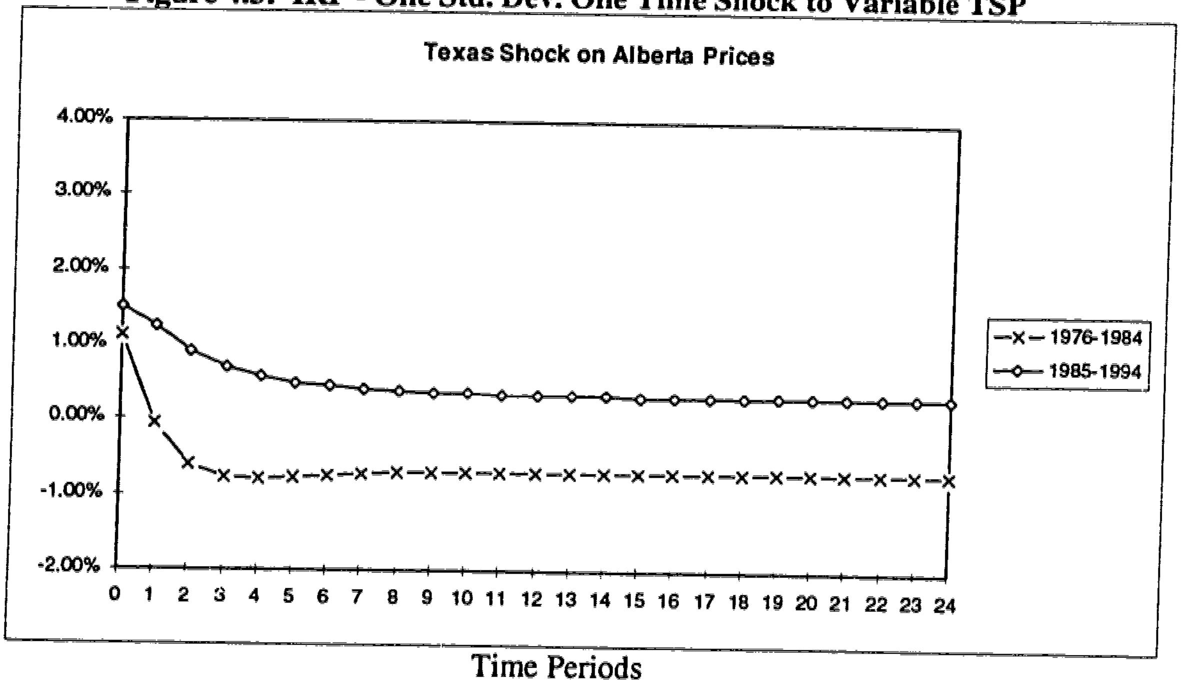
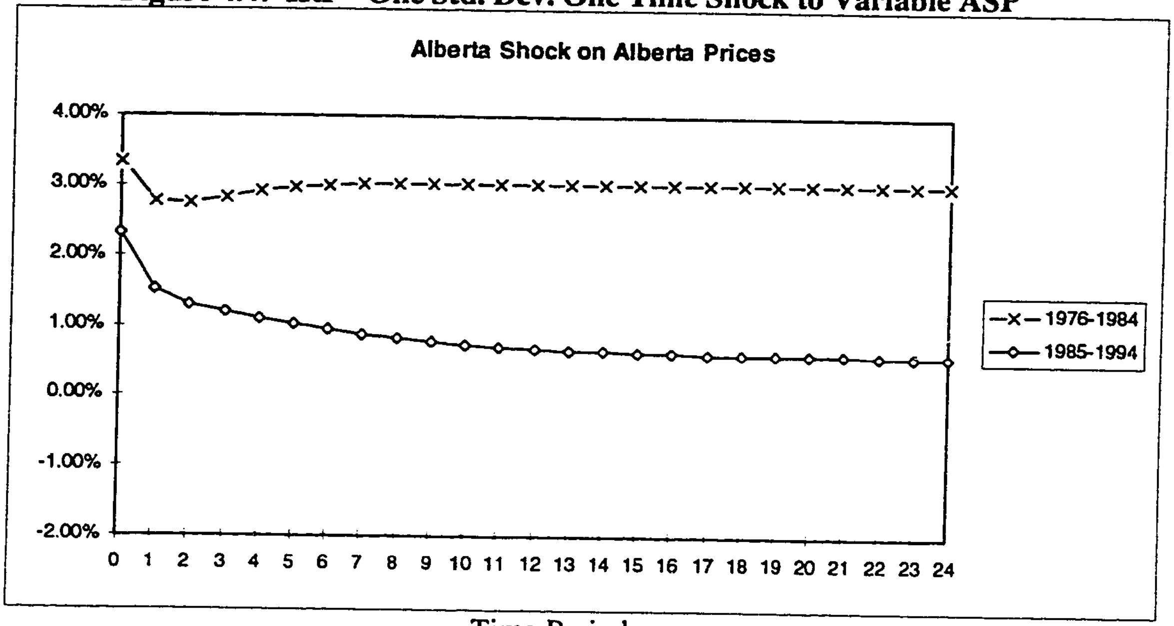
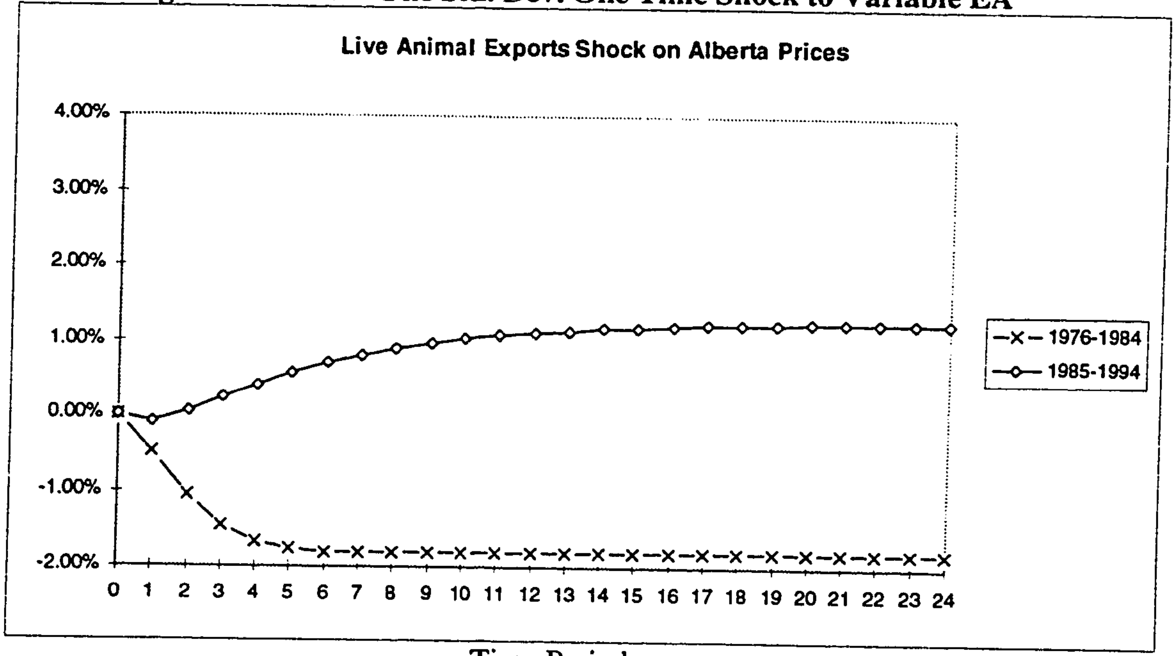


Figure 4.4: IRF - One Std. Dev. One Time Shock to Variable ASP



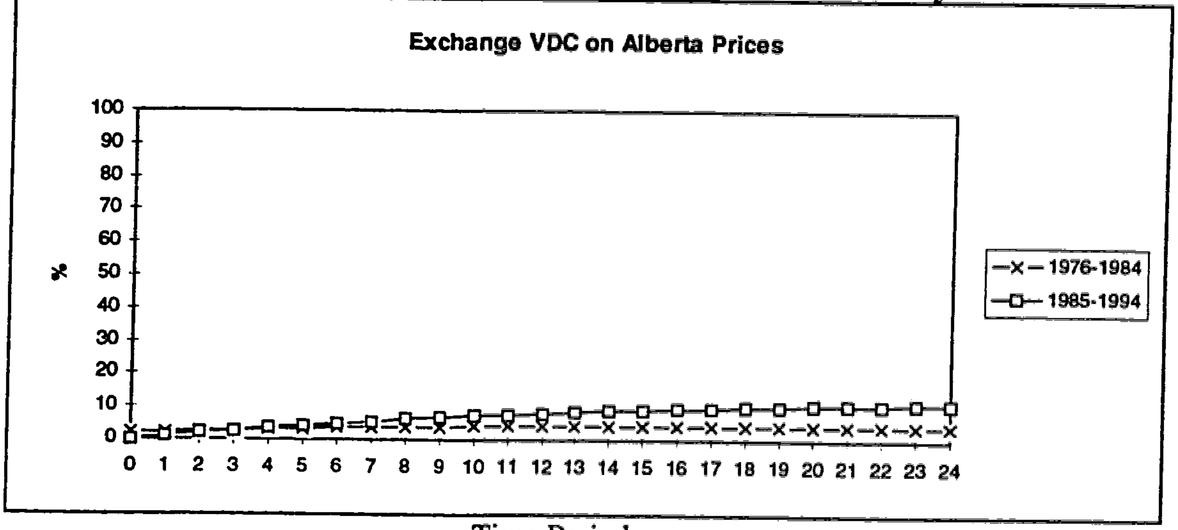
Time Periods

Figure 4.5: IRF - One Std. Dev. One Time Shock to Variable EA



Time Periods

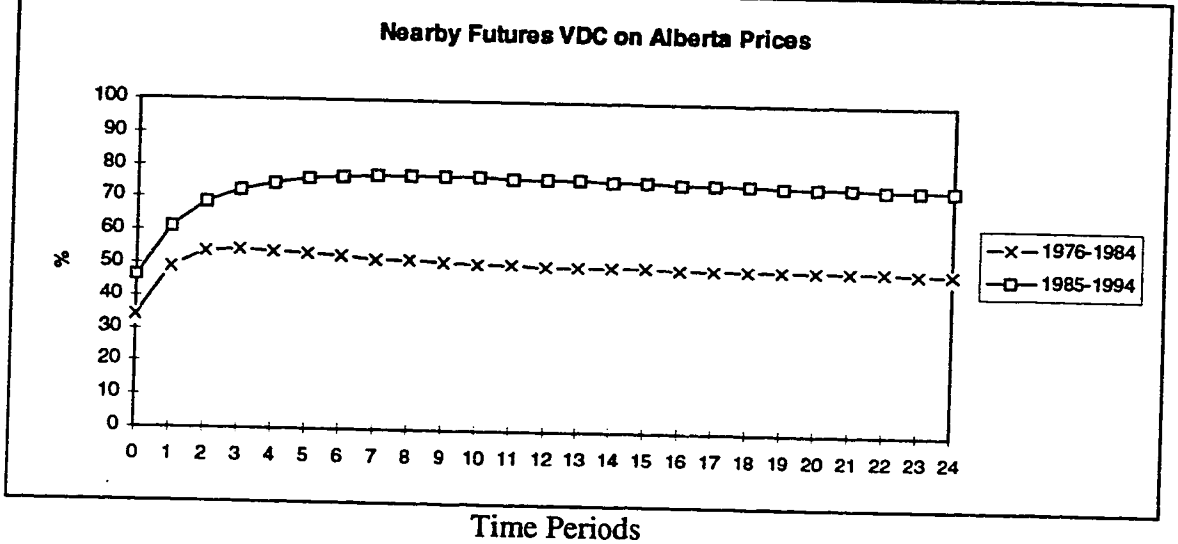
Figure 4.6: VDC - Percentage Sources of Forecast Error Caused by EX on ASP



Time Periods

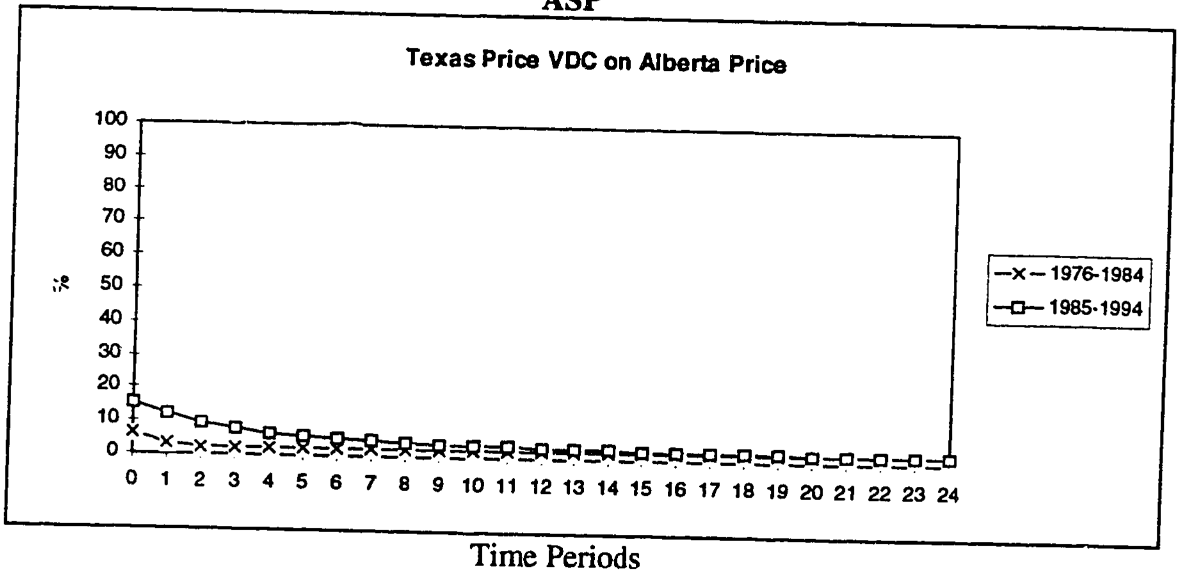
Legend:
EX=U.S./CDN $ exchange rates (logged)
FSP=Nearby Futures Live Cattle Futures Price in U.S. $ (logged)
TSP=Texas Slaughter Steer Price in U.S. $ (logged)
ASP=Alberta Slaughter Steer Price in Canadian $ (logged)
EA=Live Animal Exports from Canada in Canadian $ (logged)

Figure 4.7: VDC - Percentage Sources of Forecast Error Caused by FSP on ASP



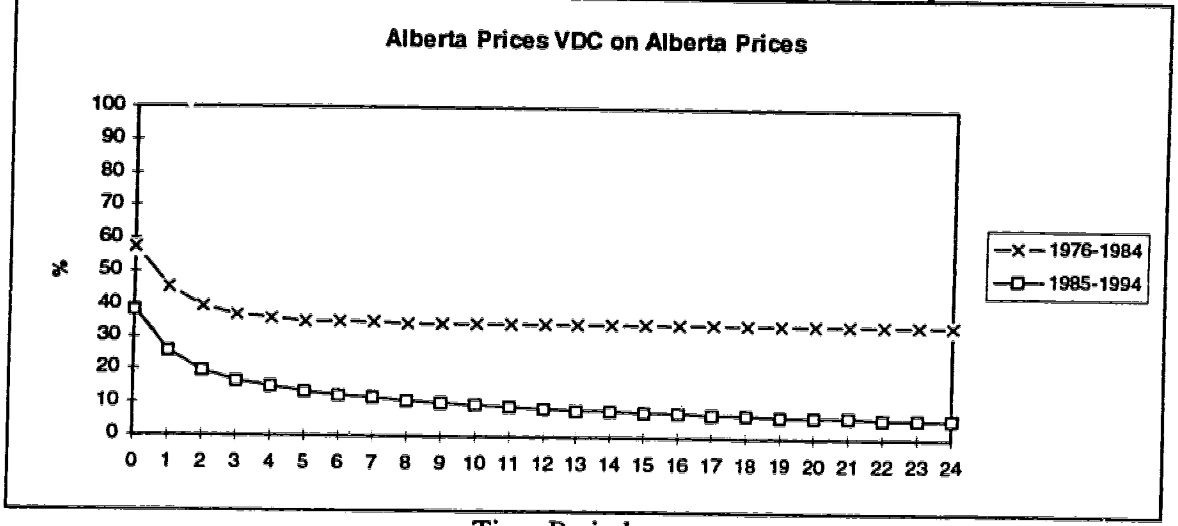
Time Periods

Figure 4.8: VDC - Percentage Sources of Forecast Error Caused by TSP on ASP



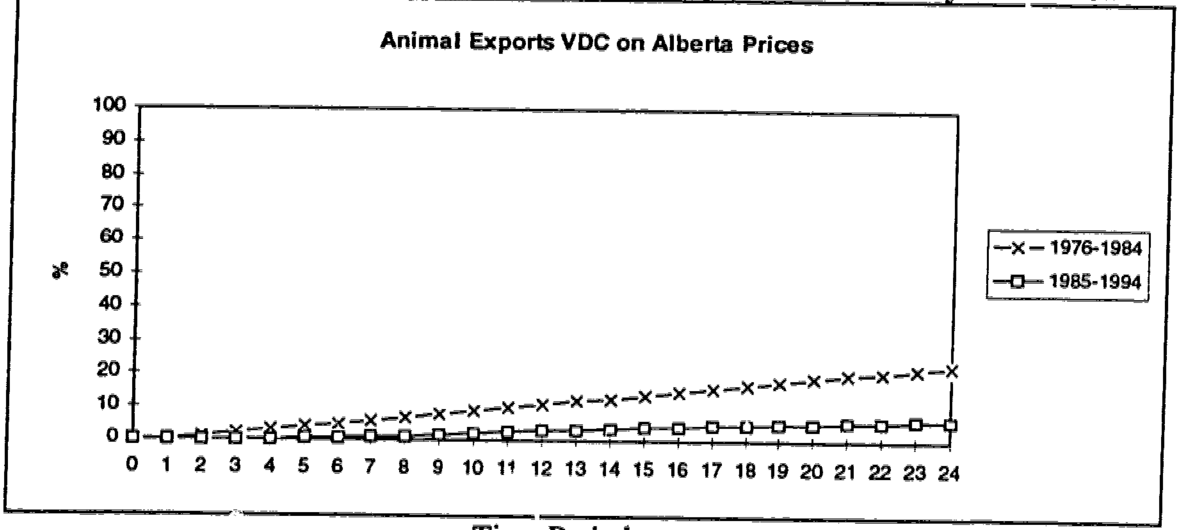
Time Periods

Figure 4.9: VDC - Percentage Sources of Forecast Error Caused by ASP on ASP



Time Periods

Figure 4.10: VDC - Percentage Sources of Forecast Error Caused by EA on ASP



Time Periods

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Chapter 5: Non-Storability and the Theory of Storage In Commodity Futures Prices

Introduction

Finance theory posits a strong relationship between the relevant commodity futures price and the spot cash market price. There are two views on the association between these prices which are not mutually exclusive. The theory of storage such as described by Kaldor (1939), Working (1948), Brennan (1958) or Telser (1958) explains the difference between the contemporaneous spot price and the futures price in terms of interest foregone on the value of the stored commodity, storage costs, and a convenience yield on inventory (Fama and French, 1987). Brennan (1991) defines the convenience yield of a commodity as the flow of services which accrues to the owner of the physical inventory but not to the owner of a contract for future delivery. The convenience yield includes potential profits from temporary local shortages or the ability to maintain a production process despite local shortages of inputs. The competing view divides the futures price into an expected risk premium and a forecast of the future spot price (Dusak, 1973; Fama and French, 1987; Shonkwiler, 1986).

The theory of storage argument is well accepted. However, storage theory relating the contemporaneous spot price and futures price does not apply when the commodity is not storable. Livestock and livestock products (e.g. cattle and beef, hogs and pork) are not storable for long periods of time. Age is important. For example, finished cattle can be withheld from market only for short periods of time (e.g. 1-2 months) without serious loss of value, yet cattle futures contracts extend ahead over one year. Not only must the investor pay storage costs on a mature animal (e.g. feeding costs), but the total value of the animal drops because of adverse changes in product quality. This suggests at best a weak relationship between current cash prices on mature animals and distant futures contract prices on non-storable commodities.

Storability in a broad sense is a requirement for a viable futures contract (Stoll and Whaley, 1993 p.78). Storability allows the market to smooth consumption and deliver the product specified by futures contract. In grains, storage ties the old crop year price with the expected production in the upcoming production year (Working, 1948). In this broader sense, animal products are storable but not in the same form as specified in the futures contract. The current physical form of the stored commodity is not a perfect substitute for the product specified in the futures contract. With live animal production, the future finished slaughter animal is stored as the current feeder animal and as a time distributed package of inputs such as feed[27]. It is the current

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[27] Currently owned feeder animals and a time distributed quantity of feed are stored, subject to substantial carrying or storage costs and convenience yield. The carrying

supply of feeder animals and the particular feeding regime upon which they are placed that determines the future supply.

Evidence from the literature supports the hypothesis that the futures price for non-storables is related to the feeder animal price and input prices. Koontz, Hudson and Hughes (1992) conclude that that prices for distant contracts on non-storable commodities depend on average feeding costs. This is another way of stating that storage costs have a major influence on futures prices for non-storable commodities. Paul and Wesson (1967) proposed that the future value of the finished animal, represented in their discussion as the futures price, was composed of the value of the feeder animal, expected costs and the expected feedlot services costs. Purcell, Flood and Plaxico (1979) found only a one way significant relationship going from futures prices to feeder cattle prices. Leuthold (1979) reported that input feed prices were significant in explaining cattle basis and Tomek (1980) elaborated on Leuthold's results to show that the cash spot cattle price moves independently of more distant cattle futures contracts. None of these studies explore the relevant theory in any depth.

At its very simplest, a futures model for non-storable commodities should include the feeder animal and some constant for the associated feed costs. There may also be some carrying costs associated with the storage facility and handling facilities. Alternatively convenience yield could be included. Convenience yield, likely a small component, would be related to the ability to substitute feeds during the feeding period, modify the animal's rate of gain so as to market the animal in a slightly different time period or sell the animal sooner if a local shortage of slaughter animals occurs prior to the target market date. The holder of the futures contract cannot benefit from any of these alternatives just mentioned.

Uncertainty concerning future feed costs could have a major impact on futures prices. Conceptually futures price models should explicitly incorporate stochastic feed costs, stochastic interest rates or stochastic convenience yield. Simplification may be possible if the effects of one or two sources of uncertainty are empirically dominant. Over the life of a contract the relative importance of these sources of risk may change. The Koontz, Hudson and Hughes (1992) results imply that feed costs may be the major risk source in distant futures contracts. Uncertainty arising from feed costs for futures contracts that are close to maturity may be low and convenience yield may be a more important source of risk at this time.

The purpose of this paper is to explore the theoretical relationship between feeder animal prices and futures prices. By explicitly modeling the non-storability issue related to the age of the investment, improved hedge ratios and improved dynamic strategies can be derived. For example, a well-specified relationship

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costs include facility use. The convenience yield includes the freedom to substitute inputs during the feeding period, modify the rate of gain to change the maturity date and select a marketing date that differs from the futures contract date.

between the futures price and the feeder prices should help a cattle feeder develop a hedge strategy. Other benefits include the possibility of improved options pricing models and improved empirical analysis of futures markets on non-storable commodities.

This paper derives closed-form solutions relating futures slaughter prices to spot feeder prices. These solutions are extended analytically or numerically to include either stochastic convenience yields or stochastic storage costs[28]. The discussion begins with a brief review of the theory of storage and an explanation of convenience yield.

Futures and the Theory of Storage

Let F(t,T) be the futures price at time t for delivery at time T and let S*(t) be the log normally distributed commodity spot price for the finished market ready animal. Assume a constant continuously compounded risk free interest rate r, a continuous constant proportional storage costs u, and a continuous constant proportional convenience yield δ. Following, for example, Brennan and Schwartz (1985), Ramaswamy and Sundaresan (1985) or McDonald and Siegel (1984), futures prices[29] are related to spot prices by the well known relationship[30].

$$F(t,T) = S^{*}(t)\exp\{(r+u-\delta)(T-t)\} \tag{5.1}$$

The futures price is increased by the interest costs of holding the inventory, increased by the storage costs of holding inventory and decreased by the convenience of not having physical commodity available to sell in the spot market. The owner of the cash commodity expects compensation for storage costs and interest foregone on the investment. This compensation is reduced by the convenience yield (dividend) that accrues to the owner of the product. A drawback to this simple model is that the sign of the basis never changes where from equation (5.1) basis is defined as $F\text{-}S^{*}=S^{*}[\exp\{(r+\mu-\delta)(T-t)\}-1]$. Casual observation demonstrates that basis does change sign in some non-storable commodities.

Fama and French (1987) test implications arising from a discrete version of this futures model. The above model implies there is a one for one relationship between changes in basis and changes in the exponential of interest rates. They test the model using a proxy for the spot commodity price for a finished animal and do not consider the relevant feeder animal prices. They find that interest rates are not a major contributing factor to basis variance for animals and animal products. Fama and French's (1987) results for animals and animal products are inconsistent with the

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[28] Stochastic interest rates could be substituted in as the second stochastic variable in the model.

[29] Under the assumption of constant interest rates the futures contract and the forward contract are the same (for examples see Hull).

[30] Log normality is not required to derive this relationship between the futures and the cash price.

predictions from the theory of storage model[31] above but they conclude these results are consistent with the theory of storage where marginal convenience yield varies due to seasonals in production or demand. The Fama and French inconsistencies may arise from incorrect model specification and the inclusion of slaughter spot prices instead of feeder spot prices. Adjustments to the futures model for non-storable commodities are proposed in the next section.

Futures Models for Non-storable Commodities

In this section valuation models are derived relating the futures price to the current spot feeder price. Reasons for using spot feeder animal prices rather than spot slaughter prices are justified first. The assumptions are given and, lastly, models incorporating feeder prices are derived and explained. Production risk is not included in this analysis.

Based on the empirical results cited above, Equation (5.1) does not adequately model future prices for non-storable commodities. Due to high storage costs[32], one would expect a model relating the futures price to the spot price cash price to yield futures prices far greater than current slaughter prices. Casual observation of futures and spots prices reveals that distant futures are not substantially different from spot prices for slaughter animals. Either the convenience yield for the non-storable is very high or the storage model above is inappropriate. High convenience yields would imply that owners of market ready inventory would be prepared to hold this inventory for longer periods of time; however, casual observation does not show this to be a frequent occurrence. This leads to the conclusion that equation (5.1) does not adequately model futures prices for non-storables. A more appropriate model would relate the futures price to the prices of the storable form of the commodity.

The stored commodity (e.g. the feeder animal and the time distributed feed inputs) is not a substitute for the product specified in the futures contract. The feeder animal, through time and storage costs (e.g. feeding), has the potential to become the commodity specified in the futures contract. This potential must be represented in any futures pricing model.

Furthermore, the spot feeder price chosen for the model must be for animals that mature at the same time as the futures contract matures. The spot feeder price in the model is not for the same weight or quality of animal over time. Animal weights increase as the time to maturity decreases. Using a cattle example, the reader can envisage the model as starting with a 225 kilogram feeder animal and tracking the spot feeder price per kilogram of this same animal over time to a finished weight of

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[31] Fama and French (1987) find that animal products and some wood products have the highest basis standard deviations of the commodities that they test. They attribute this result to the perishability or bulk of these products which make them expensive to store.

[32] These storage costs include feed costs and adverse quality changes in the animal.

525 kilograms. The spot feeder price used in the futures model must be for the feeder animal that has the potential to match the futures contract specifications at contract maturity. These attributes of non-storable commodities are incorporated into the following futures models.

Model I: Proportional Inputs

Following the spirit of the proportional convenience yield and proportional storage cost model presented above, similar assumptions are used to derive the first model. The notation and assumptions used are:

- Feeder price evolution is exogenously specified as $dS = \alpha_S S dt + \sigma_S S dw_S$ where dw is a standard wiener process[33]. The drift term may be a function of time as the weight of the animal changes. This process exogenously specifies some future expected supply-demand relationship in the market that is represented by the current feeder animal price. The feeder price, S, is the price per unit (e.g. dollars per kilogram).
- The non stochastic rate of gain of the animal is proportional to the size of the animal, $dQ = m(t)Qdt$. This implies that given the starting weight Q_0, $Q = Q_0 \exp\{\int_0^t m(v)dv\}$. That is, Q is the current animal weight. The drift term m(t) can viewed as a growth rate that varies over the feeding period for the animal. This allows sufficient flexibility to accommodate any changes in the rate of gain of feeder animals at different times of the feeding period.
- Since feed costs increase with animal size, the non stochastic proportional feed cost is based on the current value of the animal, X•[S Q] where X is the proportionality factor. This specification is only approximately correct but it allows feed costs per time period to increase as the animal grows.
- Define Q* as the finished weight of the animal (as specified in the futures contract) and Q* is constant. Therefore $Q^* = Q\exp\{\int_t^T m(v)dv\}$.
- The proportional convenience yield on feeder cattle is a constant δ_C.

Result Ia: The futures price for the non-storable commodity under these assumptions is:

(5.2) $$F = S\exp\{(r + X - \delta_C)(T - t) - \int_t^T m(v)dv\}$$

Proof: See Appendix A2.

This result is similar to the standard result presented earlier. However S represents the price per unit of the feeder animal that can be ready for market by time

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[33] The log normality distributional assumption is not necessary to derive the simplest futures models such as equation (5.1), however, it is required for the more complicated models that include other stochastic variables.

T. F represents the futures price per unit of the finished marketable animal. Feeders are priced to earn the risk free rate (r) on the investment plus cover all feeding costs (X) with allowance for any potential benefit from holding the spot commodity (δ_C). Additionally, the owner of the animal benefits from the growth of the animal represented by the term $\int_t^T m(v)dv$. It is this term (missing in equation (5.1)) that ties the feeder animal price to the futures price.

The difference F-S is described as the margin[34]. The margin is usually negative because the growth potential associated with bringing feeders to delivery age more than compensates for the feed and interest costs. Feed and interest contribute to a positive margin but these are usually more than offset by the convenience yield and by the potential growth rate m(t). If storage costs, in particular feed costs, are high then this margin can become positive. Indeed, the run up in corn prices in 1996 to record or near record high nominal prices resulted in positive margins in the cattle industry. High feeding costs represented by a higher X increases this margin. This simple model fits the prices observed in the market. When feed costs are high, the margin is larger or even positive. An animal with better growth potential commands a higher price and the margin is smaller. The futures to spot ratio decreases as convenience yield rises, decreases as animal growth rates rise and increases as proportional feed costs rise.

The investor using this model to hedge price risk has to determine what is being hedged. Is it the current value of the feeder animal portfolio, the expected value of the livestock portfolio upon completion of the feeding program or the expected value of a general investment portfolio at the end of the feeding program? Assume for the moment the investor hedges the current value of the livestock feeder portfolio. The inverse of the optimal hedge ratio, $F_S = \exp\{(r + X - \delta_c)(T - t) - \int_t^T m(v)dv\}$ changes with time. Here, F_S is the first derivative of the futures price with respect to the feeder price S and the optimal hedge ratio is $1/F_S$. F_S is the rate of change of the futures price with the contemporary age matched feeder price, otherwise called in the options literature, the delta. The rate of weight gain becomes an important part of the optimal hedge calculation and results in an optimal hedge different than that used by Herbst, Kare and Marshall (1993) who use a model similar to equation (5.1) to explore the time to convergence impact on optimal hedges for currencies. This optimal hedge ratio model may be appropriate for feeder cattle investors who plan to resell quickly in the feeder market.

Now assume that the investor hedges the future expected value of the portfolio of animals at the end of the feeding program. This is the appropriate approach for the investor committed to feeding the animals until slaughter. The investor chooses this

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[34] To avoid confusion with the usual definition of basis as the difference between the contemporay spot cash price, S^*, and the futures price, F, this difference between category age-matched feeder price, S, and the futures price is called the margin.

approach since the animal portfolio changes with time and it is the future composition of the portfolio that is to be protected. The investor must still determine the value or quantity to hedge and this requires some forecast of the expected spot slaughter price and its relationship to the futures price. The optimal hedge with respect to the expected cash price requires an estimate of the market price of risk for the cash commodity, λ_S.

The inverse of the optimal hedge becomes $F_{E[S]} = \exp\{-\lambda_S \sigma_S \tau\}$ where the derivative F is with respect to the expected spot price E[S] and τ=T-t. This optimal hedge is justified as follows. The forecast spot slaughter price is implicit in the futures price (and in the current age-matched feeder price) although the futures price is likely a biased forecast[35] (Hull ch. 7 1989) and this is shown below. This bias increases with increasing time to maturity. Under an equivalent martingale measure (Dothan, 1990; Cox and Huang, 1989) with expectation denoted by $\hat{E}$, F=$\hat{E}(S_T)$ where T is the date of contract maturity. Assume the market price of risk for S, λ_S, is constant. Then $\alpha_S - \lambda_S \sigma_S = r + u + \delta_C - \int_t^T m(v)dv$ is the risk-adjusted drift rate for returns on S in a risk neutral world and it follows that $F(S,\tau) = S\exp\{(\alpha_S - \lambda_S \sigma_S)\tau\}$. It also follows under an equivalent martingale measure that $\hat{E}(S_T) = E(S_T)\exp\{\lambda_S \sigma_S \tau\}$ since $E(S_T) = S\exp\{\alpha_S \tau\}$[36]. Therefore $F = E(S_T)\exp\{\lambda_S \sigma_S \tau\}$. Estimation of the market price of risk for S is required for this calculation.

Including a second stochastic variable such as convenience yields or storage costs (e.g. feed costs) increases the model complexity. Observability of the second variable is a desirable feature. The validity of adding stochastic feed costs or stochastic convenience yields is an empirical question but feed costs clearly have the potential to vary widely during a feeding period. Adding stochastic proportional feed costs to model I raises questions about the stochastic process followed by X, presents problems justifying the feed cost tradability assumption, or presents problems identifying a market price of risk for X. Assumptions in these areas are not easily supported. Consideration of stochastic feed costs is deferred until a different set of assumptions are given.

Stochastic convenience yields, which are not directly observable, are considered next since models incorporating stochastic convenience yield have

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[35] Fama and French's (1987) results indicate that live cattle futures prices have some power to forecast the spot price but this power decreases with increasing time to maturity. Other studies have concluded that the futures price is not a good forecast of the future spot price for time periods longer than 4 months (Shonkwiler, 1986; Just and Rausser, 1981).

[36] Consequently only if λ_S=0 will the current futures price be an unbiased predictor of the spot slaughter price at time T.

received a great deal of attention in the finance literature. The model presented below demonstrates that stochastic convenience yields can be incorporated into this model to match other models developed in the finance literature (Shimko, 1994, Brennan, 1991 and others). Empirically it is expected that feed costs are a much greater source of risk although convenience yield may be an important factor when cattle are close to marketable slaughter weight. This model incorporating stochastic convenience yield provides an alternative model for empirically testing different models on non-storable commodities.

Shimko (1994), Brennan (1991) and Gibson and Schwartz (1990, 1991) define an exogenously specified mean-reverting process (the Ornstein-Uhlenbeck) for convenience yields. The Ornstein-Uhlenbeck convenience yield process is

$$d\delta_C = k(\bar{\delta} - \delta_C)dt + \sigma_\delta dw_\delta$$

(5.3) where

$$dw_\delta dw_S = \rho_{\delta S}$$

and where k >0 is the speed of adjustment back to some long run mean $\bar{\delta}$. This convenience yield model can be regarded as the reduced form of a model that includes consumption, production and storage (Brennan, 1991). For example, a higher convenience yield may arise from an unexpected short term increased demand for highly marbled beef which can only be met with specific age-matched feeder cattle. Only holders of the physical inventory can benefit from this demand.

Brennan (1991) calculates the stochastic convenience yield using various models and concludes this mean-reverting model is superior to the constant proportional assumption used in Result Ia. However, Brennan's (1991) and Gibson and Schwartz's (1991) empirical tests were used on storable products. In contrast, Fama and French (1987) using the simple futures model equation (5.1), do not find reliable evidence of time varying risk premiums for hogs, pork bellies or cattle although they contradictorily report seasonal changes in the basis which implies the presence of a time-varying variable in the futures price. Time varying risk premiums are consistent with a stochastic convenience yield (Fama and French, 1987), stochastic interest rates or stochastic storage.

Result Ib: . The futures pricing model with mean-reverting stochastic convenience yield is:

$$\begin{aligned} F &= S\exp\{(r+X)(T-t) - \int_t^T m(s)ds\}K(\delta_C,\tau) \\ K(\delta_C,\tau) &= \exp\{-\Delta\tau + (\Delta - \delta_C)U(\tau) - \frac{\sigma_\delta^2}{4k^2}U^2(\tau) \\ \Delta &= \bar{\delta} + \frac{\sigma_\delta(\rho_{S\delta}\sigma_S - \lambda_\delta)}{k} - \frac{\sigma_\delta^2}{2k^2} \\ U(\tau) &= (1-\exp\{-k\tau\})/k \end{aligned} \tag{5.4}$$

Proof: See Shimko (1994)

This analytic expression is more complicated than Result Ia. Furthermore, a new term, λ_δ, which represents the market price of risk per unit of convenience yield must be introduced into the model. Market risk, which is not directly observable, is added to the model since no tradable asset based on the risk found in the convenience yield exists. There are now two stochastic variables in the solution and it is impossible to fully hedge feeder cattle price risk using the futures contract alone. The applicability of such a model is an empirical question but interesting observations are derived from this analytic solution.

The term $K(\delta,\tau)$ is a convenience yield discount factor applied to the spot price since the futures position does not enjoy the benefits of the convenience yield. The futures price depends on the volatility parameters. Increasing feeder price volatility causes futures prices to rise (fall) if $\rho_{s\delta} > 0$ ($\rho_{s\delta} < 0$). Convenience yield volatility has an ambiguous effect on the futures price. Shimko points out that F may be increasing, decreasing, convex or concave in τ whereas for Result Ia, F is monotonically increasing in τ.

The inverse of the optimal hedge for the current value of the portfolio, $F_S = \exp\{(r+X)(T-t) - \int_t^T m(v)dv\}K(\delta_c,\tau)$ decreases as convenience yields increase. Controlling for the convenience yield and storage costs, the futures price should vary with interest rates which contradicts the empirical findings of Fama and French (1987).

Two futures pricing models were presented in this section relating feeder animal prices to futures prices. Both models are based on proportional storage costs and on proportional convenience yields. The applicability of these models for pricing options on feeder cattle, determining hedge ratios for feeder cattle or assessing the models forecasting ability are subject to empirical examination. Both models provide hedging strategies for offsetting the risk for the cattle buyer. A different set of assumptions is next used to adjust these models.

Model II: Unit Inputs

The proportional storage costs used for results Ia and Ib imposes restrictions on how the cost of storage is calculated. By far the biggest cost of storage is the feed costs and these feed costs are priced based on prevailing market prices for feed grains. Subject to empirical verification, it is expected that interest rates, convenience yields and other carrying costs such as feedlot charges are relatively constant over the feeding period. Thus, the next two models directly incorporate the feed grain price into the model. The market prices of these feed grains are readily observable and thus easy to input into such a model. Different assumptions regarding the rate of gain are used.

The exogenously specified lognormal feeder price evolution remains the same. The other assumptions (assuming a constant proportional convenience yield on feeder animals) are

- $dQ = bdt$ where b is the rate of daily gain[37]. This implies that $Q^* = Q + b\tau$.
- The feed cost for a single animal per unit of time is baXdt where 'a' is some constant of proportionality that converts the rate of gain to units of input. The X could now be considered the market or futures price of barley or corn.

Result IIa: Using these assumptions the futures price model becomes

$$F = \frac{1}{Q^*}[SQ + U(\tau)]\exp\{(r-\delta_c)\tau\}$$

(5.5) where

$$U(\tau) = \frac{[\exp\{r\tau\}-1]baX}{\exp\{r\tau\}r}$$

Proof: See Appendix A2.

This solution is very similar to the usual model when storage costs are based on the unit of time. U(τ) represents the present value of feed costs for one animal. Very simply, the futures price equals the risk-adjusted return on the current value of the animal SQ and the present value of feeding costs. Dividing by Q* gives the futures price per unit of product.

Result IIa and Result Ia are similar, however, Result IIa more closely follows the actual costs of feeding over the feeding period and uses feed grain prices directly in the model. Adding stochastic feed costs to the model is now relatively simple (although an analytic solution may not exist). The exogenous lognormal stochastic process for X is

$$dX = \alpha_X X dt + \sigma_X X dw_X \tag{5.6}$$

$$\text{where } dw_X dw_S = \rho_{XS}$$

Result IIb: Under the assumption that storage costs continue even if the value of the animal drops to zero[38], the futures price must satisfy the following partial differential equation (pde).

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[37] This can be relaxed to let the rate of gain vary over time such that $dQ = b(t)dt$

[38] This assumption implies that if the feeder animal value went to zero, the owner could not abandon the animal and must still feed it to market weight. Practically, the potential for conditions inducing abandonment seem minuscule.

$$0=-Z_\tau+Z_H Xba+(r-\delta_C)HZ_H+rXZ_H+$$
$$\frac{1}{2}\left[\sigma_S^2 H^2 Z_{HH}+\sigma_X^2 X^2 Z_{XX}+2\rho_{XS}\sigma_S\sigma_X XSZ_{HX}\right]$$

where $Z=FQ^*$, $H=SQ$

(5.7) with boundary conditions for $Z[H,X,\tau]$

1. $Z[H,X,0]=H$
2. $Z[H,0,t]=H\exp\{(r-\delta_C)t\}$
3. $Z[0,X,t]=baX\tau$ (total stochastic feed cost present value)
4. $\lim\limits_{H\to\infty} Z_H[H,X,t]<\infty$

Proof: See Appendix A2.

To date an analytic solution to this pde has not been derived and a numerical solution is required. The boundary conditions imply that; (1) the value of the feeder animal at its finished weight is equal to the value of the animal specified in the futures contract; (2) the futures model collapses to the simple model if there is zero storage cost; (3) even if feeder prices drop to 0 the owner of the animal will still be compensated for the continuing storage cost which have a present value of abXτ[39] and (4) eliminates rational bubbles that can exist in these types of models.

The advantage of using this model for the futures price is that it uses an observable tradable price X. The two price variables X and S do not have to be estimated using some latent variable estimation techniques such as are required to derive the convenience yield in Result Ib. Furthermore, optimal hedges can be determined numerically.

Conclusion

Four different futures price models for non-storable commodities were derived based on the spot feeder animal price rather than on the spot slaughter price. Results Ia and IIa are very similar to the simple models in the literature and show how the current feeder value is tied to the relevant futures price. Result Ib is a variation of the Shimko's (1994) result incorporating unspecified stochastic convenience yields into the model. A challenge with this form of the model is estimating the stochastic yield parameters. Result IIb does not as yet admit an analytic solution but it includes a stochastic feed cost which would have a strong bearing on the price of cattle over longer feeding periods. The benefit of using this model is that both the spot price and the storage costs are immediately observable in the market. The validity of these models and their ability to price futures better than conventional models is an

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[39] See Appendix II for a proof of this value. Since X is assumed to be a traded asset with no convenience yield, this gives the present value of the feed costs. This theoretical result agrees with empirical results from Koontz, Hudson and Hughes (1992).

empirical question. Certainly, the theoretical justification for investigating these futures models for non-storable commodities is compelling.

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Chapter 6: Thesis Conclusion

Agricultural businesses are an important component of the Western Canadian economy. These investments usually represent a large non-diversified portion of an investor's wealth. Consequently, risk management, valid investment analysis or serious analysis of risk models are important. The unifying thesis theme in Chapters 2 through 5 was the examination of finance applications to agriculture business. Risk in farm machinery investment, sources of risk in Western Canadian cattle prices and risk pricing models in non-storable commodities were analyzed. Each of these risks incorporated age, time or space components.

Tractor and combine secondary asset market data were used to estimate and separate out historical economic depreciation, embodied technological change and time value change. This focused on the time and age component of the asset. Combines and tractors generally exhibit constant geometric economic depreciation on a year to year basis for the age component. Depreciation rates vary by manufacturer. Farm investors can use these manufacturer specific depreciation rates reported here to improve terminal asset value estimates and thereby reduce investment risk.

A potential source of error in forecasting terminal asset values comes from changes related to time. There is a predictable time component to the constant quality asset index that has not been investigated in previous studies. Unanticipated shocks to demand should be followed by price reversion to long-run average manufacturing costs as industry capacity adjusts to demand. This reversion component is predicable. A forecasting trial using root mean square error measures supports this hypothesis. Investment risk over longer planning horizons may be lower when both the age component, depreciation, and time component estimates are employed.

A synthetic financial portfolio was created to match the financial risk inherent in a non-diversified farm machinery portfolio. Risk premia were estimated for machinery. Risk premia in terminal combine values are consistent with a risk premium ranging from 5.5% to 8.3%. For tractors the risk premium range is 2.4% to 3.6% with the greatest risk over the shorter investment horizons. These risk premia can be added to the risk free rate in comparable maturity long term bonds to derive an appropriate discount rate for NPV analysis.

The analysis of risk in agriculture continued with a study on the sources of risk in Alberta cattle prices. Here risk was associated with the spatial component of an agricultural asset. A five variable Vector Autoregression model investigated the dynamic interactions of Alberta slaughter steer prices with U.S. cattle prices and the Canada/U.S. exchange rate for the time periods 1976 to 1984 and 1985 to 1994.

Alberta prices are quite sensitive to changes in United States cattle prices. An equally likely shock to the exchange rate results in a much 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 price instability comes from the United States cattle market. The second greatest source of price instability after U.S. futures prices is from unidentified Alberta sources or basis risk. Basis risk decreased in importance in the second time period. This is likely due to the closer economic ties developed with the spatially separate U.S. cattle market. The third largest source of risk comes from United States cash prices for risk that is not already measured by the futures price. The U.S.-Canada exchange rate was a minor source of risk in Alberta slaughter steer prices over both time periods. The U.S. live cattle futures contracts should be useful risk management tools for the Western Canadian cattle investor.

Finally the age component was incorporated directly into four different futures price models for non-storable commodities such as cattle. Spot feeder animal prices rather than spot slaughter price were specifically included in futures pricing models. Two derived models are very similar to the simple arbitrage futures pricing models in the literature and show how the current feeder value is tied to the relevant futures price. A third model incorporates an unspecified stochastic convenience yield into the model. A challenge with this form of the model will be estimating the stochastic yield parameters. The final model does not as yet admit an analytic solution but it includes a stochastic feed cost which would have a strong bearing on the price of cattle over longer feeding periods. The benefit of using this final model is that both the spot price and the storage costs are immediately observable in the market. The validity of these models and their ability to price futures better than conventional models is an empirical question. Certainly, the theoretical justification for investigating these futures models for non-storable commodities is compelling and would be a fruitful avenue of research.

The research on futures models and farm machinery depreciation is related by the age risk component. A major determinant of a farm machine's value is its age. An asset such as a tractor deteriorates over time and its age is an important determinant of value. Non-storable commodities like cattle are like machinery in that age matters. Cattle are unlike machinery in that vintage is not important. In a cattle futures contract both time and age should be specified in the sense that an animal must be delivered at a certain date and at a specified age. In general, an animal of a different age cannot be substituted for the required type of animal. Similarly, when evaluating a tractor or combine investment, age matters. A three year old tractor is not the same as a one year tractor of the same make and model when it comes to evaluating the investment and forecasting the terminal values.

Further research in farm machinery risk, slaughter cattle risk or futures pricing models on non-storable commodities will be very useful. Extensions to this research will help practioners and others understand farm investment risk, analyze farm investments and improve decision making.

Appendix A1: Risk And Forecasting Issues In Tractor And Combine Depreciation

This appendix contains tables providing additional information on the study in Chapter 2. Tables A.1.1 and A.1.2 name the specific combine and tractor model series. Table A.1.3 contains the test results on constant geometric depreciation. Test results on differences in depreciation rates between manufacturers are reported in Table A.1.4. Combine technology comparison tests are in Table A1.5. Derivation of the estimating procedure for the reverting model follows.

Table A1.1: Combine Manufacturers and Model Series Number Used in the Study

Manufacturer	Model	Technology	Capacity	Year Introduced
Allis Gleaner	L2	conventional	small	1977
Allis Gleaner	L3	conventional	small	1983
Allis Gleaner	N5	rotary	medium	1979
John Deere	6600	conventional	small	1970
John Deere	6620	conventional	small	1979
John Deere	7700	conventional	medium	1970
John Deere	7720	conventional	medium	1979
International Harvester	915	conventional	small	1969
International Harvester	1440	rotary	small	1977
International Harvester	1460	rotary	medium	1977
Massey Ferguson	750	conventional	small	1973
Massey Ferguson	760	conventional	medium	1972
Massey Ferguson	850	conventional	small	1982
Massey Ferguson	860	conventional	medium	1982
New Holland	1500	conventional	small	1973
New Holland	TR70	rotary	small	1975
New Holland	TR75	rotary	small	1979
New Holland	TR76	rotary	small	1985
New Holland	TR85	rotary	medium	1979
New Holland	TR86	rotary	medium	1985

1. Conventional. represents conventional technology and rotary represents rotary threshing technology. The year of first manufacture uses the Official Guide data and there is not always agreement between the main tables for average as is values and their list of serial numbers on dates of introduction. Small or medium indicate the authors' relative comparison of threshing capacities and are not exact specifications. Deutz bought Gleaner in the 1980's and continued the same combine lines under slightly different names. Case purchased IH in the mid 1980's and continued the same combine lines under slightly different names.

Table A1.2: Tractor Manufacturers and Model Series Number Used in the Study

Manufacturer	Model	Horse Power	Year Introduced
Allis Chalmers	7020	100-110	1978
Allis Chalmers	7040	130-140	1975
Allis Chalmers	7045	140-150	1978
Case	1070	100-110	1970
Case	1175	120-130	1971
Case	1270	120-130	1972
Case	1370	140-150	1972
Case	2090	100-110	1978
Case	2094	110-120	1983
Case	2096	110-120	1984
Case	2290	120-130	1978
Case	2294	130-140	1983
John Deere	4240	110-120	1978
John Deere	4250	120-130	1983
John Deere	4255	120-130	1989
John Deere	4430	120-130	1973
John Deere	4440	130-140	1978
John Deere	4450	140-150	1983
John Deere	4455	140-150	1989
Deutz	DX6.50	120-130	1984
Deutz	DX140	130-140	1979
Deutz	D13006	120-130	1972
Ford	9600	130-140	1973
Ford	TW20	130-140	1979
International Harvester	1066	120-130	1971
International Harvester	1086	130-140	1976
International Harvester	1466	140150	1971
International Harvester	1486	140-150	1976
International Harvester	5088	130-140	1981
Massey Ferguson	1150	130-140	1970
Massey Ferguson	1155	140-150	1973
Massey Ferguson	2705	120-130	1978
White	2135	130-140	1976
White	2150	140-150	1975

Table A1.3: Summary of Constant Geometric Depreciation Test Results For Combines and Tractors[1] for Differing Time Periods

Manufacturer	Half Year Deprec. Test Stat.	Yearly Spring to Spring Deprec. Test Statistics	Yearly Fall to Fall Deprec. Test Statistics
Combines			
Allis Gleaner	0.88	0.62	0.22
John Deere	2.42*	0.17	0.25
IH	1.75	0.10	0.33
Massey F.	2.37*	0.43	0.51
N. Holland	4.84*	0.12	0.31
Tractors			
Allis C.	5.05*	8.54*	5.40*
Case	3.94*	0.31	0.23
John Deere	2.54*	2.69*	1.85
Deutz	1.21	0.60	0.54
Ford	1.75	0.53	0.31
IH	2.06*	0.95	0.21
Massey F.	1.13	0.81	0.66
White	1.68	0.1.23	0.1.13

1. These F tests are used on equation (2.2) by restricting the difference $\ln(D_{\tau}) - \ln(D_{\tau-i})$ to be constant for a single manufacturer over all ages. A * indicates significant at the 5% level.

2. The combine F test for half year, spring to spring and fall to fall have (12, 2135), (6, 2135) and (6, 2135) degrees of freedom respectively. The tractor tests for half year, spring to spring and fall to fall have (18, 2968), (9, 2968) and (9, 2968) degrees of freedom respectively.

Table A1.4: Testing Depreciation Rates For Differences Between Manufacturers Comparing $\ln(D_\tau)_{JD}=...=\ln(D_\tau)_{MF}$ over different ages τ

Age (τ)[1]	Tractor F-Test	Combine F Test
2	1.43 (7, 2968)	0.94 (4, 2135)
2.5	2.42	1.85
3	3.38	3.44
3.5	5.13	4.98
4	5.45	6.44
4.5	8.55	10.15
5	11.88	10.39
5.5	16.51	16.37
6	23.47	16.53
6.5	26.46	22.87
7	32.76	22.71
7.5	35.72	32.71
8	41.57	29.27
8.5	44.82	39.26
9	48.56	
9.5	53.10	
10	62.22	
10.5	74.97	
11	93.48	
11.5	87.81	

1. This shows the F-test results on age by age tests as to whether the depreciation rates differ by manufacturer. Nearly all tests reject the hypothesis of equal depreciation rates. (Numbers in brackets are F-test degrees of freedom)

Table A1.5: Selected Comparison of Rotary Combine Technology to Conventional Technology Testing $\mathrm{Ln}(B_i)=..=\mathrm{Ln}(B_k)$

Models Compared	F Test (Degrees of Freedom)
N5, JD7720, IH1460, NHTR85	6.7 (3, 2135)
JD6620, TR75	67.6 (1, 2135)

JD7720 and JD6620 represent conventional technology and the tests are significantly different from 0 at the 1% level. T-tests comparing the JD7700 individually to each of the three other combines also indicate significant differences between the technologies.

Reverting Model Estimation

The reversion to a time trend model uses estimates from equation (2.2) in the main paper as the independent variable. This presents an errors in variables problem when estimating equation (2.3) in Chapter 2. The methods used to solve for this problem are presented here. Briefly the method is based upon the fact that the time variables used in equation (2.3) have an error component attached to them that can be corrected by using additional information from equation (2.2). The derivation of this adjustment is given here.

Assume the estimated constant quality asset value, P_t; has a measurement error of the following form.

(A1.1) $$P_t = P_t^* + \mu_t$$

where P_t is the observed value, P_t^* is the true value and μ_t is the measurement error which is independently normally distributed as $\mu_t \sim N(0, \sigma_\mu^2)$. The true reversion model is

(A1.2) $$P_t^* - P_{t-1}^* e^\delta = \beta (P_1^* e^{\delta(t-2)} - P_{t-1}^*) + v_t$$

where δ is the rate of geometric change in manufacturing costs, β is the rate of reversion to the trend during one time period and v_t is the true model error which is distributed as $v_t \sim N(0, \sigma_v^2)$ with μ and v independent[40]. By assumption in the main paper P_1^* is measured without error. Substitute the observed values on the left hand side above to get

(A1.3) $$P_t - P_{t-1} e^\delta = \beta (P_1^* e^{\delta(t-2)} - P_{t-1}^*) + v_t + \mu_t - \mu_{t-1} e^\delta$$

We immediately observe that right hand side P_{t-1}^* is not independent of the error term. The ordinary least squares (OLS) estimates are biased and inconsistent. Next find the probability limit of b (plim b), the OLS estimator of β when using the observed P_t. Using Slutsky's theorem this estimator is

(A1.4) $$\text{plim}\, b = \frac{\text{plim}\ \frac{1}{T} \sum_{t=2}^{T} [P_t - P_{t-1} e^\delta][P_1 e^{\delta(t-2)} - P_{t-1}]}{\text{plim}\ \frac{1}{T} \sum_{t=2}^{T} [P_1 e^{\delta(t-2)} - P_{t-1}]^2}$$

Substitute for P_t using (A1.1) and (A1.3) to get

(A1.5)

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[40] An alternative specification for the reverting model was also estimated which gave similar parameter estimates. This model was **Error! Objects cannot be created from editing field codes.**.

$$\text{plim } b = \frac{\text{plim } \frac{1}{T}\sum_{t=2}^{T}[\beta(P_1^* e^{\delta(t-2)} - P_{t-1}^*) + v_t + \mu_t - \mu_{t-1}e^{\delta}][P_1^* e^{\delta(t-2)} - P_{t-1}^* + \mu_1 e^{\delta(t-2)} - \mu_{t-1}]}{\text{plim } \frac{1}{T}\sum_{t=2}^{T}[P_1^* e^{\delta(t-2)} - P_{t-1}^* + \mu_1 e^{\delta(t-2)} - \mu_{t-1}]^2}$$

Multiplying out (A1.5) and taking the probability limit gives

$$\text{plim b} = \frac{\beta\ Q^* + \bar{\sigma}_\mu^2 e^\delta}{Q^* + \bar{\sigma}_\mu^2} \quad \text{where}$$

$$Q^* = \text{plim}\left[\frac{\sum_{t=2}^{T} P_{t-1}^{*2}}{T} + \frac{\sum_{t=2}^{T} P_1^{*2} e^{\delta(t-2)2}}{T} + \frac{\sum_{t=2}^{T} -2P_{t-1}^* P_1^* e^{\delta(t-2)}}{T}\right]$$

(A1.6)

$$\bar{\sigma}_\mu^2 e^\delta = \text{plim } \frac{\sum_{t=2}^{T} \mu_{t-1}^2 e^\delta}{T} \quad \text{and where}$$

$$\text{plim } \frac{\sum_{t=2}^{T} v_t \mu_{t-1}}{T} = 0, \text{ plim } \frac{\sum_{t=2}^{T} \mu_t \mu_{t-1}}{T} = 0$$

Equation (A1.6) shows that the direction of bias is related to the "mean" of the variances of the P_t. A consistent estimator of β is derived by subtracting $\bar{\sigma}_\mu^2 e^\delta$ from the numerator and $\bar{\sigma}_\mu^2$ from the denominator in the first equation in (A1.6). The Hall model estimated in Chapter 2 provides estimates for the variance of each P_t where we assume these variance estimates are consistent estimates of μ^2_{t-1}. These estimates of $\hat{\sigma}_t^2$ were used to estimate $\bar{\sigma}_\mu^2$ following the equations in (A1.6).

Following the theoretical discussion above the reverting model OLS estimates for β were adjusted to make the estimator consistent. The results from this model were used to compare the Root Mean Square Errors (RMSE) of two different terminal asset value forecasts in Chapter 2.

Appendix A2: Derivation of Futures Pricing Models for Chapter 5

Result Ia: The replicating portfolio approach is used to complete the proof for Chapter 5, Result Ia. Assume the feeder animal is a tradable asset and that the futures price is a function of the value of the feeder animal. Define Z=F Q* as the value of a finished animal at contract expiry, H=S Q as the spot value of the feeder animal and τ=T-t as the time remaining to animal market maturity. Then F=F(H,τ) which also implies Z=Z(H, τ). Following the usual derivation of the partial differential equation (pde), form a portfolio (Π) long Z and short $Z_H H$ such that $\Pi = Z - Z_H H$. By Ito's lemma

$$d\Pi = dZ - Z_H dH$$

$$where$$

$$dZ = -Z_\tau + Z_H dH + \frac{1}{2} Z_{HH} dH^2$$

$$dH = QdS + SdQ$$

$$dH^2 = Q^2 dS^2 = Q^2 S^2 \sigma_s^2 dt$$

then the instantaneous change in the portfolio value is

$$d\Pi = -Z_\tau dt + \tfrac{1}{2} Z_{HH} H^2 \sigma_S^2 dt$$

Since the portfolio Π is risk free and the investment cost for the futures contract is 0, the portfolio's total expected return (capital gains and dividends) is the risk free rate. This gives the following pde:

$$r[-Z_H H] = -Z_\tau + \tfrac{1}{2} Z_{HH} H^2 \sigma_S^2 - \delta_C Z_H H + X Z_H H$$

with boundary conditions for Z[H, τ]

$$Z[0,t] = 0$$

$$Z[H,0] = H$$

$$\lim_{H \to \infty} Z_H[H,0] < \infty$$

The δ_C term represents the convenience yield paid on the short positions to the holder of the long position and the X term represents the savings in storage costs on the short position. The first boundary condition imposes the constraint that if the feeder price ever goes to zero it stays at zero thereafter. The second boundary conditions states that the value of a finished animal at contract expiration must equal the value of the animal in the futures contract. This is the standard pde for a futures contract and the problem can be solved using Laplace transform (Shimko 1992) to give

$$Z = H \exp\{(r + X - \delta_C)\tau\}$$

After substituting for Z and H and simplifying, result Ia is derived. QED.

Result IIa: The replicating portfolio approach is used to complete the proof for Result IIa. The same assumptions and notation are used as in Result Ia. Following the usual derivation of the partial differential equation (pde), form a risk free portfolio (Π) long Z and short Z_HH. By Ito's lemma and the removal of all risk the pde is:

$$0 = -Z_\tau + (r - \delta_C)HZ_H + baXZ_H + \frac{1}{2}\sigma_S^2 H^2 Z_{HH}$$

with boundary conditions for $Z(H,\tau)$

$$Z(0,\tau) = 0$$

$$Z(H,0) = H$$

The short position pays the convenience yield δ_C but essentially receives a dividend because there are Z_H animals that are "short" which saves abXdt feed costs each instant. Based on other results in the literature guess that the solution is

$$Z = [H + U(\tau)]\exp\{(r - \delta_C)\tau\}$$

This gives the following pde upon substitution

$$0 = baX - rU(\tau) - U_\tau(\tau)$$

with boundary condition

$$U(0) = 0$$

Direct integration of the last pde above gives $U(\tau)$[41] and Result IIa immediately follows. QED. Allowing the rate of gain to vary with time (e.g. dQ=b(t)dt) changes Result IIa to $U(\tau) = \exp\{-r\tau\}\int_t^T abX(s)\exp\{rs\}ds$.

Result IIb: Further explanations regarding Result IIb are presented here. The pde is derived by forming a portfolio long Z and short Z_HH and short Z_XX. This portfolio is risk free and using the risk free arguments leads to the pde in Result IIb. The pde boundary conditions 1 and 2 are obvious, however further explanation of boundary condition 3, $Z[0,X,t] = baX\tau$ is required.

The model assumes storage costs continue even if the value of the feeder animal declines to 0. Deriving the storage costs present value is equivalent to valuing an asset $G(X,\tau)$ that pays a dividend each instant aXbdt and has 0 value at $\tau=0$. By Ito's lemma

$$dG = -G_\tau dt + G_X dX + \frac{1}{2}G_{XX}X^2\sigma_X^2 dt$$

Form a portfolio long G and short G_XX. Using the risk free valuation technique the pde becomes

$$r(G - G_X X) = -G_\tau + \frac{1}{2}G_{XX}X^2\sigma_X^2 + Xba$$

where the boundary conditions for $G[X,\tau]$

$$G[0,\tau] = 0$$

$$G]X,0] = 0$$

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[41] Mathematica was used to solves parts of this problem.

Notice that the dividend Xba is included in the pde. The solution by Laplace transform (to remove the time derivative) gives $G=Xba\tau$. This is the present value of the future expected feeding costs. Since X is assumed to be a traded asset, then today's price is the risk adjusted present value of feed prices. Therefore no further discounting of future feed costs is required. Since X is not always a traded asset for investment purposes, the futures prices could be used instead. If X has a constant proportional convenience yield δ_X then the solution becomes $\frac{baX}{\delta_X} - \frac{baX}{\delta_X}\exp\{-\delta_X \tau\}$.