ECONOMETRIC MODELS OF MANITOBA CROP ACREAGE DEMAND AND YIELD RESPONSE UNDER RISK AND UNCERTAINTY

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BY

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ABSTRACT

The purpose of this research is to estimate econometric models of crop supply response for Manitoba using data aggregated at the provincial level for 1960-1987. In contrast to most other studies, this research (a) decomposes crop supply response to price into acreage and yield components which are estimated separately and (b) estimates duality models incorporating risk aversion.

First, ad hoc static and distributed lag models of crop yield response to expected price and price variance for crops were estimated. In static models expected price was insignificant and price variance was often significant. In contrast a distributed lag in expected prices was often significant in risk-neutral models, and distributed lags in expected prices and price variance were generally significant.

Second, static duality models of crop acreage allocations were estimated. Models with yields (or the distribution of yields) predetermined relative to acreage decisions were emphasized. Results generally indicated that both mean and variance of revenues per acre (or of crop prices) were significant allowing for risk aversion and uncertainty of either (but not both) crop prices or crop yields.

Third, dynamic duality models of crop yields were formulated assuming adjustment costs for crop yields as well as for capital investment, nonstatic expectations for prices and crop acreages, risk aversion and price uncertainty (risk is modelled as timeless rather than as temporal). Preliminary results indicate that price variance and lags in adjustment are significant in crop yield equations, as in the earlier ad hoc distributed lag models.

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CHAPTER ONE

INTRODUCTION

The purpose of this thesis is to develop and estimate econometric models of crop supply response for Manitoba. There are two aspects of this study that are unique in comparison to most other studies: (a) crop supply response is decomposed into acreage and yield response where both of these components are to be estimated, and (b) risk aversion is incorporated into these models, which often have a duality framework.

Most empirical models of crop response have consisted either of acreage demand equations or crop output supply equations (essentially a reduced form of acreage and yield components), and prices are often reported to have significant effects in these models. On the other hand there have been relatively few published studies of crop yield response to price, and in many of these studies price is reported to have an insignificant effect on yield. These crop yield models are static and use methodologies common to many acreage demand/output supply studies. This contrast in results suggests that substantially different model specifications are required for studies of acreage demand and yield response. In this case there are substantial gains in efficiency and understanding when the acreage and yield components of crop supply response are estimated directly rather than as reduced form output supply equations (the standard arguments for estimating a structural model over a reduced form model somewhat apply here).

The advantages of a duality approach in static and dynamic models of production are well known, but there have been relatively few studies incorporating risk aversion into duality theory and even fewer applications of duality incorporating risk aversion. This study emphasizes the importance of risk aversion and price uncertainty in modeling Manitoba crop production behavior. This emphasis is incorporated into both static and dynamic duality models. Output (yield) uncertainty is also considered to some extent.

This thesis consists of three studies: a study of crop yield response using essentially ad hoc distributed lag models (chapter two); a study of crop acreage demand using static duality models (chapter three); and a study of crop yield response using dynamic duality models (chapter four). These studies are introduced as follows.

MODELS OF GRAIN YIELD RESPONSE TO PRICE

In spite of the large number of econometric studies of crop supply response, few studies have focussed explicitly on crop yields. Studies of crop supply response have generally modelled crop acreage or crop output levels. These crop acreage demand models have ignored any impacts of economic variables on crop yields (e.g. Nerlove; Behrman; Just; Chavas and Holt; Clark and Klein; Coyle 1993); whereas crop output supply models have not decomposed supply response into crop acreage and yield components (e.g. Griliches; LaFrance and Burt; Shumway; Weaver; Antle; Shumway, Saez and Gottret; but see Herdt for an exception). In the multioutput farm, changes in crop acreages correspond approximately to changes in enterprise mix, and changes in crop yield may largely reflect factor substitution within an enterprise. Moreover lags in response may be considerably different for crop acreages and yields (e.g. many acreage demand studies assume that yields are predetermined).

Thus in order to understand crop supply response, it is important to measure both its acreage and yield components.

The few studies of crop yield response have assumed essentially static risk-neutral models and have obtained mixed results. Houck and Gallagher (H-G) assumed that U.S. annual corn yield for 1951-71 depends on the ratio of fertilizer and corn prices (expectations were modelled as a one year lag), corn acres harvested, weather and dummies for acreage restrictions. Prices were significant in the estimated models, and the elasticity of yield with respect to corn price varied from 0.25 to 0.75. Menz and Pardey updated the H-G data to 1980 and concluded that price did not have a significant effect on yield for 1972-80. Reed and Riggins estimated a similar model for Kentucky corn yields 1960-79 and concluded that price was insignificant. Love and Foster estimated per acre production functions and fertilizer demands (rather than specifying yield as a function of price) for corn, wheat and soybeans using U.S. data, 1964-86. Since fertilizer input was insignificant in the per acre production functions, price did not appear to have a significant impact on yield. Choi and Helmburger estimated a similar model and concluded that yields are not sensitive to price changes.

Chapter two estimates yield response equations for major field crops in Manitoba, 1961-87. The study emphasizes risk aversion, price uncertainty and also distributed lags, in contrast to all other studies of crop yield response to price. This emphasis on risk and distributed lags is motivated by the following assumptions: crop yields respond gradually to price changes, farmers are risk averse, and there is generally more uncertainty regarding prices in the distant future than in the immediate future (so that gradual or dynamic responses such as changes in yield presumably are more sensitive to price uncertainty than are reallocations of land among crops).

Results can be summarized as follows. As in most other studies, prices are insignificant in simple risk-neutral static (one period) models of crop yield. However, allowing for risk aversion in static models, price variances are often significant in yield equations. Extending the analysis to distributed lag models for crop yields, sums of lagged coefficients for both expected prices and price variances are often significant. These results demonstrate that it is feasible and perhaps essential to incorporate dynamics and risk aversion into models of crop yield price response.

DUALITY MODELS OF CROP ACREAGE DEMANDS

Agricultural economists have often modelled crop production decisions in terms of acreage responses rather than output supplies (e.g. Nerlove 1956, 1972; Askari and Cummings; Behrman; Houck and Ryan; Just; Chavas and Holt). The standard argument is that acreage planted is unaffected by subsequent weather and hence may proxy planned output more closely than does observed output. In addition it is often assumed that crop yield is predetermined.

In contrast, duality models of crop production have only recently incorporated acreage demands (Chambers and Just; Paris). However these models, which assume joint output and acreage decisions (conditional on quasi-fixed inputs), are relatively complex. Several other studies have estimated acreage allocations under duality (Coyle 1993; Moore and

Negri; Moore, Gollehon and Carey).

Chapter three estimates models of crop acreage allocations for Manitoba agriculture within a duality framework. In contrast to other duality studies, we emphasize models with predetermined yields and risk aversion. The assumption of predetermined yields, which is common in the nonduality literature, substantially simplifies specification of duality models of acreage allocations. Moreover estimates of crop yield price response models for Manitoba support this assumption (see previous chapter).

Risk preferences are modelled within linear and nonlinear mean-variance frameworks, and proxies for price uncertainty are emphasized. This study provides the first empirical application of recent extensions of static duality theory under mean-variance risk preferences (Coyle 1992, 1995). In addition, we suggest a simple methodology for combining weather station data and aggregate production data to obtain a measure of yield uncertainty. Previous studies have assumed that measures of yield uncertainty obtained using aggregate (rather than farm level) data necessarily underestimate yield uncertainty at the farm level.

Results of the study indicate that the methodologies applied here are tractable in modelling crop acreage demands and support the assumptions that price and yield uncertainty influence acreage decisions. Models with yields (or mean and variance of yields) treated as predetermined generally provided more reasonable results than models with yields not predetermined. Results for models assuming price uncertainty or yield uncertainty generally led to anticipated results for the major crop (wheat), but results for impacts of variances in revenues per acre for other crops were more ambiguous. The one major disappointment of the study is that models combining both price uncertainty and yield uncertainty generally did not lead to reasonable results.

DYNAMIC DUALITY MODELS OF CROP YIELDS

A major criticism of the methodology in chapter two is the ad hoc nature of distributed lag models. In contrast duality theory has been extended to dynamics within an optimal control or calculus of variations framework (e.g. Epstein 1981b; Berndt, Fuss and Waverman) and has been applied to agriculture (e.g. Vasavada and Chambers; Stefanou; Howard and Shumway; Weersink and Tauer). However until recently (Coyle 1995b; Arnade and Coyle) all dynamic duality studies have assumed risk neutrality. Moreover dynamic duality models of crop yield response have not been formulated.

In contrast to the distributed lag models of chapter two, chapter four formulates and estimates optimal control models of crop yield response based on dynamic duality. These models incorporate risk aversion and price uncertainty. Yield uncertainty is not considered here because (a) it has not yet been incorporated into dynamic duality theory with risk aversion and (b) it may be less important than price uncertainty over a long time horizon as in most dynamic models (this assumes that weather shows less correlation over time than do prices, so effects of weather uncertainty are more likely to cancel out over time).

CHAPTER TWO

MODELS OF GRAIN YIELD RESPONSE TO PRICE

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The few studies of crop yield response have assumed essentially static risk-neutral models and have obtained mixed results. Houck and Gallagher (H-G) assumed that U.S. annual corn yield for 1951-71 depends on the ratio of fertilizer and corn prices (expectations were modelled as a one year lag), corn acres harvested, weather and dummies for acreage restrictions. Prices were significant in the estimated models, and the elasticity of yield with respect to corn price varied from 0.25

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This paper estimates yield response equations for major field crops in Manitoba, 1961-87. The study emphasizes risk aversion, price uncertainty and also distributed lags, in contrast to all other studies of crop yield response to price. This emphasis on risk and distributed lags is motivated by the following assumptions: crop yields respond gradually to price changes, farmers are risk averse, and there is generally more uncertainty regarding prices in the distant future than in the immediate future (so that gradual or dynamic responses such as changes in yield presumably are more sensitive to price uncertainty than are reallocations of land among crops).

Results can be summarized as follows. As in most other studies, prices are insignificant in simple risk-neutral static (one period) models of crop yield. However, allowing for risk aversion in static models, price variances are often significant in yield equations. Extending the analysis to distributed lag models for crop yields, sums of lagged coefficients for both expected prices and price variances are often significant. These results demonstrate that it is feasible and perhaps essential to incorporate dynamics and risk aversion into models of crop yield price response.

MODEL SPECIFICATION

A static risk-neutral yield response equation for the major Manitoba grain crops is specified as follows:

$$(1)\quad y_t^i = \beta_{i0} + \beta_{i1}\, Ep_t^i \,/\, w_t^1 + \beta_{i2}\, w_t^2 \,/\, w_t^1 + \beta_{i3}\, w_t^1 + \beta_{i4}\, K_t \,/\, z_t + \beta_{i5}\, z_t^i + \beta_{i6}\, G_t + \beta_{i7}\, t + e_t^i \qquad i = 1,.,M \qquad t = 1,.,T.$$

A loglinear version of this equation is defined by replacing $(y, Ep/w^1, w^2/w^1, w^1, K/z, G)$ in (1) by their logarithms. Here y^i is yield of crop i, Ep^i is expected price of crop i, w^1 is wage rate for hired labor, w^2 is an aggregate price index for variable crop inputs (e.g. fertilizer), K is an aggregate quantity index for the stock of physical capital in crops, z is total acreage in crops, z^i is acreage in crop i, G is a crop growth weather index, and t is a time trend. Assuming disjoint technologies, yield y^i is specified as a function of own price Ep^i but not of prices Ep^j for other crops. A standard assumption in risk-neutral models is that only relative prices matter, i.e. output supplies and yields are homogeneous of degree zero in expected prices (Ep, w). However the term $\beta_{i3}\, w_t^1$ is included in this model because such homogeneity restrictions are often rejected in empirical research. The alternative numeraire w^2 is also considered. Since capital requirements per acre are similar for the major grain crops (e.g. Manitoba Agriculture), K / z is used as a proxy for capital per acre for crop i. The term $\beta_{i5}\, z_t^i$ is included in order to allow for the possibility of nonconstant returns to scale or that the average quality of land varies with the quantity of land planted to a crop. [1]

The above static model is modified as follows allowing for risk aversion and price uncertainty. The simplest alternative is to add a proxy Vp^i for the variance of price of crop i, normalized by w^1, to (1):

$$(2)\quad y_t^i = \beta_{i0} + \beta_{i1}\, Ep_t^i / w_t^1 + \beta_{i2}\, w_t^2 / w_t^1 + \beta_{i3}\, w_t^1 + \beta_{i4}\, K_t / z_t + \beta_{i5}\, z_t^i + \beta_{i6}\, G_t + \beta_{i7}\, t + \beta_{i8}\, Vp_t^i / w_t^1 + e_t^i$$

$$i = 1,.,M \qquad t = 1,.,T.$$

The homogeneity conditions corresponding to constant absolute risk aversion (CARA) are implied by the restriction $\beta_{i3} = 0$, $i = 1,.,M$ (e.g. Pope; Coyle 1992). Alternatively Vp^i can be normalized by the square of w^1 and a proxy W for initial wealth, normalized by w^1, can be added to (1):

$$(3)\quad y_t^i = \beta_{i0} + \beta_{i1}\, Ep_t^i / w_t^1 + \beta_{i2}\, w_t^2 / w_t^1 + \beta_{i3}\, w_t^1 + \beta_{i4}\, K_t / z_t + \beta_{i5}\, z_t^i + \beta_{i6}\, G_t + \beta_{i7}\, t + \beta_{i8}\, Vp_t^i / (w_t^1)^2 + W_t / w_t^1 + e_t^i$$

$$i = 1,.,M \qquad t = 1,.,T.$$

Here the restriction $\beta_{i3} = 0$, $i = 1,.,M$ implies the homogeneity conditions corresponding to constant relative risk aversion (CRRA) (Pope).

Distributed lags for expected prices and price variances can be incorporated into the above models. In principle the assumption of lags in adjustment implies distributed lags should also be added for other price-related variables w^2 / w^1 and w^1, and for W / w^1 in CRRA models, but for simplicity these variables are omitted. These variables generally are insignificant in static models, and models cannot be estimated with distributed lags for all of these variables. The risk-neutral, CARA and CRRA distributed lag models are specified, respectively, as follows:

$$(4)\quad y_t^i = \beta_{i0} + \Sigma_{s=0}^{S} \gamma_{is}\ Ep_{t-s}^i / w_{t-s}^1 + \beta_{i4}\ K_t / z_t + \beta_{i5}\ z_t^i + \beta_{i6}\ G_t + \beta_{i7}\ t + e_t^i$$

$$(5)\quad y_t^i = \beta_{i0} + \Sigma_{s=0}^{S} \gamma_{is}\ Ep_{t-s}^i / w_{t-s}^1 + \beta_{i4}\ K_t / z_t + \beta_{i5}\ z_t^i + \beta_{i6}\ G_t + \beta_{i7}\ t + \Sigma_{s=0}^{S} \psi_{is}\ Vp_{t-s}^i / w_{t-s}^1 + e_t^i$$

$$(6)\quad y_t^i = \beta_{i0} + \Sigma_{s=0}^{S} \gamma_{is}\ Ep_{t-s}^i / w_{t-s}^1 + \beta_{i4}\ K_t / z_t + \beta_{i5}\ z_t^i + \beta_{i6}\ G_t + \beta_{i7}\ t + \Sigma_{s=0}^{S} \psi_{is}\ Vp_{t-s}^i / (w_{t-s}^1)^2 + e_t^i$$

$$i = 1,.,M \qquad t = 1,.,T.$$

Both unrestricted and polynomial distributed lag models are considered, and the lag length (S) is generally specified as 8 years.

DATA

Yield models were constructed for the following major crops in Manitoba using annual data for 1961-87: wheat, barley, oats, canola, flax and rye. This corresponds to the period for which a crop growth index of weather conditions was available for Manitoba. Expected crop output prices were modeled using data on market prices and Canadian Wheat Board (CWB) payments for crops (Statistics Canada b, Canadian Wheat Board). Three alternative measures of expected crop prices were considered: (a) a one year lag on market prices, (b) the sum of the most recently observed components of CWB payments at planting time (current initial payments, plus adjustment and interim payments for crop marketed in the previous year, plus final payment for crop marketed two years previously) for crops covered by the CWB (wheat, barley and oats), and (c) predicted values of market prices plus government payments from time series models. Case (b) will be referred to as expected CWB prices and was found to be useful in explaining crop acreage decisions in Western Canada (Coyle 1993). Alternative proxies for variances of crop prices were calculated somewhat similarly (see below).

Input price indexes were obtained for hired labor, machinery and equipment, and variable inputs (e.g. fertilizer) for crops (Statistics Canada a). An index of the stock of physical capital in the crop sector was calculated as the current value of machinery and equipment (Statistics Canada b) deflated by its price index. Crop acreages were defined as the estimated areas sown annually for harvest (Statistics Canada c,d). Weather was proxied by a crop growth index GRODEX (Dyer, Narayanan and Murray), and initial stock of wealth was proxied as the value of land and buildings plus machinery and equipment (Statistics Canada b).

RESULTS FOR RISK-NEUTRAL STATIC MODELS

Linear equations (1) and similar loglinear equations for yields of all crops were estimated using alternative measures of crop price expectations: (a) a one year lag on market prices plus government payments, (b) expected CWB prices for CWB crops wheat, barley and oats (see above), and (c) forecasts from ARIMA and GARCH models expressing market prices as a distributed lag of prices. Equations (1) were estimated by ordinary least squares (OLS) and by two stage least squares (2SLS) (specifying crop acres z^i as endogenous and treating other crop prices Ep^j / w^1 as additional instruments), and by Zellner's seemingly unrelated regressions technique (SUR) and 3SLS. Equations (1) dropping crop acreage z^i as an explanatory variable were estimated by OLS and SUR. Models were also estimated imposing zero homogeneity ($\beta_{i3} = 0$), dropping the factor price ratio, and using the other input price as numeraire. A dummy variable for the LIFT program was insignificant. Cochrane-Orcutt type corrections for autocorrelation were applied as appropriate. Models were estimated using Shazam 7.0.

Several diagnostic tests were conducted. First, it was concluded that the crop yield data does not have unit roots. It has been argued that the asymptotic value of the Durbin-Watson d statistic is zero in cases of models with random walk data, and in turn d is likely to be low in models with data generated by random walks (Phillips; Durlauf and Phillips). In this study d is never below 1.5. and is often above 2.0. Moreover Dickey-Fuller and Phillips-Perron unit root tests, allowing for the possibility of trend stationarity, rejected the hypothesis of a unit root in all cases. Second, the crop yield equations apparently are homoskedastic based on Glejser and Harvey test results. This conclusion is consistent with Yang, Koo and Wilson, who argued that weather is primarily responsible for heteroskedasticity in crop yields and in turn using weather as an explanatory variable should eliminate heteroskedasticity in crop yield equations.

OLS results for loglinear models using lagged market prices for crops and expected CWB prices are presented in Table 1 for wheat, barley and oats. These are the three major crops (in terms of acreage) over most of the data period (with canola becoming third in importance after 1979). The price numeraire, factor price ratio, crop acreage and capital variables in (1) were jointly insignificant and so are omitted from the models reported here. Results using forecasts from ARIMA models are excluded from Table 1 since these forecasts led to poor results for all models considered in the study. These poor results are consistent with another study suggesting that reported crop price expectations for a group of Saskatchewan farmers are not adequately explained by such forecasts (Sulewski, Spriggs and Schoney).

Results in Table 1 for loglinear models indicate that coefficient estimates for expected crop prices are insignificant in the reported yield equations for wheat, barley and oats. This is also true for estimates of the corresponding yield equations for canola, rye and flax (t-ratios for lagged market prices are -1.73, 1.76 and -1.05, respectively). Crop prices were also insignificant (or coefficient estimates were negative) in all other risk-neutral static models estimated for this study. Similar results were obtained for linear models.

RESULTS FOR RISK-AVERSE STATIC MODELS

Equations (2) and (3) and similar loglinear equations were also estimated using various proxies for variances of crop prices. The variance Vp_t^i was generally calculated from expected prices and actual prices as in several other studies (e.g. Chavas and Holt; Coyle 1992):

$$\text{(7)} \quad var_t(p^i) = 0.50\,(p_{t-1}^i - E_{t-2}p_{t-1}^i)^2 + 0.33\,(p_{t-2}^i - E_{t-3}p_{t-2}^i)^2 + 0.17\,(p_{t-3}^i - E_{t-4}p_{t-3}^i)^2 \qquad i = 1,.,6$$

that is current variance equals the sum of squares of prediction errors of the previous three years, with declining weights 0.50, 0.33 and 0.17. Proxies for price variances were calculated in this manner corresponding to cases where expected prices are measured as a one year lag in market price and as expected CWB prices. [2] Price variances were also estimated as GARCH(1,1) processes for models relating current market price to a distributed lag of price, but estimates of (2)-(3) using these variances were poor. Yield equations were estimated in a manner similar to (1). [3] Factor price ratio, numeraire price, crop acreage and capital variables were jointly insignificant, so these are omitted from equations (2)-(3) reported here.

OLS results for loglinear versions of several linear mean-variance (CARA) equations (2), where the price numeraire is omitted ($\beta_{i3} = 0$), are reported in Table 2. Similar results were obtained for CRRA equations (3). Three specifications of crop expected price and variance are considered: a market price specification (both expected price and variance are defined in terms of lagged market price); a CWB price specification (both expected price and variance are defined by expected CWB price), and a hybrid model (using a CWB expected price and a market price measure of variance). Expected prices remain insignificant in all cases. Coefficients of price variances are generally significant and negative in market price and hybrid models for wheat, barley and oats, but price variances are not significant in CWB price models. Expected prices and price variances were insignificant for other crops. Results similar to Table 2 were obtained for linear models.

Our result that price variance is often more significant than expected price in static models of yield response is somewhat surprising, since it is generally assumed in static models of decisions under risk that elasticities of response are greater for expected prices than for price variances. However there is a plausible explanation of our result if static models are inadequate for specifying crop yield decisions. Suppose that yield decisions depend primarily upon lagged expected prices and price variances rather than upon current period expectations (as in the above static models). By construction the correlations between current period price variances (7) and lagged price variances are greater than the correlations between current period expected prices and lagged expected prices. Therefore static models presumably are mis-specified by omitting relevant lagged expected prices and price variances, and the largest correlations between included and omitted variables concerns current period and lagged price variances. In turn, our empirical results are to be expected if our static models of crop yield response are more correctly specified as dynamic.

RESULTS FOR RISK-NEUTRAL DISTRIBUTED LAG MODELS

Risk-neutral distributed lag (DL) models (4) were estimated using various lag lengths and polynomial restrictions. In base cases lag lenths for expected crop prices were specified as 8 years, and distributed lags were unrestricted or restrictions were in terms of a fourth degree polynomial (Almon lag). Unrestricted DL models were considered because estimates from PDL models are inconsistent unless true coefficients lie exactly on the approximating polynomial (e.g. Johnston). Crop acreage z^i was often deleted from regressions. All three models of expected crop prices were considered, but again results were always poor using price forecasts from ARIMA models. Hypotheses of homoskedasticity were not rejected.

In contrast to single period models, the measure of capital stock per crop acre (K / z) was often significant. However the corresponding coefficients were generally negative, which suggests that there are serious errors in measurement of capital stocks relevant to individual crops. [4] Moreover results are highly sensitive to the specification of capital stocks, perhaps due in part to the higher collinearity introduced by the distributed lags.

OLS results for loglinear versions of risk-neutral PDL models (4), where the proxy for capital stock is omitted, are reported in Table 3 for wheat, barley and oats. In order to facilitate comparison of results, all estimates in this Table are for the base case PDL(0,8,4), where there is an eight period lag and a fourth degree polynomial. L0 indicates current period expected price (i.e. a one year lag on market price, or the current expected CWB price), L1 indicates a one year lag on expected price, etc. Sum of lag coefficients and t-ratios for the sum are presented for both the polynomial distributed lag (PDL) models and the corresponding unrestricted distributed lag (UDL) models. The sums of the lag coefficients for expected price are insignificant, with the exception of the expected CWB price model for oats. However there is some indication of a significant 2-3 year lag in response for wheat and perhaps a 3-4 year lag for barley. Similar results hold for rye and flax. The t-ratio of sum of coefficients for lagged market price in rye and flax equations is 2.43 and 1.55 (in contrast to -0.25 for canola).

Results for analogous PDL(0,8,4) models, where the proxy for capital stock is included, are reported in Table 4. Here the sum of lag coefficients for expected prices generally are much more significant, with the exception of the market price model for wheat. Individual coefficients are significant over lags varying from 1-3 years (wheat), 1-5 years (barley) and 1-7 or 2-5 years (market and CWB models, respectively, for oats). Results are similar for rye and flax. Similar results were also obtained for linear models.[5]

Since misspecification of lag length and order of a PDL generally leads to inconsistent estimates (Trivedi and Pagan), and different lag lengths are not conveniently nested within a polynomial of a given degree, attempts were made to select PDL's as follows. First an unrestricted loglinear DL model similar to (4) with a lag length of S = 10 years using market or CWB expected price was estimated for a crop, and a sequence of hypotheses ($H_0^{(1)}$: $\gamma_{i10} = 0$; $H_0^{(2)}$: $\gamma_{i10} = 0$, $\gamma_{i9} = 0$; etc.) were tested as standard F-tests in order to determine the lag length s^* (e.g. Pagano and Hartley; Kmenta). Given the lag length s^*, PDL models of degree s^*-1, s^*-2, etc. were estimated until the nested polynomial restrictions (implied by Pascal's triangle) were rejected. Since the true level of significance for an individual test in this sequence depends on (and decreases with) the nominal level of significance for previous tests in the sequence, it has been argued that nominal significance levels should be very low for tests at high degrees of the polynomial and higher for tests at lower degrees (Trivedi and Pagan; Judge et. al.). Thus a significance level of .01 was selected for F tests of PDL restrictions at high degrees (e.g. $s^* - 1$), and a significance level of .05 was selected for tests at lower degrees. Of course the true levels of significance under such sequential hypothesis testing are unknown.

Selected lag lengths were 7-9 years, with one exception of 5 years (canola). A second degree polynomial was selected for all crops except rye (a fourth degree PDL). The low degree of the polynomials may reflect the relatively small size of the data set. The sum of lag coefficients for expected market price and corresponding t-ratios for final PDL models (excluding proxy for capital stock) are as follows: 1.3342 (2.68) for wheat, 0.6940 (1.16) for barley , 1.1826 (1.13) for oats , -0.3122 (1.24) for canola, 0.6260 (2.95) for rye, and 0.3776 (0.67) for flax. The corresponding results for CWB price models are 1.7588 (2.83) for wheat, 0.8510 (1.23) for barley and 1.4451 (3.49) for oats. In contrast to Table 3, the sum of lag coefficients (and all individual lag coefficients excluding the end points) for wheat yield equations are significant. These sums of lag coefficients can be interpreted loosely as long-run elasticities of yield response to expected price.

These PDL results suggest that yields for wheat and oats are responsive to price, and that long-run elasticities of response exceed 1.0. This is in sharp contrast to results for static models, where price was always insignificant. Thus the earlier results apparently can be largely attributed to the mis-specification of models as static rather than dynamic. Nevertheless earlier static results (Table 2) suggest that the above PDL models are still mis-specified by excluding price variance. Price variance is incorporated into PDL's in the next section, and in these cases expected price is significant in yield equations for barley as well as wheat and oats.

RESULTS FOR RISK-AVERSE DISTRIBUTED LAG MODELS

Risk-averse DL models (5)-(6) were also specified using distributed lags for both expected crop price and variance of crop price. Mean and variance of crop price expectations were measured using lagged market price, CWB payments, and a hybrid of these two models. Forecasts from ARIMA and GARCH models for market prices were also considered but led to poor results. As in the risk-neutral DL models, results are often sensitive to the specification of capital.

Results for loglinear versions of the risk-averse linear mean-variance PDL(0,8,4) models (5), where the proxy for capital stock is omitted, are reported in Table 5 for wheat, barley and oats. Since OLS estimates show substantial (negative) autocorrelation, GLS estimates are presented for an AR(1) model using a Cochrane-Orcutt type iterative procedure. AR(2) models and maximum likelihood and grid search methods were also considered, but results were less satisfactory in these cases. OLS estimates and standard errors were broadly similar to Table 5. Results were also similar for model (6).

In Table 5, the sums of lag coefficients for expected price are generally significant when these prices are modeled as expected CWB prices rather than as lagged market prices, and the sum of lag coefficients for price variance is also significant (negative) in six of nine cases for these crops. In addition, t-ratios for the sum of unrestricted lag coefficients of crop price mean and variance (market price model) are 3.06 and -1.88 for canola, 3.34 and -0.18 for rye, and 2.37 and -2.90 for flax. The sum of lag coefficients, which can be interpreted loosely as long-run elasticities of yield response, are always substantially larger in magnitude for expected price than for price variance. This is consistent with other studies of output supply (e.g. Behrman; Just; Chavas and Holt; Pope and Just; Coyle 1992).

Attempts were also made to select linear mean-variance PDL's essentially in the same manner as for risk-neutral PDL's. In contrast to risk-neutral PDL's, first order Cochrane-Orcutt type GLS was applied for all models. Unrestricted models with ten year lags on both mean and variance of price could not be estimated satisfactorily due to data limitations, so it was decided to use the lag lengths selected for the risk-neutral PDL's. It was also more difficult to select the degree of polynomial due to autocorrelation as well as limited data. Third degree polynomials were selected in all cases except for canola (second degree). The sum of lag coefficients for expected price and price variance and corresponding t-ratios for several selected PDL models (excluding capital stock) are as follows: 1.1069 (2.92) and -0.1269 (2.89) for wheat CWB model, 1.4217 (2.61) and -0.1621 (2.65) for barley hybrid model, 1.602 (3.06) and -0.1182 (1.96) for oats hybrid model, -0.3175 (0.85) and 0.0168 (0.32) for canola, 0.8644 (3.83) and -0.0808 (1.91) for rye, and -0.5057 (0.36) and -.0073 (0.07) for flax. Note that these results are somewhat less significant than corresponding base case PDL results in Table 5, and this may reflect in part the greater difficulty in selecting lag length and degree of polynomial in this case.

Although PDL results suggest that crop yields may well depend on lagged expected price and lagged price variance, it is not clear whether current period expected price and price variance influence yield.

Current period expected price is always insignificant in risk-neutral PDL's and is only significant in one of nine linear mean-variance PDL's reported in Table 5. However the current period variance is significant in five cases reported in Table 5. Since these measures of variance are relatively crude and the current period proxy may be correlated with true lagged price variances, coefficient estimates for current period measure of price variance may actually reflect the contributions of lagged price variance to current yield. This interpretation seems somewhat plausible given the unambiguous results for risk-neutral models and assuming that yields as well as outputs are more responsive to expected price than to price variance.

CONCLUSION

In contrast to all other econometric studies of crop yield response to price, this study explores the importance of risk aversion, price uncertainty and distributed lags in explaining crop yield response. This emphasis reflects the following common assumptions regarding crop agriculture: crop yields respond gradually to price changes, farmers are risk averse, and there is generally more uncertainty regarding prices in the distant future than in the immediate future.

Results are reported for major field crops in Manitoba, 1961-87. Expected prices are insignificant in risk-neutral static models of crop yield (as in most other studies). However, when price variances are added to the static models, coefficients of these price variances are often significant (and negative). A somewhat plausible explanation of this contrast between expected price and price variance in static models is that true models are dynamic and price variances are highly correlated over time. The importance of dynamics and risk aversion in explaining crop yields is illustrated by results for risk-neutral and risk-averse distributed lag nmodels. The sum of lag coefficients is often significant for both expected price and price variance, and these elasticities of long-run response are substantially greater in magnitude for expected price than for price variance.

In sum, this study indicates that it is tractable, and perhaps essential, to accomodate risk aversion and substantial lags in crop yield price response models. In contrast to static models of crop acreage demand (e.g. Coyle 1993), here the effects of at least expected prices on crop yield were insignificant in static models. The lagged effects of prices and uncertainty on crop yields appear to be substantial. This suggests a significant difference in response patterns for crop yields and crop acreage demands. In turn disaggregating models of crop supply response into these components presumably can lead to substantial gains both in understanding of supply response and in efficiency of estimation.

A next step in developing models for crop yield decisions is to incorporate risk aversion and uncertainty into formal dynamic models, e.g. dynamic duality models, as a possible alternative to the distributed lag models of crop yield considered here. These can be estimated jointly with static duality models of crop acreage demands under risk aversion, which are most easily specified when yields can be treated as predetermined.

FOOTNOTES

1. A reduced form equation for yield can be defined by omitting z^i from (1). However, in the case of nonconstant returns to scale (or variation in average quality of land) and assuming that total crop land z is a fixed allocatable input, prices Ep^j of other outputs (and perhaps z) should be included in the reduced form (Shumway, Pope and Nash).

2. Measures of yield uncertainty were also considered in this study. Variance of weather was calculated from GRODEX data similarly to (7) for each of six weather stations in Manitoba and averaged over stations, and this was combined with estimates of production functions explaining yield in terms of weather in order to calculate proxies for variance of yield for each crop. Then variance of price and yield were combined into measures of variance of revenue per acre for each crop. Econometric results are not reported here because this approach entailed a loss of four observations for static models and twelve observations for distributed lag models (so results incorporating yield uncertainty are not comparable to other results reported here for static models, and such estimation is not tractable in risk-averse distributed lag models).

3. Geometric lag models similar to (1)-(3) were also specified by adding a lagged crop yield, and these models were estimated by OLS and instrumental variable methods with Cochrane-Orcutt type autocorrelation corrections. However expected prices and price variances remained insignificant, and coefficients for lagged crop yield were often insignificant.

4. It should be noted that other studies of crop yield price response (e.g. H-G) have not reported results using proxies for capital.

5. In principle distributed lags can be explained in terms of either price expectations (where current expectations are a distributed lag of past prices) or lags in adjustment of supply/yield. However price expectations would presumably attach higher weights to the more recently observed prices, whereas estimates of the coefficient for L0 (a one year lag on market price, or current expected CWB price) are always insignificant in the distributed lags for Tables 3-4. Moreover, given the definition of an expected CWB price, it seems difficult to explain any results for distributed lags for these CWB models in terms of adaptive price expectations (e.g. the initial payments component of the expected CWB price is known at the time of planting, so there is no need to predict initial payments for the current year in terms of a distributed lag of past initial payments). Thus it seems reasonable to attribute our PDL results primarily to lags in supply/yield response.

Table 2.1 Estimates for One Period Risk-Neutral Models (Log Linear Models)

	Wheat		Barley		Oats	
	coeff	t-ratio	coeff	t-ratio	coeff	t-ratio
Lagged market price	-.1034	0.75	-.1019	0.78	-.0953	0.70
Weather	.5952	3.32	.7294	3.99	.8400	4.84
Trend	.0137	2.72	.0226	4.14	.0123	2.20
Constant	-3.856	3.71	-4.612	4.45	-5.254	5.31
R^2/DW	.6229	1.84	.7609	1.73	.6882	1.66
Expected CWB price	-.0218	0.17	-.0879	0.77	.0254	0.20
Weather	.6119	3.39	.7357	4.02	.8498	4.85
Trend	.0156	2.99	.0226	4.07	.0167	2.15
Constant	-4.023	3.85	-4.641	4.49	-5.396	5.36
R^2/DW	.6141	1.78	.7606	1.62	.6821	1.57

Table 2.2 Estimates for One Period Linear Mean-Variance Models (Log Linear Models)

	Wheat		Barley		Oats	
	coeff	t-ratio	coeff	t-ratio	coeff	t-ratio
Lagged market price	.0270	0.20	.1040	0.68	.0546	0.34
Market price variance	-.0453	2.33	-.0619	2.20	-.0494	1.63
Weather	.5982	3.64	.8047	4.66	.8385	5.00
Trend	.0206	3.76	.0352	4.62	.0217	2.75
Constant	-4.007	4.20	-5.228	5.23	-5.375	5.61
R^2/DW	.6972	2.19	.8041	1.98	.7219	1.79
Expected CWB price	.1454	1.12	.0642	0.50	.1240	0.98
Market price variance	-.0541	2.76	-.0576	2.15	-.0534	2.03
Weather	.6110	3.84	.7943	4.62	.8415	5.12
Trend	.0247	4.36	.3385	4.61	.0272	3.04
Constant	-4.220	4.57	-5.150	5.20	-5.509	5.82
R^2/DW	.7131	2.31	.8023	2.08	.7321	1.61
Expected CWB price	-.0217	0.16	-.0898	0.81	.0220	0.17
CWB price variance	-.0047	0.17	-.0496	1.60	.0117	0.30
Weather	.6159	3.31	.7946	4.39	.8531	4.76
Trend	.0159	2.87	.0247	4.46	.0174	2.11
Constant	-4.041	3.77	-4.945	4.85	-5.452	5.22
R^2/DW	.6146	1.78	.7854	1.70	.6834	1.59

Table 2.3 Estimates of Risk-Neutral Polynomial Distributed Lag (Log Linear Models)

		Wheat		Barley		Oats	
		coeff	t-ratio	coeff	t-ratio	coeff	t-ratio
Lagged market price	LO	-.0471	0.29	-.0033	0.02	-.1474	0.75
	L1	.1303	1.51	.0241	0.24	.0587	0.50
	L2	.1733	2.27	.1090	1.26	.0765	0.67
	L3	.1490	1.85	.1679	1.92	.0248	0.19
	L4	.1064	1.06	.1617	1.55	-.0187	0.12
	L5	.0771	0.93	.0954	1.12	-.0172	0.13
	L6	.0745	0.95	.0178	0.20	.0252	0.22
	L7	.0945	1.10	.0221	0.22	.0634	0.54
	L8	.1149	0.65	.2455	1.36	.0115	0.05
Weather		.6536	3.53	.8151	4.11	.8507	4.35
Trend		.0358	2.55	.0486	2.76	.0176	0.60
Constant		-5.157	3.80	-5.804	4.30	-5.442	4.08
R^2/DW		.7069	2.26	.8012	1.93	.7022	1.70
Σ lagged coeff (PDL)		.8731	1.49	.8401	1.35	.0767	0.08
Σ lagged coeff (UDL)		.8953	1.39	1.135	1.70	.1943	0.18

Table 2.3 cont...

		Wheat		Barley		Oats	
		coeff	t-ratio	coeff	t-ratio	coeff	t-ratio
Expected CWB price	LO	.0764	0.52	-.0018	0.02	.1921	1.49
	L1	.1426	1.42	.0108	0.11	.0021	0.02
	L2	.1975	2.08	.1175	1.22	.0818	1.12
	L3	.2174	2.12	.2015	2.12	.2018	3.06
	L4	.1963	1.62	.2049	1.97	.2336	3.06
	L5	.1456	1.35	.1278	1.36	.1493	2.25
	L6	.0943	0.93	.0292	0.29	.0217	0.26
	L7	.0890	0.86	.0261	0.25	.0246	0.27
	L8	.1936	0.98	.2941	1.73	.4324	2.99
Weather		.7058	3.77	.7257	3.95	.8606	5.31
Trend		.0446	2.73	.0517	2.86	.0882	3.36
Constant		-6.120	3.87	5.534	4.41	-7.315	6.08
R^2/DW		.7023	2.21	.8129	1.81	.8067	1.90
Σ lagged coeff (PDL)		1.353	1.81	1.010	1.50	1.339	2.81
Σ lagged coeff (UDL)		1.316	1.63	1.081	1.38	1.487	3.23

Table 2.4 Estimates of Risk-Neutral Polynomial Distributed Lag (Log Linear Models - Using Capital Proxy)

		Wheat		Barley		Oats	
		coeff	t-ratio	coeff	t-ratio	coeff	t-ratio
Lagged market price	LO	-.0580	0.39	.0775	0.55	.0675	0.41
	L1	.1936	2.30	.1572	1.57	.3477	2.87
	L2	.2192	3.00	.2251	2.60	.4258	3.25
	L3	.1538	2.08	.2506	3.06	.4038	2.76
	L4	.0870	0.94	.2246	2.40	.3537	2.25
	L5	.0625	0.82	.1593	2.05	.3174	2.32
	L6	.0784	1.09	.0890	1.08	.3066	2.59
	L7	.0868	1.10	.0688	0.77	.3028	2.67
	L8	-.0055	0.03	.1761	1.11	.2572	1.46
Capital		-.5692	2.16	-.8094	2.67	-1.187	3.63
Weather		.5256	2.93	.6997	3.94	.6541	4.03
Trend		.0452	3.33	.0798	4.14	.1233	3.32
Constant		-8.133	4.38	-10.92	4.87	-14.12	5.41
R^2/DW		.7672	2.14	.8576	1.99	.8280	2.00
Σlagged coeff (PDL)		.8179	1.53	1.428	2.44	2.782	2.63
Σlagged coeff (UDL)		.8383	1.41	1.722	2.91	3.123	2.64

Table 2.4 cont...

		Wheat		Barley		Oats	
		coeff	t-ratio	coeff	t-ratio	coeff	t-ratio
Expected CWB price	LO	.1561	1.28	.0891	0.88	.1996	1.80
	L1	.3108	3.23	.2246	2.03	.1137	1.32
	L2	.3251	3.77	.3160	3.06	.1736	2.44
	L3	.2770	3.25	.3447	3.74	.2455	4.17
	L4	.2180	2.21	.3106	3.33	.2564	3.88
	L5	.1737	1.97	.2323	2.71	.1933	3.26
	L6	.1429	1.71	.1465	1.59	.1039	1.35
	L7	.0986	1.18	.1087	1.20	.0958	1.16
	L8	-.0129	0.08	.1928	1.33	.3374	2.62
Capital		-.8714	3.29	-.9339	3.05	-.6625	2.78
Weather		.5472	3.43	.6156	3.91	.7715	5.40
Trend		.0686	4.53	.0951	4.59	.1220	4.76
Constant		-11.35	5.55	-11.88	5.11	-11.71	6.20
R^2/DW		.8139	2.40	.8767	2.14	.8648	2.22
Σ Lag coeff (PDL)		1.689	2.74	1.965	3.05	1.719	3.98
Σ Lag coeff (UDL)		1.632	2.41	2.267	3.02	1.716	3.81

Table 2.5: Estimates of Linear Mean-Variance Polynomial Distributed Lag (Log Linear Models - Corrected for First Order Autocorrelation)

		Wheat		Barley		Oats	
		coeff	t-ratio	coeff	t-ratio	coeff	t-ratio
Lagged market price	LO	-.2090	1.38	.1997	1.44	.1842	0.96
	L1	.1017	1.19	.2471	2.83	.1150	1.37
	L2	.1226	1.83	.2387	3.37	.1415	1.91
	L3	.0205	0.30	.2466	3.35	.1840	2.16
	L4	-.0848	0.87	.2987	2.80	.1967	1.76
	L5	-.1196	1.08	.3781	2.90	.1677	1.73
	L6	-.0568	0.47	.4233	2.83	.1188	1.51
	L7	.0844	0.86	.3282	2.63	.1058	1.29
	L8	.2381	1.50	-.0578	0.25	.2181	1.26
Market price variance	LO	-.0636	2.71	.0298	0.87	-.0687	2.53
	L1	-.0082	0.75	.0005	0.03	-.0245	1.68
	L2	.0095	1.11	-.0012	0.08	-.0158	1.07
	L3	.0125	1.51	-.0039	0.25	-.0235	1.73
	L4	.0143	1.15	-.0212	1.17	-.0330	2.46
	L5	.0195	1.15	-.0510	2.35	-.0352	3.02
	L6	.0232	1.03	-.0760	2.92	-.0259	1.99
	L7	.0112	0.63	-.0633	3.16	-.0060	0.39
	L8	-.0399	1.74	.0350	1.44	.0187	1.10
Weather		.5871	2.67	.5027	2.33	.9010	4.86
Trend		.0139	0.79	.1071	5.40	.0822	3.34
Constant		-3.929	3.07	-5.335	4.45	-6.906	5.76
R^2/DW		.8565	2.32	.9199	2.34	.8838	2.01
Σlag coeff :Ep (PDL)		.0971	0.16	2.303	3.82	1.432	1.98
:Vp (PDL)		-.0215	0.72	-.1512	2.33	-.2140	4.64
:Ep (UDL)		-1.487	1.99	1.860	1.74	2.737	2.69
:Vp (UDL)		-.0387	1.29	-.0907	1.26	-.2328	6.09

Table 2.5: cont...

		Wheat		Barley		Oats	
		coeff	t-ratio	coeff	t-ratio	coeff	t-ratio
Expected CWB price	LO	.0228	0.11	.2188	1.79	.3175	2.32
	L1	.1567	1.45	.3208	2.60	.0193	0.24
	L2	.1544	1.78	.2962	3.00	.0229	0.42
	L3	.0985	1.04	.2515	3.07	.1228	2.52
	L4	.0465	0.37	.2430	2.55	.1900	3.09
	L5	.0308	0.22	.2773	2.30	.1722	2.77
	L6	.0593	0.44	.3109	2.00	.0934	1.10
	L7	.1147	1.12	.2506	1.88	.0547	0.59
	L8	.1550	0.69	-.0470	0.23	.2332	1.92
Market price variance	LO	-.0488	2.13	-.0151	0.55	-.0502	2.70
	L1	-.0046	0.42	-.0253	1.75	-.0046	0.39
	L2	.0080	0.81	-.0152	1.11	.0034	0.25
	L3	.0063	0.67	-.0087	0.69	-.0074	0.57
	L4	.0016	0.11	-.0166	1.20	-.0226	1.82
	L5	-.0004	0.02	-.0369	2.24	-.0322	3.24
	L6	.0005	0.02	-.0546	2.52	-.0307	2.73
	L7	-.0015	0.08	-.0420	2.34	-.0168	1.15
	L8	-.0178	0.61	.0416	1.78	.0060	0.37
Weather		.5329	2.17	.6625	3.30	.8330	4.85
Trend		.0376	1.64	.1046	4.76	.0978	3.96
Constant		4.557	2.79	-6.356	5.12	-7.120	6.89
R^2/DW		.8351	2.20	.9082	2.15	.9118	1.98
Σlag coeff :Ep (PDL)		.8388	1.09	2.122	3.04	1.226	2.67
:Vp (PDL)		-.0567	1.29	-.1729	2.90	-.1553	3.64
:Ep (UDL)		2.265	2.23	4.680	8.78	1.061	2.79
:Vp (UDL)		.0664	1.36	-.1908	7.06	-.1650	2.85

Table 2.5: cont..

		Wheat		Barley		Oats	
		coeff	t-ratio	coeff	t-ratio	coeff	t-ratio
Expected CWB price	LO	.2753	1.84	.1103	1.03	.0328	0.25
	L1	.2707	3.74	.2396	2.47	.1314	1.21
	L2	.2748	3.78	.2852	3.65	.2660	3.76
	L3	.2306	3.21	.2666	4.06	.3150	5.57
	L4	.1280	1.73	.2099	3.04	.2389	3.15
	L5	.0047	0.07	.1480	2.07	.0799	0.71
	L6	-.0547	0.70	.1199	1.37	-.0373	0.21
	L7	.0819	0.93	.1716	1.88	.0937	0.54
	L8	.5942	3.43	.3552	3.24	.7617	5.38
CWB expected price	LO	-.0735	3.43	-.0663	3.55	-.0465	1.40
variance	L1	.0001	0.01	.0072	0.49	-.0417	1.66
	L2	.0306	1.91	.0367	2.01	.0145	0.65
	L3	.0244	1.82	.0248	2.01	.0525	1.60
	L4	-.0069	0.50	-.0019	0.20	.0398	1.04
	L5	-.0463	2.40	-.0329	2.78	-.0188	0.67
	L6	-.0715	3.03	-.0542	3.28	-.0814	2.87
	L7	-.0551	3.27	-.0517	3.58	-.0693	1.63
	L8	.0358	1.36	-.0117	0.85	.1338	2.52
Weather		.4461	2.87	.3047	1.63	.7258	4.84
Trend		.0658	5.44	.0833	4.99	.1167	2.85
Constant		-5.009	4.23	-3.821	3.88	-7.323	7.38
R^2/DW		.8831	2.49	.9304	2.50	.9271	2.26
Σlag coeff :Ep (PDL)		1.806	3.57	1.906	3.08	1.882	2.66
:Vp (PDL)		-.1624	4.12	-.1540	3.92	-.0171	0.37
:Ep (UDL)		1.702	3.87	1.819	1.98	2.023	2.02
:Vp (UDL)		-.1387	3.89	-.1657	3.18	.0223	0.27

CHAPTER THREE

DUALITY MODELS OF CROP ACREAGE DEMANDS

Agricultural economists have often modelled crop production decisions in terms of acreage responses rather than output supplies (e.g. Nerlove 1956, 1972; Askari and Cummings; Behrman; Houck and Ryan; Just; Chavas and Holt). The standard argument is that acreage planted is unaffected by subsequent weather and hence may proxy planned output more closely than does observed output. In addition it is often assumed that crop yield is predetermined.

In contrast, duality models of crop production have only recently incorporated acreage demands (Chambers and Just; Paris). However these models, which assume joint output and acreage decisions (conditional on quasi-fixed inputs), are relatively complex. Several other studies have estimated acreage allocations under duality (Coyle 1993; Moore and Negri; Moore, Gollehon and Carey).

This study estimates models of crop acreage allocations for Manitoba agriculture within a duality framework. In contrast to other duality studies, we emphasize models with predetermined yields and risk aversion. The assumption of predetermined yields, which is common in the nonduality literature, substantially simplifies specification of duality models of acreage allocations. Moreover estimates of crop yield price response models for Manitoba support this assumption (see previous chapter).

Risk preferences are modelled within linear and nonlinear mean-variance frameworks, and proxies for price uncertainty are emphasized.

This study provides the first empirical application of recent extensions of static duality theory under mean-variance risk preferences (Coyle 1992, 1995). In addition, we suggest a simple methodology for combining weather station data and aggregate production data to obtain a measure of yield uncertainty. Previous studies have assumed that measures of yield uncertainty obtained using aggregate (rather than farm level) data necessarily underestimate yield uncertainty at the farm level.

MODEL SPECIFICATION ASSUMING PREDETERMINED YIELDS

Consider a multioutput firm with a fixed amount of total crop land Z that can be allocated between M crop enterprises, and assume that net revenues per acre r^j are predetermined for all enterprises $j = 1,.,M$ (i.e. input levels per acre and yields are predetermined, aside from the unanticipated effects of weather). Then the risk-neutral firm's acreage allocation $z = (z^1,.,z^M)$ solves the maximization problem [1]

$$(1) \quad R(r,Z) = \max_{z\geq 0} \ \Sigma_{j=1}^{M} r^j z^j \quad \text{s.t. } \Sigma_{j=1}^{M} z^j = Z$$

where R(r,Z) is linear homogeneous and convex in r, and Hotelling's lemma is satisfied:

$$(2) \quad z^j(r,Z) = \partial R(r,Z)/\partial r^j \qquad j = 1,.,M .$$

Thus acreage demand equations are specified given a functional form for the dual net revenue or profit function R(r,Z), and these equations satisfy standard homogeneity, reciprocity and curvature conditions.

Alternatively assume linear mean-variance risk preferences, i.e. assume a utility function $U = ER - \alpha/2\ VR$ where (ER,VR) denote mean and variance of the firm's subjective probability distribution for net revenues and the coefficient of absolute risk aversion α is constant. Uncertainty in net revenues per acre r may reflect either price uncertainty or yield uncertainty. Instead of assuming that yields are predetermined, it may sometimes be appropriate to assume that the mean and variance of the distribution for yield are predetermined. The firm's utility maximization problem is

$$(3) \quad U^*(Er,Vr,Z) = \max_{z\geq 0} \; U \equiv \Sigma_{j=1}^{M} Er^j z^j - \alpha/2 \, \Sigma_{i=1}^{M} \Sigma_{j=1}^{M} Vr_{ij} z^i z^j$$
$$\text{s.t.} \quad \Sigma_{j=1}^{M} z^j = Z \, .$$

Here $Er = (Er^1,..,Er^M)$ is the vector of expected net revenues per acre and Vr is a vector of the distinct covariances $cov(r^i,r^j)$ $(i,j = 1,..,M)$ between net revenues per acre for the M enterprises. $U^*(Er,Vr,Z)$ is linear homogeneous and convex in (Er,Vr), and the following equations analogous to Hotelling's lemma are satisfied:

$$(4) \quad z^j(Er,Vr,Z) = \partial U^*(Er,Vr,Z)/\partial Er^j \qquad j = 1,..,M$$

and

$$(5) \quad -\alpha/2 \; z^j(Er,Vr,Z)^2 = \partial U^*(Er,Vr,,Z)/\partial Vr_{jj}$$
$$-\alpha \; z^i(Er,Vr,Z) \; z^j(Er,Vr,Z) = \partial U^*(Er,Vr,,Z)/\partial Vr_{ij}$$

(Coyle 1992). Acreage demand equations (4) are homogeneous of degree zero in (Er,Vr) and satisfy standard reciprocity conditions. Functional forms can be specified as in Coyle.

More generally assume nonlinear mean-variance risk preferences, i.e. assume a utility function $U = W_0 + ER - \alpha(W_0 + ER,VR)/2\ VR$, where W_0 is initial wealth and the coefficient of absolute risk aversion α varies with $(W_0 + ER,VR)$. Then the firm's utility maximization problem is

$$(6) \quad U^*(Er,Vr,W_0,Z) = \max_{z\geq 0} \; U \equiv W_0 + \Sigma_{j=1}^{M} Er^j z^j$$

$$- \alpha(W_0 + \Sigma_{j=1}^{M} Er^j z^j, \Sigma_{i=1}^{M} \Sigma_{j=1}^{M} Vr_{ij} z^i z^j)/2\ \Sigma_{i=1}^{M} \Sigma_{j=1}^{M} Vr_{ij} z^i z^j$$

$$\text{s.t.} \quad \Sigma_{j=1}^{M} z^j = Z .$$

$U^*(\lambda\ Er, \lambda^2\ Vr, \lambda\ W_0, Z) = \lambda\ U^*(Er, Vr, W_0, Z)$ (scalar $\lambda > 0$) in the case of constant relative risk aversion (CRRA), $U^*(.)$ is quasiconvex in (Er, W_0) (given U strictly increasing in W_0 + ER), and the following equations analogous to Roy's theorem are satisfied:

$$(7) \quad z^j(Er, Vr, W_0, Z) = \partial U^*(Er, Vr, W_0, Z)/\partial Er^j \ / \ \partial U^*(Er, Vr, W_0, Z)/\partial W_0 \qquad j = 1,.,M.$$

The equilibrium coefficient of absolute risk aversion α^* for any given (Er, Vr, W_0, Z) can be calculated directly from the dual in the case of CRRA. In addition,

$$(8) \quad \partial U^*(Er, Vr, W_0, Z)/\partial W_0 = 1 - \partial\alpha(W_0+ER, VR)/\partial(W_0+ER)\ VR/2$$

(Coyle 1995a).

MODEL SPECIFICATION WHEN YIELDS ARE NOT PREDETERMINED

Chambers and Just (C-J) constructed the following model where output (y), variable input (x) and acreage allocation decisions (z) are made jointly:

$$(9) \quad \pi(p,w,K,Z) = \max_{z \geq 0} \ \pi(p,w,K,z) \quad \text{s.t. } \Sigma_{j=1}^{M} z^j = Z$$

where Z is the level of quasi-fixed inputs and

$$(10) \quad \pi(p,w,K,z) = \max_{(y,x) \in T(z,K)} \ \Sigma_{j=1}^{M} p^j y^j - \Sigma_{i=1}^{N} w^i x^i .$$

Thus the conditional profit function $\pi(p,w,K,z)$ is linear homogeneous and convex in (p,w), satisfies Hotelling's lemma

$$(11) \quad y^j = \partial\pi(p,w,K,z)/\partial p^j \qquad j = 1,.,M$$

$$x^i = -\ \partial\pi(p,w,K,z)/\partial w^i \qquad i = 1,.,N$$

and in addition

$$(12) \quad \partial\pi(p,w,K,z)/\partial z^i = \partial\pi(p,w,K,z)/\partial z^j \qquad i,j = 1,.,M$$

assuming an interior solution to (9). Note that the specification of these acreage demand equations is more complex than (2) where yields are predetermined. Assuming a normalized quadratic conditional profit function $\pi(p,w,K,z)$, acreage demands $z(p,w,K,Z)$ as well as output supplies and variable input demands are linear in exogenous variables, but acreage demand equations are nonlinear in parameters of the dual.

Assuming linear mean-variance risk preferences and price uncertainty (without yield uncertainty), problem (9) can be respecified as

$$(13) \quad U^*(Ep,w,Vp,K,Z) = \max_{z\geq 0} \; U^*(Ep,w,Vp,K,z) \quad \text{s.t. } \Sigma_{j=1}^{M} z^j = Z$$

where (Ep,Vp) denote means and covariances for output prices and

$$(14) \quad U^*(Ep,w,Vp,K,z) = \max_{(y,x)\in T(z,K)} \; \Sigma_{j=1}^{M} Ep^j y^j - \Sigma_{i=1}^{N} w^i x^i . - \alpha/2 \, \Sigma_{i=1}^{M} \Sigma_{j=1}^{M} Vp_{ij} \, y^i y^j .$$

Properties of the conditional dual $U^*(Ep,w,Vp,K,z)$ are discussed in Coyle (1992), and in addition

$$(15) \quad \partial U^*(Ep,w,Vp,K,z)/\partial z^i = \partial U^*(Ep,w,Vp,K,z)/\partial z^j \qquad i,j = 1,.,M.$$

This specification of acreage demands is more complex than (4) where yields are predetermined. Moreover the specification of the joint acreage demand, output supply and variable input demand model becomes substantially more complex when yields are uncertain (Coyle 1995b). In contrast, equations (4) apply to both price and yield uncertainty when yields are predetermined (or, more correctly, the nonweather component of yield is predetermined). Extensions of the C-J model to nonlinear risk preferences can also be constructed in a similar manner.

MEASUREMENT OF UNCERTAINTY

Most studies of supply response use time series data that is highly aggregated over individuals and regions, e.g. often national or state level data. Since prices faced by different firms are highly correlated with each other over time, the variation over time in aggregate prices presumably provides a reasonable measure of price uncertainty at the firm level. A proxy for price variance Vp_t^i for commodity i at time t has been calculated as follows in several other studies (e.g. Chavas and Holt; Coyle 1992):

$$(16) \quad var_t(p^i) = 0.50\ (p_{t-1}^i - E_{t-2}p_{t-1}^i)^2 + 0.33\ (p_{t-2}^i - E_{t-3}p_{t-2}^i)^2 + 0.17\ (p_{t-3}^i - E_{t-4}p_{t-3}^i)^2$$

that is current variance equals the sum of squares of prediction errors of the previous three years, with declining weights 0.50, 0.33, 0.17. On the other hand it is well known that variation in aggregate yield will substantially underestimate yield uncertainty at the farm level because yields vary by region. As a result it is often argued that farm level data on production is required in order to model the effects of yield uncertainty on production. Of course, even aside from this argument, there are well known advantages to using panel data sets over aggregate time series data sets. The difficulty is that there often is no alternative to such aggregate data sets, as in this study of Manitoba agriculture.

Here we propose a simple method for combining aggregate production data with weather station data in order to obtain a measure of yield uncertainty. This method should often be feasible and does not share the bias resulting from the use of variation in aggregate yield as a measure of variation or uncertainty in yields at the farm level.

Consider a single output production function $y = f(x,\omega)$ where output y is a function of input levels x and a stochastic weather variable ω. A first order approximation to output variance Vy conditional on x is

$$(17) \quad Vy(x) = \{\partial f(x,E\omega)/\partial\omega\}^2 \; V\omega$$

where $(E\omega, V\omega)$ are the mean and variance of the distribution for ω (e.g. Goldberger). This approximation is exact if the production function is a Gorman Polar form in terms of ω, and the approximation generalizes to a vector ω of weather variables.

Suppose that time series data on a crop-specific weather index is available for several weather stations within a region (alternatively data for multiple weather variables contributing to crop production may be available). Let ω_t^s be the level of this weather variable at station s at time t. Then a measure of variance can be constructed for each weather station and averaged over stations, e.g.

$$(18) \quad V\omega_t^s = 0.50\,(\omega_{t-1}^s - E_{t-2}\omega_{t-1}^s)^2 + 0.33\,(\omega_{t-2}^s - E_{t-3}\omega_{t-2}^s)^2 + 0.17\,(\omega_{t-3}^s - E_{t-4}\omega_{t-3}^s)^2 \qquad s = 1,..,S\ .$$

$$(19) \quad V\omega_t = \Sigma_{s=1}^{S}\, V\omega_t^s \,/\, S \quad .$$

The production function $y = f(x,\omega)$ can be estimated using aggregate data (y,x) and the average of weather data over the stations, e.g. $E\omega_t = \Sigma_{s=1}^{S}\, \omega_t^s / S$. Then estimates of the production function $y = f(x,E\omega)$ can be used to calculate the marginal impact of weather $\partial f(x,E\omega)/\partial\omega$. Given $V\omega$ defined as in (19) (rather than as a variance for aggregate weather $E\omega$), a proxy for yield uncertainty Vy can be constructed as in (17).

The simplest approach to calculating a proxy for yield uncertainty is to estimate a production function as above and then use this proxy in a duality model, but it is also possible to estimate this proxy jointly with a duality model where yield is not predetermined. For example, applying the envelope theorem to the linear mean-variance model

$$(20) \quad U^*(p,w,E\omega,V\omega,K,Z) = \max_{z\geq 0} \; \Sigma_{j=1}^{M} U^{j*}(p^j,w,E\omega,V\omega,K^j,z^j)$$

$$\text{s.t. } \Sigma_{j=1}^{M} z^j = Z$$

$$U^{j*}(p^j,w,E\omega,V\omega,K^j,z^j) = \max_{x\geq 0} \; p^j f(x^j,K^j,E\omega) - \Sigma_{i=1}^{N} w^i x^{ij}$$

$$- \alpha/2 \; \{\partial f(x^j,K^j,E\omega)/\partial\omega\}^2 \; V\omega$$

implies

$$(21) \quad \partial U^{j*}(.)/\partial V\omega = - \alpha/2 \; \{\partial f(x^j,K^j,E\omega)/\partial\omega\}^2 \; .$$

In turn Vy^j can be proxied in terms of parameters of the dual as

$$(22) \quad Vy^j = - (2/\alpha) \; \partial U^{j*}(.)/\partial V\omega \; V\omega \; .$$

Thus Vy can be calculated jointly with the dual model (20). However the simpler approach has the advantage of relating the proxy for Vy directly to production and weather data.

DATA

The data is similar to data used in the previous chapter. Acreage demand models were constructed for the following major crops in Manitoba using annual data for 1961-87: wheat, barley, oats, canola, flax and rye. This corresponds to the period for which a crop growth index of weather conditions was available for Manitoba. Expected crop output prices were modeled using data on market prices and Canadian Wheat Board (CWB) payments for crops (Statistics Canada b, Canadian Wheat Board).

Three alternative measures of expected crop prices were considered: (a) a one year lag on market prices plus government payments, (b) the sum of the most recently observed components of CWB payments at planting time (current initial payments, plus adjustment and interim payments for crop marketed in the previous year, plus final payment for crop marketed two years previously) for crops covered by the CWB (wheat, barley and oats), and (c) predicted values of market prices plus government payments from time series models. Case (b) will be referred to as expected CWB prices and was found to be useful in explaining crop acreage decisions in Western Canada (Coyle 1993). Alternative proxies for variances of crop prices and variances of crop yields were calculated using (16) and (18)-(19), respectively.

Input price indexes were obtained for hired labor, machinery and equipment, and variable inputs (e.g. fertilizer) for crops (Statistics Canada a). An index of the stock of physical capital in the crop sector was calculated as the current value of machinery and equipment (Statistics Canada b) deflated by its price index. Crop acreages were defined as the estimated areas sown annually for harvest (Statistics Canada c,d). Weather was proxied by a crop growth index GRODEX (Dyer, Narayanan and Murray), and initial stock of wealth was proxied as the value of land and buildings plus machinery and equipment (Statistics Canada b).

RESULTS FOR RISK-NEUTRAL MODELS

Assume predetermined yields and a generalization of a normalized quadratic functional form $R^*(r^*,Z)$ for the dual net revenue model (1):

$$(23)\quad R^*_t = \beta_0 + \Sigma^3_{i=1}\, \beta_i\, r^{*i}_t + 0.5\, \Sigma^3_{i=1}\, \Sigma^3_{j=1}\, \beta_{ij}\, r^{*i}_t\, r^{*j}_t + \Sigma^3_{i=1}\, \beta_{i4}\, r^{*i}_t Z_t$$
$$+ \Sigma^3_{i=1}\, \beta_{i5}\, r^{*i}_t\, Z_{t-1} + \Sigma^3_{i=1}\, \beta_{i6}\, r^{*i}_t\, r^4_t + \Sigma^3_{i=1}\, \beta_{i7}\, r^{*i}_t\, d_t$$
$$+ \Sigma^3_{i=1}\, \beta_{i8}\, r^{*i}_t\, t$$

where $R^* \equiv R\ /\ (r^4\ Z)$, $r^{*i} \equiv r^i\ /\ r^4$ $(i = 1,2,3)$, and r^4 is a Tornqvist approximation to a Divisia price index for oats, flax and rye. $i = 1,2,3$ denote wheat, barley and canola, respectively. For simplicity a four crop model is specified here using the Divisia price index as numeraire, but five crop models were also considered. Applying Hotelling's lemma (2) to (23),

$$(24)\quad sz^i_t = \beta_i + \Sigma^3_{j=1}\, \beta_{ij}\, r^{*j}_t + \beta_{i4}\, Z_t + \beta_{i5}\, (Z_t - Z_{t-1}) + \beta_{i6}\, r^4_t$$
$$+ \beta_{i7\ t} + \beta_{i8}\, t + e^i_t \qquad\qquad i = 1,2,3$$

where $sz^i \equiv z^i\ /\ Z$. The static risk-neutral model (1) implies that R is linear homogeneous in r, i.e. $\beta_{i6} = 0$ $(i = 1,2,3)$. This permits a simple test of the homogeneity assumption. Constant returns to scale in production implies $\beta_{i4} = 0$ $(i = 1,2,3)$. The rate of change in total crop acreage $(Z_t - Z_{t-1})$ is included in the model assuming that crop acreage demands depend on lags in adjustment of the overall crop rotation (Coyle 1993). The acreage demands (24) are consistent with a dual revenue function (23) if the following reciprocity (symmetry) conditions for integrability are satisfied by the demands:

$$(25)\quad \beta_{12} = \beta_{21} \qquad \beta_{13} = \beta_{31} \qquad \beta_{23} = \beta_{32}\quad .$$

Several simplifying assumptions are adopted in this model. First, since capital and labor requirements per acre are essentially identical for the different crops in Manitoba (e.g. Manitoba Agriculture), measures of capital stock and labor wage are omitted from this model. Second, since total expenses per acre for other variable inputs are relatively similar for different crops over this data period, these expenses are excluded from the model. Third, r is defined as expected revenues per acre, which is measured as the product of expected output price and lagged yield: $r_t^i = Ep_t^i\ (y_{t-1}^i\ /\ z_{t-1}^i)$.

If yields are not predetermined, then acreage demands are specified implicitly by M - 1 first order conditions (12) in terms of the conditional dual $\pi(p,w,K,z)$ and the constraint $\Sigma_{j=1}^{M}\ z^j = Z$. Solving these first order conditions generally leads to acreage demand equations that are nonlinear in coefficients. Alternatively, rather than specifying a functional form for $\pi(p,w,K,z)$, we can specify functional forms for the reduced form acreage demands z(p,w,K,Z) that are analogous to (24):

$$(26)\quad sz_t^i = \beta_i + \Sigma_{j=1}^{3}\ \beta_{ij}\ p_t^{*j} + \beta_{i4}\ Z_t + \beta_{i5}\ (Z_t - Z_{t-1}) + \beta_{i6}\ p_t^4 + \beta_{i7}\ d_t + \beta_{i8}\ t + e_t^i \qquad i = 1,2,3$$

where $p^{*i} \equiv p^i\ /\ p^4$ (i = 1,2,3) and p^4 is a Tornqvist approximation to a Divisia price index for oats, flax and rye. Reciprocity conditions analogous to (25) do not generally apply here.

Models (24) and (26) were specified using alternative measures of crop price expectations: (a) a one year lag on market prices plus government payments, (b) expected CWB prices for CWB crops wheat, barley and oats (see above), and (c) forecasts from ARIMA and GARCH models expressing market prices as a distributed lag of prices. However forecasts from ARIMA models led to poor results. This is consistent with another study suggesting that reported crop price expectations for a group of Saskatchewan farmers are not adequately explained by such forecasts (Sulewski, Spriggs and Schoney).

Tests were conducted for unit roots and cointegration. Standard unit root tests (e.g. Dickey-Fuller, Phillips-Perron) test the null hypothesis of unit roots but it is well known that these tests have very low power, i.e. these tests may well accept the null hypothesis of a unit root even though it is false (e.g. DeJong, Naukervis, Savin and Whiteman; Kwiatkowski, Phillips, Schmidt and Shin). As a result Kwiatkowski et al have presented a test where the null hypothesis is that the data is stationary around a linear trend and the alternative hypothesis is a unit root. Regarding data on crop acreages (and shares), hypotheses of unit roots were not rejected using standard tests (Dickey-Fuller, Phillips-Perron), but hypotheses of stationarity were also not rejected using the test of Kwiatkowski et al. Similar results were obtained for the numeraire expected net revenue per acre r^4 and the numeraire expected price p^4. On the other hand, results from standard unit root tests and the test by Kwiatkowski et al all suggested that relative expected net revenues per acre r^* and relative expected prices p^* (using both expected CWB and lagged market prices) do not have unit roots. Results of Dickey-Fuller and Phillips-Perron tests for unit roots in residuals for equations (24) and (25) did not reject the hypothesis of unit roots, so there is no support for cointegration.[2]

Durbin-Watson statistics were also considered in assessing the possibility of unit roots. It has been argued that the asymptotic value of the Durbin-Watson d statistic is zero in cases of models with random walk data, and in turn d is likely to be low in models with data generated by random walks (Phillips; Durlauf and Phillips). OLS estimates of (24) and (26) generally showed d values of 1.5 or higher with the exception of barley. For example, OLS estimation of (24) using expected CWB prices led to d values of 1.72, 1.21, 2.02 and 1.68 for wheat, barley, canola and other crops, respectively.

In sum, there is no strong support for unit roots or for cointegration. Tests indicate unambiguously that the major explanatory variables (normalized net revenues per acre or normalized prices) do not have unit roots. As a result, even if there are unit roots in some variables, the standard time series fixup of first differencing the data is not appropriate. [3] Therefore classical procedures for estimation and inference will be used in this study.

Share equations for models (24) and (26) were estimated by the SUR (seemingly unrelated regressions) method. Singularity of the four equation share model implies that one equation (here the fourth equation for the share of other crops) must be dropped for purposes of estimation. Since OLS estimates indicated autocorrelation for various equations, AR(1) models were estimated for these equations using Cochrane-Orcutt type GLS transformations prior to SUR estimation. This generally implies that SUR estimates are not invariant to the choice of equation omitted from the model (Berndt and Savin).

In principle serial correlation in OLS residuals may reflect either model misspecification or serial correlation of disturbances. Tests of common factor restrictions are recommended to help distinguish between these possibilities (Davidson and MacKinnon 1993). A GLS transformation for an AR(1) model was applied to a share equation (24) or (26), and the model was estimated with and without imposing the nonlinear restrictions on coefficients implied by AR(1). For each equation showing serial correlation in residuals, an asymptotic F test did not reject the nonlinear restrictions implied by AR(1). Thus it appears that serial correlation reflects AR disturbances rather than model misspecification, and in this case it is presumably appropriate to transform models for AR disturbances.

Table 1 reports OLS-AR(1) estimates for several models (24) and (26) assuming (a) predetermined yields and expected CWB prices, (b) predetermined yields and lagged market prices, and (c) endogenous yields and expected CWB prices. [4] Results assuming endogenous yields and lagged market prices were poor and are not presented here. Joint test results were calculated using SUR as discussed above and are reported in Table 2. Coefficient estimates in Table 1 are somewhat different from SUR estimates due to differences in AR transformations by equation, but these single equation estimates are presented because estimates of an equation are independent of specification errors in other equations. Results in Table 1 indicate that all estimates of direct (own-price) effects on acreage demands are positive and significant. All cross price effects are negative (with the exception of wheat in the canola demand equations, where t-ratios are less than 1.0). The numeraire is insignificant in each of the separate demand equations. The coefficient of the adjustment cost variable DZ = $Z_t - Z_{t-1}$ is insignificant in each of the wheat and canola equations but DZ is significant in barley equation (c).

Test results are reported in Table 2 for models estimated by SUR with AR(1) corrections where appropriate. Homogeneity (β_{i6} = 0, 1 = 1,2,3) is not rejected in any of these four models. Reciprocity (25) for models with predetermined yields is rejected when expected prices are modeled as lagged market prices but is not rejected at the .05 level using expected CWB prices. However the difference in significance for reciprocity restrictions is small for these two models. Constant returns to scale (CRTS) is rejected at the .05 level for all four models, but CRTS is almost accepted at the .05 level for model B (predetermined yields and lagged market prices). The hypothesis that acreage demands are unaffected by the rate of change in total crop acreage ($DZ_t = Z_t - Z_{t-1}$) (zero adjustment costs) is not rejected for models with predetermined yields but is rejected at the .05 level for the other models. Estimates of acreage demands imposing the accepted restrictions were similar to Table 1.

RESULTS FOR LINEAR MODELS WITH PRICE UNCERTAINTY

The above risk-neutral acreage demand equations can be generalized to allow for risk aversion and price uncertainty as follows. Assuming predetermined yields and constant absolute risk aversion (CARA), i.e. linear mean-variance risk preferences, equations (24) can be generalized as

$$(27) \quad sz_t^i = \beta_i + \Sigma_{j=1}^{3} \beta_{ij} Er_t^{*j} + \beta_{i4} Z_t + \beta_{i5} (Z_t - Z_{t-1}) + \beta_{i6} Er_t^4 + \beta_{i7} d_t + \beta_{i8} t + \Sigma_{j=1}^{4} \gamma_{ij} Vr_{jjt}^* + e_t^i \qquad i = 1,2,3 .$$

We will loosely refer to (27) as a CARA model, although strictly speaking it satisfies CARA only under homogeneity conditions. Under CARA, the above coefficients (β,γ) can be interpreted as coefficients of the derivatives $\partial U^*(.)/\partial Er_i$ (i = 1,2,3) of the dual (see (4)). Here the mean and variance of revenues per acre r are normalized as follows: Er^{*j}

$\equiv Er^j / Er^4$ and $Vr^*_{jj} \equiv Vr_{jj} / Er^4$, where $Er^j_t \equiv Ep^j_t \, yld^j_{t-1}$ and $Vr_{jjt} \equiv Vp_{jjt} \, (yld^j_{t-1})^2$ (yld denotes yield). In principle each equation depends on six covariances Vr^*_{jk} $(j \neq k)$ as well as the four variances Vr^*_{jj}, but these covariances are omitted in order to keep estimation of the model tractable. The homogeneity and reciprocity retrictions on acreage demands (27) that are implied by the linear mean-variance model (3) are $\beta_{i6} = 0$ $(i = 1,2,3)$ and (25), respectively, as in the risk-neutral model (e.g. Pope 1980, 1988; Coyle 1992). Risk neutrality implies the following restrictions:

$$(28) \quad \gamma_{ij} = 0 \qquad i,j = 1,2,3 \; .$$

In this case the acreage demands reduce to (24) for the normalized quadratic form (23).

Alternatively, assuming predetermined yields and constant relative risk aversion (CRRA), equations (24) can be generalized as:

$$(29) \quad sz^i_t = \beta_i + \Sigma^3_{j=1} \beta_{ij} \, Er^{*j}_t + \beta_{i4} \, Z_t + \beta_{i5} \, (Z_t - Z_{t-1}) + \beta_{i6} \, Er^4_t + \beta_{i7} \, d_t + \beta_{i8} \, t + \gamma_{i0} \, W^*_{0t} + \Sigma^4_{j=1} \gamma_{ij} \, Vr^{**}_{jjt} + e^i_t \qquad i = 1,2,3 \; .$$

where $W^*_0 \equiv W_0 / Er^4$ (W_0 is initial wealth) and $Vr^{**}_{jj} \equiv Vr_{jj} / (Er^4)^2$ in contrast to $Vr^*_{jj} \equiv Vr_{jj} / Er^4$ in the linear mean-variance equations (27). This will be loosely referred to as a CRRA model, although strictly speaking it satisfies CRRA only under homogeneity conditions. Note from the envelope relations (7) that the coefficients (β,γ) cannot generally be interpreted as coefficients of the dual $U^*(.)$. Instead (29) is an approximation to a reduced form for a structural model (7). In contrast to the risk-neutral and linear mean-variance model with predetermined yields, reciprocity does not generally apply to the demands (29) (Pope 1980; Coyle 1995a). CRRA implies the restrictions $\beta_{i6} = 0$ (i = 1,2,3) for (29) (Pope 1988; Coyle 1995a). Risk neutrality implies $\gamma_{i0} = 0$ (i = 1,2,3), i.e. initial wealth W_0^* does not influence acreage decisions, as well as (28) for (29).

In cases where crop yields are not predetermined, analogous acreage demands can be specified by replacing mean and variance of revenues per acre by mean and variance of price. For example we can specify the following acreage demand equations analogous to (27) and (29) for CARA and CRRA risk preferences, respectively:

$$(30)\quad sz_t^i = \beta_i + \Sigma_{j=1}^{3} \beta_{ij}\, Ep_t^{*j} + \beta_{i4}\, Z_t + \beta_{i5}\, (Z_t - Z_{t-1}) + \beta_{i6}\, Ep_t^4 + \beta_{i7}\, d_t + \beta_{i8}\, t + \Sigma_{j=1}^{4} \gamma_{ij}\, Vp_{jjt}^{*} + e_t^i \qquad i = 1,2,3$$

$$(31)\quad sz_t^i = \beta_i + \Sigma_{j=1}^{3} \beta_{ij}\, Ep_t^{*j} + \beta_{i4}\, Z_t + \beta_{i5}\, (Z_t - Z_{t-1}) + \beta_{i6}\, Ep_t^4 + \beta_{i7}\, d_t + \beta_{i8}\, t + \gamma_{i0}\, W_{0t}^{*} + \Sigma_{j=1}^{4} \gamma_{ij}\, Vp_{jjt}^{**} + e_t^i \qquad i = 1,2,3$$

where $Ep^{*j} \equiv Ep^j / Ep^4$, $Vp_{jj}^* \equiv Vp_{jj} / Ep^4$, $W_0^* \equiv W_0 / Ep^4$, and $Vp_{jj}^{**} \equiv Vp_{jj} / (Ep^4)^2$. Reciprocity does not generally apply to these models of acreage demands (e.g. Coyle 1993), but restrictions for homogeneity and risk neutrality are similar to restrictions for the analogous models with predetermined yields.

Alternative measures of expected crop prices were specified as in the risk neutral models. Variances of crop prices were specified as in (16) using both expected CWB prices and lagged market prices as Ep. In addition price variances were measured as variance of disturbance for GARCH(1,1) models expressing market price as a distributed lag of price; but poor estimates of acreage demands were obtained by this method. One possible interpretation of these poor results is that variance as well as mean of producers' subjective probability distributions for prices are not well specified by such bounded rational expectations models.

Share equations for models (27), (29)-(31) were estimated in the same manner as in the risk neutral models. Tables 3 and 4 present OLS-AR(1) results for three models within a CARA and CRRA framework, respectively. Table 3A-B presents estimates of (27) for a hybrid price model (expected prices Ep are proxied by expected CWB prices for CWB crops and lagged market prices for other crops; price variances Vp are proxied using (16) and lagged market prices) and a market price model (Ep is proxied by lagged market prices, and Vp is proxied using (16) and Ep as lagged market prices), respectively. Table 3C presents estimates of (30) for a hybrid price model. Yields are predetermined in 3A-B and are not predetermined in 3C.

These linear mean-variance models in Table 3 are similar to risk neutral models in Table 1 except for the addition of four (normalized) price variances to each equation. Comparing the two tables, addition of the price variances decreases the significance of expected net revenues Er^* or expected prices Ep^*, to some extent. Test results for these models are reported in Table 5. Restrictions (28) corresponding to risk neutrality are not rejected at the .05 level for any of the cases reported. Homogeneity is rejected in only one of six cases, and reciprocity is not rejected in all three cases. These results may reflect in part the lower level of significance of expected revenues per acre or expected prices in linear mean-variance models.

Results for similar CRRA models are reported in Table 4. Table 4A-B presents estimates of (29) for a hybrid price and market price model assuming that yields are predetermined, and Table 4C presents estimates of (31) for a hybrid model assuming that yields are not predetermined. As expected under risk aversion, the coefficient for variance of wheat revenue per acre or price is significant and negative in the wheat equation, and the coefficient for variance of canola revenue per acre or price is significant and negative in the canola equation. On the other hand, the coefficient for variance of barley revenue per acre or price is positive in the barley equation but is insignificant in two of three cases. Initial wealth W_0^* is significant in wheat and barley equations.

Test results for CRRA models are reported in Table 5. Restrictions (28) deleting price variances are rejected for all CRRA models at both .05 and .01 levels of significance. This contrast with results for CARA models may be explained as follows: CRRA is generally recognized in the theoretical literature on risk as a more appropriate assumption than CARA. Initial wealth W_0^* is significant in five of six models. These test results regarding coefficients of Vr^{**} or Vp^{**} and W_0^* imply rejection of risk neutrality. On the other hand, homogeneity is rejected at the .05 level in five of six cases (and at the .01 level in three of six cases). This suggests that risk preferences may violate CRRA as well as CARA.

RESULTS FOR LINEAR MODELS WITH YIELD AND PRICE UNCERTAINTY

A measure of yield uncertainty can be constructed from time series data for Manitoba weather stations and from estimates of an aggregate production function $y = f(x,\omega)$, as outlined above. The first order approximation (17) to the variance Vy is exact in the case of a production function $y = a(x) + \omega\ b(x)$, which can be viewed as a Gorman polar form in ω. This is also somewhat similar to a Just-Pope production function except that data on the weather variable ω is available and is used as an explanatory variable rather than being incorporated into the residual disturbance. This production function also implies that the expected value of output y depends on nonstochastic inputs x and only the first moment of the stochastic weather variable ω. The following production function is specified for each crop:

$$(32)\quad yld_t^i = a_{i0} + a_{i1}\,(x_t/Z_t) + a_{i2}\,z_t^i + a_{i3}\,t + \omega_t\,\{b_{i0} + b_{i1}\,(x_t/Z_t) + b_{i2}\,z_t^i + b_{i3}\,t\} + e_t^i \qquad i = 1,..,6$$

where yld^i denotes yield of crop i, x is a Tornqvist quantity index for variable crop inputs (fertilizer, chemicals, seed), Z is total crop acreage, and z^i is acres of crop i. ω is defined here as the average of weather data over the six Manitoba weather stations ($E\omega_t = \Sigma_{s=1}^{6}\,\omega_t^s / 6$). The weather data is measured as a crop growth weather index (GRODEX) (Dyer, Narayanan and Murray). Then the marginal impact of weather on yield is

$$(33)\quad \partial yld^i/\partial\omega = b_{i0} + b_{i1}\,(x_t/Z_t) + b_{i2}\,z_t^i + b_{i3}\,t \qquad i = 1,...,6.$$

A more general production function would specify a(.) and perhaps b(.) as quadratic rather than linear, but the resulting multicollinearity leads to substantial imprecision in estimating (33) (e.g. calculated $\partial yld^i/\partial\omega$ was negative in various years). Given estimates of (33), then variance in yield can be calculated from the GRODEX weather station data using (17)-(19).

In previous sections we emphasized models with yields treated as predetermined. Similarly, recognizing that yields depend on current weather conditions, we can assume that the mean and variance of the distribution for yield is predetermined. In this case acreage demands (27) and (29) under price uncertainty and predetermined yields are easily generalized to include yield uncertainty. Here $Vr_{jjt} = Vp_{jjt} (yld^j_{t-1})^2 + Vy_{jjt} (Ep^j_t)^2$ assuming that producers' subjective probability distributions for price and yield are independent. Ignoring price uncertainty implies $Vr_{jjt} \equiv Vy_{jjt} (Ep^j_t)^2$. Similarly $Er^j_t = Ep^j_t\, yld^j_{t-1}$ assuming independent distributions for price and yield and using lagged yield as a proxy for expected yield.

If the mean and variance of yield are not predetermined, then acreage demands (30)-(31) under price uncertainty are modified by adding the mean and variance of weather:

$$(34) \quad sz^i_t = \beta_i + \Sigma^3_{j=1} \beta_{ij} Ep^{*j}_t + \beta_{i4} Z_t + \beta_{i5} (Z_t - Z_{t-1}) + \beta_{i6} Ep^4_t + \beta_{i7} d_t + \beta_{i8} t + \Sigma^4_{j=1} \gamma_{ij} Vp^*_{jjt} + \gamma_{i5} E\omega_t + \gamma_{i6} V\omega_t + e^i_t \qquad i = 1,2,3$$

$$(35) \quad sz^i_t = \beta_i + \Sigma^3_{j=1} \beta_{ij} Ep^{*j}_t + \beta_{i4} Z_t + \beta_{i5} (Z_t - Z_{t-1}) + \beta_{i6} Ep^4_t + \beta_{i7} d_t + \beta_{i8} t + \gamma_{i0} W^*_{0t} + \Sigma^4_{j=1} \gamma_{ij} Vp^{**}_{jjt} + \gamma_{i5} E\omega_t + \gamma_{i6} V\omega_t + e^i_t \qquad i = 1,2,3$$

where $E\omega$ and $V\omega$ are mean and variance of weather. As in (30)-(31), $Ep^{*j} \equiv Ep^j / Ep^4$, $Vp^*_{jj} \equiv Vp_{jj} / Ep^4$, $W^*_0 \equiv W_0 / Ep^4$, and $Vp^{**}_{jj} \equiv Vp_{jj} / (Ep^4)^2$. In contrast to (30) with price uncertainty, CARA does not imply homogeneity ($\beta_{i6} = 0$, $i = 1,2,3$) for (34). On the other hand, CRRA (plus independence of distributions for price and yield) does imply the analogous homogeneity restriction for (35) (Coyle 1995b). As in (30)-(31), reciprocity is not satisfied. Restrictions for risk neutrality include omission of $V\omega$ ($\gamma_{i6} = 0$, $i = 1,2,3$) as well as Vp^*, Vp^{**} and W^*_0. Estimation of the unrestricted production functions (32) using Manitoba data generally led to insignificant coefficients, and corresponding calculated marginal impacts of weather on yield (33) were negative for several years. In contrast coefficient estimates of restricted production functions ($a_{i2} = b_{i1} = b_{i3} = 0$) were generally significant and led to positive calculated impacts of weather on yield for all years. Estimates of these restricted production functions were used in calculating yield variances from (17)-(19) for use in acreage demand models.

Single equation estimates of acreage demands (27) and (29) assuming yield uncertainty and no price uncertainty are reported in Table 6. Here the mean and variance of yield are assumed to be predetermined. The coefficients of wheat variance (Vr^1) in the wheat equation and barley variance (Vr^2) in the barley equation are generally negative and significant in the CARA (linear mean-variance) models, as expected. In contrast these coefficients are not significant in CRRA models. In the case of yield uncertainty the CRRA normalization of revenue variance ($Vr^{i**} = Vyld^i \ (Ep^{i*})^2$) apparently leads to more correlation with normalized prices (Ep^*) than does the CARA normalization ($Vr^{i*} = Vyld^i \ Ep^{i*} \ Ep^i$). Poor results are obtained for variances in canola equations. Test results for these models are reported in Table 7 (A and B). Variances are jointly significant at the .05 level and homogeneity is not generally rejected. Results for reciprocity in the CARA models and significance of initial wealth in CRRA models are mixed.

Given the difficulties in obtaining precise estimates of the impacts of weather on yields in this study, the above results are interpreted here as somewhat encouraging. On the other hand attempts to estimate (27) and (29) combining the measures of price and yield uncertainty were unsuccessful. Variances were generally insignificant in wheat and barley acreage equations, although coefficients of variances were significant (with anticipated signs) in canola equations. Test results for these models are reported in Table 7: variances generally are jointly insignificant at the .05 level.

Single equation estimates of two acreage demand models when mean and variance of yields are not predetermined are reported in Table 8. Assuming risk aversion and yields but not prices are uncertain, the mean and variance of weather ($E\omega$, $V\omega$) and normalized initial wealth (W_0^*) are added to (24). Alternatively mean and variance of weather are added to the CRRA model (29) with price uncertainty. In contrast to Table 6 where mean and variance of yield are assumed to be predetermined, own expected price and price variance effects are generally insignificant, with the exception of canola. Mean and variance of weather are insignificant with the exception of the CRRA canola equation.

RESULTS FOR NONLINEAR MODELS

If mean-variance risk preferences are nonlinear, then parameters of the dual generally cannot be estimated by linear methods. Above we estimated reduced form acreage demands when risk preferences are nonlinear mean-variance. In this section we estimate parameters of the dual by nonlinear methods when risk preferences are nonlinear and yields or the mean and variance of yields are predetermined. We do not consider models with mean and variance of yields determined jointly with acreage demands due to the complexity of this model (e.g. Coyle 1995b) and the poor results for corresponding reduced forms in the previous section. The most obvious approach is to specify a functional form for the dual $U^*(.)$ assuming no yield uncertainty (or mean and variance of yield predetermined), and to specify acreage demand equations using the envelope relations (7). For example assuming a normalized quadratic dual $U^*(.)$, acreage demand equations for wheat, barley and canola can be specified as

$$
\begin{aligned}
(36) \quad sz_t^i = \{&\beta_i + \Sigma_{j=1}^3 \beta_{ij} Er_t^{*j} + \beta_{i4} Z_t + \beta_{i5} (Z_t - Z_{t-1}) + \beta_{i6} Er_t^4 \\
&+ \beta_{i7} d_t + \beta_{i8} t + \gamma_{i0} W_{0t}^* + \Sigma_{j=1}^4 \gamma_{ij} Vr_{jjt}^{**}\} \\
/ \{&\beta_5 + \Sigma_{j=1}^3 \beta_{5j} Er_t^{*j} + \beta_{54} Z_t + \beta_{55} (Z_t - Z_{t-1}) + \beta_{56} Er_t^4 \\
&+ \beta_{57} d_t + \beta_{58} t + \gamma_{50} W_{0t}^* + \Sigma_{j=1}^4 \gamma_{5j} Vr_{jjt}^{**}\} + e_t^i \\
&\qquad\qquad i = 1,2,3.
\end{aligned}
$$

Estimation of these equations requires a normalization (e.g. $\beta_5 = 1$) for the purposes of identification of coefficients. The numerator on the right hand side of (36) represents $\partial U^*(.)/\partial Er^i$ and the denominator is $\partial U^*(.)/\partial W_0$. In contrast to the reduced form equations (29), coefficients of (36) correspond to parameters of a normalized quadratic dual. Nevertheless inspection of (36) indicates that (29) is not the reduced form implied by the structural model (36) (unless $\partial U^*(.)/\partial W_0 = 1$, the denominator in (36) implies that the reduced form cannot be additive in variables as in (29)). Nonlinear mean-variance risk preferences implies that acreage demands do not show reciprocity even if yields are predetermined (i.e. $\partial sz^i/\partial Er^j \neq \partial sz^j/\partial Er^i$) (Pope 1980; Coyle 1995a), but a normalized quadratic dual does imply symmetry restrictions ($\beta_{ij} = \beta_{ji}$, $i,j = 1,2,3$ and $\gamma_{i0} = \beta_{5i}$, $i = 1,2,3$). CRRA is satisfied under the homogeneity restrictions $\beta_{i6} = 0$ ($i = 1,2,3,5$). Risk neutrality is satisfied if W_0^*, Vr^{**} can be omitted from the model and $\partial U^*(.)/\partial W_0 = 1$, i.e. (36) reduces to (24) ($r^* \equiv Er^*$).

However equations (36) are highly nonlinear in coefficients. Attempts to estimate these equations separately or as a system using all nonlinear algorithms available in Shazam 7.0 and various starting values for coefficients were unsuccessful. Indeed even convergence was not achieved.

An alternative to direct estimation of acreage demands (7) such as (36) is to specify the following system (substituting (8) into (7)):

$$(37)\quad z^i = \partial U^*(Er,Vr,W_0,Z)/\partial Er^i \;/\; \{1 - \partial\alpha(W_0+ER,VR)/\partial(W_0+ER)\ VR/2\} \qquad i = 1,2,3$$

$$(38)\quad \partial\alpha(W_0+ER,VR)/\partial(W_0+ER)\ VR/2 = 1 - \partial U^*(Er,Vr,W_0,Z)/\partial W_0 \quad .$$

These equations can be estimated given functional forms for $\alpha(.)$ as well as $U^*(.)$. CRRA implies $\alpha(\lambda\ EW, \lambda^2\ VW) = \lambda^{-1}\ \alpha(EW,VW)$ (e.g. Coyle 1995a); so $\lambda \equiv (VW)^{-1/2}$ yields $\alpha(EW/VW^{1/2},\ 1) = VW^{1/2}\ \alpha$, i.e. $\alpha = VW^{-1/2}\ g(EW/VW^{1/2})$. A quadratic approximation to the function g(.) is not restrictive in terms of the maximization hypothesis (6), which places second order restrictions on $\alpha(.)$. Thus, assuming CRRA, we specify the functional form for $\alpha(.)$ as follows:

$$(39)\quad \alpha = c_0 \;/\; VR^{0.5} + c_1\ (W_0 + ER)\ /\ VR + c_2\ (W_0 + ER)^2\ /\ VR^{1.5}$$

where $ER \equiv \Sigma_{i=1}^{4}\ Er^i\ z^i$, $VR \equiv \Sigma_{i=1}^{4}\ Vr^i\ (z^i)^2$, (c_0, c_1, c_2) are coefficients, and in turn $\partial\alpha(.)/\partial EW = c_1\ /\ VR + 2\ c_2\ (W_0+ER)\ /\ VR^{1.5}$. Given (39) and a normalized quadratic dual, equations (37) can be specified as

$$(40)\quad sz_t^i = \{\beta_i + \Sigma_{j=1}^{3}\ \beta_{ij}\ Er_t^{*j} + \beta_{i4}\ Z_t + \beta_{i5}\ (Z_t - Z_{t-1}) + \beta_{i6}\ Er_t^4 + \beta_{i7}\ d_t + \beta_{i8}\ t + \gamma_{i0}\ W_{0t}^* + \Sigma_{j=1}^{4}\ \gamma_{ij}\ Vr_{jjt}^{**}\}$$

$$/ \{1 - (c_1 / VR + 2\, c_2\, (W_0+ER) / VR^{1.5})\, VR / 2\} \quad i = 1,2,3 .$$

Similarly, solving (38) for VR given a normalized quadratic dual and $\alpha(.)$ satisfying (39),

$$(41) \quad (W_0 + ER) / VR^{0.5} = 1/c_2 - \{\beta_5 + \Sigma_{j=1}^{3} \beta_{5j}\, Er_t^{*j} + \beta_{54}\, Z_t + \beta_{55}\, (Z_t - Z_{t-1}) + \beta_{56}\, Er_t^4 + \beta_{57}\, d_t + \beta_{58}\, t + \gamma_{50}\, W_{0t}^* + \Sigma_{j=1}^{4} \gamma_{5j}\, Vr_{jjt}^{**}\}/c_2 - c_1/2c_2 .$$

The reduced form for this equation is

$$(42) \quad (W_0 + ER) / VR^{0.5} = \rho_5 + \Sigma_{j=1}^{3} \rho_{5j}\, Er_t^{*j} + \rho_{54}\, Z_t + \rho_{55}\, (Z_t - Z_{t-1}) + \rho_{56}\, Er_t^4 + \rho_{57}\, d_t + \rho_{58}\, t + \tau_{50}\, W_{0t}^* + \Sigma_{j=1}^{4} \tau_{5j}\, Vr_{jjt}^{**}$$

where $\rho_5 = (2 - c_1 - 2\,\beta_5) / 2c_2$, $\rho_{5j} = \beta_{5j} / c_2$ $(j = 1,..,8)$, $\tau_{5j} = \gamma_{5j} / c_2$ $(j = 0,..,4)$. The most ambitious approach to estimating this model is joint estimation of the full structural model (40)-(41) by nonlinear methods, but this approach did not lead to reasonable results although convergence was achieved.

In contrast the following approach to estimation of the nonlinear system was relatively successful here: (a) acreage demand equations (40) are estimated jointly by nonlinear methods, and (b) the reduced form equation (42) is estimated by linear methods. Estimates of (c_1,c_2) from (40) and results for (42) provide estimates of parameters for $\partial U^*(.)/\partial W_0$. A Davidon-Fletcher-Powell quasi-Newton algorithm encoded in Shazam 7.0 was used for maximum likelihood estimation of a nonlinear seemingly unrelated regression system for (40). As in most applications of duality with time series data (e.g. estimation of dual cost functions), (nonlinear) three stage least squares was not considered here. Since R^2's for reduced form equations using time series data generally are quite high, coefficient estimates using SUR and 3SLS are likely to be quite similar.

Initial estimates (starting values) for coefficients in the nonlinear system were obtained as follows: (a) an essentially linear approximation to $W_0 + ER = U^*(.) + \alpha(.)\ VR/2$ (6) was estimated to obtain starting values for c_1 and c_2; (b) individual acreage demand equations (40) were estimated by nonlinear methods using these starting values for (c_1, c_2) and results from CRRA linear models (29) as starting values for coefficients of $\partial U^*(.)/\partial Er_i$; and (c) estimates of (c_1, c_2) from (a) and coefficient estimates of $\partial U^*(.)/\partial Er_i$ from (b) were used as starting values in nonlinear estimation of the joint system of acreage demands (40). Results from CARA linear models (27) were also considered as starting values in step (b), but this did not substantially change the final results for nonlinear estimation of the system (40).

Results for acreage demands (40) obtained by nonlinear estimation of single equations are reported in Tables 9 and 10. Table 9 assumes price uncertainty without yield uncertainty (yields are predetermined), and Table 10 assumes yield uncertainty (mean and variance of yields are predetermined) without price uncertainty. Significance levels and signs of coefficient estimates (but not magnitudes) for the numerator in acreage demands (40) are somewhat similar to Tables 4 and 6 for linear reduced form CRRA models. These results suggest that derivatives $\partial U^*(.)/\partial Er_i$ vary substantially with Er^* and Vr^{**}. Estimates of c_1 and c_2 of course vary by equation but often lie within the 95 percent confidence intervals for estimates in other equations.

Estimates for the linear reduced form equation (42) are also reported in Tables 9 and 10. These results suggest that Er^* and Vr^{**}

generally are insignificant within the functional form for the derivative $\partial U^*(.)/\partial W_0$. This conclusion, that Er^* and Vr^{**} are much less significant in the derivative $\partial U^*(.)/\partial W_0$ than in the derivatives $\partial U^*(.)/\partial Er_i$, is not entirely surprising. Our earlier results for reduced form acreage demand models suggest that Er^* and Vr^{**} generally influence acreage demands; so the envelope relations (7) suggest that Er^* and Vr^{**} are significant either in derivatives $\partial U^*(.)/\partial Er_i$ and/or in the derivative $\partial U^*(.)/\partial W_0$. In the extreme case of linear mean-variance risk preferences (CARA), $\partial U^*(.)/\partial W_0 = 1$ for all (Er^*, Vr^{**}), i.e. $\partial U^*(.)/\partial W_0$ is independent of (Er^*, Vr^{**}). Thus, if risk preferences are roughly approximated by CARA, Er^* and Vr^{**} should be more significant in derivatives $\partial U^*(.)/\partial Er_i$ than in $\partial U^*(.)/\partial W_0$. Although CRRA is a more realistic assumption than CARA, the relatively small significance of (Er^*, Vr^{**}) in (42) may be interpreted as consistent with the somewhat reasonable performance of several linear CARA models in this study.

Nonlinear seemingly unrelated regression (SUR) results for the system of acreage demand equations (40) are reported in Tables 11 and 12 assuming price uncertainty and yield uncertainty (predetermined mean and variance of yields), respectively. As expected, significance levels generally are higher for SUR (with across-equation restrictions on c_1 and c_2) than for separate estimation of acreage demands.

Estimates for coefficients c_1 and c_2 in these Tables (and in Tables 9-10) together with (39) imply decreasing absolute risk aversion (DARA) for all years, i.e. $\partial\alpha(.)/\partial EW < 0$ at (EW^*, VW^*) for all years. DARA is a stylized fact in the theoretical literature on risk. Local coefficients of absolute risk aversion α^* are not calculated since this would require reliable estimates of either c_0 or of all coefficients of $\partial U^*(.)/\partial Vr_{ii}^{**}$ $(i = 1,.,4)$ (Coyle 1995a). Neither c_0 nor all coefficients of $\partial U^*(.)/\partial Vr^{**}$ can be inferred from estimates of (40) and (42).

CONCLUSION

This study of crop acreage demands in Manitoba apparently is the first application of recent theory on duality with price uncertainty to use data disaggregated by crops. In addition this study suggests and applies a simple methodology for combining weather station data and production data aggregated over agents (regions) to obtain a measure of yield uncertainty. Apparently this methodology has not been noted in previous production literature. Models where yields are predetermined, or to be more precise the mean and variance of the distribution of yield are predetermined, are emphasized here. This is in keeping with other studies (including an econometric study for Manitoba) suggesting that crop yields may often be largely predetermined. In addition this assumption greatly simplifies estimation of acreage demand models.

Results of the study indicate that the methodologies applied here are tractable in modelling crop acreage demands and support the assumptions that price and yield uncertainty influence acreage decisions. Models with yields (or mean and variance of yields) treated as predetermined generally provided more reasonable results than models with yields not predetermined. Results for models assuming price uncertainty or yield uncertainty generally led to anticipated results for the major crop (wheat), but results for impacts of variances in revenues per acre for other crops were more ambiguous. The one major disappointment of the study is that models combining both price uncertainty and yield uncertainty generally did not lead to reasonable results.

In sum, this study suggests that duality models of crop acreage demands incorporating risk aversion and uncertainty are tractable and promising. However further progress presumably requires more accurate measurement of farmers' subjective price and yield (or weather) uncertainty.

FOOTNOTES

1. Note that, even if yields (or net revenues per acre r) are not predetermined, model (1) is correctly specified if there is constant returns to scale in production (and technology is disjoint). In this case, given exogenous output prices p and variable input prices w, the average (marginal) net return per acre r^j is independent of acreage z^j, so r is independent of the allocation z.

2. Shazam 7.0 was used throughout this study.

3. In addition, even if there is cointegration, standard methods for estimating cointegrated time series models are not appropriate for structural models such as (24) and (26) (see Park and Ogaki, Clark and Klein for a discussion and application of canonical cointegrating regression and SUR).

4. The alternative specifications of acreage demands in terms of crop prices (yield not predetermined) and crop revenues per acre (yield predetermined) were compared using J-tests (Davidson and MacKinnon 1981), but results were ambiguous. Predictions of crop acreage shares from (24) using revenues per acre were significant when added to (26) using prices. This was true for both price specifications in (24) and (26) (in terms of expected CWB prices or lagged market prices). On the other hand, predicted shares from (26) were insignificant when added to (24) only in the case of lagged market prices. Thus J-test results favored predetermined yields in the case of lagged market prices, but results were ambiguous in the case of expected CWB prices.

Table 3.1 Estimates of Risk-Neutral Acreage Demands

A. Yield predetermined, expected CWB price

	Wheat (AR1)			Barley (AR1)			Canola (OLS)		
	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]
r^{1*}	.1156	2.81	.261	-.0644	1.97	-.337	.0084	0.29	.127
r^{2*}	-.0373	0.88	-.067	.1146	3.41	.477	-.0054	0.17	-.065
r^{3*}	-.0633	1.85	-.133	-.0494	1.82	-.241	.1181	5.10	1.652
r^4	.0311	0.06	.001	-4.945	1.37	-.217	2.268	1.05	.286
Z	.0037	1.06	.615	-.0049	1.78	-1.890	-.0008	0.75	-.967
DZ	-.0007	0.35	-.001	.0021	1.44	.011	-.0002	0.26	-.004
T	-.2344	0.45	-.072	1.113	2.72	.798	.2758	1.47	.567
DLIFT	-9.638	2.42	-.007	1.776	0.56	.003	-3.132	1.22	-.017
constant	21.06	1.02	.466	45.78	2.82	2.344	-3.943	0.48	-.579
R^2/DW	.8438	1.83		.8980	1.43		.9021	2.02	
B. Yield predetermined, lagged market price								(AR1)	
r^{1*}	.1836	2.61	.375	-.0731	1.29	-.345	.0260	0.70	.353
r^{2*}	-.0384	0.41	-.064	.2182	2.90	.847	-.1453	2.71	-1.620
r^{3*}	-.0811	2.37	-.177	-.0234	0.85	-.118	.0896	4.51	1.304
r^4	-2.830	0.69	-.053	-2.103	0.63	-.090	2.435	1.17	.301
Z	.0061	1.71	1.018	-.0076	2.55	-2.916	-.0008	0.66	-.950
DZ	-.0009	0.48	-.002	.0027	1.77	.014	.0002	0.22	.003
T	-.3985	0.85	-.123	1.165	2.81	.835	.4984	2.79	1.025
DLIFT	-6.265	1.56	-.005	-1.549	0.47	-.003	-.8377	0.37	-.005
constant	2.509	0.11	.055	53.33	2.99	2.731	3.976	0.48	.584
R^2/DW	.8384	1.95		.8885	1.62		.9135	1.91	

Table 3.1: cont...

C. Yield not predetermined, expected CWB price

	Wheat (AR1)			Barley (AR1)			Canola (OLS)		
	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]
p^{1*}	.0658	2.38	.274	-.0398	1.79	-.385	.0030	0.17	.083
p^{2*}	-.0148	0.39	-.041	.0871	2.91	.568	-.0195	0.75	-.365
p^{3*}	-.0228	1.30	-.149	-.0239	1.70	-.362	.0464	4.76	2.014
p^{4}	-1.187	0.18	-.016	-5.819	1.12	-.188	2.197	0.91	.203
Z	.0059	1.68	.993	-.0059	2.06	-2.286	-.0026	2.27	-2.872
DZ	-.0021	1.18	-.004	.0031	2.19	.016	.0007	0.80	.011
T	-.5676	1.02	-.175	1.306	2.85	.936	.4147	2.13	.853
DLIFT	-1.742	1.77	-.006	2.286	0.67	.004	-4.068	1.59	-.022
constant	7.890	0.35	.174	51.55	2.86	2.640	7.433	0.95	1.092
R^2/DW	.8207	1.73		.8773	1.39		.8947	1.91	

[a] Coefficients are in units of 10^{-2}.
[b] Elasticities are evaluated at data means.

Table 3.2: Test Results for Risk-Neutral Acreage Demands

	Homogeneity		Reciprocity		CRTS		Zero Adj. Cost	
	F-stat	Prob	F-stat	Prob	F-stat	Prob	F-stat	Prob
a. Yield predetermined, expected CWB price	0.55	0.648	2.84	0.045	5.40	0.002	2.22	0.096
b. Yield predetermined, lagged market price	1.06	0.370	2.41	0.076	2.79	0.049	1.62	0.194
c. Yield not predetermined, expected CWB price	0.80	0.498	-	-	8.67	0.0001	3.48	0.022
d. Yield not predetermined, lagged market price	1.53	0.217	-	-	5.85	0.002	4.42	0.008

Note: Degrees of freedom for F statistic are (3,54) for all tests.

Table 3.3: Estimates of Acreage Demands under Price Uncertainty CARA

A. CWB Ep, market Vp, yield predetemined

	Wheat (OLS)			Barley (OLS)			Canola (OLS)		
	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]
r^{1*}	.1639	2.25	.371	-.0857	1.29	-.449	-.0144	0.51	-.217
r^{2*}	-.1096	1.49	-.197	.1780	2.66	.742	-.0053	0.19	-.064
r^{3*}	-.0770	1.20	-.162	-.0177	0.30	-.086	.1051	4.24	1.47
r^{4}	11.48	1.82	.219	-8.403	1.50	-.370	2.704	1.11	.342
Z	.0017	0.40	.282	-.0113	2.90	-4.35	-.0003	0.19	-.353
DZ	-.0003	0.10	-.001	.0044	1.87	.024	-.0004	0.37	-.006
T	-.6943	1.60	-.215	1.983	4.99	1.42	.3071	1.83	.632
DLIFT	-15.22	2.08	-.013	-3.134	0.47	-.006	-1.322	0.47	-.007
Vr^{1*}	-.0111	1.55	-.063	.0001	0.02	.002	-.0007	0.24	-.025
Vr^{2*}	.0039	0.31	.021	.0126	1.12	.157	-.0050	1.06	-.181
Vr^{3*}	.0050	1.45	.044	.0017	0.53	.033	-.0038	2.83	-.217
Vr^{4*}	.0039	0.31	.022	-.0131	1.13	-.168	.0088	1.81	.325
constant	31.29	1.29	.692	79.14	3.58	4.050	-4.758	0.51	-.699
R^2/DW	.8164	1.76		.8411	1.36		.9429	2.18	

Table 3.3: cont...

B. market Ep, market Vp, yield predetermined

	Wheat (OLS)			Barley (AR1)			Canola (OLS)		
	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]
r^{1*}	.2750	2.95	.562	-.0869	1.41	-.411	.0149	0.39	.202
r^{2*}	-.0113	0.08	-.019	.2182	2.39	.848	-.1087	1.92	-1.21
r^{3*}	-.0997	1.79	-.219	-.0059	0.18	-.030	.0844	3.70	1.22
r^{4}	9.649	1.46	.180	-1.384	0.25	-.059	3.019	1.12	.373
Z	.0022	0.53	.371	-.0077	2.07	-2.94	-.0002	0.12	-.219
DZ	.0016	0.61	.004	.0024	1.34	.013	.0001	0.06	.001
T	-.7681	1.78	-.238	1.233	2.81	.884	.4453	2.52	.916
DLIFT	-11.23	1.79	-.009	-2.261	0.58	-.004	.1967	0.08	.001
Vr^{1*}	-.0075	1.13	-.041	.0013	0.27	.017	-.0001	0.03	-.003
Vr^{2*}	-.0075	0.63	-.039	.0068	0.75	.083	-.0063	1.30	-.221
Vr^{3*}	.0040	1.27	.034	-.0014	0.54	-.027	-.0033	2.55	-.186
Vr^{4*}	.0116	0.89	.063	-.0078	0.91	-.099	.0081	1.52	.295
constant	15.85	0.54	.351	52.82	2.42	2.70	-1.199	0.10	-.176
R^2/DW	.8301	1.72		.9024	1.79		.9409	1.83	

Table 3.3: Cont...

C. CWB Ep, market Vp, yield not predetermined

	Wheat (OLS)			Barley (AR1)			Canola (OLS)		
	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]
p^{1*}	.1010	2.25	.422	-.0369	1.59	-.357	-.0191	1.13	-.529
p^{2*}	-.0636	0.96	-.179	.0741	2.27	.483	-.0178	0.71	-.333
p^{3*}	-.0422	1.35	-.275	-.0065	0.38	-.098	.0334	2.85	1.44
p^{4}	11.63	1.63	.162	-6.649	0.95	-.215	2.217	0.83	.206
Z	.0064	1.42	1.06	-.0069	1.98	-2.64	-.0005	0.27	-.505
DZ	-.0037	1.55	-.008	.0025	1.69	.013	.0007	0.79	.011
T	-.9549	2.01	-.296	1.352	2.80	.969	.4010	2.25	.825
DLIFT	-11.47	1.35	-.009	-1.383	0.32	-.003	.5195	0.16	.003
Vp^{1*}	-.0046	1.33	-.069	-.0003	0.15	-.010	.0005	0.39	.051
Vp^{2*}	-.0027	0.36	-.024	.0070	1.57	.149	-.0037	1.32	-.223
Vp^{3*}	.0004	0.60	.022	.0004	1.02	.050	-.0007	3.17	-.294
Vp^{4*}	.0031	1.11	.095	-.0028	1.71	-.203	.0018	1.72	.369
constant	4.550	0.19	.101	54.76	2.72	2.80	-.1766	0.02	-.026
R^2/DW	.7965	1.77		.9505	1.70		.9401	2.04	

[a] Coefficients are in units of 10^{-2}.
[b] Elasticities are evaluated at data means.

Table 3.4: Estimates of Acreage Demands under Price Uncertainty CRRA

A. CWB Ep, market Vp, yield predetermined

	Wheat (AR1)			Barley (OLS)			Canola (OLS)		
	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]
r^{1*}	.1213	2.06	.275	-.0299	0.54	-.156	-.0062	0.21	-.094
r^{2*}	-.0817	1.81	-.147	.1323	2.46	.551	-.0187	0.65	-.224
r^{3*}	-.0985	2.32	-.207	-.0003	0.01	.002	.1130	4.62	1.58
r^{4}	21.26	4.57	.404	-13.87	2.79	-.611	.6645	0.25	.084
Wo^{*}	.0035	4.58	.325	-.0033	3.38	-.706	-.0005	0.95	-.304
Z	.0024	0.99	.413	-.0123	4.06	-4.74	-.0001	0.08	-.146
DZ	-.0005	0.31	-.001	.0055	3.03	.029	-.0003	0.25	-.004
T	-1.846	5.11	-.572	3.029	6.86	2.17	.4496	1.90	.925
DLIFT	-18.56	4.53	-.015	-1.995	0.38	-.004	-.3081	0.11	-.002
Vr^{1**}	-.0133	2.24	-.072	-.0009	0.15	.011	.0002	0.06	.006
Vr^{2**}	0	0.01	0	.0151	1.63	.174	-.0047	0.95	-.155
Vr^{3**}	.0129	4.11	.107	-.0026	0.79	-.050	-.0054	3.12	-.302
Vr^{4**}	.0062	0.71	.032	-.0183	1.77	-.217	.0085	1.55	.291
constant	20.65	1.63	.457	88.77	5.20	4.54	-4.468	0.49	-.656
R^2/DW	.9354	2.38		.9135	2.37		.9500	2.18	

Table 3.4: cont...

B. market Ep, market Vp, yield predetermined

	Wheat (AR1)			Barley (OLS)			Canola (OLS)		
	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]
r^{1*}	.2211	2.60	.452	-.0710	0.79	-.336	.0353	0.89	.478
r^{2*}	.0197	0.19	.033	.2701	2.38	1.05	-.1083	2.15	-1.21
r^{3*}	-.1329	3.14	-.292	.0284	0.61	.144	.0973	4.72	1.42
r^{4}	19.04	4.84	.355	-15.38	2.89	-.663	.8789	0.37	.108
Wo^{*}	.0030	3.04	.285	-.0033	2.82	-.734	-.0009	1.71	-.569
Z	.0023	0.83	.388	-.0103	2.87	-3.96	-.0008	0.49	-.858
DZ	.0009	0.44	.002	.0045	1.91	.024	-.0006	0.59	.010
T	-1.735	3.83	-.538	2.761	5.24	1.98	.7146	3.05	1.47
DLIFT	-14.37	3.44	-.012	-.4827	0.10	-.001	.6636	0.29	.004
Vr^{1**}	-.0104	2.35	-.055	.0061	1.03	.075	-.0003	0.11	-.011
Vr^{2**}	-0109	1.41	-.054	.0111	1.16	.126	-.0051	1.20	-.166
Vr^{3**}	.0106	3.83	.091	-.0072	2.12	-2.12	-.0051	3.37	-.290
Vr^{4**}	.0167	1.45	.085	-.0135	1.11	-1.11	.0073	1.34	.245
constant	11.66	0.49	.258	70.25	2.72	2.72	2.515	0.22	.370
R^2/DW	.9192	2.48		.8942	1.98		.9578	2.04	

Table 3.4: cont...

C. CWB Ep, market Vp, yield not predetermined

	Wheat (OLS)			Barley (OLS)			Canola (OLS)		
	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]
p^{1*}	.0546	1.79	.228	-.0195	0.64	-.189	-.0185	0.94	-.513
p^{2*}	.0236	0.57	.067	.0540	1.31	.352	-.0251	0.94	-.469
p^{3*}	-.0301	1.62	-.197	.0115	0.62	.175	.0298	2.49	1.29
p^{4}	27.92	5.53	.390	-20.55	4.10	-.664	-.9805	0.30	-.091
Wo^{*}	.0025	4.03	.329	-.0023	3.69	-.694	-.0002	0.41	-.143
Z	.0038	1.46	.633	-.0133	5.13	-5.11	0	0.02	.030
DZ	-.0025	1.84	-.006	.0044	3.26	.024	.0007	0.74	.010
T	-2.091	5.63	-.648	3.291	8.93	2.36	.5039	2.11	1.04
DLIFT	-13.97	2.71	-.012	-8.254	1.61	-.016	1.808	0.54	.010
Vp^{1**}	-.0042	2.64	-.080	-.0003	0.21	-.014	.0008	0.76	.098
Vp^{2**}	.0008	0.24	.009	.0077	2.36	.215	-.0033	1.57	-.266
Vp^{3**}	.0010	3.38	.086	-.0002	0.51	-.029	-.0006	3.21	-.347
Vp^{4**}	.0010	0.79	.042	-.0025	2.01	-.245	.0014	1.69	.383
constant	7.153	0.52	.158	94.43	6.98	4.83	-.2154	0.02	-.032
R^2/DW	.9367	2.35		.9353	2.34		.9452	2.03	

[a] Coefficients are in units of 10^{-2}.
[b] Elasticities are evaluated at data means.

Table 3.5: Test Results for Acreage Demands under Price Uncertainty

	Homogeneity		Reciprocity		CRTS		Zero Adj. Cost		-Vp		-Wo	
I. CARA	F-stat	Prob	F-stat	Prob	F-stat	Prob	F-stat	Prob	F-stat	Prob	F-stat	Prob
a. yield predetermined, CWB Ep, market Vp	1.93	0.139	0.71	0.551	5.81	0.002	2.52	0.071	1.62	0.122	-	-
b. yield predetermined, market Ep, market Vp	2.47	0.075	1.62	0.198	2.80	0.052	1.56	0.213	1.62	0.123	-	-
c. yield predetermined, CWB Ep, CWB Vp	1.67	0.186	2.23	0.098	8.42	.0002	3.08	0.038	1.46	0.180	-	-
d. yield not predetermined, CWB Ep, market Vp	1.56	0.214	-	-	6.71	0.001	3.02	0.040	1.70	0.101	-	-
e. yield not predetermined, market Ep, market Vp	3.49	0.024	-	-	3.15	0.035	2.07	0.118	1.68	0.065	-	-
f. yield not predetermined, CWB Ep, CWB Vp	1.41	0.252	-	-	12.98	0	4.03	0.013	1.77	0.087	-	-

Table 3.5: cont...

II. CRRA	Homogeneity F-stat	Homogeneity Prob	Reciprocity F-stat	Reciprocity Prob	CRTS F-stat	CRTS Prob	Zero Adj. Cost F-stat	Zero Adj. Cost Prob	-Vp F-stat	-Vp Prob	-Wo F-stat	-Wo Prob
a. yield predetermined, CWB Ep, market Vp	5.55	0.003	-	-	7.89	0.00	3.80	0.018	3.19	0.003	6.82	0.001
b. yield predetermined, market Ep, market Vp	3.54	0.023	-	-	3.83	0.01	2.51	0.073	3.14	0.003	4.05	0.013
c. yield predetermined, CWB Ep, CWB Vp	1.36	0.269	-	-	13.52	0	5.06	0.005	2.70	0.009	3.45	0.026
d. yield not predetermined, CWB Ep, market Vp	14.35	0	-	-	10.16	0	5.33	0.004	4.11	0.0004	9.26	0.0001
e. yield not predetermined, market Ep, market Vp	5.55	0.003	-	-	5.33	0.00	3.18	0.036	2.73	0.009	2.05	0.123
f. yield not predetermined, CWB Ep, CWB Vp	3.79	0.018	-	-	22.58	0	4.72	0.007	3.20	0.003	5.54	0.003

Note: Degrees of freedom for F-statistics are (a) (3,42) for all tests under CARA except for test of price covariance (-Vp) (12,42) and (b) (3,39) for all tests under CRRA except for test of price covariances (-Vp) (12,39).

Table 3.6: Estimates of Acreage Demands under Yield Uncertainty: Mean and Variance of Yields Predetermined

A. CWB Ep, CARA

	Wheat (OLS)			Barley (OLS)			Canola (OLS)		
	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]
r^{1*}	.3512	3.50	.845	-.2293	1.95	-1.15	-.0118	0.16	-.161
r^{2*}	-.4512	3.02	-.877	.4906	2.80	1.99	.0473	0.44	.520
r^{3*}	-.1109	2.16	-.250	-.0904	1.50	-.425	.1458	3.96	1.85
r^{4}	7.229	1.49	.151	-5.717	1.00	-.249	1.776	0.51	.209
Z	.0129	5.37	2.23	-.0145	5.15	-5.26	-.0005	0.29	-.487
DZ	-.0023	1.24	-.005	.0064	2.91	.027	0	0.01	0
T	-1.184	3.06	-.427	2.224	4.89	1.67	28.45	1.02	.579
DLIFT	-8.898	1.56	-.009	-.2857	0.04	-.001	-1.350	0.33	-.007
Vr^{1*}	-.0289	2.48	-.183	.0192	1.41	.254	.0039	0.48	.142
Vr^{2*}	.1039	2.13	.324	-.1152	2.01	-.749	-.0169	0.48	-.298
Vr^{3*}	.0390	1.59	.154	.0068	0.24	.056	-.0152	0.86	-.338
Vr^{4*}	-.1117	3.13	-.402	.0637	1.52	.478	.0191	0.75	.388
constant	-24.85	1.43	-.560	92.70	4.54	4.36	-11.01	0.88	-1.40
R^2/DW	.9274	1.54		.8387	2.00		.8980	1.90	

Table 3.6: cont...

B. market Ep, CARA

	Wheat (OLS)			Barley (OLS)			Canola (OLS)		
	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]
r^{1*}	.4093	4.00	.853	-.2552	1.46	-1.11	-.0313	0.50	-.369
r^{2*}	-.4490	3.27	-.775	.5598	2.43	2.05	.0546	0.65	.542
r^{3*}	-.0926	2.31	-.212	-.0529	0.77	-.252	.1035	4.17	1.33
r^{4}	4.677	1.40	.097	-3.886	0.68	-.168	3.443	1.67	.404
Z	.0144	6.57	2.50	-.0163	4.36	-5.91	-.0027	1.99	-2.64
DZ	-.0033	2.25	-.007	.0073	2.86	.032	.0012	1.33	.014
T	-.9345	3.50	-.337	1.917	4.22	1.44	.4439	2.69	.904
DLIFT	-1.933	0.46	-.002	-5.541	0.78	-.011	-2.312	0.89	-.012
Vr^{1*}	-.0490	3.58	-.233	.0317	1.36	.315	.0154	1.82	.415
Vr^{2*}	.2009	3.95	.511	-.1625	1.87	-.863	-.0865	2.75	-1.24
Vr^{3*}	.0224	1.22	.089	.0036	0.12	.030	-.0048	0.42	-.108
Vr^{4*}	-.1474	4.85	-.454	.0901	1.74	.579	.0486	2.59	.846
constant	-45.97	2.99	-1.030	103.3	3.95	4.86	7.190	0.76	.915
R^2/DW	.9547	1.86		.7871	1.83		.9527	1.65	

Table 3.6: cont...

C. CWB Ep, CRRA

	Wheat (OLS)			Barley (OLS)			Canola (OLS)		
	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]
r^{1*}	.2369	2.00	.570	-.1225	1.04	-.615	.0136	0.22	.185
r^{2*}	-.4806	2.71	-.934	.3806	2.15	1.54	.0812	0.86	.892
r^{3*}	-.0738	1.06	-.166	-.0741	1.06	-.348	.1141	3.07	1.45
r^{4}	2.277	0.36	.047	-9.468	1.49	-.412	5.088	1.51	.599
Wo^{*}	.0002	0.10	.016	-.0016	0.98	-.339	.0015	1.74	.864
Z	.0120	4.01	2.09	-.0131	4.34	-4.73	.0007	0.42	.662
DZ	-.0057	2.23	-.012	.0075	2.91	.032	.0016	1.16	.019
T	-1.154	1.62	-.416	2.454	3.45	1.85	-.2347	0.62	-.478
DLIFT	-19.05	1.45	-.019	3.723	0.28	.008	6.420	0.92	.035
Vr^{1**}	-.0218	1.35	-.138	.0147	0.91	.194	-.0031	0.36	-.112
Vr^{2**}	.1322	2.16	.484	-.077	1.26	-.588	-.0402	1.24	-.832
Vr^{3**}	.0227	0.85	.107	.0032	0.12	.031	-.0133	0.93	-.356
Vr^{4**}	-.0945	2.48	-.433	.0334	0.88	.319	.0243	1.20	.629
constant	-8.935	0.40	-.201	86.31	3.85	4.06	-20.12	1.68	-2.56
R^2/DW	.9078	1.90		.8513	2.31		.9288	1.80	

Table 3.6: cont...

D. market Ep, CRRA

	Wheat (OLS)			Barley (OLS)			Canola (AR1)		
	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]
r^{1*}	.3038	1.96	.634	-.2275	1.34	-.990	.0133	0.30	.157
r^{2*}	-.3354	1.75	-.590	.5348	2.54	1.96	-.1097	1.93	-1.09
r^{3*}	-.0766	1.04	-.175	-.0356	0.44	-.170	.0703	3.01	.907
r^{4}	-.0470	0.01	-.001	-4.645	0.67	-.201	7.737	4.73	.908
Wo^{*}	.0006	0.37	.065	-.0014	0.74	-.300	.0023	5.52	1.32
Z	.0127	3.16	2.21	-.0161	3.66	-5.85	.0028	2.66	2.75
DZ	-.0029	1.20	-.006	.0068	2.57	.029	.0005	0.71	.006
T	-.8654	1.16	-.312	2.031	2.48	1.53	-.6305	4.06	-1.28
DLIFT	1.889	0.19	.002	-7.089	0.65	-.014	5.213	1.72	.029
Vr^{1**}	-.0437	1.52	-.205	.0448	1.42	.439	-.0044	0.49	-.116
Vr^{2**}	.1760	2.38	.520	-.1599	1.97	-.986	-.0541	2.70	-.902
Vr^{3**}	-.0107	0.38	-.053	.0141	0.46	.147	.0069	0.85	.194
Vr^{4**}	-.0929	2.60	-.355	.0602	1.54	.480	.0015	0.17	.033
constant	-32.56	1.26	-.734	104.96	3.71	4.93	-15.02	2.51	-1.91
R^2/DW	.9050	1.63		.8152	2.09		.9796	1.76	

[a] Coefficients are in units of 10^{-2}.
[b] Elasticities are evaluated at data means.

Table 3.7: Test Results for Acreage Demands under Yield Uncertainty: Mean and Variance of Yield Predetermined

	Homogeneity		Reciprocity		CRTS		Zero Adj. Costs		-Vr		-Wo	
	F-stat	Prob	F-stat	Prob	F-stat	Prob	F-stat	Prob	F-stat	Prob	F-stat	Prob
I. CARA												
A. CWB Ep; Vp=0	1.87	0.156	3.41	0.030	12.27	0	3.78	0.020	2.45	0.023	-	-
B. market EP: Vp=0	1.45	0.247	2.13	0.117	21.61	0	5.22	0.005	5.56	0	-	-
C. CWB Ep, market Vp	0.15	0.926	1.25	0.309	3.79	0.020	2.33	0.094	1.32	0.257	-	-
D. market Ep, market Vp	1.08	0.371	2.04	0.129	1.97	0.139	1.26	0.307	1.25	0.295	-	-
E. CWB Ep, CWB Vp	2.11	0.120	1.07	0.374	6.80	0.001	2.54	0.075	1.61	0.141	-	-
II. CRRA												
A. CWB Ep; Vp=0	1.43	0.255	-	-	8.44	0	4.08	0.016	2.41	0.028	1.56	0.220
B. market EP: Vp=0	3.61	0.026	-	-	5.60	0.004	4.59	0.010	3.79	0.002	3.64	0.025
C. CWB Ep, market Vp	0.93	0.438	-	-	4.55	0.010	3.50	0.029	2.12	0.051	2.68	0.067
D. market Ep, market Vp	0.67	0.579	-	-	2.68	0.067	2.39	0.090	1.89	0.082	1.51	0.233
E. CWB Ep, CWB Vp	2.14	0.118	-	-	7.46	0.001	4.24	0.014	2.78	0.013	1.23	0.319

Note: Degrees of freedom for F-statistics are (a) (3,30) for all tests under CARA except for test of revenue covariance (-Vr) (12,30) and (b) (3,27) for all tests under CRRA except for test of revenue covariances (-Vr) (12,27).

Table 3.8: Estimates of Acreage Demands under Yield Uncertainty: Mean and Variance of Yield not Predetermined

A. CWB Ep (Vp=0)
(yield uncertainty only)

	Wheat (OLS)			Barley (OLS)			Canola (OLS)		
	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]
p^{1*}	-.0039	0.07	-.017	.0166	0.31	.155	.0185	0.54	.466
p^{2*}	.0086	0.11	.026	.0682	0.88	.425	-.0543	1.08	-.917
p^{3*}	-.0372	1.67	-.264	-.019	0.88	-.281	.0563	4.04	2.25
p^{4}	14.30	1.81	.212	-20.49	2.66	-.633	1.531	0.31	.128
Wo^{*}	.0021	1.92	.305	-.0024	2.30	-.741	.0001	0.07	.039
Z	.0137	5.33	2.38	-.0125	5.01	-4.54	-.0027	1.70	-2.68
DZ	-.0041	2.19	-.008	.0065	3.58	.028	.0006	0.49	.007
T	-2.023	3.24	-.729	3.130	5.15	2.35	.3807	0.97	.775
DLIFT	2.966	0.43	.003	-4.296	0.65	-.009	-5.369	1.25	-.030
E_{ω}	.0452	1.35	.305	-.0191	0.59	-.269	-.0210	0.99	-.801
V_{ω}	-.0005	1.49	-.102	.0001	0.46	.064	-.0001	0.69	-.169
constant	-4.926	2.23	-1.11	94.49	4.39	4.44	15.22	1.10	1.93
R^2/DW	.8911	1.91		.8334	1.81		.8830	2.14	

Table 3.8: cont...

B. CWB Ep, market Vp, CRRA
(price and yield uncertainty)

	Wheat (OLS)			Barley (OLS)			Canola (OLS)		
	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]
p^{1*}	-.0017	0.03	-.007	-.0674	1.13	-.625	.0441	1.56	1.11
p^{2*}	.1031	1.31	.308	.1137	1.27	.709	-.1346	3.16	-2.27
p^{3*}	-.0368	1.67	-.261	.0017	0.07	.026	.0452	3.80	1.81
p^4	31.18	3.28	.462	-12.67	1.18	-.391	-13.20	2.57	-1.10
Wo^*	.0031	3.05	.454	-.0014	1.22	-.430	-.0011	2.07	-.940
Z	.0058	1.73	1.01	-.0130	3.42	-4.70	.0031	1.70	3.02
DZ	-.0027	1.82	-.006	.0049	2.91	.021	.0001	0.09	.001
T	-2.390	4.53	-.862	2.784	4.66	2.09	.8318	2.92	1.69
DLIFT	-6.968	1.12	-.007	-4.341	0.62	-.009	2.467	0.73	.014
Vp^{1**}	-.0044	2.04	-.100	-.0014	0.56	-.065	.0034	2.85	.425
Vp^{2**}	.0042	0.90	.059	.0103	1.95	.301	-.0069	2.75	-.548
Vp^{3**}	.0009	2.64	.083	-.0002	0.46	-.034	-.0007	3.77	-.361
Vp^{4**}	.0003	0.21	.015	-.0027	1.62	-.278	.0010	1.29	.287
E_∞	.0567	1.62	.383	.0357	0.90	.504	-.0467	2.47	-1.78
V_∞	-.0001	0.38	-.022	-.0001	0.07	-.010	-.0004	2.48	-.435
constant	-22.50	1.18	-.507	82.67	3.84	3.88	.6559	0.06	.083
R^2/DW	.9632	2.19		.9239	2.93		.9708	2.73	

[a] Coefficients are in units of 10^{-2}.
[b] Elasticities are evaluated at data means.

Table 3.9: Estimates of Acreage Demands under Price Uncertainty (Yields Predetermined): Non-Linear CRRA Single Equation Models

A. CWB Ep, market Vp

	Wheat (AR1)		Barley		Canola		$EW/VW^{0.5}$[b]	
	coeff[a]	t-ratio	coeff[a]	t-ratio	coeff[a]	t-ratio	coeff[a]	t-ratio
r^{1*}	.5039	3.63	-.1216	0.65	-.0262	0.29	-2.938	0.28
r^{2*}	-.2030	1.62	.4926	2.41	-.0338	0.36	15.63	1.53
r^{3*}	-.3720	3.46	-.0127	0.09	.5169	4.97	3.207	0.37
r^{4}	13.54	0.70	-53.70	2.74	-1.013	0.12	-1077	1.14
Wo^{*}	-.0008	0.21	-.0137	3.87	-.0027	1.56	.0559	0.30
Z	-.0131	1.06	-.0581	4.62	.0031	0.53	2.209	3.82
DZ	.0092	1.52	.0264	3.37	-.0029	0.83	-.8774	2.52
T	3.953	1.24	13.43	6.50	1.596	2.06	-284.9	3.40
DLIFT	-58.73	3.49	-8.958	0.60	-1.544	0.18	638.8	0.65
Vr^{1**}	-.0321	2.18	.0034	0.18	.0003	0.03	.7430	0.66
Vr^{2**}	.0323	1.28	.0706	2.16	-.0182	1.22	-2.304	1.31
Vr^{3**}	.0289	3.11	-.0107	0.98	-.0221	3.78	-.1430	0.23
Vr^{4**}	.0116	0.49	-.0771	2.03	.0281	1.72	.3953	0.20
constant	188.5	2.77	409.2	5.48	-42.47	1.24	-10988	3.39
c_1	-698.5	4.07	-709.9	6.88	-479.5	4.37	-	-
c_2	3.084	2.51	2.127	0.81	-5.560	1.17	-	-
R^2/DW	.9398	2.04	.9155	2.27	.9530	1.96	.8721	1.23

Table 3.9: cont...

B. market Ep, market Vp

	Wheat		Barley		Canola		$EW/VW^{0.5b}$	
	coeff[a]	t-ratio	coeff[a]	t-ratio	coeff[a]	t-ratio	coeff[a]	t-ratio
r^{1*}	.9136	2.83	-.3898	1.40	.1571	1.23	8.741	0.67
r^{2*}	-.3549	0.82	.8387	2.00	-.4045	2.66	32.73	1.99
r^{3*}	-.5702	3.14	.0587	0.36	.3933	4.87	6.455	0.96
r^{4}	72.55	3.72	-50.85	2.73	2.645	0.39	-1188	1.54
Wo^{*}	.0133	3.05	-.0111	2.73	-.0039	2.05	-.1741	1.01
Z	.0028	0.17	-.0517	3.98	-.0027	0.57	1.823	3.49
DZ	.0025	0.26	.0219	2.66	.0023	0.77	-.6201	1.78
T	-5.677	2.63	11.79	6.84	2.818	3.66	-193.3	2.53
DLIFT	-67.62	3.58	-8.189	0.52	2.669	0.43	1027	1.40
Vr^{1**}	-.0562	2.42	.0184	0.93	-.0018	0.23	1.003	1.16
Vr^{2**}	-.0085	0.23	.0641	1.79	-.0193	1.62	-2.481	1.79
Vr^{3**}	.0492	3.73	-.0225	1.82	-.0197	4.20	-.6685	1.36
Vr^{4**}	.0529	1.20	-.0618	1.49	.0259	1.63	.9252	0.52
constant	125.7	1.16	358.3	4.12	5.143	0.15	-11211	2.99
c_1	-720.1	8.78	-698	7.19	-532.1	4.35	-	-
c_2	1.157	0.88	3.945	1.36	-1.819	0.43	-	-
R^2/DW	.9037	2.32	.9003	1.78	.9581	1.96	.8620	1.51

[a] Coefficients are in units of 10^{-2}.
[b] This linear reduced form equation is estimated by OLS.

Table 3.10: Estimates of Acreage Demands under Yield Uncertainty (Mean and Variance of Yields Predetermined): Non-Linear CRRA Single Equation Models

A. CWB Ep

	Wheat		Barley		Canola		$EW/VW^{0.5b}$	
	coeff[a]	t-ratio	coeff[a]	t-ratio	coeff[a]	t-ratio	coeff[a]	t-ratio
r^{1*}	1.067	2.21	-.2362	0.85	.0470	0.31	-5.476	1.25
r^{2*}	-1.903	2.37	.6209	1.24	.0989	0.47	15.25	2.33
r^{3*}	.0509	0.12	-.4843	3.31	.1531	1.40	8.106	3.14
r^4	5.451	0.21	-25.69	2.01	13.54	1.78	-129.1	0.55
Wo^*	-.0004	0.06	-.0029	0.93	.0039	1.91	-.0429	0.71
Z	.0525	3.69	-.0291	2.95	.0053	1.44	-.3250	2.91
DZ	-.0267	2.48	.0203	3.71	.0041	1.45	.1147	1.20
T	-5.761	2.07	6.697	3.60	-.2816	0.34	22.70	0.86
DLIFT	-57.37	0.94	-10.04	0.39	9.945	0.63	806.8	1.66
Vr^{1**}	-.1097	1.80	.0333	0.85	-.0118	0.58	.5062	0.85
Vr^{2**}	.5511	2.08	-.0905	0.59	-.0609	0.81	-3.821	1.69
Vr^{3**}	-.0394	0.24	.0968	1.64	.0105	0.28	-2.614	2.63
Vr^{4**}	-.4743	2.90	.0330	0.40	.0342	0.74	1.504	1.06
constant	56.40	0.48	215.3	3.54	-67.35	2.72	2785	3.35
c_1	-665.6	4.27	-782.5	6.54	-871.4	6.22	-	-
c_2	-15.95	1.36	15.39	3.16	17.67	2.99	-	-
R^2/DW	.9191	1.94	.8903	2.47	.9451	1.71	.9474	2.83

Table 3.10: cont...

B. market Ep

	Wheat		Barley		Canola		EW/VW$^{0.5b}$	
	coeff^a	t-ratio	coeff^a	t-ratio	coeff^a	t-ratio	coeff^a	t-ratio
r^{1*}	1.392	2.92	-.6018	1.94	.0287	0.26	-4.150	0.60
r^{2*}	-.9142	1.38	1.263	2.85	-.2852	1.44	10.70	1.25
r^{3*}	.2487	0.79	-.3565	2.49	.0710	1.11	8.467	2.57
r^4	5.085	0.25	-17.39	1.71	17.09	3.37	96.35	0.34
Wo^*	-.0002	0.03	-.0025	0.83	.0046	3.56	-.0480	0.62
Z	.0394	2.85	-.0366	3.74	.0078	2.54	-.3878	2.15
DZ	-.0123	1.63	.0191	3.74	.0019	0.95	.0472	0.44
T	-3.826	1.64	5.670	3.52	-.5431	0.94	10.63	0.32
DLIFT	4.030	0.14	-9.096	0.48	4.134	0.61	-117.2	0.26
Vr^{1**}	-.2039	2.50	.1260	2.29	.0059	0.24	.7456	0.58
Vr^{2**}	.6455	2.86	-.3105	1.80	-.1684	2.09	-4.207	1.27
Vr^{3**}	-.1697	1.80	.0070	1.44	.0615	2.72	-1.281	1.02
Vr^{4**}	-.4434	3.75	.1286	1.57	.0218	0.56	.8750	0.55
constant	-.9009	0.01	246.1	4.22	-46.64	2.56	3389	2.94
c_1	-464.5	3.90	-747.0	6.37	-906.5	7.67	-	-
c_2	-20.48	3.05	15.28	3.78	17.20	4.85	-	-
R^2/DW	.9423	1.97	.8810	2.78	.9752	2.65	.9219	2.46

[a] Coefficients are in units of 10^{-2}.
[b] This linear reduced form equation is estimated by OLS.

Table 3.11: Estimates of Acreage Demands under Price Uncertainty (Yields Predetermined): Non-Linear CRRA System Equation Models (SUR)

A. CWB Ep, market Vp

	Wheat		Barley		Canola	
	coeff^a	t-ratio	coeff^a	t-ratio	coeff^a	t-ratio
r^{1*}	1.066	3.26	-.2682	0.88	-.0541	0.38
r^{2*}	-.7211	2.16	1.106	3.41	-.1953	1.20
r^{3*}	-1.007	3.81	-.0205	0.08	1.007	6.21
r^4	201.2	6.79	-119.7	3.71	9.083	0.57
Wo^*	.0326	5.51	-.0301	4.87	-.0041	1.32
Z	-.0177	0.94	-.1241	6.33	-.0036	0.38
DZ	.0010	0.09	.0562	5.24	-.0009	0.15
T	-11.75	3.96	29.03	8.81	4.309	3.05
DLIFT	-176.9	6.00	-19.40	0.60	-2.217	0.13
Vr^{1**}	-.1545	4.60	.0078	0.23	.0017	0.09
Vr^{2**}	.0493	0.96	.1512	2.79	-.0461	1.46
Vr^{3**}	.1148	5.98	-.0236	1.24	-.0511	4.50
Vr^{4**}	.0809	1.43	-.1688	2.83	.0865	2.36
constant	418.0	3.89	877.4	7.68	-26.02	0.49
c_1	-1755	13.28	-1755	13.28	-1755	13.28
c_2	3.633	3.14	3.633	3.14	3.633	3.14
R^2/DW	.9301	2.73	.9154	2.29	.9478	2.26

Table 3.11: cont...

B. market Ep, market Vp

	Wheat		Barley		Canola	
	coeff[a]	t-ratio	coeff[a]	t-ratio	coeff[a]	t-ratio
r^{1*}	1.136	3.57	-.4651	1.43	.1751	1.10
r^{2*}	-.5490	1.35	1.395	3.24	-.6294	3.11
r^{3*}	-.7411	4.11	.1303	0.82	.5299	6.13
r^{4}	95.13	4.41	-81.22	4.00	5.963	0.64
Wo^{*}	.0173	3.80	-.0176	4.01	-.0046	2.16
Z	-.0022	0.14	-.0638	5.07	-.0048	0.77
DZ	.0051	0.53	.0277	3.16	.0037	0.87
T	-6.558	3.04	15.99	7.65	3.976	4.13
DLIFT	-88.83	4.89	6.200	0.34	3.699	0.41
Vr^{1**}	-.0743	3.38	.0313	1.52	-.0010	0.10
Vr^{2**}	-.0034	0.09	.0733	2.01	-.0298	1.79
Vr^{3**}	.0641	4.90	-.0372	2.92	-.0288	4.87
Vr^{4**}	.0648	1.51	-.0810	1.73	.0443	2.08
constant	197.7	1.77	438.5	4.86	19.69	0.44
c_1	-981.0	12.81	-981.0	12.81	-981.0	12.81
c_2	2.123	2.11	2.123	2.11	2.123	2.11
R^2/DW	.9031	2.30	.8978	1.91	.9572	2.10

[a] Coefficients are in units of 10^{-2}.

Table 3.12: Estimates of Acreage Demands under Yield Uncertainty (Mean and Variance of Yields Predetermined): Non-Linear CRRA System Equation Models (SUR)

A. CWB Ep

	Wheat		Barley		Canola	
	coeff^a	t-ratio	coeff^a	t-ratio	coeff^a	t-ratio
r^{1*}	2.490	3.62	-1.022	1.94	.1217	0.39
r^{2*}	-5.335	4.99	3.178	3.83	.6851	1.50
r^{3*}	-1.052	3.18	-.8852	2.51	.9108	4.56
r^4	30.03	0.87	-87.93	2.78	46.49	2.65
Wo^*	.0027	0.31	-.0135	1.80	.0137	3.13
Z	.1291	5.82	-.1132	6.18	.0081	1.07
DZ	-.0594	3.98	.0667	4.67	.0144	2.13
T	-11.93	2.85	22.26	5.29	-1.941	1.07
DLIFT	-218.9	2.87	15.89	0.27	53.57	1.49
Vr^{1**}	-.2254	2.53	.1301	1.75	-.0298	0.72
Vr^{2**}	1.457	4.50	-.6279	2.52	-.3451	2.20
Vr^{3**}	.3397	2.41	.0983	0.82	-.0909	1.27
Vr^{4**}	-.9731	5.16	.2663	1.72	.2078	2.16
constant	-165.2	1.42	760.9	5.55	-189.5	3.38
c_1	-1926	7.06	-1926	7.06	-1926	7.06
c_2	11.64	3.79	11.64	3.79	11.64	3.79
R^2/DW	.8942	1.98	.8681	2.36	.9351	1.74

Table 3.12: cont...

B. market Ep

	Wheat		Barley		Canola	
	coeff[a]	t-ratio	coeff[a]	t-ratio	coeff[a]	t-ratio
r^{1*}	2.390	3.42	-1.654	2.57	.1242	0.56
r^{2*}	-2.965	3.45	3.879	4.67	-.7171	2.60
r^{3*}	-.8398	2.33	-.4022	1.23	.5127	4.43
r^{4}	-.7530	0.03	-38.59	1.47	48.07	4.83
W^{o*}	.0068	0.88	-.0099	1.39	.0119	4.37
Z	.1104	5.48	-.116	6.42	.0127	2.03
DZ	.0229	2.06	.0502	4.73	.0039	1.14
T	-7.145	2.24	15.16	4.86	-2.301	2.12
DLIFT	20.02	0.43	-48.82	1.16	11.03	0.69
Vr^{1**}	-.3541	2.53	.0034	2.68	-.0177	0.39
Vr^{2**}	1.493	4.60	-1.132	3.62	-.3379	3.12
Vr^{3**}	-.0392	0.29	.1234	1.01	.0557	1.24
Vr^{4**}	-.7399	4.62	.4331	2.91	.0602	1.23
constant	-327.8	2.78	755.2	6.49	755.3	6.49
c_1	-1481	10.87	-1481	10.87	-1481	10.87
c_2	8.129	3.57	8.129	3.57	8.129	3.57
R^2/DW	.8772	1.68	.8377	2.20	.9630	2.85

[a] Coefficients are in units of 10^{-2}.

CHAPTER FOUR

DYNAMIC DUALITY MODELS OF CROP YIELDS

The few econometric studies of crop yield response to price have assumed essentially static risk-neutral models and have obtained mixed results. Houck and Gallagher (H-G) assumed that U.S. annual corn yield for 1951-71 depends on the ratio of fertilizer and corn prices (expectations were modelled as a one year lag), corn acres harvested, weather and dummies for acreage restrictions. Prices were significant in the estimated models, and the elasticity of yield with respect to corn price varied from 0.25 to 0.75. Menz and Pardey updated the H-G data to 1980 and concluded that price did not have a significant effect on yield for 1972-80. Reed and Riggins estimated a similar model for Kentucky corn yields 1960-79 and concluded that price was insignificant. Love and Foster estimated per acre production functions and fertilizer demands (rather than specifying yield as a function of price) for corn, wheat and soybeans using U.S. data, 1964-86. Since fertilizer input was insignificant in the per acre production functions, price did not appear to have a significant impact on yield. Choi and Helmburger estimated a similar model and concluded that yields are not sensitive to price changes.

In contrast, chapter two of this study estimated distributed lag models of crop yield response for major field crops in Manitoba, 1961-87. The study emphasized risk aversion and distributed lags based on the following assumptions: crop yields respond gradually to price changes, farmers are risk averse, and there is generally more uncertainty regarding prices in the distant future than in the immediate future (so that gradual or dynamic responses such as changes in yield presumably are more sensitive to price uncertainty than are reallocations of land among crops). Results indicated that distributed lag models of crop yield response are more appropriate than static models, and that risk aversion and price uncertainty influence crop yield respnse. These results demonstrate that it is feasible and perhaps essential to incorporate dynamics and risk aversion into models of crop yield price response. However a major criticism of the methodology in chapter two is the ad hoc nature of distributed lag models.

Duality theory has been extended to dynamics within an optimal control or calculus of variations framework (e.g. Epstein 1981b; Berndt, Fuss and Waverman) and has been applied to agriculture (e.g. Vasavada and Chambers; Stefanou; Howard and Shumway; Weersink and Tauer). However until recently (Coyle 1995b; Arnade and Coyle) all dynamic duality studies have assumed risk neutrality. Moreover dynamic duality models of crop yield response have not been formulated.

In contrast to the distributed lag models of chapter two, here we formulate and estimate optimal control models of crop yield response based on dynamic duality. These models incorporate risk aversion and price uncertainty. Yield uncertainty is not considered here because (a) it has not yet been incorporated into dynamic duality theory with risk aversion and (b) it may be less important than price uncertainty over a long time horizon as in most dynamic models (this assumes that weather shows less correlation over time than do prices, so effects of weather uncertainty are more likely to cancel out over time).

MODEL SPECIFICATION UNDER RISK NEUTRALITY

Models of crop yield decisions can be substantially simplified under the common assumption that crop technologies are approximately disjoint, i.e. the output level of an enterprise depends only on input levels for that enterprise (and not on levels of inputs allocated to other enterprises). In this case yield decisions for an enterprise conditional on acreage decisions can be specified as independent of prices for other outputs. It is convenient to specify yield decisions as conditional on acreage decisions because acreage decisions for an enterprise do depend on prices for other outputs, to the extent that total cropland for the farm is fixed in at least the short run (Shumway, Pope and Nash). The standard yield production function for enterprise i is $yld^i = yld^i(x^i, K^i, I^i, z^i)$ where (x^i, K^i, z^i) denote the levels of variable inputs, stock of capital and amount of cropland allocated to enterprise i, respectively, and I^i is gross capital investment in the enterprise. Investment I^i is an argument of the production function assuming that capital adjustment costs are internal to the firm. Assuming that cropland for enterprise i is fixed at level z_0^i, a standard dynamic optimization problem for yields would be

$$(1) \qquad \max_{\{(x^i(t), I^i(t))\}} \int_{t=0}^{\tau} [p^i \, yld^i(x^i(t), K^i(t), I^i(t), z_0^i) \, z_0^i - w \, x^i(t) - w^k \, K^i(t)] \, e^{-rt} \, dt$$

$$\text{s.t.} \qquad \dot{K}^i = I^i - \delta K^i \qquad\qquad K^i(0) = K_0^i$$

where p^i is output price, w is variable input price(s), w^k is rental price for capital, and r is a discount rate. In keeping with the usual convention in dynamic duality models, capital is costed at the rental rate. Alternatively the term $w^k K^i$ in the objective function can be replaced by $p^k I^i$ where p^k is the asset (purchase) price of capital.

There are several serious defects of the above standard optimal control model as a model of crop yield decisions: (a) crop acreage z^i and prices presumably should not be treated as fixed over the planning horizon and (b) costs of adjustment presumably should not be associated only with capital investment. Since farmers may well intend to alter the allocation of cropland among different crops over the planning period, the yield decision model for enterprise i should be specified as conditional on the time profile of planned acreages $\{z^i(t)\}$ over $t = 0,.,\tau$. Changes in planned yields involve changes in input proportions or techniques, and it is not necessarily the case that these changes are indexed perfectly by the level or vintage of capital. For example capital requirements per acre are essentially the same for major crops, so lags in yield adjustment should be similar for enterprises with increasing (decreasing) acreages if these lags are solely due to costs of capital adjustment. The substantial differences in estimates of distributed lag yield models between different crops (as reported in chapter two and appendix) suggest that lags in yield responses cannot be explained solely by lags in a common capital investment process.

The simplest tractable approach that incorporates these considerations into a dynamic model of yield response is to specify equations of motion for crop acreages, prices and yields in the model along with initial conditions. For simplicity we assume that the risk-neutral firm forms expectations for prices over the planning horizon but does not incorporate the possibility of acquiring new price information over time into its planning problem (risk is perceived in the plan as timeless rather than temporal, in the terminology of Machina). Relatively few dynamic duality models have incorporated temporal risk (Stefanou; Chavas). Model (1) can be modified as follows:

(2) $J^i(p_0^i, w, w^k, K_0^i, yld_0^i, z_0^i, r) =$

$$\max_{\{(x^i(t), I^i(t))\}} \int_{t=0}^{\tau} [p^i(t)\, yld^i(t)\, z^i(t) - w\, x^i(t) - w^k\, K^i(t)]\, e^{-rt}\, dt$$

$$\text{s.t.} \quad \dot{K}^i = I^i - \delta K^i \qquad K^i(0) = K_0^i$$

$$\dot{yld}^i = f^i(yld^i, x^i, K^i, I^i, z^i) \qquad yld^i(0) = yld_0^i$$

$$\dot{z}^i = g^i(z^i) \qquad z^i(0) = z_0^i$$

$$\dot{p}^i = h^i(p^i) \qquad p^i(0) = p_0^i.$$

Here the production function is specified as $yld^i = yld^i(x^i, K^i, \dot{yld}^i, I^i, z^i)$ or equivalently (assuming $\partial yld^i(.)/\partial \dot{yld}^i \neq 0$) as the equation of motion $\dot{yld}^i = f^i(yld^i, x^i, K^i, I^i, z^i)$, as above. This allows for internal adjustment costs with respect to both capital stocks and yields. Of course this generalization of the standard adjustment cost model retains the central weakness of such models, i.e. there is no explanation of the source or mechanism of adjustment costs. Since the yield decision problem is defined as conditional on acreage decisions, the equations of motion for both acreage z^i and output price p^i are exogenous to the problem in contrast to equations of motion for capital and yield.

Another generalization of the standard adjustment cost model will be considered here. The standard adjustment cost model $y = f(x,K,I)$

assumes that output y at time t depends only on current levels (at t) of x,K,I. However, as we shall see, this is quite restrictive in the sense that it does not lead to a general distributed lag model. A more general assumption is that output depends directly on lagged as well as current value of investment. In our case we shall assume that yields depend directly on lagged values of change in yield: $yld_t^i = yld^i(x_t^i, K_t^i, \dot{yld}_t^i, \dot{yld}_{t-1}^i, .., \dot{yld}_{t-s}^i, I_t^i, z_t^i)$ or equivalently $\dot{yld}_t^i = f^i(yld_t^i, x_t^i, K_t^i, \dot{yld}_{t-1}^i, .., \dot{yld}_{t-s}^i, I_t^i, z_t^i)$ where s is the length of the lag. Then the optimal control problem (2) is modified as follows:

$$(3) \quad J^i(p_0^i, w, w^k, K_0^i, yld_0^i, \dot{yld}_{-1}^i, .., \dot{yld}_{-s}^i, z_0^i, r) =$$

$$\max_{\{(x^i(t), I^i(t))\}} \int_{t=0}^{\tau} [p^i(t)\ yld^i(t)\ z^i(t) - w\ x^i(t) - w^k\ K^i(t)]\ e^{-rt}\ dt$$

$$\text{s.t.} \quad \dot{K}^i = I^i - \delta K^i \qquad K^i(0) = K_0^i$$

$$\dot{yld}^i = f^i(yld^i, x^i, K^i, L^s(\dot{yld}^i), I^i, z^i) \qquad yld^i(0) = yld_0^i$$

$$\dot{z}^i = g^i(z^i) \qquad z^i(0) = z_0^i$$

$$\dot{p}^i = h^i(p^i) \qquad p^i(0) = p_0^i$$

where $L^s(\dot{yld}^i)$ denotes the s period distributed lag in $\dot{yld}^i$.

Since problems (2) and (3) are autonomous, and assuming an infinite planning horizon ($\tau = \infty$), the corresponding Hamilton-Jacobi equations at t = 0 can be expressed as

$$(4) \quad r\ J^i(.) - \partial J^i(.)/\partial z_0^i\ g^i(.) - \partial J^i(.)/\partial p_0^i\ h^i(.)$$

$$= \max_{(x^i, I^i)} p^i\ yld^i\ z^i - w\ x^i - w^k\ K^i$$

$$+ \partial J^i(.)/\partial K_0^i\ (I^i - \delta K^i) + \partial J^i(.)/\partial yld_0^i\ f^i(.)\ .$$

For example, Epstein and Denny (Appendix A) and Luh and Stefanou state somewhat analogous Hamilton-Jacobi equations. Applying the envelope theorem to (4) with respect to prices p_0^i, w and w^k, respectively,

$$\text{(5a)}\quad r\, \partial J^i/\partial p_0^i - \partial^2 J^i/\partial z_0^i \partial p_0^i\, g^i(.) - \partial^2 J^i/\partial p_0^{i2}\, h^i(.) - \partial J^i/\partial p_0^i\, \partial h^i/\partial p_0^i$$
$$= yld^i\, z^i + \partial^2 J^i(.)/\partial K_0^i \partial p_0^i\, (I^i - \delta\, K^i) + \partial^2 J^i(.)/\partial yld_0^i \partial p_0^i\, f^i(.)$$

$$\text{(5b)}\quad r\, \partial J^i/\partial w - \partial^2 J^i/\partial z_0^i \partial w\, g^i(.) - \partial^2 J^i/\partial p_0^i \partial w\, h^i(.)$$
$$= -x^i + \partial^2 J^i(.)/\partial K_0^i \partial w\, (I^i - \delta\, K^i) + \partial^2 J^i(.)/\partial yld_0^i \partial w\, f^i(.)$$

$$\text{(5c)}\quad r\, \partial J^i/\partial w^k - \partial^2 J^i/\partial z_0^i \partial w^k\, g^i(.) - \partial^2 J^i/\partial p_0^i \partial w^k\, h^i(.)$$
$$= -K^i + \partial^2 J^i(.)/\partial K_0^i \partial w^k\, (I^i - \delta\, K^i) + \partial^2 J^i(.)/\partial yld_0^i \partial w^k\, f^i(.) \quad .$$

Equations (5) specify yield supply, variable input demand and investment demand equations in terms of the functional form for the dual $J^i(.)$. Since capital requirements per acre are similar for different crops, equations (5a) and (5c) can be estimated given data on total physical capital in crops. On the other hand, variable input requirements per acre do vary by crop. In order to estimate variable input demand equations given data on total employment of variable inputs in crops, we can define a dual J(.) as the sum of duals $J^i(.)$ for all crops: J(.) = $\Sigma_{i=1}^{M}\ J^i(.)$. Then envelope relations similar to (5) apply to J(.), specifying a yield supply equation for each crop and aggregate demand equations for variable inputs and capital investment. The duals $J^i(.)$ and J(.) have standard homogeneity and convexity properties if $h^i(.)$ in equations of motion for price are linear homogeneous in price (Epstein 1981b; Luh and Stefanou).

MODEL SPECIFICATION UNDER RISK AVERSION

The mean-variance approach has usually been applied under the assumption of linearity. The firm's utility function is

(6) $\quad U = EW - (\alpha/2)\ VW \qquad \alpha > 0$

where α is a constant coefficient of absolute risk aversion, and (EW,VW) are the mean and variance of the distribution for the net present value of terminal wealth W. In forming its production plan, the firm assumes that output price p^i is a random variable distributed independently but with mean and variance (Ep and Vp) changing over time. For simplicity the firm does not incorporate the possibility of acquiring new price information over time into its planning problem (risk is timeless rather than temporal). The mean and variance of terminal wealth W^i from production in enterprise i are

$$(7) \quad EW^i = \int_{t=0}^{\tau} [Ep^i(t)\ yld^i(t)\ z^i(t) - w\ x^i(t) - w^k\ K^i(t)]\ e^{-rt}\ dt$$

$$VW^i = \int_{t=0}^{\tau} Vp^i(t)\ (yld^i(t)\ z^i(t))^2\ e^{-2rt}\ dt \quad .$$

The risk-neutral problem (2) can be generalized to linear mean-variance risk preferences as follows:

$$(8) \quad J^i(Ep_0^i, w, w^k, Vp_0^i, K_0^i, yld_0^i, z_0^i, r) =$$

$$\max_{\{(x^i(t), I^i(t))\}} \int_{t=0}^{\tau} [Ep^i(t)\ yld^i(t)\ z^i(t) - w\ x^i(t) - w^k\ K^i(t)]\ e^{-rt}\ dt$$

$$- (\alpha/2) \int_{t=0}^{\tau} Vp^i(t)\ (yld^i(t)\ z^i(t))^2\ e^{-2rt}\ dt$$

$$\begin{array}{lllll}
\text{s.t.} & \dot{K}^i & = I^i - \delta K^i & K^i(0) & = K_0^i \\
& \dot{yld}^i & = f^i(yld^i, x^i, K^i, I^i, z^i) & yld^i(0) & = yld_0^i \\
& \dot{z}^i & = g^i(z^i) & z^i(0) & = z_0^i \\
& \dot{Ep}^i & = h^i(Ep^i) & Ep^i(0) & = Ep_0^i \\
& \dot{Vp}^i & = k^i(Vp^i) & Vp^i(0) & = Vp_0^i
\end{array}$$

where an additional equation of motion is added for price variance Vp. Similarly model (3) is generalized to linear mean-variance risk preferences as

$$(9)\quad J^i(Ep_0^i, w, w^k, Vp_0^i, K_0^i, yld_0^i, \dot{yld}_{-1}^i, .., \dot{yld}_{-s}^i, z_0^i, r) =$$

$$\max_{\{(x^i(t), I^i(t))\}} \int_{t=0}^{\tau} [Ep^i(t)\ yld^i(t)\ z^i(t) - w\ x^i(t) - w^k\ K^i(t)]\ e^{-rt}\ dt$$

$$- (\alpha/2) \int_{t=0}^{\tau} Vp^i(t)\ (yld^i(t)\ z^i(t))^2\ e^{-2rt}\ dt$$

$$\text{s.t.} \quad \dot{K}^i = I^i - \delta\ K^i \qquad K^i(0) = K_0^i$$

$$\dot{yld}^i = f^i(yld^i, x^i, K^i, L(\dot{yld}^i), I^i, z^i) \qquad yld^i(0) = yld_0^i$$

$$\dot{z}^i = g^i(z^i) \qquad z^i(0) = z_0^i$$

$$\dot{Ep}^i = h^i(p^i) \qquad Ep^i(0) = Ep_0^i$$

$$\dot{Vp}^i = k^i(Vp^i) \qquad Vp^i(0) = Vp_0^i.$$

Assuming an infinite planning horizon ($\tau = \infty$), the Hamilton-Jacobi equations at $t = 0$ corresponding to (8) and (9) are

$$(10)\quad r\ J^i(.) - \partial J^i(.)/\partial z_0^i\ g^i(.) - \partial J^i(.)/\partial Ep_0^i\ h^i(.) - \partial J^i(.)/\partial Vp_0^i\ k^i(.)$$

$$= \max_{(x^i, I^i)} Ep^i\ yld^i\ z^i - w\ x^i - w^k\ K^i - (\alpha/2)\ Vp^i\ (yld^i\ z^i)^2$$

$$+ \partial J^i(.)/\partial K_0^i\ (I^i - \delta\ K^i) + \partial J^i(.)/\partial yld_0^i\ f^i(.)\ .$$

Hamilton-Jacobi equations under linear mean-variance risk preferences are derived by Arnade and Coyle. Applying the envelope theorem to (10) with respect to prices Ep_0^i, w and w^k, respectively,

$$(11a)\quad r\ \partial J^i/\partial Ep_0^i - \partial^2 J^i/\partial z_0^i \partial Ep_0^i\ g^i(.) - \partial^2 J^i/\partial Ep_0^{i2}\ h^i(.)$$

$$- \partial J^i/\partial Ep_0^i\ \partial h^i/\partial Ep_0^i - \partial^2 J^i(.)/\partial Vp_0^i \partial Ep_0^i\ k^i(.)$$

$$= yld^i\ z^i + \partial^2 J^i(.)/\partial K_0^i \partial Ep_0^i\ (I^i - \delta\ K^i) + \partial^2 J^i(.)/\partial yld_0^i \partial Ep_0^i\ f^i(.)$$

$$(11b)\quad r\ \partial J^i/\partial w - \partial^2 J^i/\partial z_0^i \partial w\ g^i(.) - \partial^2 J^i/\partial Ep_0^i \partial w\ h^i(.)$$

$$- \partial^2 J^i(.)/\partial Vp_0^i \partial w\ k^i(.)$$

$$= -x^i + \partial^2 J^i(.)/\partial K_0^i \partial w\ (I^i - \delta\ K^i) + \partial^2 J^i(.)/\partial yld_0^i \partial w\ f^i(.)$$

$$(11c)\quad r\,\partial J^i/\partial w^k - \partial^2 J^i/\partial z_0^i \partial w^k\, g^i(.) - \partial^2 J^i/\partial Ep_0^i \partial w^k\, h^i(.) - \partial^2 J^i/\partial Vp_0^i \partial w^k\, k^i(.)$$
$$= -K^i + \partial^2 J^i(.)/\partial K_0^i \partial w^k\, (I^i - \delta\, K^i) + \partial^2 J^i(.)/\partial yld_0^i \partial w^k\, f^i(.) \quad .$$

Homogeneity and convexity properties are similar to Arnade and Coyle. As in risk-neutral models, it is often convenient to estimate equations (11) in terms of an dual $J(.) = \Sigma_{i=1}^{M} J^i(.)$.

In principle dynamic duality models of crop yields can also be constructed assuming nonlinear mean-variance risk preferences. The corresponding utility function is $U = W_0 + EW - \alpha(W_0 + EW, VW)/2\ \ VW$, where W_0 is initial (nonrandom) wealth and (EW,VW) are the mean and variance of the distribution of the net present value of the terminal wealth W from production in all enterprises. Tractable envelope relations can be derived for such models (e.g. Coyle 1995b). However nonlinearity of the mean-variance relation implies that yield decisions for an enterprise (conditional on acreage decisions) can no longer be specified as independent of prices for other outputs. For example a change in expected output price Ep^j for enterprise j implies a change in equilibrium expected wealth EW^* and in turn a change in the equilibrium coefficient of absolute risk aversion $\alpha^* = \alpha(W_0 + EW^*, VW^*)$, which affects yield decisions in any other enterprise i (even controlling for acreage decisions). Due to this substantial increase in model complexity, nonlinear mean-variance dynamic duality models of crop yield decisions will not be considered here.

DATA

Yield models were constructed for the following major crops in Manitoba using annual data for 1961-87: wheat, barley, oats, canola, flax and rye. This corresponds to the period for which a crop growth index of weather conditions was available for Manitoba. Expected crop output prices were modeled using data on market prices and Canadian Wheat Board (CWB) payments for crops (Statistics Canada b, Canadian Wheat Board). Four alternative measures of expected crop prices were considered: (a) a one year lag on market prices, (b) a one year lag in market prices plus the difference between one and two period lags in market prices, (c) the sum of the most recently observed components of CWB payments at planting time (current initial payments, plus adjustment and interim payments for crop marketed in the previous year, plus final payment for crop marketed two years previously) for crops covered by the CWB (wheat, barley and oats), and (d) predicted values of market prices plus government payments from time series models. Case (b) will be referred to as expected CWB prices and was found to be useful in explaining crop acreage decisions in Western Canada (Coyle 1993). Alternative proxies for variances of crop prices were calculated somewhat similarly (see below).

Input price indexes were obtained for hired labor, machinery and equipment, and variable inputs (e.g. fertilizer) for crops (Statistics Canada a). An index of the stock of physical capital in the crop sector was calculated as the current value of machinery and equipment (Statistics Canada b) deflated by its price index, and a quantity index of crop variable inputs was costructed in a similar manner. Crop acreages were defined as the estimated areas sown annually for harvest (Statistics Canada c,d). Weather was proxied by a crop growth index GRODEX (Dyer, Narayanan and Murray). As in most empirical applications of dynamic duality, a constant real rate of discount r is assumed. Here r = 0.03 as in the study of U.S. agriculture by Howard and Shumway.

RESULTS FOR RISK-NEUTRAL MODELS

A normalized quadratic functional form is assumed for the duals to the optimal control problems (2):

$$(12)\quad J^{i*} = \beta_{i0} + \Sigma_j \beta_{ij} v_i^j + 1/2\, \Sigma_j \Sigma_k \beta_{ijk} v_i^j v_i^k \qquad i = 1,.,6$$

where $v_i \equiv (Ep^{i*}, w^{2*}, w^{k*}, LKZ, z^i, Lyld^i, t)$, $J^{i*} = J^i / (w^1 z^i)$, $Ep^{i*} = Ep^i / w^1$ $(i = 1,.,6)$, $w^{2*} = w^2 / w^1$, $w^{k*} = w^k / w^1$, $J^* = J / (w^1 Z)$. Ep^i is expected crop output price for enterprise i, w^1 is the hired labor wage (the numeraire price), w^2 is the price index for variable crop inputs, w^k is a proxy for the rental price of capital, LKZ is a one year lag on the ratio of total stock of machinery and equipment to total cropland (K/Z is a proxy for K^i/Z^i), z^i is acres in crop i, $Lyld^i$ is a one year lag in crop yield for enterprise i, and t is a time trend. The assumption of disjoint technologies and the specification of yield decisions conditional on acreage decisions simplifies the structure of the dual with respect to Ep^*, z and Lyld, i.e. there are no interactions between these variables for different enterprises. Constant returns to scale for the enterprise technology implies that z^i can be excluded from v_i in (12), so that (12) provides a second order differential approximation to J irrespective of constant returns to scale. Second order differential approximations to the dual such as (12) are quite restrictive since dynamic optimization implies third order properties of the dual (Epstein 1981b), but nevertheless most econometric applications of dynamic duality assume only second order approximations to the dual in order to keep the model tractable.

The following approximations were used in equations of motion for (2):

$$\text{(13)} \quad \dot{K}^i_t = K^i_t - K^i_{t-1} \qquad \dot{yld}^i_t = yld^i_t - yld^i_{t-1}$$

$$\dot{z}^i_t = z^i_t - z^i_{t-1} \qquad \dot{Ep}^i_t = Ep^i_t - Ep^i_{t-1} \quad .$$

Consequently a one year lag of the endogenous variables yield and capital stock are specified as exogenous in the dual. On the other hand current price expectations are expressed as parameters of the dual: Ep_t is defined and exogenous at time t, and the static nature of expectations models emphasized here implies that the anticipated change in (expected) prices $\dot{Ep}^i_t$ is proxied by the most recently observed change in prices, $Ep^i_t - Ep^i_{t-1}$. Similarly, since problem (2) is conditional on crop acreages as well as expected prices, we can select current acreages as parameters of the dual and proxy $\dot{z}^i_t$ by $z^i_t - z^i_{t-1}$.

The Hamilton-Jacobi equation (4) evaluated at t can be expressed in terms of the functional form $J^{i*}(.)$ (12) as (dividing both sides of (4) by $w^1_t\ z^i_t$, which leaves the solution unchanged)

$$\text{(14)} \quad r\ J^{i*}(.) - (\partial J^{i*}(.)/\partial z^i + J^{i*}/z^i)\ \dot{z}^i - \partial J^{i*}(.)/\partial Ep^{i*}\ \dot{Ep}^i/w^1$$

$$= \max_{(x^i, I^i)} \quad Ep^{i*}\ yld^i - w^*\ x^i/z^i - w^{k*}\ K^i/z^i$$

$$+ \partial J^{i*}(.)/\partial \tilde{K}^i\ (I^i - \delta\ K^i)/z^i + \partial J^{i*}(.)/\partial yld^i\ \dot{yld}^i$$

where $\tilde{K}^i \equiv K^i / z^i$. In order to verify that (14) is equivalent to (4) divided by $w^i z^i$, note that $J^{i*} \equiv J^i / w^1 z^i$ and $Ep^{i*} \equiv Ep^i / w^1$ implies $\partial J^{i*}(.)/\partial Ep^{i*} = \partial J^i(.)/\partial Ep^i /z^i$, $\partial J^{i*}(.)/\partial \tilde{K}^i = \partial J^i(.)/\partial K^i /w^1$, $\partial J^{i*}(.)/\partial yld^i = \partial J^i(.)/\partial yld^i /w^1 z^i$, and $\partial J^i(.)/\partial z^i = \partial J^{i*}(.)/\partial z^i w^1 z^i + J^{i*} w^1$. Applying the envelope theorem to (14) with respect to Ep^{i*} implies (similarly to (5a)),

$$(15) \quad r\, \partial J^{i*}/\partial Ep^{i*} - \partial^2 J^{i*}/\partial z^i \partial Ep^{i*}\, \dot{z}^i - (1/z^i)\, \partial J^{i*}/\partial Ep^{i*}\, \dot{z}^i$$
$$- \partial^2 J^{i*}/\partial Ep^{i*2}\, \dot{Ep}^i/w^1 - \partial J^{i*}/\partial Ep^{i*}\, \partial(\dot{Ep}^i/w^1)/\partial Ep^{i*}$$
$$= yld^i + \partial^2 J^{i*}(.)/\partial \tilde{K}^i \partial Ep^{i*}\, \dot{K}^i/z^i + \partial^2 J^{i*}(.)/\partial yld^i \partial Ep^{i*}\, \dot{yld}^i \,.$$

Approximating as in (13) and solving for yield of crop i,

$$(16) \quad yld_t^i = \{r\, \partial J^{i*}/\partial Ep_t^{i*} - \partial^2 J^{i*}/\partial z_t^i \partial Ep_t^{i*}\, (z_t^i - z_{t-1}^i)$$
$$- (1/z_t^i)\, \partial J^{i*}/\partial Ep_t^{i*}\, (z_t^i - z_{t-1}^i)$$
$$- \partial^2 J^{i*}/\partial Ep_t^{i*2}\, (Ep_t^i - Ep_{t-1}^i)/w_t^1 - \partial J^{i*}/\partial Ep_t^{i*}$$
$$- \partial^2 J^{i*}(.)/\partial \tilde{K}_{t-1} \partial Ep_t^{i*}\, (K_t - K_{t-1})/Z_t$$
$$+ \partial^2 J^{i*}(.)/\partial yld_{t-1}^i \partial Ep_t^{i*}\, yld_{t-1}^i\}$$
$$/ \{1 + \partial^2 J^{i*}(.)/\partial yld_{t-1}^i \partial Ep_t^{i*}\}$$
$$= \{(r - 1 - (z_t^i - z_{t-1}^i)/z_t^i)\, \partial J^{i*}/\partial Ep_t^{i*} - \partial^2 J^{i*}/\partial z_t^i \partial Ep_t^{i*}\, (z_t^i - z_{t-1}^i)$$
$$- \partial^2 J^{i*}/\partial Ep_t^{i*2}\, (Ep_t^i - Ep_{t-1}^i)/w_t^1$$
$$- \partial^2 J^{i*}(.)/\partial \tilde{K}_{t-1} \partial Ep_t^{i*}\, (K_t - K_{t-1})/Z_t$$
$$+ \partial^2 J^{i*}(.)/\partial yld_{t-1}^i \partial Ep_t^{i*}\, yld_{t-1}^i\}$$
$$/ \{1 + \partial^2 J^{i*}(.)/\partial yld_{t-1}^i \partial Ep_t^{i*}\} \qquad i = 1,.,6$$

where $\tilde{K}_{t-1} \equiv (K/Z)_{t-1}$.

Specifying $\partial J^{i*}/\partial Ep_t^{i*}$ as

$$(17) \quad \partial J^{i*}/\partial Ep_t^{i*} = a_i + a_{i1}\, Ep_t^{i*} + a_{i2}\, w_t^{2*} + a_{i3}\, w_t^{k*} + a_{i4}\, t + a_{i5}\, \tilde{K}_{t-1}$$
$$+ a_{i6}\, z_t^i + a_{i7}\, yld_{t-1}^i \qquad i = 1,.,6$$

and substituting into (16),

$$(18)\quad yld_t^i = \{(r - 1 - (z_t^i - z_{t-1}^i)/z_t^i)\ (a_i + a_{i1}\ Ep_t^{i*} + a_{i2}\ w_t^{2*} + a_{i3}\ w_t^{k*} + a_{i4}\ t + a_{i5}\ \tilde{K}_{t-1} + a_{i6}\ z_t^i + a_{i7}\ yld_{t-1}^i)$$
$$- a_{i6}\ (z_t^i - z_{t-1}^i) \ - a_{i1}\ (Ep_t^i - Ep_{t-1}^i)/w_t^1$$
$$- a_{i5}\ (K_t - K_{t-1})/Z_t + a_{i7}\ yld_{t-1}^i\}$$
$$/\ \{1 + a_{i7}\}$$
$$= \{(r - 1 - (z_t^i - z_{t-1}^i)/z_t^i)\ (a_i + a_{i2}\ w_t^{2*} + a_{i3}\ w_t^{k*} + a_{i4}\ t)$$
$$+ a_{i1}\ ((r - 1 - (z_t^i - z_{t-1}^i)/z_t^i) Ep_t^{i*} - (Ep_t^i - Ep_{t-1}^i)/w_t^1)$$
$$+ a_{i5}\ ((r - 1 - (z_t^i - z_{t-1}^i)/z_t^i)\ \tilde{K}_{t-1} \ - (K_t - K_{t-1})/Z_t)$$
$$+ a_{i6}\ ((r - 1 - (z_t^i - z_{t-1}^i)/z_t^i) z_t^i - (z_t^i - z_{t-1}^i))$$
$$+ a_{i7}\ ((r - 1 - (z_t^i - z_{t-1}^i)/z_t^i) yld_{t-1}^i + yld_{t-1}^i)\}$$
$$/\ \{1 + a_{i7}\} \qquad\qquad i = 1,.,6\ .$$

Equations (18) can be estimated by linear methods as

$$(19)\quad yld_t^i = (r - 1 - (z_t^i - z_{t-1}^i)/z_t^i)\ (b_i + b_{i2}\ w_t^{2*} + b_{i3}\ w_t^{k*} + b_{i4}\ t)$$
$$+ b_{i1}\ ((r - 1 - (z_t^i - z_{t-1}^i)/z_t^i) Ep_t^{i*} - (Ep_t^i - Ep_{t-1}^i)/w_t^1)$$
$$+ b_{i5}\ ((r - 1 - (z_t^i - z_{t-1}^i)/z_t^i)\ \tilde{K}_{t-1} \ - (K_t - K_{t-1})/Z_t)$$
$$+ b_{i6}\ ((r - 1 - (z_t^i - z_{t-1}^i)/z_t^i) z_t^i - (z_t^i - z_{t-1}^i))$$
$$+ b_{i7}\ ((r - 1 - (z_t^i - z_{t-1}^i)/z_t^i) yld_{t-1}^i + yld_{t-1}^i)$$
$$i = 1,.,6$$

where coefficients of the structural equations (18) can be solved as

$$(20)\quad a_{i7} = b_{i7}\ /\ (1 - b_{i7})$$
$$a_i = b_i\ (1 + a_{i7}) \qquad a_{ij} = b_{ij}\ (1 + a_{i7}) \qquad i,j = 1,.,6\ .$$

In the case of model (3) where the equation of motion for yield involves an s-period lag on $\dot{yld}^i$, $\partial J^{i*}/\partial Ep_t^{i*}$ is specified as (instead of (17))

$$(21)\quad \partial J^{i*}/\partial Ep_t^{i*} = a_i + a_{i1}\ Ep_t^{i*} + a_{i2}\ w_t^{2*} + a_{i3}\ w_t^{k*} + a_{i4}\ t + a_{i5}\ \tilde{K}_{t-1}$$

$$+ a_{i6}\, z_t^i + a_{i7}\, yld_{t-1}^i + \Sigma_{s=1}^{S}\, \gamma_s\, (yld_{t-s}^i - yld_{t-s-1}^i)$$

$$i = 1,.,6 \; .$$

Then the reduced form equation for yield analogous to (19) is

$$\begin{aligned}
(22)\quad yld_t^i = {} & (r - 1 - (z_t^i - z_{t-1}^i)/z_t^i)\ (b_i + b_{i2}\, w_t^{2*} + b_{i3}\, w_t^{k*} + b_{i4}\, t \\
& + \Sigma_{s=1}^{S}\, \tilde{\gamma}_s\, (yld_{t-s}^i - yld_{t-s-1}^i)) \\
& + b_{i1}\ ((r - 1 - (z_t^i - z_{t-1}^i)/z_t^i)Ep_t^{i*} - (Ep_t^i - Ep_{t-1}^i)/w_t^1) \\
& + b_{i5}\ ((r - 1 - (z_t^i - z_{t-1}^i)/z_t^i)\ \tilde{K}_{t-1}/Z_t - (K_t - K_{t-1})/Z_t) \\
& + b_{i6}\ ((r - 1 - (z_t^i - z_{t-1}^i)/z_t^i)z_t^i - (z_t^i - z_{t-1}^i)) \\
& + b_{i7}\ ((r - 1 - (z_t^i - z_{t-1}^i)/z_t^i)yld_{t-1}^i + yld_{t-1}^i) \qquad i = 1,.,6
\end{aligned}$$

where coefficients of the corresponding structural equations can be calculated in a manner similar to (20).

Demand equations for variable crop input and investment in model (2) can be constructed in a similar manner from the multienterprise dual $J^* = \Sigma_{i=1}^{6}\, J^{i*}$ where J^* is a normalized ($J^* = J\ /\ (w^1\ Z)$) quadratic $J^* = \beta_0 + \Sigma_j\ \beta_j\ v^j + 1/2\ \Sigma_j\ \Sigma_k\ \beta_{jk}\ v^j\ v^k$ in $v \equiv (Ep^*, w^{2*}, w^{k*}, LKZ, Z, Lyld, t)$. Then equations (5b-c) and approximations (13) imply

$$\begin{aligned}
(23)\quad & r\ \partial J^*/\partial w_t^{2*} - \partial^2 J^*/\partial Z_t \partial w_t^{2*}\ (Z_t - Z_{t-1}) - (1/Z_t)\ \partial J^*/\partial w_t^{2*}\ (Z_t - Z_{t-1}) \\
& - \Sigma_i\ \partial^2 J^*/\partial Ep_t^{i*} \partial w_t^{2*}\ (Ep_t^i - Ep_{t-1}^i)/w_t^1 \\
& = - x_t^2/Z_t + \partial^2 J^*(.)/\partial \tilde{K}_{t-1} \partial w_t^{2*}\ (K_t - K_{t-1})/Z_t \\
& \quad + \Sigma_i\ \partial^2 J^*(.)/\partial yld_{t-1}^i \partial w_t^{2*}\ (yld_t^i - yld_{t-1}^i) \\
(24)\quad & r\ \partial J^*/\partial w_t^{k*} - \partial^2 J^*/\partial Z_t \partial w_t^{k*}\ (Z_t - Z_{t-1}) - (1/Z_t)\ \partial J^*/\partial w_t^{k*}\ (Z_t - Z_{t-1}) \\
& - \Sigma_i\ \partial^2 J^*/\partial Ep_t^{i*} \partial w_t^{k*}\ (Ep_t^i - Ep_{t-1}^i)/w_t^1 \\
& = - K_t/Z_t + \partial^2 J^*(.)/\partial \tilde{K}_{t-1} \partial w_t^{k*}\ (K_t - K_{t-1})/Z_t \\
& \quad + \Sigma_i\ \partial^2 J^*(.)/\partial yld_{t-1}^i \partial w_t^{k*}\ (yld_t^i - yld_{t-1}^i) \quad .
\end{aligned}$$

$\partial J^*(.)/\partial w^{2*}$ and $\partial J^*(.)/\partial w^{k*}$ are specified as

$$(25)\quad \partial J^*/\partial w_t^{2*} = \beta_7 + \Sigma_{i=1}^{6}\ \beta_{7i}\ Ep_t^{i*} + \beta_{77}\ w_t^{2*} + \beta_{78}\ w_t^{k*} + \beta_{79}\ \tilde{K}_{t-1}$$

$$+ \beta_{710}\, Z_t + \Sigma_{i=1}^{6} \beta_{7,10+i}\, yld_{t-1}^{i} + \beta_{717}\, t$$

$$\partial J^* / \partial w_t^{k*} = \beta_8 + \Sigma_{i=1}^{6} \beta_{8i}\, Ep_t^{i*} + \beta_{87}\, w_t^{2*} + \beta_{88}\, w_t^{k*} + \beta_{89}\, \tilde{K}_{t-1}$$

$$+ \beta_{810}\, Z_t + \Sigma_{i=1}^{6} \beta_{8,10+i}\, yld_{t-1}^{i} + \beta_{817}\, t \quad .$$

Combining (23)-(25),

$$\begin{aligned}
(26) \quad x_t^2/Z_t = & - (r - (Z_t - Z_{t-1})/Z_t)\ \partial J^*/\partial w_t^{2*} + \partial^2 J^*/\partial Z_t \partial w_t^{2*}\ (Z_t - Z_{t-1}) \\
& + \Sigma_i\ \partial^2 J^*/\partial Ep_t^{i*} \partial w_t^{2*}\ (Ep_t^i - Ep_{t-1}^i)/w_t^1 \\
& + \partial^2 J^*(.)/\partial \tilde{K}_{t-1} \partial w_t^{2*}\ (K_t - K_{t-1})/Z_t \\
& + \Sigma_i\ \partial^2 J^*(.)/\partial yld_{t-1}^i \partial w_t^{2*}\ (yld_t^i - yld_{t-1}^i) \\
= & - (r - (Z_t - Z_{t-1})/Z_t)\ (\beta_7 + \beta_{77}\, w_t^{2*} + \beta_{78}\, w_t^{k*} + \beta_{717}\ t) \\
& - \beta_{710}\ ((r - (Z_t - Z_{t-1})/Z_t) Z_t + (Z_t - Z_{t-1})) \\
& - \Sigma_i\ \beta_{7i}\ ((r - (Z_t - Z_{t-1})/Z_t) Ep_t^{i*} - (Ep_t^i - Ep_{t-1}^i)/w_t^1) \\
& - \beta_{79}\ (r - (Z_t - Z_{t-1})/Z_t)\ \tilde{K}_{t-1} - (K_t - K_{t-1})/Z_t \\
& - \Sigma_i\ \beta_{7,10+i}\ (r - (Z_t - Z_{t-1})/Z_t)\ yld_{t-1}^i - (yld_t^i - yld_{t-1}^i)
\end{aligned}$$

$$\begin{aligned}
(27) \quad (K_t - K_{t-1})/Z_t = & \{(r - (Z_t - Z_{t-1})/Z_t)\ \partial J^*/\partial w_t^{k*} \\
& - \partial^2 J^*/\partial Z_t \partial w_t^{k*}\ (Z_t - Z_{t-1}) \\
& - \Sigma_i\ \partial^2 J^*/\partial Ep_t^{i*} \partial w_t^{k*}\ (Ep_t^i - Ep_{t-1}^i)/w_t^1 + K_t/Z_t \\
& - \Sigma_i\ \partial^2 J^*(.)/\partial yld_{t-1}^i \partial w_t^{k*}\ (yld_t^i - yld_{t-1}^i)\} \\
& /\ \partial^2 J^*(.)/\partial K_{t-1} \partial w_t^{k*} \\
= & \{(r - (Z_t - Z_{t-1})/Z_t)\ (\beta_8 + \beta_{87}\, w_t^{2*} + \beta_{88}\, w_t^{k*} \\
& + \beta_{89}\, \tilde{K}_{t-1} + \beta_{817}\ t) \\
& + \beta_{810}\ ((r - (Z_t - Z_{t-1})/Z_t)\ Z_t - (Z_t - Z_{t-1})) \\
& + \Sigma_i\ \beta_{8i}\ ((r - (Z_t - Z_{t-1})/Z_t) Ep_t^{i*} - (Ep_t^i - Ep_{t-1}^i)/w_t^1) + K_t/Z_t \\
& + \Sigma_i\ \beta_{8,10+i}\ ((r - (Z_t - Z_{t-1})/Z_t)\ yld_{t-1}^i - (yld_t^i - yld_{t-1}^i))\}\ /\beta_{89}.
\end{aligned}$$

In addition to model (19), the following simpler specification was considered:

$$(28)\, yld_t^i = b_i + b_{i1}\, Ep_t^{i*} + b_{i2}\, w_t^{2*} + b_{i3}\, w_t^{k*} + b_{i4}\, t + b_{i5}\, \tilde{K}_{t-1} + b_{i6}\, z_t^i + b_{i7}\, yld_{t-1}^i + b_{i8}\, (Ep_t^i - Ep_{t-1}^i)/w_t^1 + b_{i9}\, (K_t - K_{t-1})/Z_t + b_{i10}\, (z_t^i - z_{t-1}^i) + b_{i11}\, Grodex_t + b_{i12}\, DLift_t + e_t^i$$

$$i = 1,.,6.$$

The key differences are (a) this model does not impose the restrictions on coefficients of initial levels and changes in variables (e.g. (19) specifies the effects of Ep^i and $\dot{E}p^i$ in terms of a single coefficient b_{i1}) and (b) J^{i*} is not specified as normalized by z^i. A similar simplification of model (23) can also be constructed.

For empirical estimation, the average value of the crop growth weather index (GRODEX) for Manitoba and a dummy variable for the LIFT program were added to models (19) and (23) for crop yields in the same manner as (e.g.) the time trend. There was not strong evidence of unit roots or heteroskedasticity (see chapter two). However the presence of a lagged dependent variable(s) in these equations complicates testing for autocorrelation and estimation in the presence of autocorrelation. Test results for autocorrelation were inconclusive: the Durbin h-statistic was generally undefined but suggested autocorrelation in some cases, whereas an asymptotically equivalent test procedure suggested no autocorrelation (Durbin 1970). Since ordinary least squares is inconsistent here given autocorrelation, and an iterative Cochrane-Orcutt procedure may not converge to a global solution, these models were estimated by a grid search and maximum likelihood procedure as AR(1) using Shazam 7.0.

The above models were estimated by ordinary least squares, iterative Cochrane-Orcutt, and grid search plus maximum likelihood for

AR(1). Four models of price expectations were considered (see above). In addition the following simplified model was considered:

$$(29)\quad yld_t^i = b_i + b_{i1}\, Ep_t^{i*} + b_{i2}\, w_t^{2*} + b_{i3}\, w_t^{k*} + b_{i4}\, t + b_{i5}\,((r-1)\,K_{t-1} + K_{t-2}) + b_{i6}\,((r-1)\,z_t^i + z_{t-1}^i) + b_{i7}\, yld_{t-1}^i + b_{i11}\, Grodex_t + b_{i12}\, DLift_t + e_t^i \qquad i = 1,.,6.$$

This model essentially assumes static price expectations ($\dot{Ep}^i = 0$) and J^{i*} is not normalized by z^i. Ordinary least squares results for wheat, barley and oats crop yield equations (29) assuming expected prices are equal to lagged market prices are reported in Table 1 (grid searches for AR(1) models indicated no autocorrelation in these cases). Expected prices are insignificant, and the one year lags in crop yields (L1yld) have negative rather than positive coefficients. Results for similar models allowing for a four year unrestricted lag on crop yield are reported in Table 2. Again expected prices are insignificant and lags in crop yields have negative coefficients. The negative coefficients on lagged crop yields are somewhat surprising. Similar results were obtained for standard Nerlove partial adjustment models of crop yields.

Models (19), (22) and (28) were also estimated by ordinary least squares, iterative Cochrane-Orcutt, and grid search plus maximum likelihood for AR(1). Results for (19) and (22) (where equality of coefficients regarding initial conditions and equations of motion is imposed) often indicated positive coefficients for lagged crop yields (as expected) and positive but insignificant price effects. In contrast results for (28) were generally similar to Tables 1 and 2.

RESULTS FOR RISK-AVERSE MODELS

The above risk-neutral models are generalized to linear mean-variance risk preferences and price uncertainty as in models (8) and (9). In the case of model (8) the derivative $\partial J^{i*}(.)/\partial Ep^{i*}$ is specified as

$$(30)\quad \partial J^{i*}/\partial Ep_t^{i*} = a_i + a_{i1}\, Ep_t^{i*} + a_{i2}\, w_t^{2*} + a_{i3}\, w_t^{k*} + a_{i4}\, t + a_{i5}\, \tilde{K}_{t-1} + a_{i6}\, z_t^i + a_{i7}\, yld_{t-1}^i + a_{i8}\, Vp_t^{i*} \qquad i = 1,.,6$$

where $Vp_t^{i*} = Vp_t^i \,/\, w_t^1$. Proceeding as in the risk-neutral case, the Hamilton-Jacobi equation (10) implies

$$(31)\quad r\, J^{i*}(.) - (\partial J^{i*}(.)/\partial z^i + J^{i*}/z^i)\, \dot{z}^i - \partial J^{i*}(.)/\partial Ep^{i*}\, \dot{Ep}^i/w^1 - \partial J^{i*}(.)/\partial Vp^{i*}\, \dot{Vp}^i/w^1$$

$$= \max_{(x^i, I^i)}\; Ep^{i*}\, yld^i - w^*\, x^i/z^i - w^{k*}\, K^i/z^i - (\alpha/2)\, Vp^{i*}\, (yld^i)^2\, z^i + \partial J^{i*}(.)/\partial \tilde{K}^i\, (I^i - \delta\, K^i)/z^i + \partial J^{i*}(.)/\partial yld^i\, \dot{yld}^i$$

and yield equations (19) are generalized as

$$(32)\quad yld_t^i = (r - 1 - (z_t^i - z_{t-1}^i)/z_t^i)\, (b_i + b_{i2}\, w_t^{2*} + b_{i3}\, w_t^{k*} + b_{i4}\, t)$$
$$+ b_{i1}\, ((r - 1 - (z_t^i - z_{t-1}^i)/z_t^i) Ep_t^{i*} - (Ep_t^i - Ep_{t-1}^i)/w_t^1)$$
$$+ b_{i5}\, ((r - 1 - (z_t^i - z_{t-1}^i)/z_t^i)\, \tilde{K}_{t-1} - (K_t - K_{t-1})/Z_t)$$
$$+ b_{i6}\, ((r - 1 - (z_t^i - z_{t-1}^i)/z_t^i) z_t^i - (z_t^i - z_{t-1}^i))$$
$$+ b_{i7}\, ((r - 1 - (z_t^i - z_{t-1}^i)/z_t^i) yld_{t-1}^i + yld_{t-1}^i)$$
$$+ b_{i8}\, ((r - 1 - (z_t^i - z_{t-1}^i)/z_t^i) Vp_t^{i*} - (Vp_t^i - Vp_{t-1}^i)/w_t^1) \qquad i = 1,.,6$$

where $\dot{Vp}_t^i \equiv Vp_t^i - Vp_{t-1}^i$. Similarly yield equations (22) are generalized as

$$(33)\quad yld_t^i = (r - 1 - (z_t^i - z_{t-1}^i)/z_t^i)\, (b_i + b_{i2}\, w_t^{2*} + b_{i3}\, w_t^{k*} + b_{i4}\, t$$

$$+ \Sigma_{s=1}^{S} \tilde{\gamma}_s \ (yld^i_{t-s} - yld^i_{t-s-1}))$$

$$+ b_{i1} \ ((r - 1 - (z^i_t - z^i_{t-1})/z^i_t)Ep^{i*}_t - (Ep^i_t - Ep^i_{t-1})/w^1_t)$$

$$+ b_{i5} \ ((r - 1 - (z^i_t - z^i_{t-1})/z^i_t) \ \tilde{K}_{t-1}/Z_t \ - (K_t - K_{t-1})/Z_t)$$

$$+ b_{i6} \ ((r - 1 - (z^i_t - z^i_{t-1})/z^i_t)z^i_t - (z^i_t - z^i_{t-1}))$$

$$+ b_{i7} \ ((r - 1 - (z^i_t - z^i_{t-1})/z^i_t)yld^i_{t-1} + yld^i_{t-1})$$

$$+ b_{i8} \ ((r - 1 - (z^i_t - z^i_{t-1})/z^i_t)Vp^{i*}_t - (Vp^i_t - Vp^i_{t-1})/w^1_t)$$

$$i = 1,.,6 \ .$$

Yield equations (28) are generalized as

$$(34) \quad yld^i_t = b_i + b_{i1} \ Ep^{i*}_t + b_{i2} \ w^{2*}_t + b_{i3} \ w^{k*}_t + b_{i4} \ t + b_{i5} \ \tilde{K}_{t-1}$$

$$+ b_{i6} \ z^i_t + b_{i7} \ yld^i_{t-1} + b_{i8} \ (Ep^i_t - Ep^i_{t-1})/w^1_t$$

$$+ b_{i9} \ (K_t - K_{t-1})/Z_t + b_{i10} \ (z^i_t - z^i_{t-1}) + b_{i11} \ Grodex_t$$

$$+ b_{i12} \ DLift_t + b_{i13} \ Vp^{i*}_t + b_{i14} \ (Vp^i_t - Vp^i_{t-1})/w^1_t + e^i_t$$

$$i = 1,.,6 \ .$$

Finally equations (26)-(27) for crop variable input and investment generalize as

$$(35) \quad x^2_t/Z_t = - (r - (Z_t - Z_{t-1})/Z_t) \ (\beta_7 + \beta_{77} \ w^{2*}_t + \beta_{78} \ w^{k*}_t + \beta_{717} \ t)$$

$$- \beta_{710} \ ((r - (Z_t - Z_{t-1})/Z_t)Z_t \ + (Z_t - Z_{t-1}))$$

$$- \Sigma_i \ \beta_{7i} \ ((r - (Z_t - Z_{t-1})/Z_t)Ep^{i*}_t - (Ep^i_t - Ep^i_{t-1})/w^1_t)$$

$$- \beta_{79} \ (r - (Z_t - Z_{t-1})/Z_t) \ \tilde{K}_{t-1} - (K_t - K_{t-1})/Z_t$$

$$- \Sigma_i \ \beta_{7,10+i} \ (r - (Z_t - Z_{t-1})/Z_t) \ yld^i_{t-1} - (yld^i_t - yld^i_{t-1})$$

$$- \Sigma_i \ \beta_{7,17+i} \ ((r - (Z_t - Z_{t-1})/Z_t)Vp^{i*}_t - (Vp^i_t - Vp^i_{t-1})/w^1_t)$$

$$(36) \quad (K_t - K_{t-1})/Z_t = \{(r - (Z_t - Z_{t-1})/Z_t) \quad (\beta_8 + \beta_{87} \ w^{2*}_t + \beta_{88} \ w^{k*}_t$$

$$+ \beta_{89} \ \tilde{K}_{t-1} + \beta_{817} \ t)$$

$$+ \beta_{810} \ ((r - (Z_t - Z_{t-1})/Z_t) \ Z_t - (Z_t - Z_{t-1}))$$

$$+ \Sigma_i \ \beta_{8i} \ ((r - (Z_t - Z_{t-1})/Z_t)Ep^{i*}_t - (Ep^i_t - Ep^i_{t-1})/w^1_t) + K_t/Z_t$$

$$+ \ \Sigma_i \ \beta_{8,10+i} \ ((r - (Z_t - Z_{t-1})/Z_t) \ yld^i_{t-1} - (yld^i_t - yld^i_{t-1})$$

$$+ \Sigma_i \beta_{8,17+i} ((r - (Z_t - Z_{t-1})/Z_t) Vp_t^{i*} - (Vp_t^i - Vp_{t-1}^i)/w_t^1)\} / \beta_{89}.$$

The above models were estimated by ordinary least squares, iterative Cochrane-Orcutt, and grid search plus maximum likelihood for AR(1). Four models of price expectations were considered (see above), along with similar models of price variances. In addition price variance terms were added to the simplified model (29):

$$(37) \quad yld_t^i = b_i + b_{i1} Ep_t^{i*} + b_{i2} w_t^{2*} + b_{i3} w_t^{k*} + b_{i4} t + b_{i5} ((r - 1) K_{t-1} + K_{t-2}) + b_{i6} ((r - 1) z_t^i + z_{t-1}^i) + b_{i7} yld_{t-1}^i + b_{i8} Vp_t^{i*} + b_{i11} Grodex_t + b_{i12} DLift_t + e_t^i \qquad i = 1,.,6 .$$

Ordinary least squares results for wheat, barley and oats crop yield equations (37) assuming expected prices are equal to lagged market prices, and price variance is calculated as in (7) of chapter two using these price expectations, are reported in Table 3 (grid searches for AR(1) models indicated no autocorrelation in these cases). Coefficients of price variance are significant and negative (as expected) in barley and oats crop yield equations. In addition coefficients of expected price are positive but insignificant in these equations, and lagged crop yield is insignificant. Results for similar models allowing for a four year unrestricted lag on crop yield are reported in Table 4. Here both expected price and price variance are significant with anticipated signs in barley and oats crop yield equations. However coefficients of lagged yields generally are significant and negative. Similar results were obtained for standard Nerlove partial adjustment models of crop yields with price variances added.

Somewhat similar results were obtained for models (32)-(34). Price variances and expected prices generally were significant with anticipated signs. Results for (32) and (33) (where equality of coefficients regarding initial conditions and equations of motion is imposed) often indicated positive coefficients for lagged crop yields (as expected).

CONCLUSION

This study has formulated dynamic duality models of crop yield response under risk neutrality and linear mean-variance risk preferences with price uncertainty. These models are tractable for empirical research. Only preliminary results for these models are reported here. As in the case of the ad hoc distributed lag models reported in chapter two, these results indicate that risk aversion and price uncertainty are important in explaining crop yield price response.

Table 4.1: Risk-Neutral Crop Yields: Market Prices, No Distributed Lag On Yields (OLS)

	Wheat			Barley			Oats		
	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]
p^*	-11.61	1.87	-.301	-7.780	0.76	-.119	-6.281	0.83	-.105
W^*	1846.9	1.02	.400	-494.9	0.21	-.089	-1087.4	0.68	-.230
W^{k*}	10.27	0.49	.163	21.36	0.77	.282	29.81	1.38	.462
Grodex	.0844	1.70	.346	.1171	1.88	.399	.1334	2.88	.535
T	1.215	2.08	.234	2.210	2.63	.355	1.224	1.96	.231
DLIFT	-18.38	1.60	-.009	-19.38	1.47	-.008	-15.66	1.44	-.008
L1YLD	-17.56	0.85	-.174	-8.994	0.37	-.088	-10.22	0.42	-.101
KK[c]	2.142	1.45	-.007	2.233	1.18	-.006	1.663	1.19	-.006
ZZ[d]	.0002	0.04	.0001	-.0055	0.50	-.001	-.0087	0.56	-.008
constant	25.29	0.64	.348	24.07	0.43	.276	17.09	0.42	.230
R^2/DW	.7622	1.89		.8273	1.98		.7944	1.88	

[a] Coefficients are in units of 10^{-2}

[b] Elasticities are evaluated at data means.

[c] $KK \equiv (r-1)\,K_{t-1} + K_{t-2}$

[d] $ZZ \equiv (r-1)\,z_t^i + z_{t-1}^i \quad (r=0.03)$

Table 4.2: Risk-Neutral Crop Yields: Market Prices, Distributed Lag On Yields (OLS)

	Wheat			Barley			Oats		
	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]
p^*	-8.071	1.24	-.209	1.726	0.18	.027	.9070	0.10	.015
W^*	-1542	0.59	-.334	-5086	1.98	-.917	-3786	1.69	-.802
W^{k*}	48.44	1.56	.768	60.41	2.19	.797	48.98	2.00	.759
Grodex	.0775	1.44	.318	.0821	1.42	.280	.1046	2.09	.420
T	2.934	2.31	.566	5.461	3.93	.877	2.347	2.49	.442
DLIFT	-23.42	2.00	-.012	-21.75	1.90	-.009	-17.70	1.60	-.009
L1YLD	-56.36	1.81	-.559	-39.57	1.69	-.386	-37.52	1.28	-.369
L2YLD	-49.09	1.75	-.480	-56.97	2.77	-.541	-37.08	1.70	-.355
L3YLD	-24.84	1.07	-.238	-23.22	1.18	-.213	-20.60	1.02	-.192
L4YLD	-7.083	0.33	-.067	-25.91	1.43	-.230	-9.391	0.55	-.086
KK[c]	.3841	0.20	-.001	1.446	0.83	-.004	2.031	1.43	-.007
ZZ[d]	.0044	0.83	.002	-.0071	0.71	-.001	-.0090	0.05	-.001
constant	90.50	1.66	1.25	115.2	2.01	1.32	87.99	1.50	1.18
R^2/DW	.8072	1.93		.8938	2.09		.8306	1.65	
ΣLag coeff YLD	-137.4	1.64		-145.7	2.72		-104.6	1.64	

[a] Coefficients are in units of 10^{-2}.

[b] Elasticities are evaluated at data means.

[c] $KK \equiv (r-1)\ K_{t-1} + K_{t-2}$

[d] $ZZ \equiv (r-1)\ z_t^{\,i} + z_{t-1}^{\,i} \quad (r{=}0.03)$

Table 4.3: Risk-Averse Crop Yields: Market Prices, No Distributed Lag On Crop Yields (OLS)

	Wheat			Barley			Oats		
	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]
p^*	-5.475	0.35	-.142	24.99	1.87	.385	15.33	1.26	.256
W^*	973.5	0.35	.211	-4354	1.92	-.786	-1890	1.27	-.400
W^{k*}	3.833	0.15	.061	13.95	0.62	.184	13.70	0.65	.212
Vp^*	-.1291	0.43	-.015	-1.534	3.14	-.083	-1.215	2.16	-.061
Grodex	.0847	1.67	.348	.1017	2.01	.347	.1189	2.79	.477
T	1.230	2.05	.237	3.268	4.30	.525	1.747	2.84	.329
DLIFT	-17.25	1.43	-.009	-11.65	1.06	-.005	-13.62	1.37	-.007
L1YLD	-17.32	0.82	-.172	-26.49	1.30	-.258	-15.49	0.70	-.152
KK[c]	2.179	1.44	-.008	2.097	1.36	-.006	2.440	1.85	-.008
ZZ[d]	.0007	0.14	.0003	.0056	0.59	.001	.0002	0.01	.0002
constant	35.47	0.76	.489	60.75	1.30	.697	26.29	0.71	.354
R^2/DW	.7649	1.86		.8932	2.06		.8407	1.91	

[a] Coefficients are in units of 10^{-2}.
[b] Elasticities are evaluated at data means.
[c] $KK \equiv (r-1)\ K_{t-1} + K_{t-2}$
[d] $ZZ \equiv (r-1)\ z_t^i + z_{t-1}^i \quad (r=0.03)$

Table 4.4: Risk-Averse Crop Yields : Market Prices, Distributed Lag On Crop Yields (OLS)

	Wheat			Barley			Oats		
	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]	coeff[a]	t-ratio	elas[b]
P^*	8.442	0.51	.219	29.39	2.71	.452	27.58	2.19	.461
W^*	-4502	1.19	-.975	-8028	3.81	-1.45	-5213	2.67	-1.10
W^{k*}	39.74	1.25	.630	44.44	2.10	.586	34.61	1.64	.536
Vp^*	-.3356	1.08	-.039	-1.499	3.45	-.081	-1.402	2.66	-.070
Grodex	.0782	1.46	.321	.0606	1.39	.207	.0822	1.93	.330
T	3.330	2.53	.642	5.345	5.12	.858	3.172	3.75	.598
DLIFT	-21.60	1.83	-.011	-14.41	1.63	-.006	-16.08	1.74	-.008
L1YLD	-63.81	2.01	-.632	-49.22	2.77	-.480	-49.53	1.99	-.487
L2YLD	-59.89	2.03	-.585	-53.07	3.44	-.504	-42.83	2.34	-.410
L3YLD	-27.74	1.19	-.265	.2836	0.02	.003	-27.01	1.59	-.252
L4YLD	-10.47	0.48	-.099	-16.65	1.21	-.148	-7.768	0.54	-.071
KK[c]	.1120	0.06	-.0004	2.034	1.55	-.006	3.015	2.43	-.010
ZZ[d]	.0065	1.15	.002	.0078	0.89	.001	.0118	0.80	.011
constant	130.3	1.99	1.79	136.5	3.15	1.56	109.7	2.21	1.48
R^2/DW	.8231	1.93		.9446	2.26		.8903	1.95	
ΣLag coeff YLD	-161.9	1.88		-118.7	2.91		-127.1	2.36	

[a] Coefficients are in units of 10^{-2}.

[b] Elasticities are evaluated at data means.

[c] $KK \equiv (r-1)\ K_{t-1} + K_{t-2}$

[d] $ZZ \equiv (r-1)\ z_t^{\,i} + z_{t-1}^{\,i}$ $(r{=}0.03)$

CHAPTER FIVE

CONCLUSION

The purpose of this thesis is to develop and estimate econometric models of crop supply response for Manitoba. There are two aspects of this study that are unique in comparison to most other studies: (a) crop supply response is decomposed into acreage and yield response where both of these components are to be estimated, and (b) risk aversion is incorporated into these models, which often have a duality framework.

Most empirical models of crop response have consisted either of acreage demand equations or crop output supply equations (essentially a reduced form of acreage and yield components), and prices are often reported to have significant effects in these models. On the other hand there have been relatively few published studies of crop yield response to price, and in many of these studies price is reported to have an insignificant effect on yield. These crop yield models are static and use methodologies common to many acreage demand/output supply studies. This contrast in results suggests that substantially different model specifications are required for studies of acreage demand and yield response. In this case there are substantial gains in efficiency and understanding when the acreage and yield components of crop supply response are estimated directly rather than as reduced form output supply equations (the standard arguments for estimating a structural model over a reduced form model somewhat apply here).

The advantages of a duality approach in static and dynamic models of production are well known, but there have been relatively few studies incorporating risk aversion into duality theory and even fewer applications of duality incorporating risk aversion. This study emphasizes the importance of risk aversion and price uncertainty in modeling Manitoba crop production behavior. This emphasis is incorporated into both static and dynamic duality models. Output (yield) uncertainty is also considered to some extent.

This thesis consists of three studies: a study of crop yield response using essentially ad hoc distributed lag models (chapter two); a study of crop acreage demand using static duality models (chapter three); and a study of crop yield response using dynamic duality models (chapter four). These conclusions of these three studies are stated as follows.

MODELS OF GRAIN YIELD RESPONSE TO PRICE

In contrast to all other econometric studies of crop yield response to price, chapter two explores the importance of risk aversion, price uncertainty and distributed lags in explaining crop yield response. This emphasis reflects the following common assumptions regarding crop agriculture: crop yields respond gradually to price changes, farmers are risk averse, and there is generally more uncertainty regarding prices in the distant future than in the immediate future.

Results are reported for major field crops in Manitoba, 1961-87. Expected prices are insignificant in risk-neutral static models of crop yield (as in most other studies). However, when price variances are added to the static models, coefficients of these price variances are often significant (and negative). A somewhat plausible explanation of this contrast between expected price and price variance in static models is that true models are dynamic and price variances are highly correlated over time. The importance of dynamics and risk aversion in explaining crop yields is illustrated by results for risk-neutral and risk-averse distributed lag nmodels. The sum of lag coefficients is often significant for both expected price and price variance, and these elasticities of long-run response are substantially greater in magnitude for expected price than for price variance.

In sum, this study indicates that it is tractable, and perhaps essential, to accomodate risk aversion and substantial lags in crop yield price response models. In contrast to static models of crop acreage demand (e.g. Coyle 1993), here the effects of at least expected prices on crop yield were insignificant in static models. The lagged effects of prices and uncertainty on crop yields appear to be substantial. This suggests a significant difference in response patterns for crop yields and crop acreage demands. In turn disaggregating models of crop supply response into these components presumably can lead to substantial gains both in understanding of supply response and in efficiency of estimation.

A next step in developing models for crop yield decisions is to incorporate risk aversion and uncertainty into formal dynamic models, e.g. dynamic duality models, as a possible alternative to the distributed lag models of crop yield considered here. These can be estimated jointly with static duality models of crop acreage demands under risk aversion, which are most easily specified when yields can be treated as predetermined.

DUALITY MODELS OF CROP ACREAGE DEMANDS

Chapter three, an econometric study of crop acreage demands in Manitoba, apparently is the first application of recent theory on duality with price uncertainty to use data disaggregated by crops. In addition this study suggests and applies a simple methodology for combining weather station data and production data aggregated over agents (regions) to obtain a measure of yield uncertainty. Apparently this methodology has not been noted in previous production literature. Models where yields are predetermined, or to be more precise the mean and variance of the distribution of yield are predetermined, are emphasized here. This is in keeping with other studies (including an econometric study for Manitoba) suggesting that crop yields may often be largely predetermined. In addition this assumption greatly simplifies estimation of acreage demand models.

Results of the study indicate that the methodologies applied here are tractable in modelling crop acreage demands and support the assumptions that price and yield uncertainty influence acreage decisions. Models with yields (or mean and variance of yields) treated as predetermined generally provided more reasonable results than models with yields not predetermined. Results for models assuming price uncertainty or yield uncertainty generally led to anticipated results for the major crop (wheat), but results for impacts of variances in revenues per acre for other crops were more ambiguous. The one major disappointment of the study is that models combining both price uncertainty and yield uncertainty generally did not lead to reasonable results.

In sum, this study suggests that duality models of crop acreage demands incorporating risk aversion and uncertainty are tractable and promising. However further progress presumably requires more accurate measurement of farmers' subjective price and yield (or weather) uncertainty.

DYNAMIC DUALITY MODELS OF CROP YIELDS

Chapter four has formulated dynamic duality models of crop yield response under risk neutrality and linear mean-variance risk preferences with price uncertainty. These models are tractable for empirical research. Only preliminary results for these models are reported here. As in the case of the ad hoc distributed lag models reported in chapter two, these results indicate that risk aversion and price uncertainty are important in explaining crop yield price response.

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APPENDIX A

UNITS OF MEASUREMENT

Acreage	Thousands of acres
Output	Thousands of metric tonnes
Prices/Value	Canadian dollars per metric tonne

Crop Acreage

Year	Wheat	Barley	Canola	Oats	Rye	Flax
1951	2326	2040	-	1643	53	655
1952	2368	2165	7	1611	72	500
1953	2300	2365	5	1412	138	420
1954	2139	2202	9	1510	92	444
1955	2075	2090	7	1485	89	531
1956	2199	1548	29	1950	68	789
1957	2200	1704	28	1500	73	865
1958	2480	1584	21	1430	72	550
1959	2670	1270	12	1420	83	575
1960	2800	930	33	1500	83	707
1961	2914	655	29	1300	79	748
1962	3042	629	32	1794	119	667
1963	3153	584	45	1620	95	820
1964	3385	497	84	1635	133	1025
1965	3240	601	145	1525	133	1350
1966	3255	875	170	1530	100	1107
1967	3520	970	145	1600	141	660
1968	3400	1170	91	1580	120	820
1969	2500	1200	196	1530	163	1100
1970	1400	1500	400	1260	130	1100
1971	2519	2052	581	1395	128	566
1972	2600	2100	470	1140	81	500
1973	3000	2100	400	1300	82	600
1974	2800	1800	500	1200	102	700
1975	3100	1500	750	1100	117	750
1976	3800	1600	250	1250	92	525
1977	3200	1900	500	1050	110	750
1978	3400	1750	1050	750	125	750
1979	3000	1450	1350	450	125	1250
1980	3300	2000	800	450	150	800
1981	3900	2350	600	600	190	700
1982	4000	2000	850	550	230	900
1983	4600	1750	950	550	210	750
1984	4450	1800	1200	550	220	1050
1985	4850	1850	1000	480	193	1050
1986	4950	1550	1000	450	77	1030
1987	4850	1700	1000	450	64	800
1988	4820	1400	1550	400	121	700

1989	5170	1600	1150	500	230	700
1990	5430	1550	950	430	220	800

Crop Output

Year	Wheat	Barley	Canola	Oats	Rye	Flax
1951	1442	1219	-	895	21	118
1952	1551	1546	2	1002	31	117
1953	1306	1328	2	817	71	97
1954	789	958	3	555	40	102
1955	1143	871	2	771	45	112
1956	1524	915	11	1357	28	203
1957	1334	719	8	740	31	89
1958	1660	958	6	771	31	119
1959	1687	719	4	771	42	117
1960	1796	523	11	863	42	163
1961	926	196	8	370	22	109
1962	2177	457	13	1373	76	198
1963	1660	348	17	956	53	236
1964	2313	348	33	1126	71	269
1965	2150	479	54	1141	76	411
1966	2150	610	47	987	61	266
1967	2449	718	52	1018	67	144
1968	2477	936	43	1249	63	264
1969	1742	914	79	1064	75	259
1970	830	1110	163	817	72	292
1971	2014	2047	272	1172	83	149
1972	1878	1851	192	848	46	149
1973	2095	1807	174	972	54	193
1974	1605	1154	192	663	63	167
1975	2123	1110	283	771	76	213
1976	2803	1459	102	941	68	160
1977	2749	2047	290	894	84	330
1978	2831	1851	578	632	99	317
1979	2041	1263	567	308	79	444
1980	1905	1568	294	278	75	210
1981	3326	2330	306	463	175	261
1982	3701	2373	399	524	213	436
1983	3410	1589	397	401	163	297
1984	3742	1938	544	432	195	439
1985	5226	2526	635	494	167	559
1986	4478	1851	578	463	61	572
1987	3946	1938	585	416	46	406
1988	2401	1089	612	224	58	198
1989	4063	1546	399	339	198	221
1990	5865	2014	499	409	193	422

Crop Market Prices

Year	Wheat	Barley	Canola	Oats	Rye	Flax
1951	59.00	52.00	-	46.00	61	152
1952	59.89	50.98	71	40.20	56	126
1953	49.97	41.80	88	37.61	34	97
1954	48.13	42.25	83	40.20	37	104
1955	52.17	43.17	87	41.50	37	110
1956	47.77	38.58	79	33.72	38	102
1957	48.50	37.20	66	33.72	35	98
1958	49.97	37.20	64	36.31	33	103
1959	50.71	35.82	87	41.50	35	120
1960	59.00	39.00	88	40.00	34	108
1961	65.00	48.00	79	41.00	43	130
1962	62.00	44.00	77	38.00	41	118
1963	63.00	45.00	110	36.00	49	112
1964	60.00	48.00	119	42.00	41	116
1965	61.00	48.00	108	46.00	41	106
1966	65.00	50.00	108	49.00	42	106
1967	60.00	41.00	85	45.00	43	121
1968	48.00	36.00	83	32.00	39	112
1969	46.00	32.00	106	35.00	34	101
1970	52.00	34.00	102	37.00	34	87
1971	50.00	32.00	95	34.00	29	86
1972	68.00	58.00	137	58.00	51	161
1973	158.00	115.00	258	106.00	105	374
1974	147.00	102.00	312	99.00	89	376
1975	130.00	105.00	225	93.00	99	258
1976	103.00	92.00	257	73.00	85	267
1977	98.00	76.00	278	64.00	86	207
1978	133.00	78.00	280	64.00	102	268
1979	170.00	103.00	267	89.00	146	280
1980	203.00	137.00	280	119.00	171	320
1981	174.00	119.00	275	105.00	140	322
1982	165.00	91.00	259	81.00	87	244
1983	174.00	120.00	383	110.00	107	323
1984	172.00	121.00	351	109.00	93	317
1985	160.00	110.00	268	96.00	79	257
1986	130.00	80.00	201	90.00	62	176
1987	134.00	74.00	273	112.00	85	212
1988	197.00	124.00	307	145.00	113	351
1989	172.00	124.00	304	108.00	111	374
1990	135.00	90.00	288	80.00	85	231

Crop Expected Prices

Year	Wheat (CWB)	Barley (CWB)	Canola	Oats (CWB)	Rye	Flax
1951	-	-	-	-	-	-
1952	-	-	-	-	61	152
1953	64.51	39.96	71	65.00	56	126
1954	58.75	46.44	88	74.10	34	97
1955	57.46	44.76	83	77.50	37	104
1956	60.66	42.12	87	73.70	37	110
1957	59.12	46.11	79	74.80	38	102
1958	58.34	42.84	66	60.00	35	98
1959	59.56	43.47	64	67.40	33	103
1960	58.64	42.22	87	69.50	35	120
1961	58.42	41.02	88	77.10	34	108
1962	69.63	44.04	79	74.20	43	130
1963	70.19	55.33	77	77.20	41	118
1964	68.86	48.22	110	71.80	49	112
1965	72.54	50.43	119	69.20	41	116
1966	69.34	54.43	108	56.10	41	106
1967	80.72	59.66	108	66.65	42	106
1968	80.35	60.07	85	57.25	43	121
1969	59.31	38.95	83	50.20	39	112
1970	57.80	37.20	106	38.90	34	101
1971	57.58	42.80	102	45.30	34	87
1972	59.93	39.50	95	44.10	29	86
1973	98.68	68.43	137	82.73	51	161
1974	152.26	129.27	258	97.33	105	374
1975	168.21	121.36	312	124.73	89	376
1976	191.95	102.46	225	120.91	99	258
1977	118.72	97.17	257	107.90	85	267
1978	117.15	87.12	278	87.00	86	207
1979	157.04	92.06	280	68.00	102	268
1980	215.65	144.61	267	79.10	146	280
1981	255.11	148.89	280	130.00	171	320
1982	200.12	125.55	275	127.30	140	322
1983	195.12	102.07	259	75.00	87	244
1984	187.84	125.00	383	134.50	107	323
1985	183.98	153.02	351	106.60	93	317
1986	146.37	86.30	268	96.63	79	257
1987	110.00	60.00	201	85.90	62	176
1988	160.00	125.00	273	112.00	85	212
1989	204.02	94.08	307	145.00	113	351
1990	157.14	109.23	304	108.00	111	374

Year	Total Acreage	Crop Input Price Index	Crop Input Quantity Index	Labour Wage	Capital Stock
1951	-	-	-	-	-
1952	6723	-	-	-	-
1953	6640	0.43072	-	18.04	-
1954	6396	0.45947	-	17.72	-
1955	6277	0.44160	-	17.31	-
1956	6583	0.43901	-	18.38	-
1957	6370	0.43642	-	19.51	-
1958	6137	0.44937	-	20.36	-
1959	6030	0.45377	-	21.25	-
1960	6053	0.44444	-	21.93	-
1961	5725	0.43397	24098.58	22.40	8.80
1962	6283	0.44894	23259.49	22.90	8.60
1963	6317	0.45731	28105.70	23.30	8.90
1964	6759	0.46827	32966.31	23.80	9.30
1965	6994	0.46925	36283.63	25.00	9.80
1966	7037	0.47349	55015.24	27.00	10.20
1967	7036	0.49059	59739.77	29.00	10.50
1968	7181	0.50221	73545.09	30.00	10.70
1969	6689	0.48622	52441.12	31.40	10.40
1970	5790	0.46308	49143.18	32.50	10.00
1971	7241	0.47376	61092.01	33.90	9.60
1972	6891	0.49820	69769.29	37.00	9.70
1973	7482	0.55286	85589.87	42.00	10.00
1974	7102	0.77987	84820.68	50.70	11.30
1975	7317	1.00000	97624.00	61.80	13.20
1976	7517	1.09343	99890.72	70.50	15.60
1977	7510	1.06835	117058.52	78.20	16.10
1978	7825	1.11279	153853.65	82.50	16.10
1979	7625	1.24923	183428.07	87.20	16.80
1980	7500	1.46991	164436.73	93.90	17.70
1981	8340	1.74204	164860.81	100.00	18.20
1982	8530	1.67882	180056.69	106.60	18.20
1983	8810	1.62485	207086.25	110.90	17.90
1984	9270	1.68445	224403.84	114.40	17.70
1985	9423	1.71805	225766.41	117.60	17.80
1986	9057	1.54769	231819.70	120.10	17.70
1987	8864	1.45692	238019.90	123.00	17.60
1988	8991	1.43846	258051.00	128.50	17.00
1989	9350	1.53692	229894.20	135.00	16.60
1990	9380	1.53076	234173.20	136.90	16.20

Year	Grodex m1	Grodex m2	Grodex m3	Grodex m4	Grodex m5	Grodex m6
1951	-	-	-	-	-	-
1952	-	-	-	-	-	-
1953	-	-	-	-	-	-
1954	-	-	-	-	-	-
1955	-	-	-	-	-	-
1956	-	-	-	-	-	-
1957	-	-	-	-	-	-
1958	-	-	-	-	-	-
1959	-	-	-	-	-	-
1960	-	-	-	-	-	-
1961	158.663	92.743	236.194	152.080	184.685	190.390
1962	371.456	310.789	434.857	417.557	294.893	251.636
1963	277.205	322.797	402.871	344.651	267.287	389.067
1964	189.207	198.391	338.966	343.625	389.555	307.656
1965	296.396	269.112	328.469	317.436	216.071	291.940
1966	254.246	265.386	373.456	364.638	387.360	253.260
1967	185.093	267.605	279.361	258.412	170.753	180.993
1968	210.924	137.818	407.952	436.367	392.054	138.556
1969	273.531	222.219	313.078	325.317	217.245	258.044
1970	308.646	282.503	330.704	410.004	328.302	298.367
1971	403.567	344.184	388.297	453.519	249.871	274.351
1972	284.924	264.515	268.137	365.840	234.009	367.422
1973	290.264	269.591	359.350	331.014	267.134	271.487
1974	247.282	264.683	286.626	349.154	245.453	259.067
1975	407.575	389.347	400.487	345.647	389.473	354.152
1976	281.240	317.816	288.786	214.694	339.805	372.158
1977	250.402	389.406	346.458	334.605	273.292	227.511
1978	305.047	376.302	399.849	427.108	301.680	355.332
1979	193.390	297.518	363.789	373.598	297.477	189.268
1980	300.482	380.029	292.570	239.270	158.073	269.937
1981	303.390	304.424	90.968	374.624	304.689	186.070
1982	313.693	277.258	381.280	324.776	210.495	249.137
1983	273.349	292.663	222.750	211.905	360.627	194.868
1984	155.069	287.331	329.595	307.811	294.424	134.674
1985	279.678	366.913	401.624	431.738	382.930	316.024
1986	318.704	315.247	320.902	337.963	356.235	330.989
1987	251.327	246.631	370.202	363.306	271.718	280.881
1988	-	-	-	-	-	-
1989	-	-	-	-	-	-
1990	-	-	-	-	-	-

Year	Value of Land	Value of Machinery
1951	-	-
1952	-	-
1953	-	-
1954	-	-
1955	-	-
1956	-	-
1957	-	-
1958	-	-
1959	-	-
1960	-	-
1961	601	272
1962	615	279
1963	670	297
1964	766	322
1965	889	350
1966	984	380
1967	1132	405
1968	1247	424
1969	1197	426
1970	1184	420
1971	1175	411
1972	1253	424
1973	1502	455
1974	1962	584
1975	2320	787
1976	2780	959
1977	3302	1067
1978	4104	1203
1979	4858	1403
1980	5917	1618
1981	6883	1823
1982	6206	2015
1983	6038	2132
1984	5686	2177
1985	5401	2101
1986	5596	2231
1987	5204	2197
1988	4788	2243
1989	5077	2274
1990	5471	2290

APPENDIX B

Table B1. Estimates for One Period Risk-Neutral Models (Log Linear Models)

	Canola		Rye		Flax	
	coeff	t-ratio	coeff	t-ratio	coeff	t-ratio
Lagged market price	-.2116	1.73	.1850	1.76	-.1269	1.05
Weather	.4367	2.79	.6690	3.94	.6386	3.28
Trend	.0124	3.07	.0270	5.78	.0250	4.50
Constant	-3.257	3.68	-4.673	4.84	-4.963	4.49
R^2/DW	.6396	2.14	.7383	1.72	.7576	1.55

Table B2: Estimates for One Period Linear Mean-Variance Models (Log Linear Models)

	Canola		Rye		Flax	
	coeff	t-ratio	coeff	t-ratio	coeff	t-ratio
Lagged market price	-.3025	2.17	.1030	0.73	.0032	0.02
Market price variance	.0260	1.29	.0231	0.87	-.0362	1.11
Weather	.3894	2.45	.6347	3.63	.6747	3.43
Trend	.0099	2.24	.0220	2.96	.0322	3.76
Constant	-2.909	3.18	-4.408	4.34	-5.331	4.64
R^2/DW	.6651	2.25	.7470	1.83	.7704	1.49

Table B3: Estimates of Risk-Neutral Polynomial Distributed Lag (Log Linear Models)

		Canola		Rye		Flax	
		coeff	t-ratio	coeff	t-ratio	coeff	t-ratio
Lagged market price	LO	-.2358	1.84	.2375	2.24	-.0020	0.02
	L1	-.0383	0.35	.0571	0.89	-.0333	0.47
	L2	.0497	0.50	.0703	1.20	.0673	1.03
	L3	.0601	0.73	.1190	2.11	.1533	2.42
	L4	.0252	0.31	.0947	1.44	.1513	2.03
	L5	-.0229	0.31	.0088	0.15	.0606	0.94
	L6	-.0515	0.59	-.7770	1.25	-.0464	0.69
	L7	-.0280	0.26	-.0194	0.30	-.0245	0.33
	L8	.0807	0.50	.4071	2.96	.3445	2.57
Weather		.4208	2.45	.8385	5.30	.7120	3.77
Trend		.0124	1.54	.0438	5.23	.0449	3.95
Constant		-3.233	2.37	-6.117	6.00	-6.759	4.68
R^2/DW		.6770	2.25	.8513	2.58	.8386	1.65
Σlag coeff (PDL)		-.1608	0.25	.8902	2.43	.6706	1.55
Σlag coeff (UDL)		-.8512	1.73	1.083	4.10	.6840	1.54

Table B4: Estimates of Risk-Neutral Polynomial Distributed Lag (Log Linear Models - using Capital Proxy)

		Canola		Rye		Flax	
		coeff	t-ratio	coeff	t-ratio	coeff	t-ratio
Lagged market price	LO	-.1900	1.36	.2576	2.57	.1009	0.84
	L1	.0268	0.20	.1451	1.91	.1570	1.35
	L2	.1199	0.93	.1322	2.08	.2531	2.28
	L3	.1269	1.11	.1252	2.49	.3041	3.18
	L4	.0841	0.78	.0784	1.26	.2737	2.96
	L5	.0266	0.28	-.0055	0.10	.1743	2.11
	L6	-.0121	0.12	-.0756	1.30	.0674	0.79
	L7	.0006	0.01	-.0330	0.53	.0630	0.78
	L8	.0955	0.58	.2695	1.82	.3204	2.56
Capital		-.3332	0.85	-.5490	1.90	-1.001	2.00
Weather		.3802	2.12	.7137	4.40	.5507	2.85
Trend		.0240	1.51	.0543	5.65	.0907	3.60
Constant		-5.823	1.74	-9.025	5.00	-14.25	3.59
R^2/DW		.6894	2.11	.8761	2.59	.8681	2.05
$\sum$lag coeff (PDL)		.2784	0.34	.8938	2.60	1.714	2.60
$\sum$lag coeff (UDL)		-1.023	1.44	1.084	4.05	1.640	2.37

Table B5: Estimates of Linear Mean-Variance Polynomial Distributed Lag (Log Linear Models - Corrected for First Order Autocorrelation)

		Canola		Rye		Flax	
		coeff	t-ratio	coeff	t-ratio	coeff	t-ratio
Lagged market price	LO	.0095	0.04	.2050	1.63	.3710	2.10
	L1	.2904	1.94	.1030	1.25	.1553	1.00
	L2	.3714	2.67	.1127	1.63	.1159	0.70
	L3	.3760	2.77	.1403	2.62	.1497	0.74
	L4	.3852	2.52	.1322	1.91	.1848	0.76
	L5	.4369	2.59	.0746	1.23	.1808	0.76
	L6	.5264	2.64	-.0064	1.00	.1287	0.60
	L7	.6064	2.63	-.0445	0.65	.0510	0.29
	L8	.5864	2.07	.0663	0.26	.0012	0.01
Market price variance	LO	.0657	1.98	-.0333	1.19	-.0581	1.29
	L1	.0082	0.46	.0169	1.20	-.0383	1.15
	L2	-.0039	0.28	.0126	1.17	.0016	0.06
	L3	-.0038	0.39	-.0106	0.94	.0226	0.99
	L4	-.0104	0.69	-.0288	1.76	.0090	0.30
	L5	-.0288	1.63	-.0300	1.93	-.0321	1.09
	L6	-.0499	2.29	-.0134	1.04	-.0705	2.14
	L7	-.0507	2.26	.0100	0.84	-.0528	1.72
	L8	.0060	0.25	.0176	0.89	.0971	2.87
Weather		.2509	1.28	.7343	4.54	.4533	1.86
Trend		.0554	3.07	.0487	4.43	.0805	1.76
Constant		-7.403	4.18	-5.512	5.39	-6.308	3.06
R^2/DW		.8319	2.26	.9104	2.34	.9091	2.02
$\sum$lag coeff: Ep (PDL)		3.589	2.86	.7831	2.21	1.338	0.94
: Vp (PDL)		-.0676	0.84	-.0589	0.95	-.1215	1.19
: Ep (UDL)		6.124	3.06	.9059	3.34	3.274	2.37
: Vp (UDL)		-.1470	1.88	-.0072	0.18	-.2714	2.90