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

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BY

ATIKARN MUNDANG

A Thesis
Submitted to The Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

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The University of Manitoba
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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

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

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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:

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

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):

$$(2) \quad y^i_t = \beta_{i0} + \beta_{i1}\, Ep^i_t / w^1_t + \beta_{i2}\, w^2_t / w^1_t + \beta_{i3}\, w^1_t + \beta_{i4}\, K_t / z_t + \beta_{i5}\, z^i_t + \beta_{i6}\, G_t + \beta_{i7}\, t + \beta_{i8}\, Vp^i_t / w^1_t + e^i_t \qquad i = 1,.,M \quad t = 1,.,T.$$

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):

$$(3) \quad y^i_t = \beta_{i0} + \beta_{i1}\, Ep^i_t / w^1_t + \beta_{i2}\, w^2_t / w^1_t + \beta_{i3}\, w^1_t + \beta_{i4}\, K_t / z_t + \beta_{i5}\, z^i_t + \beta_{i6}\, G_t + \beta_{i7}\, t + \beta_{i8}\, Vp^i_t / (w^1_t)^2 + W_t / w^1_t + e^i_t \qquad i = 1,.,M \quad t = 1,.,T.$$

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):

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

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.