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Canadian Hog Supply Response: A Provincial Level Analysis

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Cahier de recherche/Working paper #2013-1

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Abstract: Canada's hog sector has faced two decades of tumultuous growth, yet there are no recent estimates of supply response. A state-space model for hog supply response is developed that accounts for the time series properties of the data while accounting for a multiplicity of unspecified sources for structural change. A GARCH process is used to estimate expected price and price volatility to investigate the role of price risk. Surprisingly, the results indicate relatively inelastic own price elasticities that are consistent with prior studies conducted over more stable periods. This implies that price variations can have substantial effects on total profits and losses. The lack of sensitivity of quantities supplied can be explained in Quebec by the presence of the ASRA program. In other provinces, we conjecture that price expectations used by farmers are quite diffuse and that marginal changes in the mean (and variance) do not have much impact. The effects of risk for supply response appear quite muted and impacts of feed price risk are potentially bigger than hog price risk.

Résumé: Le secteur porcin canadien a été confronté à une croissance tumultueuse durant les deux dernières décennies et pourtant on ne peut trouver d'études récentes sur les fonctions d'offre. Un modèle spatio-temporel de l'offre qui prend en compte les proprieties stochastiques des données et d'une multitude de sources de changement structurel a été développé. Une specification GARCH est utilisée pour estimer l'espérance et la volatilité du prix et analyser l'importance du risque. Étonnament, nmous avons trouvé que les quantités offertes sont peu sensibles aux variations de prix, un résultat semblable à ceux publiés dans des etudes couvrant des périodes plus stables. Ceci implique que des variations de prix peuvent avoir une forte incidence sur les profits totaux et les pertes. Pour la province de Québec, ce résultat s'explique par la présence du programme ASRA. Dans les autres provinces, nous faisons l'hypothèse que les prix attendus par les producteurs sont passablement diffus et que des changements à la marge dans leur espérance et leur variance ont peu d'effet. Les effets du risque sur l'offre sont relativement faibles. Le risque par rapport au prix des aliments semble avoir un effet plus fort que le risqué sur le prix du porc sur pattes.

JEL codes: Q11, Q13, and C32

Keywords: supply response, Kalman filter, ARCH and GARCH models

A different version of this document will be published in the *Canadian Journal of Agricultural Economics*

INTRODUCTION

While estimates of supply response were a mainstay of agricultural economists in the 1970's and 1980's, a search of the literature shows that the practice has very much been in decline lately[1]. The most recent published article estimating the Canadian hog supply appears to be Meilke and Moschini (1992). This lack of attention occurred despite a tumultuous period for the Canadian hog industry where the growth path of the industry has followed a sigmoid shape. Between 1988 and 1997, annual growth rates for hog production were modest with increases of 2.5%. After 1997 growth rates accelerated to 9%, and finally growth reversed between 2004 until 2009 an average negative growth rate of -2% (AAFC 2011a). This latter period is one of retrenchment as the industry faced multiple challenges of a stronger Canadian/US exchange rate, high feed prices, and mandatory country of origin labelling in the U.S. market.

The econometric challenges of estimating hog supply are many fold. First the dramatic growth in the industry leads to unit root problems with real variables such as hog supplies. Confounding this problem is the potential for structural change. Possible causes of this change include the 1995 elimination of the Western Grains Transportation Act (WGTA) which resulted in decreased prairie grain prices as transportation costs increased with the elimination of the subsidy (Schmitz, Highmoor, and Schmitz 2002). This change was quickly followed, 1996-97, by the elimination of single desk monopoly status of the three western provincial hog marketing boards (Hobbs and Young 2000)[2]. It was also a time of significant investments in hog packing facilities such as the 1999 introduction of a world class hog packing facility in Brandon, Manitoba (Grier *et al.*, 2007). With the growth of the packing sector and changes to the marketing system, producers began marketing their hogs under contract and as a result spot markets became much thinner (Mussell 2003). Production methods also began to change to intensive industrial production systems combined with more specialized vertical supply chains (Gillespie, Karantininis, and Storey, 1997 and Grier *et al.*, 2007). Subsequently both Manitoba and Quebec introduced legislation that limited the construction of new hog barns in response to environmental concerns (Tamini and Larue 2010). These changes were persistent over time and it is difficult to identify and account for all the factors inducing structural change for the industry.

One method of handling structural change in time series models, and the associated problems of non-stationary time series, is the state space approach with the state of the system representing the various unobserved components including trends, cycles, and seasonal variations. In this manuscript we employ a structural time series model (STSM) approach designed to specifically accommodate the unobservable underlying trends, cycles and seasonal factors in a more general way by allowing for the unobservable components to change stochastically over time (Harvey, 1989; Harvey, 1993, Ch. 4).

A third econometric challenge is to account for producers' response to risk. In the past 15 years there have been two periods of rapid price suppression: over the second half of 1998 the price of hogs fell by 63% and over the second half of 2007 the price fell 48%. These sharp declines combined with significant volatility (18% coefficient of variation) create a challenge to analyze the effects of price risk on producer behaviour. Identifying risk response in econometric models requires measures that are time varying. Studies by Holt and Aradhyula (1990), Holt and Moschini (1992), and Rezitis and Stavropoulos (2009) have used a generalized autoregressive conditional heteroskedasticity (GARCH) approach to generate time-varying predictions of price uncertainty and volatility to model supply response in U.S. broiler, U.S. hog and Greek hog sectors.

The objective of this study is to analyze how farm level prices affect Canadian hog producers' behaviour and to measure the effects. The study employs monthly data for each of the four largest hog producing provinces – Manitoba, Quebec, Ontario, and Alberta– in the hope that disaggregated data will shed light on important structural and institutional changes. The continual changes affecting the sector are addressed with measurement equations that describe how the observed data are generated from unobservable state variables. This study introduces two types of risk into a model of hog supply response. The approach draws on recent literature on modelling conditional variances.

The contribution of the study is not as an exercise in developing new methods, but rather an attempt to provide the best empirical analysis for the supply of Canadian hogs given the available data and modelling techniques. Up-to-date estimates of supply elasticities are required for relevant policy models to analyze issues affecting the industry such as trade policy measures and the changing competitive climate that it must operate in. At a minimum this study must attempt to determine if the prior supply elasticities are still relevant for continued policy work.

The paper is organized as follows. First, a conceptual econometric model of the hog supply that accounts for price expectations and the incorporation of risk are described. The following section presents data and econometric issues including the development of the structural times series model (STSM) approach. Next we present the empirical results for both price expectations and hog supply models. The final section presents implications and conclusions.

CONCEPTUAL MODEL

Empirical implementation of livestock supply functions requires the formation of expectations for prices because of the lag between the time decisions are made and the realization of output. This lag between decision making and production realization also introduces an element of price risk. We turn now to the derivation of the conditional mean and variance expectations, and the risk inclusive supply equations are considered in subsequent sections.

Conditional Expected Price and Variance

A basic problem that farmers face when they make their output decisions is how to form expectations about future prices. This is particularly important in hog production due to the relatively long period from the point that the decision is made to when the hog is marketed.

The measures of conditional expected price and price variance in this manuscript are based on a gestation period of 115 days plus roughly 155 days until the piglet goes to market (Haley 2009). This study assumes a relatively short period to market so the total lag in the period to market is nine months. So the conditional expected price and variance can be written as:

$$P_t^e = E(P_t | \Omega_{t-9}) \quad \text{and} \quad \sigma^2{}_t = E((P_t - P_t^e)^2 | \Omega_{t-9}) \tag{1}$$

Where E is the conditional expectation operator, and $\Omega_{t\text{-}9}$ is the information set that is available when the decision to produce is made which is 9 months prior to when the hog is marketed.

To implement this expectation process, assume that the output price can be represented an n^{th} order Univariate autoregressive process (Diebold and Pauly 1988):

$$A(L)P_t = a_0 + \varepsilon_t \tag{2}$$

where $A(L) = 1 - a_1 L - a_2 L^2 - ... - a_n L^n$ is a polynomial in the lag operator L of order n, The process is stable as long as its characteristic roots of it lie outside of the unit cycle.

The relevant time horizon (9 months) for the supply decision exceeds the frequency of the monthly data. So, conditional expectations of both output price and price variance must be iterated ahead nine periods. The conditional price expectation for period *t*, is given by the following sequence (equations 3.1 - 3.9) of one-step ahead forecasts:

$$E(P_{t-8}|\Omega_{t-9}) = A_0 + A(L)P_{t-9} \tag{3.1}$$

$$E(P_{t-7}|\Omega_{t-9}) = A_0 + A(L)E(P_{t-8}|\Omega_{t-9}) = B_0[1 + A(L)] + A^2(L)P_{t-9} \tag{3.2}$$

$$\vdots$$

$$E(P_t|\Omega_{t-9}) = A_0 + A(L)E(P_{t-1}|\Omega_{t-9}) = A_0[1 + A(L) + ... + A^8(L)] + A^9(L)P_{t-9} \tag{3.9}$$

The conditional expectation that hog farmers respond to is equation (3.9).

Autoregressive conditional heteroskedasticity (ARCH) models are used to characterize time series that exhibit time varying clustering or periods of significant volatility followed by periods of relative calm. In particular, the general class of ARCH models focus on violations of homoscedasticity (constant variances) and instead of treating it as problem they attempt to model the behaviour of the variance. As a result a prediction is computed for the variance of each error term (Engle 2001). The basic model determines the future variance (h_t) as weighted average of the squared residuals from the past where these weights are parameters to be estimated. The GARCH parameterization introduced by Bollerslev (1986) is also a weighted average of past squared residuals, but it has declining weights that never go completely to zero. This is equivalent to introducing a lagged dependent variable into the specification. Various ARCH and GARCH model are described by the order of the lags for the squared residuals and the order of the lagged dependent variables.

The conditional variance for period *t*, is given by the following sequence (equations 4.1 - 4.9) produced with one-step ahead forecasts and σ_t^2 is assumed to follow a GARCH (1,1) process:

$$h_{t-8} = \delta_0 + \delta_1 \varepsilon_{t-9}^2 + \omega_1 h_{t-9} \quad (4)$$

then,

$$E(h_{t-8}|\Omega_{t-9}) = \delta_0 + (\delta_1 + \omega§_1)E(h_{t-9}|\Omega_{t-9}) \quad (4.1)$$
$$\vdots$$
$$E(h_t|\Omega_{t-9}) = \delta_0 + (\delta_1 + \omega_1)E(h_{t-1}|\Omega_{t-9}) \quad (4.9)$$

The Supply Equation

The dominant approach to analyze decision making under uncertainty involves an expected utility model [3]. If producers are assumed to display constant absolute risk aversion and the distribution of prices is normal, then this approach can be implemented by maximizing certainty equivalent profits (expected profits less a risk premium) with respect to the supply of hogs. Expected profits are equal to expected revenues less costs. The risk premium consists of an absolute risk aversion parameter (λ) multiplied by squared output multiplied by the variance of hog prices (σ_p^2) all multiplied by one-half.

$$\underset{S_{hog}}{Max}[P^e \cdot S_{hog} - C(S_{hog}) - \frac{1}{2}\lambda S_{hog}{}^2 \sigma_p^2] \quad (5)$$

where: $S_{hog} \equiv$ output or marketings of hogs
$P^e \equiv$ expected price
$\sigma_p^2 \equiv$ *ex ante* variance of hog prices
$C(S_{hog}) \equiv$ cost function
and λ is the coefficient of risk aversion.

The first order condition is:

$$P^e - C'(S_{hog}) - \lambda S_{hog}\sigma_p^2 = 0 \quad (6)$$

Equation (6) can be solved for the optimal hog supply S^*_{hog} , which is a function of the expected hog price and expected conditional price variance. The first order condition is normalized by an industrial product price input for agricultural inputs to impose linear homogeneity on the supply function.

$$S^*_{hog} = f(P^e, \sigma_p^{2^e}) \quad (7)$$

This is a static output supply function which assumes that adjustments to the optimal supply level are instantaneous. Typically to account for the fact that desired and actual production levels can differ in the short run a Nerlovan partial adjustment model (Nerlove 1956) is introduced[4]. However, a lagged dependent variable is not included in this specification because the state space model accounts for these adjustments towards the desired level of production. Equation (7) is written in linear form with expected hog and feed prices, and the variances of hog and feed prices are included in the specification:

$$S_{hog,t} = \gamma_0 + \gamma_1 P_t^{e^{hogs}} + \gamma_2 P_t^{e^{feed}} + \varphi_1 \sigma^2_{hog\ price_t} + \varphi_2 \sigma^2_{feed\ price_t} + e_t \quad (8)$$

where e_t is a random white noise term. This approach follows Holt and Moschini (1992) and Rezitis and Stavropoulos (2009) with the modification that risk is divided between hog and feed prices and the application of a structural-times series modeling approach (Harvey 1997).

DATA AND ECONOMETRIC ISSUES

Equation (8) is used as a specification to estimate risk-responsive models of market hog supply for Alberta, Manitoba, Ontario, and Quebec. This section describes the data series employed in this study, and their sources together with an analysis of the salient features of the main variables and their time series properties. The monthly supply data consist of volumes of slaughter hogs (head)[5] marketed through domestic channels and exports. The data were obtained from Agriculture and AgriFood Canada - Market and Industry Services Branch – Red Meat Section (AAFC 2011b).

The hog price data are monthly weighted average prices for index 100 hogs (AAFC 2011c). Although individual prices are available for all four provinces, these prices are strongly correlated, with correlation coefficients of over 0.98, and each price follows the same pattern with only minor differences that are not explained by transport costs. Given that all provincial prices are essentially the same landed U.S. price, each with different transport costs, we have limited our attention to one representative hog price, the Manitoba price, to estimate conditional expected prices for all provinces except Quebec. This province is treated differently because of *Programme d'Assurance Stabilisation des Revenus Agricoles* (*ASRA*) payments and the hog price has been adjusted to include the effects of the program.

Each province's feed price is determined by whether corn or barley is the major source of energy. The Lethbridge barley price is used for the feed price in Alberta and Manitoba and the Chatham corn price is used for Quebec and Ontario. These prices were obtained from AAFC's Market Analysis Group (AAFC 2011c). All prices are normalized by the Statistics Canada's Industrial Product Price Index (*IPPI*) for fruit, vegetable, feeds and other food products which is a proxy for the price of processed feeds (Statistics Canada, 2011).

Another consideration in modeling hog supply response is the presence of government programs. Over the estimation period most government support to the hog sector involved a form of generally available non-product specific schemes that stabilized net income: *Net Income Stabilization Account* (1990-2002), *AIDA/CFIP* (1998-2002), *Canadian Agricultural Income Stabilization* (*CAIS*) Program (2002-06), and *AgriStability* (2007-2008)). Since these programs are not commodity specific or directly linked to producer prices, for the purposes of this study they are assumed not to directly affect production decisions. However, Quebec's *ASRA* program is commodity specific and directly affects the price received by producers in that it compensates them when the market price is less than the stabilized price. This stabilized price guarantees Quebec agricultural producers their cost of production. *ASRA* establishes a guaranteed minimum price where the producer is paid the maximum of either the market price or the guaranteed *ASRA* price[6]. Data for the annual guaranteed *ASRA* price are approximated as the sum of annual payments to producers (net of premiums), obtained from *La Financière Agricole du Québec* (2006), were divided by the number of Quebec hogs marketed multiplied by the cold carcass weights of a dressed hog. This per kilogram payment is available on an annual basis. A 12 month moving average of the payment is added to the market price and this adjusted price is then used to develop the expected producer price.

Table 1 provides the results of unit root tests on the data. Augmented Dickey Fuller (*ADF*), Phillips-Perron (*PP*) and Kwiatkowski, Phillips, Schmidt and Shin (*KPSS*) tests were all employed. The *KPSS* test complements the other unit root tests and tests the null hypothesis of stationarity. So this test was included to assess the reliability of the *ADF* and *PP* tests. The *ADF* and *KPSS* tests yield corroborating evidence that we could not reject unit roots for any of the variables. However, the *PP* and *KPSS* tests yield conflicting evidence for supply variables for Alberta, Ontario, and Quebec. Carrion-i-Silvestre *et al*. (2001) implemented a Confirmatory Data Analysis that provides critical values for the joint confirmation hypothesis of a unit root for wedded tests for *PP* and *KPS*. Critical values, at the 99% level were -4.110 and 0.070 for PP and KPSS. When this criterion is applied unit roots could not be rejected for any of the variables.

Table 1. Results of Unit Roots Tests

	Augmented Dickey Fuller (ADF)	Phillips-Perron	KPSS
Supply: Alberta	-2.321	-5.205 *	0.173
Supply: Manitoba	-0.981	-0.418	0.349
Supply: Ontario	-1.515	-3.702 *	0.161
Supply: Quebec	-1.146	-5.600 *	0.198
Hog Price: Quebec	-2.342	-2.843	0.211
Hog price: Rest of Canada	-3.913	-2.893	0.157
Feed price: corn	-2.01	-3.411	0.131
Feed price: barley	-2.410	-3.109	0.087

* significant at 1% level

The empirical specification of equation (8) requires more information to be implemented. This specification does not include unobservable factors such as technological improvements, institutional changes and other exogenous variables that also affect hog supply response. Introducing deterministic trends to account for these factors, when they are actually stochastic may result in mis-specified models and false inferences. The supply model that we utilize employs a structural time series model (*STSM*) approach designed to specifically accommodate the unobservable underlying trends, cycles and seasonal factors in a more general way by allowing for the unobservable components to change stochastically over time (Harvey, 1989; Harvey, 1993, Ch. 4). *STSM* models revert to a standard regression model in the absence of unobservable components (Harvey and Scott, 1994). So even if the process generating $S_{hog\,t}$ is non-stationary, these changes are explicitly accounted for through stochastic trends and therefore unit roots are not a problem.

Equation (8) can be written as a structural time series model:

$$S_{hog,t} = \mu_t + \psi_t + \phi_t + Z_{1t}'\theta + e_t \qquad (9)$$

where $S_{hog,t}$ is the monthly supply of hogs, μ_t is the trend component, ψ_t is the cyclical component, ϕ_t is the seasonal component, Z'_{1t} is the vector of explanatory variables $(P_t^{e\,hogs}, P_t^{e\,feed}, \sigma^2_{hog\ price_t}, \sigma^2_{feed\ price})$ and θ is the row vector of unknown parameters $(\gamma_1, \gamma_2, \varphi_1, \varphi_2)'$ and e_t is a random white noise error term. So equation (9) is a combination of a structural model $Z'\theta$ whose parameters θ correspond to those in the linear equation (8) and a time series decomposition of trends, seasonality and cycles.

The challenge is to show the evolution of the slowly evolving term μ_t and the cyclical component ψ_t. This process can be written in state-space form where each subsequent equation explains the evolution of the parameters in the prior equation. The trend components are assumed to have a stochastic process that is typically described as a local linear trend:

$$\mu_t = \mu_{t-1} + \beta_{t-1} + \psi_{t-1} + \eta_t \qquad \eta \sim NID(0, \sigma^2_{\eta_t}) \qquad (10)$$

$$\beta_t = \beta_{t-1} + \zeta_t \qquad \zeta \sim NID(0, \sigma^2_{\zeta_t}) \qquad (11)$$

and.

$$\begin{pmatrix} \psi_t \\ \psi_t^* \end{pmatrix} = \begin{pmatrix} \cos\lambda & \sin\lambda \\ -\sin\lambda & \cos\lambda \end{pmatrix} \begin{pmatrix} \psi_{t-1} \\ \psi_{t-1}^* \end{pmatrix} + \begin{pmatrix} \kappa_t \\ \kappa_t^* \end{pmatrix} \qquad \kappa \sim NID(0, \sigma^2_{\kappa}) \qquad (12)$$

The first equation (10) shows the evolution of the level of the trend term. In the absence of β and ψ this equation would follow a random walk. The β_t is a slope parameter for the trend and it evolves of time through equation (11). The disturbance ζ gives a random character to β_t given the level and slope in the previous period. So equations (10) and (11) represent the level and the slope of the trend which are incorporated into the hog supply function to capture technological progress and structural change. The variances σ^2_η and σ^2_ζ

are hyper-parameters and determine the form of the trend. If either is non-zero then the trend is stochastic. If both are zero the trend is linear (Jalles, 2009).

A cyclical component ψ_t is included in the hog supply model to capture longer term cycles. The cyclical component may be combined with a trend in several different ways, but in this case a cyclical trend model (see Jalles 2009) is introduced into the state equation (10). The cyclical term can either be a deterministic cycle or stochastic. When the cycle is stochastic its evolution follows the state equation (12) where the Gaussian white noise disturbance terms κ_t and κ_t^* introduce a random element so that the parameters of the cyclic function evolve randomly through time. In the absence of these disturbance terms ψ_t reverts to a deterministic cycle which can be described as a function of sines and cosines as:

$$\psi_t = \psi_0 \cdot \cos(\lambda t) + \psi_0^* \cdot \sin(\lambda t)$$

where λ is the angle frequency of the cycle measured in radians. With a stochastic cycle ψ_0 and ψ_0^* evolve over time and κ_t and κ_t^* are uncorrelated and have the same variance σ_κ^2. Shorter term seasonal variations are captured by ϕ_t. The strategy used in this paper is to introduce time invariant seasonal dummy variables.[7]

In order to estimate the unobserved components of equation (9) a Kalman (1960) algorithm is employed. Equation (9) is rewritten in state space form.

$$S_{hog,t} = \widetilde{Z}_t' \alpha_t + e_{t\,t} \qquad e \sim NID(0, P) \qquad (13)$$

where $\alpha = (\mu_t, \beta_t, \psi_t, \gamma_1, \gamma_2, \varphi_1, \varphi_1)'$ and $\widetilde{Z}_t = (1,0,1, P_t^{e\,hogs}, P_t^{e\,feed}, \sigma^2_{hog\ price_t}, \sigma^2_{feed\ price})'$ are the parameters and variables from the local level model. The Kalman filter is a recursive procedure and involves a mathematical tool which operates by means of a prediction and correction mechanism. The prediction equations show the evolution of α_t:

$$\alpha_t = T_t \alpha_{t-1} + \Omega_t \qquad \Omega \sim NID(0, Q) \tag{14}$$

$$P_t = T_t P_{t-1} T_t' + Q \tag{15}$$

Equation (14) is a transition equation which represents the relationship between the state variable α_t and its lagged values through a transition matrix (which in our case is an identity matrix with an addition unity element (1) in the second column of the first row to account for the local linear trend). The error term $\Omega = f(\eta_t, \zeta_t, \kappa_n, \kappa_t^*)$ is 1 × *n* vector and its variance is ***Q*** which is the covariance matrix of the transition equation. This is a diagonal matrix with variances $(\sigma_\eta^2, \sigma_\zeta^2, \sigma_\kappa^2, \sigma_{\kappa^*}^2\, 0,0,0,0)$ where the remaining variances on the diagonal are to zero in order to have non-time varying parameters $(\gamma_1, \gamma_2, \varphi_1, \varphi_2)'$. The parameter vector $\alpha = (\mu_t, \beta_t, \psi_t, \gamma_1, \gamma_2, \varphi_1, \varphi_1)'$ is normally distributed with a mean $\overline{\alpha}_t$ and the covariance matrix **P**. Equation (15) describes the prediction of the covariance matrix **P** as the state variables evolve over time.

The algorithm predicts the new state from the previous estimate by adding a proportional correcting term (see the Kalman gain below) times the prediction error. The updating equations are:

$$\alpha_t = \alpha_{t|t-1} + K_t (S_t - \widetilde{Z}_t \alpha_{t-1}) \tag{16}$$

$$\mathrm{P}_t = P_{t-1} - P_{t-1} \widetilde{Z}_t' (\widetilde{Z} P_{t-1} \widetilde{Z}' + \sigma_e^2 \times I_{n \times n})^{-1} \widetilde{Z}_t P_{t-1} \tag{17}$$

The main purpose of filtering is to update the knowledge of the system for each new observation $S_{hog,t+1}$ that is obtained. The Kalman gain $K_t = \dfrac{\widetilde{Z}_t \mathrm{P}_{t-1}}{(\widetilde{Z}_t' \mathrm{P}_{t-1} \widetilde{Z}_t + \sigma_e{}^2 \cdot \mathrm{I})}$ is the ratio of previous period's parameter vector α covariance matrix, relative to one-step-ahead error variance of $S_{hog,t}$ given $S_{hog,t-1}$. The denominator of the Kalman gain is therefore the variance of the forecast error. This Kalman gain adjusts the forecast errors, given the previous period parameter vector, and this adjustment is added to last period's parameter vector to give updated parameter in equation (16). The covariance matrix of the parameter vector **P** is updated through equation (17).

Once the model has been written in state-space form, the Kalman filter yields recursive estimates of the components based on current and past observations. The unknown variance parameters are estimated by constructing a likelihood function from the one step ahead prediction errors produced by the Kalman filter. The estimation is carried out by Koopman *et al.* (2009) STAMP 8.2 (Structural Time Series Analyser, Modeller and Predictor) software. This approach uses diffuse priors to get the initial state for the parameter vector and the **P** matrix.

RESULTS

Hog and feed price expectations

Preliminary visual examination of correlograms for the autocorrelations and partial autocorrelations of the hog and feed price series revealed hog price series that converged to zero after thirteen periods, and feed prices that converged after six periods. Univariate autoregressive models were run, with respect to hog and feed prices, and the residuals of these models were tested for serial correlation. The presence of serial correlation in the squared residuals is one of the implications of conditional autoregressive heteroskedasticity. Engle LM tests were run to determine the presence of ARCH effects in each of the price series. In cases of the Manitoba hog price and barley and corn prices, the hypothesis of no ARCH effects was rejected. Quebec hog prices, augmented by *ASRA*, were not found to display ARCH effects. This is not surprising given that the *ASRA* program is intended to stabilize hog producers incomes in that province.

Table 2 contains the results for autoregressive models for hog and feed prices.

Table 2: Estimates of the Hog and Feed Prices – 1988:1-2008:6

Parameter	variable	Quebec Hog Price	Manitoba Hog Price	Barley Price	Corn Price
Conditional Mean					
A_0	1	.081	0.07	.001	0.082
		(0.073)	(0.022)	(.021)	(0.000)
A_1	P_{t-1}	0.9306	0.929	1.378	1.27
		(0.000)	(0.000)	(0.000)	(0.000)
A_2	P_{t-2}			-0.532	-0.315
				(.000)	(0.000)
A_4	P_{t-4}			0.143	
				(0.000)	
A_5	P_{t-5}				-0.209
					(0.012)
A_6	P_{t-6}				0.186
					(0.006)
A_{11}	P_{t-11}	0.266	0.239		
		(0.000)	(0.000)		
A_{12}	P_{t-12}		0.238		
			(0.000)		
A_{13}	P_{t-13}	- 0.243	-0.2486	- 0.046	
		(0.000)	(0.000)	(0.008)	
Conditional Variance					
δ_0	1		.0002	.001	.002
			(0.498)	(0.021)	(0.002)
δ_1	ε_{t-1}		0.085	.314	0.333
			(0.029)	(0.009)	(0.001)
ω_1	h_{t-1}		0.897	0.375	0.413
			(0.000)	(0.021)	(0.003)
Diagnostics					
BIC		-361.626	-338.665	-610.918	-493.817
Q(12)		8.634	9.8256	11.201	6.861
		(0.3741)	(0.277)	(0.1906)	(0.5512)
Q(24)		25.598	24.392	23.671	17.546
		(0.1795)	(0.226)	(0.2571)	(0.6173)
$Q^2(12)$		16.578	11.153	8.977	12.629
		(0.121)	(0.346)	(0.534)	(0.245)
$Q^2(24)$		25.685	18.513	18.588	21.780
		(0.369)	(0.675)	(0.671)	(0.473)

Note: *P*-values are in parentheses. Coefficients are significant at *5%. *BIC* is Bayes Information Criteria. *Q(m)* is the Ljung–Box Q statistic for *m* order serial correlation, which is distributed as a Chi–squared variable with *k-p* degrees of freedom, *p* is the order of *AR(p)* process.

Bayes Information Criterion (*BIC*) was used to select the appropriate order of each autoregressive model. All coefficients that were not statistically significant were eliminated from the estimation procedure in order to obtain parsimonious estimates. Column 3 of table 2 contains estimates for the Quebec hog price, normalized by the *IPPI* feed price, resulting in very significant coefficients (*p*-values of 0.000) for the first, eleventh and thirteenth lags. Residual diagnostic tests were performed to check the explanatory power of the price equations. Ljung-Box $Q(m)$ statistics, with m equal to 12 and 24 month lags, are performed for the standardized residuals and squared standardized residuals to test for any additional serial correlation and heteroskedasticity. The null hypothesis $Q(m)=0$ that a series of residuals exhibit no autocorrelation for m lags could not be rejected with p-values well above the 5% and 10% levels of statistical significance for 12 and 24 lags; likewise the hypothesis for the absence of ARCH effects with $Q^2(m)=0$ could not be rejected with *p*-values well above conventional levels of statistical significance.

Results for GARCH models for hog, barley and corn prices are shown in columns 4, 5 and 6. The Broyden-Fletcher-Goldfarb-Shanno (BFGS) algorithm was used to obtain maximum likelihood estimates of the parameters and all estimated models achieved convergence. The equation for Manitoba hog prices produced a similar lag structure and parameter estimates as the Quebec price model with the addition of a significant lagged coefficient for the twelfth period and of course a conditional variance process. Again the Ljung-Box Q statistics do not indicate either autocorrelation or heteroskedasticity. The GARCH in mean (GARCH-M) model specified with GARCH (1, 1) conditional variance process outperformed other ARCH and GARCH variants in terms of *BIC* selection criteria. The coefficients α_1 and β_1 (see equation 4) are each significant and sum to less than unity.

This sum (0.982) is nonetheless large indicating that changes in the conditional variance are persistent and since β_1 is equal to 0.897 any shock to the conditional variance will take a long time to subside.

The coefficient on the first month's lagged hog price is the largest and most statistically significant coefficient in the hog price models. This follows because the recent past contains the most of the information about next period's price. This is consistent with the results obtained Holt and Moschini (1992) and Rezitis and Stavropoulos (2009). As with the prior studies the intra-year lagged prices were not significant. Significant lags, for the 11-13 months correspond more or less to the lags associated with gestation, raising and marketing hogs plus a bit of extra time to allow of price and market adjustments.

Columns 5 and 6 of table 2 show results for the feed prices. The lag structures are slightly different for barley and corn, with similar lags for the first month, but the number of significant lags extends to six months for corn. The lag structure reflects a different set of dynamics for feed grain prices than for hog prices with no annual echo effect and weights that decline quickly within a few months. Again the Ljung-Box Q statistics do not indicate either autocorrelation or heteroskedasticity for either model.

A simple GARCH (1, 1) specification performed best for the feed equations. Again, α_1 and β_1 are significant and add to less than one, but unlike the case of hog prices the sum is smaller indicating less persistence in the conditional variance and shocks that die out more quickly.

So the price equations captured the essential dynamics of slaughter hog prices and feed prices. The fitted values from these results and the associated residuals are used to generate measures of price risk for inclusion in the supply equations. These equations are estimated in the next section.

Hog supply equation

The fitted values and the residuals from the GARCH (1, 1) price models are used to generate measures for the conditional price expectations for hog and feed prices (see equation set 3 above) and the conditional variances of each price (see equation set 4, above) used in each of the provincial models. Table 3 presents parameter estimates of the supply equations for each of the selected provinces. All of the estimated parameters with respect to prices and risk variables have the expected signs that conform to theory where own prices have positive relationships and input prices and the cost associated with risk aversion enter the supply functions with negative signs.

The econometric approach follows Harvey (1989) by using STSM with explanatory variables and incorporating trend and cyclical variables as stochastic components. Within the state-space notation, the Kalman filter derivation rests on the assumption of normality of the initial state vector as well as the disturbances of the system. The filter's performance assumes that a system can be described through a stochastic linear model with an associated error following a normal distribution with mean zero and known variance. Therefore it is important to begin with diagnostic tests which are presented at the bottom of table 3.

The approach used to test for a normal distribution is the Bowman-Shenton (1975) statistic which is based on the third and fourth moments of the distribution of residual. This statistic has a χ^2 distribution with two degrees of freedom. The 5% critical value is 5.99. All of the Bowman-Shenton statistics in table 3 are below the critical value so the normality of residuals is not a problem.

Table 3: Estimates of Hog Supplies – Final Period State Vectors				
Parameters	Alberta	Manitoba	Ontario	Quebec
Unobserved Parameters				
μ_t	412,014.01	1,030,437.94	681,274.85	826,377.52
	(0.00)	(0.00)	(0.00)	(0.00)
β_t	1,119.55	4,034.72	1,597.20	1,668.62
	(0.00)	(0.00)	(0.00)	(0.00)
ψ_t	19,691.08	13,940.08	26,241.54	45,085.79
Observed Parameters				
$\gamma_{\text{hog price}}$	2,221,658.50	4,226,829.00	6,644,157.02	4,722,947.98
	(0.04)	(0.03)	(0.02)	(0.04)
$\gamma_{\text{feed price}}$	-3,245,304.38	-5,756,956.69	-7,032,390.42	-12,916,877.86
	(0.06)	(0.06)	(0.23)	(0.10)
$\varphi_{\text{hog price variance}}$	-270,762.85	-2,407,138.23	-688,880.90	
	(0.71)	(0.04)	(0.62)	
$\varphi_{\text{feed price variance}}$	-11,009,815.96	-31,957,835.51	-6,173,261.52	-10,342,833.2
	(0.16)	(0.05)	(0.14)	(0.12)
Dum_{Jan}		-18,102.96	-22,500.79	
		(0.03)	(0.00)	
Dum_{Feb}	48,744.69	68,126.49	71,440.53	129,757.48
	(0.00)	(0.00)	(0.00)	(0.00)
Dum_{May}	42,162.96	59,359.18	67,576.88	104,292.13
	(0.00)	(0.00)	(0.00)	(0.00)
Dum_{July}	-21,894.22		-43,541.40	-60,873.28
	(0.00)		(0.00)	(0.00)
Dum_{Sept}	-19,219.40		-50,431.47	
	(0.00)		(0.00)	
Dum_{Oct}		-14,706.75	-35,516.03	
		(.07)	(0.00)	
Dum_{Nov}	38,910.10	45,091.28	32,991.33	92,503.57
	(0.00)	(0.00)	(0.00)	(0.00)
Hyper-parameters				
σ^2_η	137,589	8.31031e+006	5.72992e+006	7.57081e+006
σ^2_ζ	0.00	0.00	0.00	0.00
σ^2_ψ	2.89790e+008	1.15068e+009	1.05897e+009	2.73820e+009
Residuals				
Normality	2.80	1.74	2.54	1.535
H	3.04	2.87	1.88	2.00
DW	1.98	2.31	1.79	2.19
Q(9)	21.463	57.17.	15.335	28.68
R_d^2	0.83	0.72	0.78	0.75

Note: *P*-values are in parentheses. *H* is a measure heteroskedasticity, *DW* is the Durbin-Watson statistic, *Q(m)* is the Ljung–Box Q statistic, and R_d^2 is a modified version of the coefficient of determination that compares the fit with random walk plus a drift

The *heteroskedasticity* test statistic, *H(h)* is the ratio of the last third *(h)* of the squared residuals relative to the first third of the squared residuals. The statistic is centered on unity and has two-sided $F_{h, h}$ distribution. Heteroskedasticity is typically not a problem in time series analysis. For Ontario and Quebec heteroskedasticity does not appear to be a problem; however, for Alberta and Manitoba a non-constant variance appears to be a bit more problematic with a significantly high test statistic that indicates an increase in the variance of the residuals over time.

Serial correlation in error terms of each model is not a problem for the first lagged residual as all of the Durbin–Watson statistics are reasonable. However, the Box–Ljung *Q*-tests indicate potential problems with the specification as the number of lagged residuals is increased to nine periods. Hall and McAleer (1989)[8] found that when the errors are normally distributed, the *Q* test is unreliable while the Durbin-Watson test is reasonably accurate. Certainly there appears to be no evidence of spurious regression. R_d^2 is a modified version of the coefficient of determination that is more appropriate for time series as it compares the fit with random walk plus a drift (Koopman *et al.* 2009).

The hype-parameters, σ_η^2 and σ_ζ^2, govern the movement of the state variables. The larger the hyper-parameters, the greater are the stochastic movements in the trend. In the limiting case when the hyper-parameters are equal to zero the model collapses to a conventional deterministic time trend. Since in each case σ_ζ^2 is equal to zero the slope component is deterministic. This is consistent with a local level model with a drift.

The expected price of hogs is positive and statistically significant for all four provinces. The expected price of feed has the correct negative sign for all four provinces. This variable is significant at the 10% level for Alberta, Manitoba, and Quebec. And it is only significant at the 23% level in Ontario. The signs on all the risk variables are negative as expected. The only risk variables that are statistically significant at the 5% level are for the province of Manitoba. The price risk variable was not included in Quebec because we were unable to find Arch effects for hog prices. This is most likely due to the ASRA program. In Alberta the "Hog Price Insurance Program" was introduced too late to have an effect on these model results but the insignificant variance could be due to the high degree of contracting in the province. The same reasoning may hold in Ontario. This leaves open the question why the variable would be significant in Manitoba. One reason may relate to the fact that the province has much higher export dependency than other provinces.

Generally price risk is more significant for feed grain price variability than for hog price variability. The conditional variances for feed prices are significant at the 15% level in Ontario and Quebec and at the 16% level in Alberta. The greater sensitivity to this variable may be due to fewer producers hedging their feed price costs than producers who have contracts with some form of hog price guarantee.

Seasonality of the data is a problem. Seasonal dummy variables were included but were not assumed to be stochastic. We eliminated all seasonal dummy variables that were insignificant so that only the significant dummy variables remain in the reported regressions.

Elasticities

Elasticities of supply with respect to expected hog and feed prices and price risk for hog and feed prices are shown in Table 4. The elasticities are evaluated at mean values for the data over of the estimation period. Since the supply models do not contain lagged dependant variables it is not possible to provide short and long run elasticises. Given relatively long periods over which the expected prices are measured the approximate time period is the short to medium term. The elasticities for the expected hog prices range from 0.1 for Manitoba to 0.2 for Quebec.

Table 4: Elasticities of hog supplies evaluated at sample means: 1992-2007				
	Alberta	Manitoba	Ontario	Quebec
hog price ^{expected}	0.125*	0.118*	0.165*	0.205*
feed price ^{expected}	-0.154**	-0.135**	-0.175	-0.266**
hog price variance	-0.015	-0.066*	-0.019	
feed price variance	-0.160	-0.230*	-0.105	-0.145

* Significant are the 5% level
** Significant are the 10% level

The conventional indicator of profitability in the hog industry is the hog-feed price ratio. So we would expect that the signs on the hog and feed price coefficients to have roughly equal magnitudes but opposite signs. However, we did not use the hog-feed price ratio as one single explanatory variable, because the two price series have quite different dynamics which warranted separation of these variables in the regression. Nonetheless the own price elasticities should be at least as large, in absolute terms as the feed price elasticities. In all cases the magnitudes of the hog and feed price elasticities are roughly similar in magnitude with the feed elasticity being slightly larger but somewhat less significant. This may be an artifact of the modelling technique. The Canadian feed sector has also undergone fundamental changes in the last two decades starting with the elimination of the WGTA and the feed freight assistance program, ranging to changes in feeding technologies to the rapid escalation of feed prices as a result of ethanol production and the emergence of biofuel by-products as an alternative feed source. These changes may have been picked up in the stochastic trend variables by the SMTS technique and hence have resulted in a lower level of significance for the feed price variable. Nonetheless higher feed prices can quickly convert profits to losses and producers may have become somewhat more sensitive to feed price swings. The sensitivity to feed price volatility can also be seen in the relatively large supply elasticities with respect to the feed price variance for Alberta and

Manitoba. Both provinces have switched from being net exporters of feed grains to net imports and the change in basis exacerbates the problem for the producer's bottom line. A significant volume of Manitoba's hog production involves weanling pigs and the decision to purchase these piglets is largely determined by relative feed prices. Table 5 presents a selection of representative elasticity estimates for selected prior studies of Canadian and other regions' hog supply response. Although the prior studies are not directly comparable with respect to estimation method, frequency, or time period, comparisons are nonetheless instructive.

Table 5 Prior Estimates of Supply Elasticities

Study	Period	Hog Price	Feed Price	Risk
			Canadian	
Moschini & Meilke	1980-89	0.042	*NA*	*NA*
Meilke and Scally		0.06 – 0.07***	*NA*	*NA*
Meilke and Coleman	1962-73	0.1 – 0.19***	*NA*	*NA*
Meilke, Zwart and Martin	1961-72	0.06 -- 0.24***	-0.5	*NA*
			Other Countries	
Holt and Moschini*	1958-90	0.172	-0.066	-0.12
Rezitis and Savropoulos **	1993-2005	0.062	-0.105	-0.164

* Estimated for U.S. hog farrowing supply
**Estimated for Greek pig supply
*** In each case the smaller elasticity is for eastern Canada and the larger for western Canada

First, the own price of supply elasticities, in all cases are very inelastic with absolute supply elasticities less than 0.27. This is consistent with the current results in table 4 where the largest elasticity is 0.2. It would be expected, that given contracting opportunities, that the more recent elasticities would smaller than prior estimates. Second, historically the elasticities in eastern Canada are smaller than for western Canada. In table 4 this trend seems to have reversed and the own price elasticities for eastern Canada appear to be a bit larger. However, the differences are small and almost the size the standard errors of the elasticities for each western province.

Third the US hog price supply elasticities are comparable to those for Ontario estimated in this study. More recent estimates for US own price elasticities may be smaller as a result of the rate of industrialization of hog production in that country.

The relatively lower of significant for feed prices contrasts with the Holt and Moschini, and Rezitis and Savropoulos studies which both found significant negative relationships between hog supplies and feed prices. Some of this difference in results may be due to the inclusion of a feed price risk variable in the current study. Allowing for 16% level of threshold for significance, this variable is negative and important in all provinces. The Holt and Moschini, and Rezitis and Savropoulos studies did not include a feed price risk variable.

The take home lesson from all of these studies is that the risk variables have a negative effect on supply response, and in the case of Manitoba feed price risk has a much bigger effect than the elasticity with respect to the expected price of hogs.

CONCLUDING REMARKS AND IMPLICATIONS

This study attempts to provide up-to-date estimates of supply response for hog marketings in Alberta, Manitoba, Ontario, and Quebec. It is unique in that it provides a regional disaggregation, accounts for output and input price risk, uses monthly data in the estimation process, and employs a structural time series model approach to account for unobservable underlying stochastic trends and cycles. The resulting short-run hog supply elasticities range from 0.1 in Manitoba to 0.2 in Quebec and are comparable with prior supply elasticity estimates obtained for Canada and the United States. This is reassuring given that a number of recent synthetic models, that are based on the prior supply elasticity estimates, and been used to examine policy issues affecting the Canadian hog sector. What this indicates is that the basic behaviour with respect to output prices and input prices has not changed significantly over time even though there have been a number of autonomous changes to the sector. The approach that we have used is sufficiently flexible to account for autonomous changes and technological progress through stochastic trends and cycles while preserving the structural behaviour of the basic model.

Having accurate and up-to-date supply elasticities is necessary for the analysis of the multiplicity of challenges facing Canada's hog sector. These challenges include rapidly rising and volatile feed prices, trade policy changes with respect to issues such as contingent protection and mandatory country of origin labeling, a stronger Canadian dollar, and other issues affecting the competitiveness of the sector. The problem is that the prior studies which estimated Canadian hog supply predated 1992. Since that time there have been a number of structural changes in the Canadian hog sector. The way that hogs are marketed has changed from boards with single desk selling authority to systems that allow producers several options to sell their hogs. The introduction of production contracts and increased vertical coordination reduce risk and should make the supply of hogs less sensitive to price fluctuations. More specialized large scale ventures should be less responsive to price changes in their production decisions as they are committed to a given level of operating capacity. Productivity improvements such as increased litter size, improved feed conversion and reduced number of days to maturity, increase the supply of hogs despite downward trending prices. So there may be a tendency for all these adjustments to reduce the sensitivity of supply to price changes. On the other hand, improved price discovery, through premiums and discounts for specific carcass attributes, may create incentives for increased marketing responsiveness to price changes. This mixture of factors is complicated and as a result over time supply could either have become either more or less inelastic. A major finding is that there have been no fundamental changes between the elasticity estimates obtained from this study and from prior studies. From a spatial standpoint, all these above factors should have had similar effects on eastern and western Canadian hog supply. However there are small but significant differences between the Ontario and Quebec hog supply estimates and those for the two western Canadian provinces.

The other major aspect of this empirical work is the question of whether it is necessary to account for risk. Hurt and Garcia (1982) argued that omitted risk can bias the size of the own price elasticity for hog supplies. This study addresses that concern and finds own price elasticities that are similar to prior studies despite the fact that risk has now been accounted for. While the estimated risk variables might not have been as statistically significant as desired, they do provide insights into the relative importance of different sources of price risk. Despite improved contracting opportunities price risks cannot be dismissed in the empirical specification of hog supply functions. The results did lend credence to the idea that feed price risk might be more important than hog price risk. This is a useful insight given recent feed price fluctuations. This finding leads to additional questions about the relative importance of integration in the Canadian hog sector in terms of downstream versus upstream the contracting between feed companies and hog producers. Consequently, there is scope for further study of risk effects in the Canadian hog sector.

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End Notes

[1] We searched the literature extensively through multiple academic and general search engines. Most of relevant empirical studies were written between 1980 and the early 1990's. Some were published in peer reviewed journals and others as theses or working papers. Although all these studies have some historical value they also have several deficiencies: none accounted for output or input price risks; provincial disaggregation was not considered; and a number of econometric implications were not addressed. We have not provided a review of all these studies but have included the most pertinent peer reviewed studies as a comparison with our results.

[2] Ontario and Quebec have remained single desk marketers for much longer than the western provinces. Starting in 1994 Quebec moved to a dual marketing system, from an electronic auction, with most of the hog supply pre-attributed to processors at a negotiated price while the remainder of the provincial supply of hogs was sold through the auction. This system fluctuated back and forth between combinations of negotiated prices and auctions until 2009, but all sales were required to go through the Fédération des producteurs de porcs du Québec. In 2009 a new market system was introduced which allowed some flexibility where processors could procure hogs directly (Gervais and Lambert, 2010). In 2008 the Ontario Farm Products Marketing Commission ended single desk pork marketing in Ontario. In 2010 the Ontario Agriculture, Food and Rural Affairs Tribunal overturned the Commission's ruling. Finally, Ontario's minister of agriculture reviewed the Tribunal finding and supported the open market option.

[3] To account for instances where peoples' choices deviate from those predicted by expected utility theory alternative approaches include prospect theory, rank-dependent expected utility, cumulative prospect theory and approaches to account for loss aversion.

[4] The effect of the lagged dependant variable is typically introduced to account for a stock adjustment process which because of biological lags, lags in adding production facilities, and other uncertainties prevents producers from immediately responding to shocks in the market. The structural time series model accounts for this dynamic adjustment process by accounting for the stochastic trends and cycles. In fact the documentation for the STAMP software explicitly discourages the "inclusion of a lagged dependant variable" see Koopman et al. (2009).

[5] The marketing of hogs was obtained from AAFC Red Meat Market Information, "M005A Monthly report of Origin of Hogs Slaughtered in Canadian Plants by Province"

[6] The pertinence of ASRA and the pre-attribution marketing system is investigated in Larue, Gervais and Lapan (2004).

[7] Holt and Moschini (1992) employed a seasonal variable that is the product of a monthly dummy variable and the logarithm of the time trend and is included to capture apparent changes in seasonality associated with improved genetics and management. This specification was no more successful than a conventional seasonal dummy that is time invariant in our specification.

[8] Hall and McAleer (1989) compared the robustness of Durbin-Watson test, Whittle's ratio test, Q test and Ljung-Box Q test with several choices of p. They found that when the errors are normally distributed, Q test is unreliable and the other tests are reasonably accurate for most sample sizes for testing an AR null hypothesis.