Greek meat supply response and price volatility in a rational expectations framework: A multivariate GARCH approach

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Abstract. *This paper examines supply response models in a rational expectations framework for each one of the four major Greek meat markets, i.e. beef, broiler, lamb and pork. A multivariate GARCH model with Cholesky decomposition is used to incorporate price volatility into the rational expectations supply response model for each meat category and as a result the conditional covariance matrix remains positive definite without imposing any restrictions on the parameters. The empirical results confirm the existence of rational behaviour by meat producers in the four examined markets and indicate that price volatility is a major risk factor in Greek meat production while feed prices and veterinarian medicine prices are both important cost factors. Furthermore, the last Common Agricultural Policy reform is found to have a negative impact on the beef and lamb production in Greece.*

Keywords: *meat supply, price volatility, rational expectations, MGARCH.*

1. Introduction

Price formation and price risk are major subjects in commodities markets. Many researchers have focused on the characterization of expectations formation in agricultural markets while Nerlove developed a supply response model that estimates farmers' response to price under the adaptive expectations hypothesis.[1-5] The adaptive expectations hypothesis assumes that decision makers form their expectations based on what happened in the past and this approach dominated the supply response analysis of agricultural products for many years. More recently, many agricultural economists have adopted the rational expectations hypothesis (REH), which assumes that producers use all the available information to form their expectations for future decisions. Focusing on commodity markets, the REH proposed by Muth has played a significant role in modeling agricultural markets.[1] However, there are some factors that can lead to a violation of the REH. For example, the collection of information is not costless. If farmers exhibit rational expectations, this suggests that the benefit from understanding market dynamics is greater than the cost of obtaining the associated information. Also, another reason for that is the presence of transaction and storage costs, which depends on the nature of the product. Although the REH may not hold exactly, it is a useful approximation and, as mentioned by Mishkin "even if not all market participants have expectations that are rational, we would still expect the market to be rational as long as some market participants stand ready to eliminate unexploited profit opportunities".[6] Based on this hypothesis, Chavas and Johnson, Wescott and Hull, and Bhati estimate the impact of several economic variables on broiler production and prices, while Goodwin, Madrical, and Martin, and Kapombe and Coyler estimate supply and demand responses in the broiler market.[7-11]

Moreover, agricultural economists have started to investigate the effects of risk aversion under the REH. The effect of price uncertainty under the REH in agricultural supply was evaluated by several researchers, e.g. Antonovitz and Green, and Seale and Shonkwiler among others.[12, 13] In the broiler industry, Hutzinger and Goodwin and Sheffrin underline the importance of uncertainty and espouse REH in studying broiler demand and supply response.[15, 14] They conclude that the REH concept can successfully characterize the supplier behaviour. Aradhyula and Holt and Holt and Aradhyula extend the REH by inducing price uncertainty and volatility in modelling the supply and demand of the broiler marker.[16, 17] More specifically, they use the Generalized Autoregressive Conditional Heteroskedasticity (GARCH) approach to generate time-varying predictions of these variables and they indicate that price volatility is an important risk factor of broiler supply in the U.S.

Price volatility represents an important risk factor of supply, especially in agricultural products, and it could affect the production level. According to Dixit, in the case where an increase of production involves significant sunk costs, price volatility has an effect on production even when agents are risk neutral.[18] Agricultural prices tend to be more volatile due to seasonality, inelastic demand, and production uncertainty and also because many agricultural products and especially fresh meat products are perishable lacking storage ability. Price fluctuations translate into a significant price risk and thus an increase in price volatility implies higher uncertainty about future prices, a fact that can affect producers' welfare especially in the absence of hedging mechanisms.

The objective of this paper is to explore the price volatility response in a rational expectations context for the four major Greek meat markets, i.e. beef, broiler, lamb, and pork. The model for each meat category is estimated in two steps. First, a Vector Error Correction Model is used to specify the cointegrating relations and provide the expectations of meat prices. Second, the demand and supply equations are specified. Several parameters, such as expected price, price volatility, and cost factors are used to specify the appropriate supply response equation of each type of meat. Furthermore, in the case of beef and lamb, the specification of the supply response model includes the milk price because milk and meat behave like competitive products and it also includes variables to evaluate the impact of the Common Agricultural Policy (CAP) since beef and lamb are the two meat categories that are affected by the CAP[1]. A market model with endogenous risk is estimated for each meat category and a multivariate GARCH (MGARCH) model with Cholesky decomposition proposed by Tsay is used to characterize the time-varying attributes of expected price and price volatility.[19] The literature offers a large number of MGARCH models but the majority of the specifications present estimation problems because it is not easy to maintain positive definiteness of the conditional covariance matrix. The advantage of the

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[1] For the period 1992–2001, an annual basic price was set and the difference between this basic price and the actual average EU market price formed the basis for the calculation of the annual premium paid to producers, while in each member state, there was a limit on the number of eligible animals. During the period 2002–2005**,** a flat rate annual premium per eligible animal was introduced and it replaced the old variable premium. The last CAP reform took place in 2003 and the main change has been the introduction of the Single Farm Payment (SFP), which came into effect in 2006. SFP is a system of annual payments to producers irrespective of production level, i.e. decoupling. Breeders receive the payment according to historical production of the period 2000–2002 without the necessity to produce.

MGARCH model with Cholesky decomposition is that the conditional covariance matrix remains positive without imposing any restrictions on the parameters.

In the Greek meat market, a group of studies by Rezitis and developed supply response models for each Greek meat market (i.e. broiler, pork, lamb, and beef) by simultaneously estimating a system of a supply function and a univariate GARCH process to formulate expected price and price volatility and incorporate possible asymmetric price volatility into each meat supply model.[20-23] In contrast to previous studies by Rezitis and Stavropoulos, the present study does not explore in detail the nature of price volatility, i.e. symmetric versus asymmetric, but it creates a rational expectations model in the context of a simultaneous supply and demand system incorporating expected price and price volatility.[20-13] Thus, the contribution of the present paper to the existing literature is that it, first, develops a rational expectations model by simultaneously estimating a supply and demand function for each Greek meat market (i.e. beef, broiler, lamb, and pork) second, incorporates expected price and price volatility into the rational expectations models by using a multivariate (M)GARCH model with Cholesky decomposition, which ensures that the conditional covariance matrix remains positive definite without imposing any restrictions on the parameters of the model; and third, provides measures of the conditional correlation coefficient between price and quantity volatilities for each meat type.

2. Rational expectation and estimation framework

In order to model the rational expectations model, the framework used by Wallis and Holt and Aradhyula is followed.[24, 17] A static market model for each meat category (i.e. beef, broiler, lamb, and pork) consists of 2 equations, i.e. demand and supply, and 2 endogenous variables, i.e. price and quantity, and it can be described as:

$$By_{it} + A_1 y_{it}^{e} + A_2 vech(y_{it}^{v}) + \Gamma_1 x_{i1t} + \Gamma_2 x^{e}_{i2t} = u_{it}\,, \tag{1}$$

where y_{it} is a 2×1 vector of price and quantity of the *i*th meat category (where *i*= beef, broiler, lamb, and pork), x_{i1t} is a k_1-dimensional vector of exogenous variables whose one period ahead values are known with certainty, and x^{e}_{i2t} is a 3×1-dimensional vector of expectations about the prices of the remaining 3 meat categories whose values in period *t* are not known in *t*-1. For example, if *i*=beef then x^{e}_{i2t} is a vector of expected prices of broiler, lamb, and pork. y_{it}^{e} is a 2×1 vector that denotes unobservable expectations formed in *t*-1 about the endogenous variables, y_{it}^{v} denotes unobservable expectations formed in *t*-1 about forecast error variances and covariances of the endogenous variables, and *vech* is the vectorization operator. The matrices B and A_1 are of the dimension 2×2, A_2 is a 2×3 matrix, Γ_1 is a $2\times k_1$ matrix, and Γ_2 is a 2×3 matrix. u_{it} is a 2×1 vector of normally distributed error terms, where $E(u_{it}/\Omega_{t-1}) = 0$ and $\mathrm{var}(u_{it}/\Omega_{t-1}) = H_{it}$ with H_{it} a 2×2 time-varying positive defined conditional covariance matrix. It should be mentioned that in equation (1) variables are used in levels under the condition that series are stationary, i.e. I(0). If series are non-stationary, i.e. I(1), they should be included in the first differences form. Moreover, if some variables are cointegrated, the error correction term should be included in equation (1).

The above model assumes that agents form their expectations according to the REH. This implies that y_{it}^{e} is an optimal one period ahead forecast, conditional on available information:

$$y_{it}^{e} = E_{t-1}(y_{it}/\Omega_{t-1})\,, \tag{2}$$

where Ω_{t-1} is the information set of all past states up to the time $t-1$. The efficient market condition can be presented as $E_m(y_{it} - y_{it}^{e}) = 0$, which indicates that all the information is reflected in the market and the expectations about the covariance matrix can be given as:

$$y_{it}^{v} = E_{t-1}\left[\big(y_{it} - E(y_{it}/\Omega_{t-1})\big)\big(y_{it} - E(y_{it}/\Omega_{t-1})\big)'\right]. \tag{3}$$

Then, the reduced form of equation (1) is given as:

$$y_{it} = -B^{-1}A_1 y_{it}^{e} - B^{-1}A_2 vech(y_{it}^{v}) - B^{-1}\Gamma_1 x_{i1t} - B^{-1}\Gamma_2 x^{e}_{i2t} + B^{-1}u_{it} \tag{4}$$

and the conditional expectations of equation (4) can be presented as:

$$y_{it}^{e} = -B^{-1}A_1 y_{it}^{e} - B^{-1}A_2 vech(y_{it}^{v}) - B^{-1}\Gamma_1 x_{i1t} - B^{-1}\Gamma_2 x^{e}_{i2t}\,. \tag{5}$$

The error in the rational expectation can be obtained by subtracting y_{it}^{e} in equation (5) from y_{it} in equation (4)

$$y_{it} - y_{it}^{e} = B^{-1}u_{it}\,. \tag{6}$$

Taking the conditional expectations of the outer product of equation (6) gives:

$$y_{it}^{v} = E_{t-1}\left[\big(y_{it} - E(y_{it}/\Omega_{t-1})\big)\big(y_{it} - E(y_{it}/\Omega_{t-1})\big)'\right] = B^{-1}H_{it}B^{-1\prime}\,. \tag{7}$$

By substituting y_{it}^{v} (Equation (7)) in Equation (5), the following is obtained:

$$y_{it}^{e} = -\Pi_{0.1}B^{-1}A_2 vech(B^{-1}\mathrm{H}_{it}B^{-1\prime}) - \Pi_{0.1}\Gamma_1 x_{t1t} - \Pi_{0.1}\Gamma_2 x^{e}_{\iota 2t}, \tag{8}$$

where $\Pi_{0.1} = (I + B^{-1}A_1)^{-1}$.

The final model is derived by substituting y_t^{v} (Equation (7)) and y_t^{e} (Equation (8)) in Equation (4) and is given by equations system (9)

$$y_{it} = \Pi_{0.2} vech(B^{-1}\mathrm{H}_{it}B^{-1\prime}) + \Pi_{0.3}x_{t1t} + \Pi_{0.4}x^{e}_{\iota 2t} + w_{it}, \tag{9}$$

where $\Pi_{0.2} = (B^{-1}A_1\Pi_{0.1} - I)B^{-1}A_2$, $\Pi_{0.3} = (B^{-1}A_1\Pi_{0.1} - I)B^{-1}A_2$, $\Pi_{0.4} = (B^{-1}A_1\Pi_{0.1} - I)B^{-1}\Gamma_2$ and $w_{it} = B^{-1}u_{it}$.

The expectations of meat prices contained in x_{i2t}^{e} of equations system (9) are obtained from the estimation of a 4×1 dimension vector autoregressive (VAR) process of the following form:

$$x_{2t} = r + \Pi_1 x_{2,t-1} + ... + \Pi_k x_{2,t-k} + e_t, \qquad t = 1, 2, …., T, \tag{10}$$

where x_{2t} is a vector of all four meat prices (i.e. beef, broiler, lamb, and pork) at time t, r is a 4×1 vector of a constant term, Π_i are 4×4 matrices of parameters with $i = 1, \ldots k$, and e_t is a 4×1 vector of errors. The VAR model assumes that all variables of x_{2t} are stationary. When the assumptions of stationarity of the VAR model are rejected but the set of variables of the system form between them linear combinations that are stationary, then it is considered that the variables are cointegrated. In that case, instead of the VAR model, the Vector Error Correction Model (VECM) is used. The VECM approach associates the divergence from the long-run equilibrium of

$$\Delta x_{2t} = v + \alpha\beta' x_{2t-1} + \Gamma_1 \Delta x_{2t-1} + ... + \Gamma_k \Delta x_{2t-k+1} + e_t, \tag{11}$$

where α and β′ are $4 \times r$ matrices, with r the number of long-run equilibrium relationships and α is called the loading matrix and measures the speed of adjustment in Δx_{2t}, while β′ is called the cointegration matrix and contains the cointegrating vectors.

In other words, the rational expectations model proposed in the present study follows a two-step estimation procedure. First, the expectations of meat prices are extracted via a VAR or VECM model and then the equations system (9) is estimated via a multivariate (M)GARCH model. Note that in the rational expectations model (9) equations depend not only on x_{i1t} and x^{e}_{i2t} but also on conditional variances and covariances of forecast errors, i.e. $H_{it} = \begin{bmatrix} \sigma_{i11,t} & \sigma_{i21,t} \\ \sigma_{i21,t} & \sigma_{i22,t} \end{bmatrix}$, associated with the supply and demand equation.

MGARCH models have been developed in order to analyse risk in multivariate dimensions. Some popular MGARCH specifications that are widely used are the diagonal VEC model proposed by Engle and Kroner but these approaches face serious shortcomings since it is not easy to maintain positive definiteness of the conditional covariance matrix without imposing strong restrictions on the parameters.[25]In order to deal with those weaknesses, in the present paper, the Cholesky decomposition approach is used.[19] The advantage of this specification is that H_{it} is positive definite without any restrictions on the parameters . Following this specification H_{it} is defined as:

$$H_{it} = L_{it}G_{it}L_{it}', \tag{12}$$

where H_{it} is positive definite, L_{it} is a lower triangular matrix with unit diagonal elements, and G_{it} is a diagonal matrix with positive diagonal elements.

For the bivariate case:

$$H_{it} = \begin{bmatrix} \sigma_{i11,t} & \sigma_{i21,t} \\ \sigma_{i21,t} & \sigma_{i22,t} \end{bmatrix},\ L_{it} = \begin{bmatrix} 1 & 0 \\ q_{i21,t} & 1 \end{bmatrix},\ G_{it} = \begin{bmatrix} g_{i11,t} & 0 \\ 0 & g_{i22,t} \end{bmatrix}. \tag{13}$$

The parameter vector relevant to volatility modeling under such a transformation becomes

$$\Xi_{it} = (g_{i11,t}, g_{i22,t}, q_{i21,t})' \tag{14}$$

and the log probability density function of w_{it} relevant to the maximum likelihood estimation is

$$l(w_{it}, \mathrm{H}_{it}) = l(b_{it}, \Xi_{it}) = -\frac{1}{2}\sum_{j=1}^{2}\left(\ln(g_{ijj,t}) + \frac{b_{i1t}^{2}}{g_{ijj,t}}\right), \tag{15}$$

where g_{ijjt} is the variance of b_{it} and $j = 1, 2$.

The advantages of using Cholesky decomposition to reparameterize H_{it} is that, first, H_{it} is positively defined if $g_{ijjt} > 0$ for all j and, second, the correlation coefficient between w_{i1t} and w_{i2t} is $\rho_{21t} = \frac{\sigma_{i21t}}{\sqrt{\sigma_{i11t}\sigma_{i22t}}} = q_{i21t} \times \frac{\sqrt{\sigma_{i11t}}}{\sqrt{\sigma_{i22t}}}$, which is time varying if $q_{i21t} \neq 0$.

3. Data and model specification

The data used in this study are monthly time series for the period of January 1993 to December 2006. All the variables used in this study are presented in Table 1. The data are obtained from the Hellenic Ministry of Rural Development and Food (HMRDF) and the National Statistical Service of Greece (NSSG). All the variables are transformed into logarithms and all the prices are deflated by the consumer price index (2006=100). In the rest of this section, the two steps of model specification are presented:

First step of model specification

The first step in specifying the final model is to obtain the expectations of meat prices (i.e. beef, broiler, lamb, and pork). Variables are tested for stationarity and Table 2 presents the results of the Augmented Dickey–Fuller (ADF) test and a unit root with structural breaks test proposed by Lanne, Lutkepohl, and Saikkonen.[26] The hypothesis that variables contain a unit root could not be rejected at the 5% significance level except for the variables bq and brq, which are stationary, and the variables pq and lq, for which the results are mixed. Then, potential cointegrating relationships are investigated. Taking into account the structure of the model, a test for cointegration between meat prices (i.e. bp, pp, lp, and brp) is performed and a VECM, described by equations system (11), is estimated. The Schwarz criterion proposed a lag order of 1, while the Hannan–Quinn criterion proposed a lag order of 2, and so, in order to avoid possible autocorrelation in the residuals, the lag order of 2 was chosen. Congregation tests developed by Johansen and Juselious were estimated results indicate that the cointegration rank equals one.[28]

Second step of model specification

The second step is to identify (inverse) demand and supply equations for each meat category. Given the results of the first step, which provide expectations of meat prices, the final forms of the (inverse) demand and supply equations for beef, broiler, lamb, and pork are provided below.

<u>Beef</u>

Demand:

$$\begin{aligned}\Delta bp_t = {} & a_{10} + a_{11}\Delta brp^e{}_t + a_{12}\Delta brp^e{}_{t-1} + a_{13}\Delta pp^e{}_t + a_{14}\Delta pp^e{}_{t-1} + a_{15}\Delta lp^e{}_t + a_{16}\Delta lp^e{}_{t-1} + a_{17}\Delta bq_t \\ & + a_{18}\Delta bq_{t-1} + a_{19}\Delta bq_{t-2} + a_{110}\Delta bq_{t-3} + a_{111}\Delta bq_{t-4} + a_{112}\Delta bq_{t-5} + a_{113}\Delta bq_{t-6} + a_{114}z_{t-1} + w_{11t}\end{aligned} \tag{16}$$

where Δbp_t are the first differences of beef price, Δbq_t are the first differences of beef quantity, $\Delta brp^e{}_t$ are the first differences of broiler expected prices, $\Delta pp^e{}_t$ are the first differences of pork expected prices, $\Delta lp^e{}_t$ are the first differences of lamb expected prices, and z_t is the cointegrating vector obtained by the estimation VECM.

Supply:

$$\begin{aligned}qb_t = {} & b_{10} + b_{11}bp_t + b_{12}vb^e{}_t + b_{13}fb_{t-26} + b_{14}vmed_{t-26} + b_{15}milkb_t + b_{16}prb_{t-12} + b_{17}D_{1t} + b_{18}(D_{1t} \times prb_{t-12}) \\ & + b_{19}qb_{t-1} + b_{110}qb_{t-2} + b_{111}qb_{t-3} + b_{112}qb_{t-4} + b_{113}qb_{t-5} + b_{114}qb_{t-6} + b_{115}qb_{t-7} + b_{116}qb_{t-8} + b_{117}qb_{t-12} + w_{12t}\end{aligned}, \tag{17}$$

where beef price, bp_t, and price volatility, vb^e_t, are included because they are considered to be important risk factors. Also, the prices of 2 senior cost factors are used: firstly, the price of feed, fb_{t-26}, which is the most important cost factor because beef production in Greece is mainly cereal-based production due to the lack of natural pastures; and, second, the price of veterinarian medicines, $vmed_{t-26}$, which is a significant cost factor because producers try to avoid production loss due to diseases. A 26-month lag period for input prices is used because the biological cycle of Greek beef is about 26 months. The price of bovine milk, $milkb_t$, is regarded as an important variable of the supply equation because it represents a kind of opportunity cost for beef and the lags of beef production are used because production needs time to adjust to the desirable levels.

Furthermore, three variables are used to capture the effect of the CAP on the beef production. Firstly, a twelve-month lag period of the annual premium paid to beef producers, prb_{t-12}, is included. The premium is an amount paid to each producer once a year. In Greece, it is usually paid at the end of each year (around November) and the only information that the producer has about the level of the premium he is going to be paid is the premium that he received last year. Thus, producers form their expectations about the premium paid one year based on the premium paid the previous year. Secondly, a dummy variable, D_{1t}, for the period from 1/2003 to 12/2006, is used to evaluate the effect of the CAP reform in relation to the decoupling of premium and production decided in 2003 and planned to take place from 2006–2013.

Thirdly, the interaction variable $D_{1t} \times prb_{t-12}$ is constructed by multiplying the premium rate (prb_{t-12}) with the dummy variable (D_{1t}) and it is used to evaluate the effect of the change from a volatile to a flat premium rate during the period 1/2003 to 12/2006.

Broiler

Demand:

$$\begin{aligned}\Delta brp_t = a_{20} + a_{21}\Delta bp^e{}_t + a_{22}\Delta bp^e{}_{t-1} + a_{23}\Delta pp^e{}_t + a_{24}\Delta pp^e{}_{t-1} + a_{25}\Delta lp^e{}_t + a_{26}\Delta lp^e{}_{t-1} + a_{27}\Delta brq_t \\ + a_{28}\Delta brq_{t-1} + a_{29}\Delta brq_{t-2} + a_{210}\Delta brq_{t-3} + a_{211}\Delta brq_{t-4} + a_{212}\Delta brq_{t-5} + a_{213}\Delta brq_{t-6} + a_{214}z_{t-1} + w_{21t}\end{aligned} \quad (18)$$

where Δbrp_t are the first differences of broiler price and Δbrq_t are the first differences of broiler produced quantity.

Supply:

$$\begin{aligned}qbr_t = b_{20} + b_{21}brp_t + b_{22}vbr^e{}_t + b_{23}fbr_{t-2} + b_{24}vmed_{t-2} + b_{25}qbr_{t-1} + b_{26}qbr_{t-2} + b_{27}qbr_{t-3} + b_{28}qbr_{t-4} + b_{29}qb_{t-5} \\ + b_{210}qbr_{t-6} + b_{211}qbr_{t-12} + w_{22t}\end{aligned} \quad (19)$$

where broiler price, brp_t, and price volatility, vbr_t^e, are included because they are considered to be significant risk factors. As in the case of beef, the prices of 2 senior cost factors are used, i.e. the price of feed, fbr_{t-2}, which is the most important cost factor and represents, on average, 65% of the broiler production cost, and the price of veterinarian medicines, $vmed_{t-2}$. A 2-lag period for input prices is used because the biological production cycle for broilers in Greece is about 50 days. Finally, lags of broiler production are included in the supply function because production needs time to adjust to the desirable level.

Lamb

Demand:

$$\begin{aligned}\Delta lp_t = a_{30} + a_{31}\Delta brp^e{}_t + a_{32}\Delta brp^e{}_{t-1} + a_{33}\Delta pp^e{}_t + a_{34}\Delta pp^e{}_{t-1} + a_{35}\Delta bp^e{}_t + a_{36}\Delta bp^e{}_{t-1} + a_{37}\Delta lq_t \\ + a_{38}\Delta lq_{t-1} + a_{39}\Delta lq_{t-2} + a_{310}\Delta lq_{t-3} + a_{311}\Delta lq_{t-4} + a_{312}z_{t-1} + w_{31t}\end{aligned} \quad (20)$$

where Δlp_t are the first differences of lamb price and Δlq_t are the first differences of lamb produced quantity.

Supply:

$$\begin{aligned}ql_t = b_{30} + b_{31}lp_t + b_{32}vl^e{}_t + b_{33}fl_{t-7} + b_{34}vmed_{t-7} + b_{35}milkl_t + b_{36}prl_{t-12} + b_{37}D_{2t} + b_{38}(D_{2t} \times prl_{t-12}) + b_{39}ql_{t-1} \\ + b_{310}ql_{t-2} + b_{311}ql_{t-3} + b_{312}qb_{t-3} + b_{313}qb_{t-4} + b_{314}qb_{t-5} + b_{315}qb_{t-6} + b_{316}qb_{t-7} + b_{317}qb_{t-8} + b_{318}qb_{t-12} + w_{32t}\end{aligned} \quad (21)$$

where lamb price, lp_t, and volatility, vl_t^e, are included because they are essential factors for the specification of the supply function. Then, the price of feed, fl_{t-7}, which is the most important cost factor, although Greek small-size breeders use also natural pasture, and the price of veterinarian medicines, $vmed_{t-7}$, which is a significant cost factor because producers try to avoid production loss due to sheep diseases, are also included. A 7-lag period for input prices is used because of the biological cycle of the lamb production, which in Greece is about 200 days. Moreover, the price of sheep milk, $milkl_t$, is regarded as an important variable of the supply equation and it represents a kind of opportunity cost for lamb. Finally, as in the case of beef production, 3 variables are used to capture the effect of the CAP on the lamb market: a 12-month lag period of the annual premium paid to producers (prl_{t-12}), a dummy variable (D_{2t}) for the period from 1/2003 to 12/2006, and the interaction variable $D_{2t} \times prl_{t-12}$.

Pork:

Demand:

$$\begin{aligned}\Delta pp_t = a_{40} + a_{41}\Delta bp^e{}_t + a_{42}\Delta bp^e{}_{t-1} + a_{43}\Delta brp^e{}_t + a_{44}\Delta brp^e{}_{t-1} + a_{45}\Delta lp^e{}_t + a_{46}\Delta lp^e{}_{t-1} + a_{47}\Delta pq_t + a_{48}\Delta pq_{t-1} \\ + a_{49}\Delta pq_{t-2} + a_{410}\Delta pq_{t-3} + a_{411}\Delta pq_{t-4} + a_{412}\Delta pq_{t-5} + a_{413}\Delta pq_{t-6} + a_{414}\Delta pq_{t-7} + a_{415}\Delta pq_{t-8} + a_{416}z_{t-1} + w_{41t}\end{aligned} \quad (22)$$

where Δpp_t are the first differences of pork price and Δpq_t are the first differences of pork produced quantity.

Supply equation:

$$\begin{aligned}qp_t = b_{40} + b_{41}pp_t + b_{42}vp^e{}_t + b_{43}fp_{t-9} + b_{24}vmed_{t-9} + b_{45}qp_{t-1} + b_{46}qp_{t-2} + b_{47}qp_{t-3} + b_{48}qp_{t-4} + b_{49}p_{t-5} \\ + b_{410}qp_{t-6} + b_{411}qp_{t-12} + w_{42t}\end{aligned} \quad (23)$$

where pork price, pp_t, and price volatility, vp_t^e, are included because they are considered to be important risk factors. The prices of two major cost factors are used, i.e. the price of feed, fp_{t-9}, which is the most important cost factor and represents about 60% of the pork production cost, and the price of veterinarian medicines, $vmed_{t-9}$. A 9-lag period for input prices is used because in Greece there is, on average, a 270-day lag between breeding and slaughter. In addition, lags of pork production are included in the supply function because production needs time to adjust to the desirable level.

Lastly, a bivariate GARCH(1,1) model for each type of meat with the Cholesky decomposition, as described in Section 3, is estimated. Note that the elements of the variance covariance matrix H_{it} of the GARCH(1,1) model are created using the following functions

$$g_{i11,t} = c_{i0} + c_{i1} b_{i1,t-1}^2 + c_{i2} g_{i11,t-1} \tag{24}$$

$$q_{i21,t} = d_{i0} + d_{i1} q_{i21,t-1} + d_{i2} w_{i2,t-1} \tag{25}$$

$$g_{i22,t} = f_{i0} + f_{i1} b_{i1,t-1}^2 + f_{i2} b_{i2,t-1}^2 + f_{i3} g_{i11,t-1} + f_{i4} g_{i22,t-1}, \tag{26}$$

where $b_{i1,t} = w_{i1t}$ and $b_{i2,t} = e_{i2t} - q_{i21,t-1} e_{i1t}$ and i = beef, broiler, lamb, and pork. Therefore, the estimated system for each meat category is constructed by the corresponding demand and supply equation and functions (24), (25), and (26) and is estimated using the maximum likelihood estimation function (15).

At this point, it has to be mentioned that the MGARCH model implies that w_{it} is normal and follows the Gaussian distribution but, in practice, the residuals are often described by excess kurtosis. In order to handle this problem, in this paper, the quasimaximum likelihood estimation proposed by Bollerslev, Engle and Wooldridge is used.[27] then the Broyden, Fletcher, Goldfarb, and Shanno (BFGS) algorithm is used to estimate the quasimaximum likelihood estimates of the system.

4. Empirical results

Tables 2, 3, 4, and 5 present analytically the results of the maximum likelihood estimates of the rational expectations bivariate GARCH models for beef, broiler, lamb, and pork, respectively. Residual diagnostic tests were performed in order to check the goodness of fit of the supply–demand systems. Specifically, Ljung–Box Q(m) statistics for 8 and 12 lags were performed for the standardized residuals and squared standardized residuals in order to check upon serial correlation and heteroskedasticity, respectively. Furthermore, a test was performed in order to check whether the rationality assumption describes the behaviour of meat producers well. Rationality is evaluated by fitting a regression of the form $Q_{it} = k_{i0} + k_1 Q_{it}^* + e_{it}$, where Q_{it} is quantity and Q_{it}^* fitted values of Q_{it} (where i = beef, broiler, lamb, and pork). The test for rationality involves a chi-square test of the joint hypothesis $\left(k_{i0}, k_{i1}\right) = \left(0,1\right)$.

The analytical results for each meat type are discussed below:

<u>*Beef*</u>: The results for the demand–supply model for the Greek beef market are presented in Table 2. The residual tests indicate that both the demand and supply equations present no heteroskedasticity and no autocorrelation for all the examined lags at the 1% level of significance, while the rationality test confirms the existence of rational behaviour by Greek beef producers. Examining the coefficients of the demand equation, it appears that broiler is the most significant short-run substitute for beef, as indicated by the estimate $a_{11} = 0.748$. The results also reveal that the beef price in the short-run is rather sticky and has a relatively small response with respect to the production level, as indicated by the small values of the coefficients of the lags of beef production. As far as the supply equation is considered, it appears that all the estimated coefficients have the theoretically expected signs and they are highly significant. The short-run supply price elasticity given by the estimated coefficient b_{11} is 0.367 while the calculated long-run supply price elasticity is 1.070. These results are similar to those obtained by Rezitis and Stavropoulos for the Greek beef industry, with a magnitude of 0.144 and 0.935 for short-run and long-run supply price elasticity, respectively.[23] It has to be mentioned that, in beef production (and also in other types of meat production such as pork and lamb), there is a possibility to observe a negative short-run producer price elasticity of supply because cattle are both a capital and a consumption good. For example, Lianos and Katranidis using annual data of the period 1966–1987, estimated negative short-run and positive long-run supply elasticity for the Greek beef industry.[29] An explanation for the positive short-run price elasticity obtained in the present study is that, in recent years, in the case of an increase in price, producers have been able to increase their herd by importing live animals and simultaneously increasing the slaughter rate.

The estimated beef price volatility, i.e. $b_{12} = -0.022$, indicates that volatility is a crucial risk factor for the beef industry. The effect of price volatility of the present study is smaller than the one obtained by Rezitis and Stavropoulos i.e. –0.145.[23] The feed cost coefficient, i.e. $b_{13} = -0.181$, indicates that feed cost is a significant cost factor and this outcome is consistent with the production process of the Greek beef industry, which is cereal-based, while the veterinarian medicine cost, i.e. $b_{14} = -0.152$, also appears to be an important production cost. Moreover, the magnitude of the bovine milk price coefficient is negative and significant, i.e. $b_{15} = -0.034$, indicating that a high milk price causes a decrease in beef supply quantity because beef and bovine milk behave like competitive products.

Parameters about CAP reveal that the annual premium rate paid to producers has a positive effect on beef production, i.e. $b_{16} = 0.238$, and the effect of the CAP reform related to the decoupling of premium and production (decided in 2003) planned to take place during 2006 to 2013, has a negative effect on beef production, i.e. $b_{17} = -0.200$. These findings reveal a rational behaviour by Greek beef producers. Even though the new CAP was decided to take place from the year 2006, the production level seems to have faced a negative impact since the CAP reform was decided, i.e. the year 2003. Greek beef producers identify the oncoming changes as far as their support from the EU is concerned; they have started adjusting their production to lower levels since 2003. Also, the coefficient of the interaction variable is positive, i.e. $b_{18} = 0.021$, indicating that the change from a volatile to a flat annual premium per animal, for the period 2003–2005, had a positive impact on beef production, which was an expected outcome since this policy instrument reduces uncertainty. The results about the CAP effect are consistent with the findings of Fabiosa *et al.* and Rezitis and Stavropoulos who indicate that the 2003 CAP reform will cause a decline in EU beef production.[30, 23] Table 2 also presents the estimated coefficients of equations (24), (25), and (26) and, as it can be seen, all the estimated parameters are statistically significant at any conventional level of significance.

Broiler: Table 3 provides the results of the broiler demand–supply system. Both the demand and supply equations present no heteroskedasticity and no autocorrelation for all the examined lags at the 1% level of significance and the rationality test confirms the existence of rational behaviour by broiler producers. The broiler demand equation shows that beef is the most important short-run substitute for broiler, i.e. $a_{21} = 0.668$. Furthermore, the broiler price seems to be quite inflexible with respect to the broiler production level as can be noticed by the small values of coefficients that represent lags of pork production**.**

With regard to the supply response equation, short-run supply price elasticity given by the estimated coefficient b_{21} is 0.366 and the calculated long-run supply price elasticity is 0.908. Note that these estimates are higher than those obtained by Rezitis and Stavropoulos with a magnitude of 0.119 for the short-run and 0.809 for the long-run elasticity.[20] The sign of the estimated coefficient for the expected price volatility is negative, i.e. $b_2 = -0.168$, as expected, but the effect of price volatility in the present study is lower than that estimated by Rezitis and Stavropoulos i.e. -0.395.[20] Both the feed cost and veterinarian medicine cost appear to be important cost factors in broiler production, with estimated coefficients of $b_{23} = -0.316$ and $b_{24} = -0.267$, respectively. Finally, the estimates obtained for lagged production are significant, which implies that production is adjusting slowly to the desirable level. Table 3 also presents the estimated coefficients of equations (24), (25), and (26) and, as it can be seen, all the estimated parameters except one are statistically significant at the 5% level of significance.

Lamb: Table 4 presents the estimated results from the bivariate GARCH model for the lamb demand–supply system. Ljung–Box Q(m) statistics for the demand and supply equations reveal that both equations present no heteroskedasticity and no autocorrelation at the 1% level of significance. Also, the weak rationality test confirms the rational behaviour of lamb producers. A closer inspection of the estimated parameters in the demand equation shows that beef, broiler, and pork are short-run substitutes for lamb, as can be noticed by the high values of coefficients a_{31}, a_{33}, a_{35}, while most coefficients of production lags are insignificant. Examining the results of the supply equation, the short-run supply price elasticity is inelastic, i.e. $b_{31} = 0.109$. The short-run supply price elasticity of the present paper is smaller than those obtained by previous studies such by Rezitis and Stavropoulos with a magnitude of 0.214; SAC and INRA with a magnitude of about 0.210; and Fotopoulos, with a magnitude between 0.300 and 0.550.[22, 31, 32] The calculated long-run supply price elasticity is elastic, with a magnitude of about 1.313. This estimate is higher than the one obtained by Fotopoulos, i.e. 0.900, and INRA, i.e. 0.840, and lower than that obtained by Rezitis and Stavropoulos, i.e. 1.797.[32, 31, 22] The sign of the estimated coefficient for the expected price volatility is negative, i.e. $b_{32} = -0.037$, as expected, and this effect of price volatility is smaller than that of Rezitis and Stavropoulos, with a magnitude of about -0.151.[22] The feed cost is significant and quite high, i.e. $b_{33} = -0.141$, while the veterinarian medicine coefficient, i.e. $b_{34} = -0.022$, is also significant but smaller, indicating that this production cost is less important. Finally, the estimated coefficient for sheep milk price is negative, indicating that a high milk price causes a decrease in the supplied quantity.

The results about the CAP effects are similar to those of the beef industry. The annual premium rate paid to producers has a positive effect on the production level, i.e. $b_{36} = 0.016$, and the effect of the CAP reform related to the decoupling of premium and production is negative, $b_{37} = -0.436$, while the interaction variable, i.e. $b_{38} = 0.124$, is positive, indicating that the change from a volatile- to a flat-annual premium per animal during the period 2003–2005 had a positive impact on lamb production. These results agree with the conclusions of Canali and Consortium and Rezitis and Stavropoulos who found that the new CAP will cause many sheep breeders to withdraw from production and especially those in the most disadvantageous areas of Greece where there are not many alternative economic activities.[22, 32] Table 4 also presents the estimated coefficients of equations (24), (25), and (26) and, as it can be seen, all the estimated parameters except 2 are statistically significant at any conventional level of significance.

Pork: The estimated parameters of the pork demand–supply system are presented in Table 5. The residual tests indicate that both the demand and supply equations present no heteroskedasticity and no autocorrelation at the 5% level of significance, while the rationality test shows that producers have rational behaviour. Analyzing the estimated parameters of the demand equation, it appears that lamb and broiler are substitutes for pork, i.e. $a_{41} = 0.367$ and $a_{43} = 0.268$, and the small size of the coefficients that represent production lags shows that in the short-run the production level has a slight effect on price. The estimated coefficients of the supply equation have the theoretically expected signs and they are statistically significant at all levels. The short-run supply price elasticity given by the estimated coefficient b_{41} is 0.244 and the calculated long-run supply price elasticity is 0.638. These results are higher than the results obtained by Rezitis and Stavropoulos, with a magnitude of 0.062 and 0.315 for the short-run and the long-run supply price elasticity, respectively.[21] The estimated coefficient for the expected price volatility is negative, i.e. $b_{42} = \text{-}0.029$, as expected, and the effect of price volatility is lower than that obtained by Rezitis and Stavropoulos, i.e. -0.164.[21] The high magnitude of the feed price coefficient, i.e. $b_{143} = -0.807$, confirms that feed is a significant cost factor in pork production and this result is in accordance with the fact that feed cost is the most important cost factor in Greek pork production, while the veterinarian medicine cost estimated coefficient, i.e. $b_{44} = \text{-}0.298$, shows that this is also an important production cost. Table 5 also presents the estimated coefficients of equations (24), (25), and (26) and, as it can be seen, all the estimated parameters are statistically significant at any conventional level of significance.

Furthermore, Figures 1, 2, and 3 plot the historical path of the conditional price volatility, quantity volatility, and conditional correlation coefficient, respectively, for each type of meat. With respect to the price volatility, lamb is the type of meat that presents the highest values of price volatility with an average of about 0.00072, broiler presents the lowest with an average of about 0.00005, while beef and pork present intermediate values of price volatility with average values of about 0.00011 and 0.00037, respectively. The highest price volatility of lamb might be due to the large number of small size producers with a weak influence in the market and limited ability to control prices while the opposite occurs in the broiler market, which is characterized by a small number of large producers with a strong influence in the market and thus high ability to control and stabilize.[22, 20] In addition, lamb and broiler markets are almost self-sufficient with limited imports. The intermediate values of price volatility for beef and pork might be because these markets are characterized by both small- and large-sized producers, while there are significant imports that provide a level of price stabilization in domestic prices.[21, 23]

The results of conditional quantity volatility indicate that beef presents the highest volatility with an average value of about 0.03721, followed by pork with a value of about 0.03313, and lamb with about 0.01496. Finally, broiler presents the lowest average values of about 0.00348. These findings can be attributed to the different biological cycles of production for each meat type. More specifically, the gestation–birth period and the maturation period until slaughtering for beef is about 26 months, for pork about 9 months, for lamb about 7 months, and for broiler about 2 months.[34] Therefore, as expected, the longer the biological cycle, the higher the volatility of quantity. Finally, the conditional correlation coefficients between price and quantity volatility shows that pork has a positive correlation coefficient with an average value of about 0.5829, lamb presents a value of about 0.0358, while beef and broiler show negative values of about -0.3597 and -0.1588, respectively.

5. Conclusions

This paper examines the supply response for four meat categories, i.e. beef, broiler, lamb, and pork, in Greece. A multivariate GARCH model with Cholesky decomposition is used to incorporate price volatility into the rational expectations supply response model for each meat category, providing that the conditional covariance matrix remains positive definite without imposing any restrictions on the parameters. The empirical results confirm the existence of rational behaviour by meat producers in all the meat categories and price volatility is found to have a significant negative effect on the production level, denoting that producers are risk averse, with broiler production presenting the highest volatility effect, i.e. $b_2 = \text{-}0.168$. Short-run supply price elasticities are positive and inelastic, indicating that in the short-run a higher price has a positive effect on the supplied quantity. The feed cost was found to be a major cost factor for production, while the milk price was found to have a negative effect on beef and lamb production, confirming that, in those two types of meat, milk and meat are competitive products. Moreover, the price of veterinarian medicines appears to be an important cost factor, especially in beef, broiler, and pork production. With regard to policy issues, the two meat types that are affected by the CAP are beef and lamb since those producers receive annual payments. The estimated results reveal that the premium paid to both beef and lamb producers has a significant positive role in the supply level, and the decoupling between premium and production, introduced by the last CAP reform, has already had a negative impact on the beef and lamb production.

Furthermore, the empirical results show that price volatility might be related to the market structure of each meat category. Markets with a large number of small producers with weak market power present higher price volatility, while a small number of large producers with strong market power present lower price volatility. In particular, the lamb sector is characterized by the highest price volatility followed by beef and pork, while broiler has the lowest volatility. In addition, the empirical results show that quantity volatility might be positively related to the length of the biological cycle of the production process. More specifically, beef presents the highest quantity volatility followed by pork, lamb, and broiler.

The results of the present study provide some interesting evidence that can help both Greek meat producers and policy makers. High price uncertainty seems to be a very important restrictive factor for meat production in Greece, mainly because there is an absence of hedging mechanisms. This fact affects production decisions and it is an essential restriction in firms' attempts to increase their size, invest in more advanced technologies, and expand into new markets. Furthermore, the premium paid to beef and lamb producers appears to have a significant positive role in the supply level and the decoupling between premium and production, introduced by the last CAP reform, has already had a negative impact on the production level. In general, Greek meat industries face difficulties in adapting successfully to the new competitive market environment as this is determined by the EU enlargement and the last CAP reform, the goal of which is to make EU farmers more competitive and market-oriented.

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Table 1. Definition of Variables	
Symbol	**Description**
bp	beef retail price (€/kg)
brp	broiler retail rice (€/kg)
lp	lamb retail price (€/kg)
pp	pork retail price (€/kg)
bq	beef produced quantity (tons)
brq	broiler produced quantity (tons)
lq	lamb produced quantity (tons)
pq	pork produced quantity (tons)
fb	beef feed price (€/kg)
fbr	broiler feed price (€/kg)
fl	lamb feed price (€/kg)
fp	pork feed price (€/kg)
vmed	veterinarian medicine price
milkb	bovine milk producer price (€/kg)
milkl	sheep milk producer price (€/kg)
prb	beef premiums (€/eligible animal)
prl	lamb premiums (€/eligible animal)

Table 2. Beef Demand and Supply																	
Demand equation																	
a_{10}	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}	a_{17}	a_{18}	a_{19}	a_{110}	a_{111}	a_{112}	a_{113}	a_{114}			
0.000 (0.000)	0.748 (0.000)	-0.030 (0.084)	0.038 (0.000)	0.025 (0.009)	0.041 (0.000)	0.007 (0.357)	-0.004 (0.000)	-0.001 (0.000)	-0.001 (0.000)	-0.003 (0.000)	-0.004 (0.000)	-0.003 (0.000)	-0.000 (0.774)	-0.168 (0.000)			
Residuals tests for Demand equation					$Q(8)$	$Q(12)$	$Q^2(8)$	$Q^2(12)$									
					9.424 (0.307)	12.000 (0.975)	3.233 (0.919)	4.387 (0.975)									
Supply equation																	
b_{10}	b_{11}	b_{12}	b_{13}	b_{14}	b_{15}	b_{16}	b_{17}	b_{18}	b_{19}	b_{110}	b_{111}	b_{112}	b_{113}	b_{114}	b_{115}	b_{116}	b_{117}
-0.946 (0.000)	0.367 (0.000)	-0.022 (0.000)	-0.181 (0.000)	-0.152 (0.000)	-0.034 (0.002)	0.238 (0.000)	-0.200 (0.000)	0.021 (0.000)	-0.081 (0.000)	0.056 (0.000)	0.047 (0.000)	0.038 (0.000)	0.027 (0.000)	0.022 (0.000)	0.022 (0.000)	0.030 (0.000)	0.496 (0.000)
Residuals tests for Supply equation					$Q(8)$	$Q(12)$	$Q^2(8)$	$Q^2(12)$									
					19.908 (0.011)	21.683 (0.041)	8.901 (0.351)	10.081 (0.608)									
Volatility equations																	
c_{10}	c_{11}	c_{12}	d_{10}	d_{11}	d_{12}	f_{10}	f_{11}	f_{12}	f_{13}	f_{14}							
0.000 (0.000)	0.817 (0.000)	-0.150 (0.000)	-0.315 (0.000)	0.126 (0.000)	-0.309 (0.000)	0.021 (0.000)	-0.144 (0.000)	0.374 (0.000)	-0.163 (0.000)	-0.908 (0.000)							
Test for Rationality					k_{10}	k_{11}		Chi-Squared									
					0.631 (0.434)	0.908 (0.000)		1.037 (0.595)									
Figures in brackets are p-values																	

Table 3. Broiler Demand and Supply																	
Demand equation																	
a_{20}	a_{21}	a_{22}	a_{23}	a_{24}	a_{25}	a_{26}	a_{27}	a_{28}	a_{29}	a_{210}	a_{211}	a_{212}	a_{213}	a_{214}			
0.002 (0.000)	0.668 (0.000)	-0.193 (0.000)	0.092 (0.001)	0.054 (0.124)	0.024 (0.076)	0.016 (0.043)	-0.031 (0.000)	0.022 (0.054)	-0.044 (0.000)	-0.030 (0.000)	0.001 (0.878)	0.005 (0.638)	-0.010 (0137)	0.053 (0.000)			
Residuals tests for Demand equation					$Q(8)$	$Q(12)$	$Q^2(8)$	$Q^2(12)$									
					8.082 (0.425)	14.492 (0.270)	1.807 (0.986)	2.720 (0.997)									
Supply equation																	
b_{20}	b_{21}	b_{22}	b_{23}	b_{24}	b_{25}	b_{26}	b_{27}	b_{28}	b_{29}	b_{210}	b_{211}						
-0.909 (0.000)	0.366 (0.000)	-0.168 (0.000)	-0.316 (0.000)	-0.267 (0.000)	0.086 (0.000)	-0.084 (0.000)	0.082 (0.000)	0.015 (0.000)	0.011 (0.000)	0.079 (0.000)	0.482 (0.000)						
Residuals tests for Supply equation					$Q(8)$	$Q(12)$	$Q^2(8)$	$Q^2(12)$									
					8.206 (0.413)	11.087 (0.521)	5.138 (0.743)	5.733 (0.928)									
Volatility equations																	
c_{20}	c_{21}	c_{22}	d_{20}	d_{21}	d_{22}	f_{20}	f_{21}	f_{22}	f_{23}	f_{24}							
0.000 (0.000)	0.634 (0.000)	0.090 (0.000)	-0.054 (0.030)	-0.879 (0.000)	-0.131 (0.626)	0.001 (0.000)	0.186 (0.000)	0.821 (0.000)	-0.034 (0.000)	-0.964 (0.000)							
Test for Rationality					k_{20}	k_{21}		Chi-Squared									
					1.980 (0.003)	0.792 (0.000)		4.390 (0.012)									
Figures in brackets are p-values																	

Table 4. Lamb Demand and Supply																		
Demand equation																		
a_{30}	a_{31}	a_{32}	a_{33}	a_{34}	a_{35}	a_{36}	a_{37}	a_{38}	a_{39}	a_{310}	a_{311}	a_{312}						
-0.001 (0.604)	0.330 (0.033)	-0.059 (0.000)	0.400 (0.000)	-0.099 (0.354)	0.546 (0.001)	0.241 (0.163)	-0.022 (0.000)	-0.010 (0.016)	-0.005 (0.458)	-0.018 (0.000)	-0.009 (0.066)	-0.294 (0.066)						
Residuals tests for Demand equation					$Q(8)$	$Q(12)$	$Q^2(8)$	$Q^2(12)$										
					11.344 (0.182)	23.555 (0.023)	7.497 (0.484)	12.638 (0.396)										
Supply equation																		
b_{30}	b_{31}	b_{32}	b_{33}	b_{34}	b_{35}	b_{36}	b_{37}	b_{38}	b_{39}	b_{310}	b_{311}	b_{312}	b_{313}	b_{314}	b_{315}	b_{316}	b_{317}	b_{318}
-0.174 (0.000)	0.109 (0.000)	-0.037 (0.000)	-0.141 (0.000)	-0.022 (0.000)	-0.035 (0.000)	0.016 (0.000)	-0.439 (0.000)	0.124 (0.000)	0.024 (0.000)	-0.012 (0.000)	0.006 (0.000)	0.004 (0.000)	-0.041 (0.000)	0.024 (0.000)	0.006 (0.000)	-0.010 (0.000)	-0.005 (0.000)	0.921 (0.000)
Residuals tests for Supply equation					$Q(8)$	$Q(12)$	$Q^2(8)$	$Q^2(12)$										
					14.273 (0.074)	22.296 (0.034)	7.412 (0.492)	18.687 (0.096)										
Volatility equations																		
c_{30}	c_{31}	c_{32}	d_{30}	d_{31}	d_{32}	f_{30}	f_{31}	f_{32}	f_{33}	f_{34}								
0.0060 (0.000)	0.568 (0.000)	0.198 (0.000)	0.003 (0.606)	0.748 (0.000)	-0.242 (0.254)	0.000 (0.004)	0.364 (0.000)	0.621 (0.000)	-0.195 (0.000)	0.393 (0.000)								
Test for Rationality					k_{30}	k_{31}		Chi-Squared										
					-0.034 (0.851)	1.002 (0.000)		3.258 (0.196)										
Figures in brackets are p-values																		

Table 5. Pork Demand and Supply																	
Demand equation																	
a_{40}	a_{41}	a_{42}	a_{43}	a_{44}	a_{45}	a_{46}	a_{47}	a_{48}	a_{49}	a_{410}	a_{411}	a_{412}	a_{413}	a_{414}	a_{415}	a_{416}	
0.003 (0.000)	0.367 (0.000	-0.047 (0.000)	0.268 (0.000)	0.141 (0.000)	-0.025 (0.000)	-0.012 (0.000	-0.022 (0.000)	-0.006 (0.000)	-0.006 (0.000)	-0.014 (0.000)	-0.007 (0.000)	-0.002 (0.000)	0.000 (0.254)	0.010 (0.000)	0.009 (0.000)	0.012 (0.000)	
Residuals tests for Demand equation					$Q(8)$	$Q(12)$	$Q^2(8)$	$Q^2(12)$									
					4.901 (0768)	11.188 (0.513)	0.675 (0.999)	17.186 (0.143)									
Supply equation																	
b_{40}	b_{41}	b_{42}	b_{43}	b_{44}	b_{45}	b_{46}	b_{47}	b_{48}	b_{49}	b_{410}	b_{411}	b_{412}	b_{413}				
-0.516 (0.000)	0.244 (0.000)	-0.029 (0.000)	-0.807 (0.000)	-0.298 (0.000)	0.043 (0.000)	0.045 (0.000)	-0.043 (0.000)	-0.047 (0.000)	0.043 (0.000)	0.042 (0.000)	0.038 (0.000)	0.040 (0.000)	0.457 (0.000)				
Residuals tests for Supply equation					$Q(8)$	$Q(12)$	$Q^2(8)$	$Q^2(12)$									
					3.516 (0.898)	9.715 (0.641	0.571 (0.999)	19.982 (0.067)									
Volatility equations																	
c_{40}	c_{41}	c_{42}	d_{40}	d_{41}	d_{42}	f_{40}	f_{41}	f_{42}	f_{43}	f_{44}							
0.000 (0.000)	-0.104 (0.000)	0.500 (0.000)	1.026 (0.000)	-0.024 (0.000)	0.094 (0.000)	0.011 (0.000)	-0.082 (0.000)	0.362 (0.000)	-0.011 (0.000)	-1.109 (0.000)							
Test for Rationality					k_{40}	k_{41}		Chi-Squared									
					-2.383 (0.045)	1.256 (0.000)		0.110 (0.196)									
Figures in brackets are p-values																	

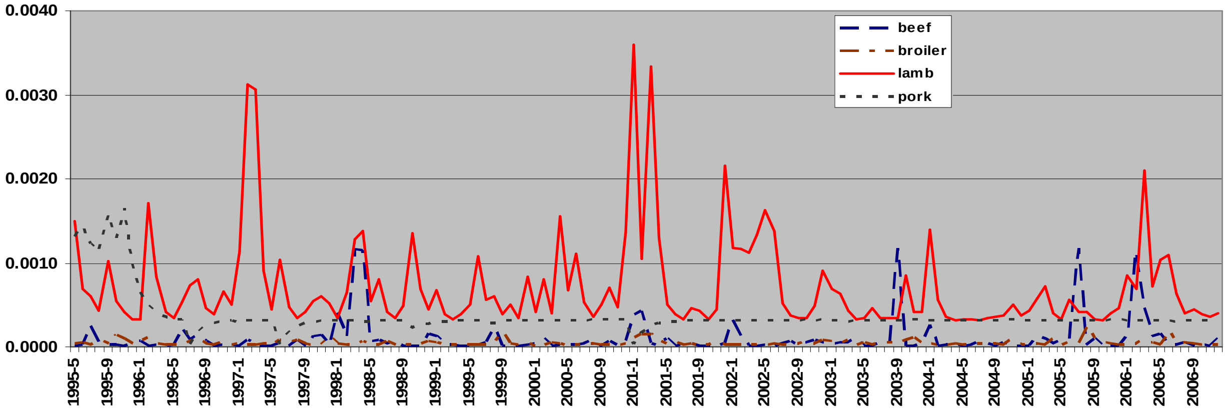

Figure 1. Conditional price volatility of each meat type

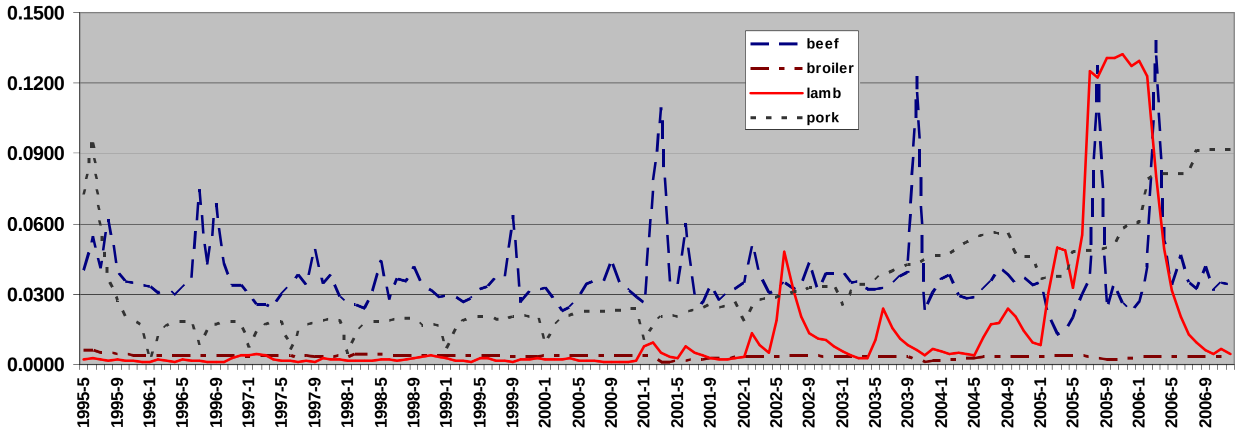

Figure 2. Conditional quantity volatility of each meat type

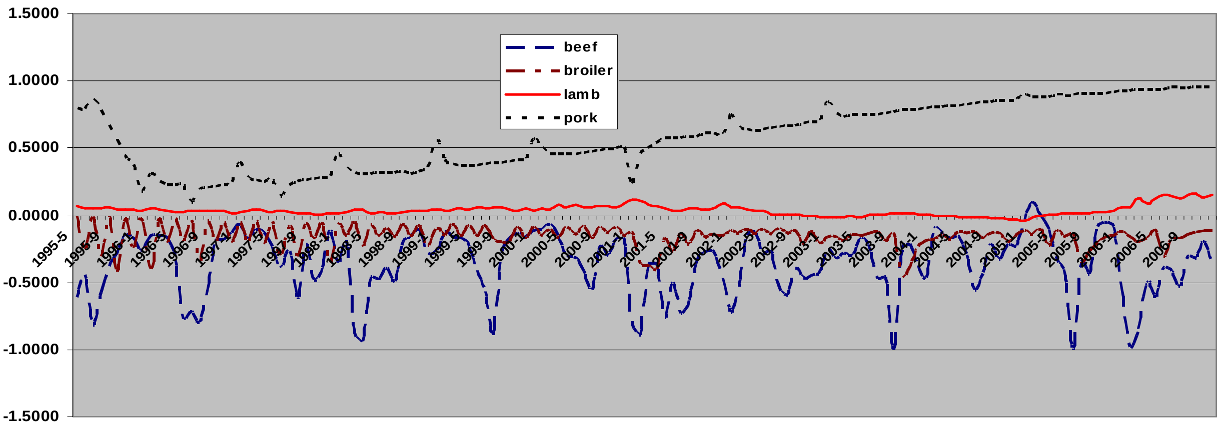

Figure 3. Conditional correlation coeficient of each meat type