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Modeling Pork Supply Response and Price Volatility: The Case of Greece

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This paper examines the supply response of the Greek pork market. A GARCH process is used to estimate expected price and price volatility, while price and supply equations are estimated jointly. In addition to the standard GARCH model, several different symmetric, asymmetric, and nonlinear GARCH models are estimated. The empirical results indicate that among the estimated GARCH models, the quadratic NAGARCH model seems to better describe producers' price volatility, which was found to be an important risk factor of the supply response function of the Greek pork market. Furthermore, the empirical findings show that feed price is an important cost factor of the supply response function and that high uncertainty restricts the expansion of the Greek pork sector. Finally, the model provides forecasts for quantity supplied, producers' price, and price volatility.

Key Words: asymmetry, GARCH, pork supply, price volatility

JEL Classifications: C510, D200, Q110

The development of the global pork production has been very dynamic in recent decades. Between 1990 and 2004, global meat production increased from 180 million tons to almost 260 million tons, and the contribution of pork to global meat production was about 38% in 2005. The world pork industry benefited from trade shocks in beef (due to Bovine Spongiform Encephalopathy, BSE) and broilers (due to Avian Influenza, or Bird Flu) and met a growth of 10.2% and 9.4% in 2004 and 2005, respectively. In 2005, China was by far the world's largest producer of pork with a share of about 48%, while the European Union (EU) was second with a share of about 19% of world production, and the United States third with approximately 9.5%. Note that the world's largest exporter of pork is the EU followed by the United States and Canada. Furthermore, international trade restrictions and protection for domestic agricultural products are diminishing in consequence of GATT negotiations. This leads to a new and more competitive economic environment for meat products.

The objective of this paper is to explore the supply response in the pork industry. Several parameters, such as expected pork producer price, price volatility, and cost factors, are used to specify the appropriate supply response model and describe producers' risk. An important element of the meat supply response, for example, pork, sheep, and beef, is the possibility of observing a negative short-run producer price elasticity of supply. This is because pig is simultaneously both consumption and capital good. If the price of pork increases and producers expect that this increase is sufficiently permanent, then they may decide to retain a larger than average numbers of females to add

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to the breeding stock in order to increase future pork production instead of slaughtering them at present. This paper also puts an emphasis on price volatility by entering expected pork price volatility in the supply equation. Price volatility represents an important risk factor of supply, especially in agricultural products. Agricultural prices tend to be more volatile due to seasonality, inelastic demand, and production uncertainty (Just; Holt and Aradhyula 1990, 1998; Holt and Moschini) and also because many agricultural products, especially fresh meat products, are perishable. Price fluctuations translate into a significant price risk. Thus, an increase in price volatility implies higher uncertainty about future prices, a fact that can affect producers' welfare especially in the absence of a hedging mechanism. Finally, pig feed price and price of veterinarian medicines were considered to be the most important cost factors in pork production. These costs were included in the supply response model. Furthermore, the goal of this paper is to provide useful information to policy makers and pork producers by forecasting quantity supplied, expected producers' price, and price volatility and also by investigating the dynamic adjustments in pork production and pork expected producers' price in response to a change in price volatility.

Supply response analysis has long been a matter of interest in agricultural economics. Recently, several authors have evaluated the effect of price uncertainty in agricultural supply response (e.g., Antonovitz and Roe; Antonovitz and Green; Seale and Shonkwiler; Goodwin and Sheffrin; Hutzinger; Chavas 1999, among others). Studies by Aradhyula and Holt and Holt and Aradhyula (1990, 1998) used price uncertainty and volatility in modeling supply and demand of the broiler market and they used the generalized autoregressive conditional heteroskedasticity (GARCH) approach to generate time-varying predictions of these variables indicating that price volatility is an important risk factor of broiler supply. Finally, Rezitis and Stavropoulos (2007a, 2007b) have estimated supply response of the Greek broiler and sheepmeat industry using alternative volatility models.

In this paper, the Generalized Autoregressive Conditional Heteroskedasticity (GARCH) process is adopted to characterize the time varying attributes of expected price and price volatility of the pork market. Engle (1982) first proposed the Autoregressive Conditional Heteroskedasticity (ARCH) process in order to model time varying conditional variance and Bollerslev expanded the model by introducing the generalized ARCH (GARCH) model. This technique is very popular in financial risk management analysis and has proved to be the most appropriate one to evaluate the effects of price uncertainty in a supply model. Also a full information maximum likelihood estimator is used to estimate the parameters of the supply equation simultaneously with the parameters of the GARCH model (Holt and Aradhyula 1990).

Since the introduction of Bollerslev's GARCH model in 1986, the literature is continuously expanding, including more specified GARCH models. In this paper, a focus is given on estimating and testing different types of symmetric, asymmetric and nonlinear GARCH models in order to specify pork expected price and volatility. An emphasis is given on asymmetric GARCH models in order to investigate the existence of possible asymmetry in the behavior of price volatility in the pork market, which is so far unknown. Asymmetric price volatility is observed when different volatility is recorded between an increase and a decrease of price of the same amount. In the case of the pork market, the existence of price asymmetry can provide useful information about possible market power. For example, the presence of positive asymmetric price volatility suggests that producers react faster to price increases due to "good news" than in case of "bad news," when the price decreases. This behavior implies that producers may have some market power, allowing them to take advantage of positive shocks by immediately increasing prices, while, in case of negative shocks, delaying price decreases. Negative asymmetric price volatility suggests that producers' position in the market chain is weak and they are unable to exploit any "good news" by immediately increasing prices, while in the case of "bad news," they are instantly forced to decrease prices. The hypothesis of asymmetric price volatility was analytically investigated by Engle and Ng, Zheng, Kinnucan, and Thompson on the U.S. food market and by Rezitis and Stavropoulos

(2007a, 2007b) for the Greek broiler and sheep-meat industry. In the current study, 10 different GARCH models are used. These models are tested and evaluated in order to investigate possible existence of asymmetry in volatility, choosing the appropriate model to describe the expected price and price volatility for estimating the pork supply response equation.

In Greece, domestic pork production in 2005 contributed about 28% of the total meat production and satisfied about 40% of the domestic demand, while imports mainly from other EU countries were needed to satisfy the local consumption. Up to the 1950s, pig production in Greece was related to self consumption. The pork industry started its evolution during the 1960s and was characterized mainly by small or medium sized farms. Advances in production technology and changes in consumer preferences were credited as the driving forces behind the rapid evolution of the pork industry in Greece over the last three decades. The Greek pork industry is mainly composed of small sized enterprises, but recently there has been a significant increase in large sized, vertically integrated enterprises with updated technology. It should be noted, however, that during the last 15 years, a decline in pork production has occurred, even though a transformation toward modern production methods and organized enterprises has taken place in the Greek pig industry. For example, since the beginning of the 1990s, pork production declined from about 150 thousand tons to about 129 thousand tons in 2005. During the aforementioned period, there was a continuous increase of domestic pork demand, which was satisfied by increasing imports which were accounted about 60% of the domestic pork consumption in 2005. Imports were mainly from EU countries, that is, The Netherlands, Germany, and France. The removal of trade barriers within the EU by 1993 increased competition from other EU countries for Greek pork producers. This caused a decrease in the Greek pork production since the Greek pig sector operated with higher production costs and lower productivity, compared with the other competing EU producers. Furthermore, after the last reform of the Common Agricultural Policy (CAP), which took place in 2003, the EU is increasingly being directed toward supporting market liberalization and rural development. The goal of this policy is to make EU agricultural industries more competitive and market-oriented. The total absence of direct support for pork producers and the continuing enlargement of the EU will exert pressure upon the Greek pork enterprises. In particular, the pork price is not expected to increase due to hard competition, while there has been an increase in price volatility after the year of 2000 as is shown in Figure 1. It appears that the change of EU agricultural policy toward market liberalization and the enlargement EU increased price volatility and thus producers' risk. A similar effect on agricultural price volatility due to market liberalization was found by Yang, Hainh, and Leatham, who concluded that the U.S. agricultural liberalization policy caused an increase in price volatility for wheat, corn, and soybeans.

The rest of the paper is organized as follows: In the next section a brief literature review of the pork industry is given. The following section presents the methodology. The next section describes the data and model specification. The section after that offers the empirical results and the final section offers concluding remarks.

Literature Review in the Pork Industry

The contribution of the present paper in the existing literature is that, firstly, it estimates a supply response model of the pork sector in Greece by introducing price volatility in the specification of the supply response model and secondly, it expands the methodology introduced by Holt and Aradhyula (1990). In particular, Holt and Aradhyula (1990) used the simple symmetric GARCH model to generate the variables of expected price and price volatility, which are introduced in the supply response model. In this study, apart from the simple symmetric GARCH model, several alternative GARCH specifications are estimated in order to check for the presence of asymmetric price volatility. This is important because it provides some useful indications about the presence of market power in the industry. In particular, positive asymmetric price volatility suggests that producers have a degree of market power, while negative asymmetric price volatility suggests that the industry has a weak influence on the market.

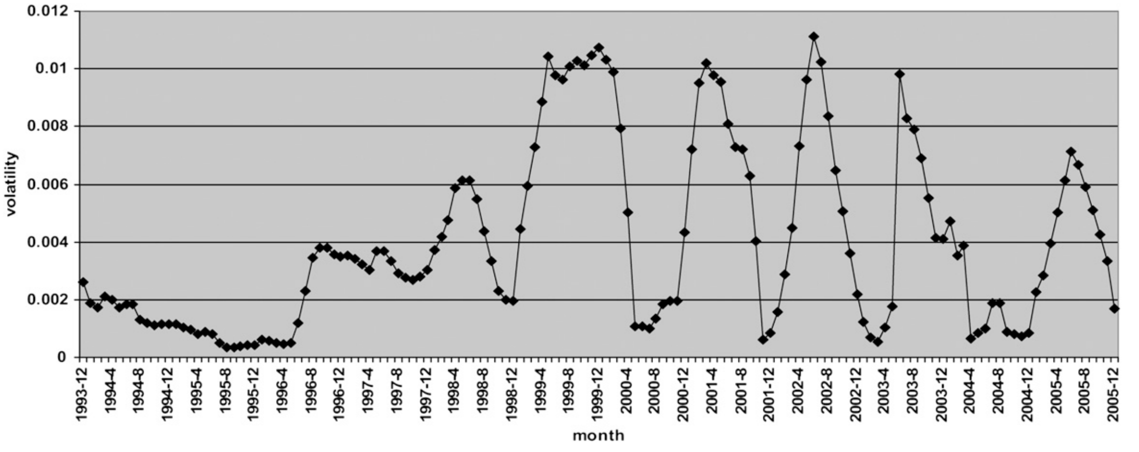

Figure 1. Actual Pork Price Volatility

Many previous studies have investigated the U.S., Canadian, and Australian pork industry. Hayenga and Hacklander investigated hog supply and demand behavior for the U.S. market and estimated a negative short-run supply price elasticity. Tamini and Gervais developed economic indexes that measure economic activity in the Quebec pork industry and Gillespie and Fulton (2001) used Markov chain analysis to model changes in the size and location of hog firms. Moreover, Holt and Johnson constructed an econometric model of supply response and incorporated relevant biological features of hog production directly into the structural specification. Holt and Moschini investigated the role of price risk in sow farrowings by using ARCH and GARCH models, suggesting small and negative risk effect, while Chavas investigated the economic rationality in the U.S. pork market suggesting the presence of heterogeneous price expectations among market participants. Finally, Richarson and O'Connor estimated the structure of supply responses in the Australian pig industry.

A few studies have investigated the European pork industry, including the study by Kuiper and Meulemberg,which used a restricted vector error correction model to forecast the long-run supply behavior of Dutch pig-farming industry. Furthermore, Nyars and Vizvari estimated a supply function for the Hungarian pork market, and Pietola and Wang applied a stochastic model to the Finland hog industry and showed that high fluctuation in piglet prices increase production risk and that this risk can be decreased through contracts within the production chain. Gjolberg and Bengtsson evaluated hog price forecasting models applied to the Nordic markets and showed that feed prices and prices of newborn pigs are good predictors of future hog prices.

Methodology

An empirical specification of the pork supply equation model can be described as:

$$(1) \qquad y_t = a_0 + a_1 P_t^e + a_2 h_t + a_3 x_{1t}' + \varepsilon_{1t}$$

where y_t is the pork production, P_t^e is the expected price, h_t is the expected price variance which measures volatility, x_{1t}' is a vector of independent variables, and ε_{1t} is a mean zero normally distributed error term with variance σ_{11}.

Then the GARCH (p, q) process is used to generate the variables P_t^e and h_t and it is given as:

$$(2) \qquad P_t \mid \Omega_{t-1} = c_0 + \sum_{i=1}^{n} c_i P_{t-i} + \varepsilon_{2t}$$

$$(3) \qquad h_t = b_0 + \sum_{i=1}^{q} b_{1i} \varepsilon_{2t-i}^2 + \sum_{i=1}^{p} b_{2i} h_{t-i}$$

$$\varepsilon_{2t} \mid \Omega_{t-1} \sim N(0, h_t)$$

where $b_0 > 0$, $b_{1i} \geq 0$ $i = 1, \ldots, q$, $b_{2i} \geq 0$ $i = 1, \ldots, p$, $\sum b_{1i} + \sum b_{2i} < 1$.

The autoregressive conditional heteroskedastic (ARCH) model (Engle 1982) allows the conditional variance, h_t, to depend on past volatility measured as a linear function of past errors, ε_{2t}, while leaving unconditional variance constant. Thus, in Equation (2), ε_{2t} is a discrete time stochastic error, and Ω_{t-1} is the information set of all past states up to the time $t-i$. Bollerslev (1986) developed the generalized ARCH (p, q) [GARCH (p, q)] specification. Following this specification, h_t is defined as in Equation (3), which is called GARCH conditional variance equation. According to Equation (3), the conditional variance h_t is specified as a linear function of p lagged squared residuals and its own q lagged conditional variances. As the variance is expected to be positive, the coefficients b_0, b_{1i}, and b_{2i} are always positive. Also the stationarity of the variance is preserved by the restriction $\sum b_{1i} + \sum b_{2i} < 1$.

The predictions of P_t^e and h_t generated by the GARCH model could be used directly to estimate supply Equation (1). But using regressors generated by a stochastic model, for example, GARCH, as factors in the estimation of Equation (1) can cause biased estimates of the parameters (Pagan). This problem can be avoided by estimating the GARCH model of Equations (2) and (3) and the supply Equation (1) jointly using the full information maximum likelihood method (Pagan and Ullah). More specifically, let ε_{1t} of Equation (1) and ε_{2t} of Equation (2) are distributed jointly as:

$$\varepsilon_t = \begin{bmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix} \sim N\left[\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{12} & h_t \end{bmatrix}\right]$$

where σ_{11} and σ_{12} are constants. Assuming conditional normality and setting as Σ_i the variance-covariance matrix, then the log likelihood function of the above system is given as

$$\text{(4)} \qquad L_T(\Theta) = -\log|\Sigma_t| - \varepsilon_t'\Sigma_t^{-1}\varepsilon_t$$

where $|\Sigma_t| = \sigma_{11}h_t - \sigma_{12}^2 = \phi_t$ and $\varepsilon_t'\Sigma_t^{-1}\varepsilon_t = [\varepsilon_{1t}^2 h_t - 2\varepsilon_{1t}\varepsilon_{2t}\sigma_{12} + \varepsilon_{2t}^2\sigma_{11}]\phi_t^{-1}$.

The GARCH model implies that ε_t is normal and follows the Gaussian distribution but in practice the residuals are often described by excess kurtosis. In order to handle this problem, Bollerslev and Wooldridge proposed the use of quasimaximum likelihood estimation. The Broyden, Fletcher, Goldfarb, and Shanno (BFGS) algorithm (Press et al.) is then used to find the maximum likelihood parameter estimates of Equation (4).

Although the simple GARCH model has been found to provide a good representation of volatility process, the literature offers many alternative specifications. A very important specification has to do with asymmetry. The asymmetric effect is observed when a different volatility is recorded in case of a fall in price than in case of an increase (i.e., bad and good news). The standard GARCH model used above cannot capture the asymmetry as far as the error term, ε_{2t}, which represents the unexpected price shock, enters the conditional variance equation as a square, indicating thus that there is no difference whether the price shock is positive or negative. Asymmetric GARCH model takes account of skewed distributions in which good news and bad news have a different effect on volatility.

A characteristic asymmetric GARCH model is the nonlinear asymmetric GARCH (NAGARCH) developed by Engle and Ng. In this model Equations (5) and (6) of the system presented above are described as:

$$\text{(5)} \qquad P_t = c_0 + \sum_{i=1}^{n} c_i P_{t-i} + \varepsilon_t,\ \varepsilon_t \mid \Omega_{t-1} \sim N(0, h_t)$$

$$\text{(6)} \qquad \begin{aligned} h_t = b_0 &+ \sum_{i=1}^{q} b_{1i}(\varepsilon_{t-i} + b_3\sqrt{h_{t-i}})^2 \\ &+ \sum_{i=1}^{p} b_{2i} h_{t-i} \end{aligned}$$

where $b_0 > 0$, $b_{1i} \geq 0$ $i = 1,\ldots, q$, $b2_i \geq 0$ $i = 1,\ldots, p$ and $\sum b_{1i} + \sum b_{2i} < 1$.
This model defines volatility as a nonlinear asymmetric function of past periods' shocks and volatility, and if $b_3 \neq 0$, then asymmetry is present. Note that b_3 is the asymmetry parameter and if b_3 is positive, then a positive shock causes more volatility than a negative shock of the same size.

Besides the NAGARCH model described above, Equations (5) and (6) have been properly modified to specify nine additional symmetric and asymmetric GARCH models, in order to detect which one of them fits better the estimated system. Finally, the 10 GARCH models estimated in this study are: linear symmetric GARCH developed by Bollerslev; nonlinear symmetric GARCH (NGARCH) developed by Engle and Bollerslev; GARCH in mean (MGARCH) developed by Engle, Lilien, and Robins; asymmetric GARCH (AGARCH) developed by Engle (1990); nonlinear asymmetric GARCH (NAGARCH) developed by Engle and Ng; quadratic asymmetric GARCH model (QGARCH) developed by Sentana; TS-GARCH symmetric model proposed by Taylor and by Schwert; threshold asymmetric GARCH (GJR-GARCH), proposed by Glosten, Jagannathan, and Runkle; nonlinear asymmetric VGARCH developed by Engle and Ng; and the exponential asymmetric GARCH model (EGARCH) developed by Nelson.

Data and Model Specification

Data used in this study are monthly time series for the period of January 1993 to December 2005. In particular, pork quantities were obtained from the Hellenic Ministry of Rural Development and Food (HMRDF) and were transformed into a pork quantity index. The pork producer price index, the pig feed price index, and the veterinarian medicines price index were obtained from the National Statistical Service of Greece (NSSG). All variables were transformed into logarithms and all prices were deflated by the consumer price index (1993 = 100).

The pork supply response Equation (1) is specified as:

$$\begin{aligned} QPP_t = \sum_{i=1}^{12} a_i D_{it} + a_{13} TR_T + a_{14} PPP_t^e \\ + a_{15} PCV_t + a_{16} PPF_{t-9} \\ + a_{17} VMED_{t-9} + a_{18} QPP_{t-1} \\ + a_{19} QPP_{t-12} + e_{1t} \end{aligned} \tag{7}$$

where QPP_t is the pork production in period t; D_{it} is a monthly dummy variable ($i = 1, 2, \ldots, 12$); TR_T is a trend component; PPP_t^e is the expected real producer price of pork in time t; PCV_t is the expected variance of real producer price of pork in time t; PLF_{t-9} is the real price of pig feed in time $t - 9$; $VMED_{t-9}$ is the real price of veterinarian medicines in time $t - 7$; and QPP_{t-i} is the pork production in period $t - i$, where $i = 1, 12$.

The monthly dummy variable (D_{it}) is used to capture the monthly seasonality effect of the production. Seasonal production is quite evident in Greek pork industry, due to the custom of pork consumption during Christmas. A trend component (TR_T) is used to capture technological change in the production process. The expected pork price, PPP_t^e, and the price volatility term, PCV_t, are considered to be important risk factors and therefore are included. Note that that producer pork price differs from imported pork price and, specifically during the examined period, the producer pork price was usually higher than the imported pork price. This difference occurs mainly because of the preferences of Greek consumers who tend to prefer domestic meat products. The estimation of the correlation between the two variables reveals that the producer pork price and the imported price present a high correlation (90%), which means that the producer pork price reflects changes in the imported price. Thus, in the specification of the model, only the producer pork price is used.

The prices of two senior cost factors are used. First, the price of feed, PPF_{t-9}, which is the most important cost factor, represents on average 60% of the pork production cost and secondly, the price of veterinarian medicines, $VMED_{t-9}$, which is a significant cost factor because producers try to avoid production loss due to disease. The knowledge of the biological nature of the production process is crucial in determining the lag lengths and dynamics involved in supply response. A 9 month lag period for these variables, that is, PPF_{t-9} and $VMED_{t-9}$, is used because in Greece there is, on average, a 270 day lag between breeding and slaughter. Therefore, a 9 month period frame is suitable for exploring the supply response in the industry. In addition, 1 and 12 lags of pork production, that is, QPP_{t-i} where $i = 1$ and 12, are included in the supply function because production needs time to adjust to the desirable level.

The specification of the real producer price of pork is given as:

$$PPP_t = c_0 + \sum_{i=1}^{12} c_i PPP_{t-i} + c_{13} TR_T + \varepsilon_{2t} \tag{8}$$

where PPP_t is the real producer price of pork in time t, TR_T is a trend component, and $PPP_{t-\mathrm{i}}$ is the real producer price of pork in time t − i where i =1, 2,. . . ,12.

The lag structure of Equation (8) is selected according to the general-to-specific methodology. The trend component (TR) is used to capture the behavior of prices during the sample period. Equation (8) is estimated for all different GARCH models, described in the literature review section above. It should be mentioned that in the case of GARCH in mean model (GARCH-M), the factor $c_{16}\sqrt{h_t}$ enters Equation (8) as far as in that model the conditional mean depends on its own conditional variance.

All the alternative GARCH models were tested for several orders such as GARCH (1, 2), GARCH (2, 1) and GARCH (2, 2) but in all cases the simple GARCH (1, 1) process fits better. Thus, the variance equation of the GARCH (1, 1) model is used and it is given by

$$h_t = b_0 + b_1 \varepsilon_{2t-1}^2 + b_2 h_{t-1} \tag{9}$$

Note that specification (9) is modified according to which GARCH approach, among those discussed in the previous section, is considered.

Empirical Results

Table 1 provides the results of unit root tests on the data. Augmented Dickey Fuller (ADF) and Phillips-Perron (PP) tests are evaluated. The pork production variable, QPP_t, remained stationary in all cases, while real pork producer price PPP_t is no stationary. The results for the real feed price, PLF, and veterinarian medicines real price, $VMED$, are mixed. These results justify the inclusion of time trend (TR) in estimated Equations (5) and (6).

The BFGS algorithm is used to obtain maximum likelihood estimates of the system constructed by the supply response Equation (7) and the price model which is described by Equations (8) and (9). Note that Equation (9) is modified according to each one of the 10 different GARCH models presented in section 3. All the estimated models achieve convergence but in the VGARCH model the coefficient b_1 has the wrong sign and as a result, the supply-price system based on this specification is not considered.

Tables 2 and 3 present the estimated parameters of the supply response and price equations for the nine alternative GARCH models (GARCH, NGARCH, GARCH-M, TSGARCH, EGARCH, NAGARCH, QGARCH AGARCH, and GJR-GARCH) which satisfy the appropriate GARCH restrictions. Residual diagnostic tests are performed in order to check the explanatory power of the nine alternative supply-price systems. In particular, Ljung-Box $Q(m)$ statistics for 6, 12, 18 month lags is performed for the standardized residuals and squared standardized residuals in order to check upon serial correlation and heteroskedasticity,

Table 1. Results of Unit Roots Tests

	Augmented Dickey Fuller (ADF)	Augmented Dickey Fuller (ADF) (with Intercept and Trend)	Phillips Perron (PP)	Phillips Perron (PP) (with Intercept and Trend)
QPP	−8.596*	−8.635*	−8.449*	−8.476*
PPP	−2.070	−2.632	−2.150	−2.860
PPF	−1.833	−3.415**	−1.854	−3.138**
VMED	−2.166**	−3.239**	−1.869	−2.778**

* = Significant at 5%

** = Significant at 10%

Table 2. Results of the Supply Response Equation

	GARCH (1,1)	NGARCH (1,1)	GARCH-M (1,1)	TS-GARCH (1,1)	EGARCH (1,1)	NAGARCH (1,1)	QGARCH (1,1)	AGARCH (1,1)	GJR-GARCH (1,1)
a_1	1.064	1.724	1.068	1.165	1.107	1.227	1.120	1.120	1.554
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
a_2	1.3257	1.910	1.268	1.839	1.279	1.340	1.300	1.327	1.683
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
a_3	1.234	1.888	1.246	1.805	1.251	1.317	1.276	1.304	1.634
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
a_4	1.276	1.922	1.288	1.845	1.288	1.360	1.314	1.347	1.653
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
a_5	1.270	1.915	1.283	1.840	1.281	1.355	1.308	1.340	1.633
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
a_6	1.329	1.980	1.344	1.900	1.339	1.420	1.366	1.401	1.721
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
a_7	1.348	2.003	1.362	1.926	1.362	1.441	1.385	1.426	1.752
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
a_8	1.341	1.999	1.355	1.923	1.357	1.434	1.381	1.420	1.761
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
a_9	1.237	1.888	1.248	1.811	1.255	1.324	1.279	1.310	1.647
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
a_{10}	1.325	1.976	1.339	1.904	1.339	1.416	1.364	1.401	1.734
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
a_{11}	1.357	2.015	1.370	1.940	1.372	1.447	1.396	1.432	1.796
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
a_{12}	1.764	2.457	1.786	2.396	1.784	1.869	1.797	1.855	2.265
	(0.136)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
a_{13}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(0.145)	(0.000)	(0.167)	(0.000)	(0.172)	(0.002)	(0.206)	(0.210)	(0.078)
a_{14}	0.131	0.088	0.123	0.119	0.145	0.062	0.126	0.078	0.147
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
a_{15}	−0.125	−0.154	−0.222	−0.151	−0.202	−0.164	−0.162	−0.211	−0.167
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Table 2. Continued.

	GARCH (1,1)	NGARCH (1,1)	GARCH-M (1,1)	TS-GARCH (1,1)	EGARCH (1,1)	NAGARCH (1,1)	QGARCH (1,1)	AGARCH (1,1)	GJR-GARCH (1,1)
a_{16}	−0.175	−0.203	−0.174	−0.204	−0.160	−0.105	−0.162	−0.115	−0.115
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
a_{17}	−0.034	−0.054	−0.034	−0.049	−0.028	−0.071	−0.039	−0.065	−0.013
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
a_{18}	0.459	0.459	0.475	0.451	0.424	0.498	0.435	0.489	0.392
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
a_{19}	0.327	0.274	0.312	0.255	0.325	0.305	0.338	0.305	0.176
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
SIC	1468.82	1477.99	1765.22	1469.75	1464.56	1478.01	1467.01	1476.71	1461.18
Residuals Tests for Supply Response Equation									
$Q(6)$	14.935	7.562	12.702	12.301	20.078	5.029	15.786	5.719	24.060
	(0.021)	(0.271)	(0.048)	(0.055)	(0.003)	(0.540)	(0.015)	(0.456)	(0.000)
$Q(12)$	26.154	18.418	23.157	20.682	31.876	18.009	28.823	18.727	30.263
	(0.010)	(0.103)	(0.026)	(0.055)	(0.001)	(0.115)	(0.004)	(0.095)	(0.003)
$Q(18)$	36.595	29.784	33.784	30.649	41.794	31.095	39.371	31.329	38.637
	(0.005)	(0.039)	(0.013)	(0.031)	(0.001)	(0.028)	(0.002)	(0.026)	(0.003)
$Q^2(6)$	32.976	17.221	29.493	22.098	42.085	11.032	33.621	13.442	38.147
	(0.000)	(0.008)	(0.000)	(0.001)	(0.000)	(0.087)	(0.000)	(0.036)	(0.000)
$Q^2(12)$	36.263	19.519	32.595	24.564	45.424	13.305	37.035	15.798	40.546
	(0.000)	(0.076)	(0.001)	(0.017)	(0.000)	(0.347)	(0.000)	(0.200)	(0.000)
$Q^2(18)$	38.426	21.723	34.524	25.401	47.262	17.236	39.493	19.455	46.381
	(0.003)	(0.244)	(0.010)	(0.114)	(0.000)	(0.507)	(0.002)	(0.364)	(0.000)

[a] Figures in brackets are p-values.
[b] SIC = The Schwarz Information Criterion is given by SIC $= L - 0.5p^*\log(T)$, where L is the maximized value of the likelihood function, p is the number of the estimated parameters and T is the number of the observations.

Table 3. Results of the Price Equation

	GARCH (1,1)	NGARCH (1,1)	GARCH-M (1,1)	TS-GARCH (1,1)	EGARCH (1,1)	NAGARCH (1,1)	QGARCH (1,1)	AGARCH (1,1)	GJR-GARCH (1,1)
c_0	0.539	0.444	0.484	0.476	0.571	0.597	0.585	0.631	0.461
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
c_1	1.017	1.081	1.013	1.016	0.998	1.015	1.050	1.032	0.947
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
c_2	−0.079	−0.060	−0.031	−0.032	−0.050	−0.050	−0.103	−0.053	−0.023
	(0.000)	(0.000)	(0.000)	(0.002)	(0.002)	(0.014)	(0.005)	(0.005)	(0.000)
c_3	−0.159	−0.170	−0.154	−0.151	−0.144	−0.132	−0.173	−0.114	−0.136
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
c_4	0.150	0.138	0.151	0.154	0.112	0.083	0.160	0.060	0.181
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.045)	(0.000)
c_5	−0.074	−0.097	−0.084	−0.088	−0.057	−0.042	−0.050	−0.046	−0.088
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)
c_6	−0.101	−0.105	−0.097	−0.096	−0.108	−0.109	−0.110	−0.108	−0.108
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
c_7	0.171	0.172	0.170	0.174	0.166	0.153	0.176	0.146	0.186
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
c_8	−0.027	−0.025	−0.035	−0.034	−0.035	−0.045	−0.048	−0.059	−0.048
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.012)	(0.000)	(0.003)	(0.003)
c_9	−0.158	−0.182	−0.166	−0.190	−0.155	−0.135	−0.164	−0.126	−0.188
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
c_{10}	0.254	0.216	0.202	0.217	0.256	0.281	0.240	0.296	0.247
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
c_{11}	0.055	0.068	0.058	0.067	0.054	0.038	0.060	0.034	0.061
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)	(0.000)	(0.012)	(0.000)
c_{12}	−0.162	−0.133	−0.129	−0.135	−0.162	−0.184	−0.162	−0.196	−0.130
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
c_{13}	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.004)	(0.000)	(0.002)	(0.004)

Table 3. Continued.

	GARCH (1,1)	NGARCH (1,1)	GARCH-M (1,1)	TS-GARCH (1,1)	EGARCH (1,1)	NAGARCH (1,1)	QGARCH (1,1)	AGARCH (1,1)	GJR-GARCH (1,1)
c_{14}			−0.006						
			(0.000)						
GARCH factors									
b_0	−0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	(0.004)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
b_1	−0.381	0.114	0.354	0.032	0.344	0.321	0.118	0.195	0.195
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
b_2	0.483	0.520	0.402	0.492	0.308	0.513	0.488	0.520	0.520
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
b_3					−0.004	−0.000	0.002	−0.008	−0.008
					(0.965)	(0.000)	(0.883)	(0.795)	(0.795)
Residuals Tests for Price Equation									
$Q(6)$	3.427	1.155	0.839	1.212	3.544	3.038	2.326	2.983	2.865
	(0.753)	(0.976)	(0.991)	(0.976)	(0.738)	(0.805)	(0.887)	(0.810)	(0.825)
$Q(12)$	10.340	6.479	6.964	7.771	11.580	12.956	7.818	14.147	6.962
	(0.581)	(0.890)	(0.861)	(0.803)	(0.479)	(0.372)	(0.799)	(0.291)	(0.860)
$Q(18)$	17.714	15.068	13.987	15.652	19.604	22.388	14.771	24.907	15.654
	(0.475)	(0.657)	(0.729)	(0.617)	(0.355)	(0.215)	(0.677)	(0.127)	(0.617)
$Q^2(6)$	3.187	2.666	3.581	2.359	3.007	3.053	3.010	2.520	4.518
	(0.785)	(0.849)	(0.733)	(0.884)	(0.808)	(0.802)	(0.807)	(0.866)	(0.607)
$Q^2(12)$	4.570	4.297	5.323	4.018	4.247	4.204	4.682	3.752	8.449
	(0.971)	(0.977)	(0.946)	(0.983)	(0.978)	(0.979)	(0.977)	(0.987)	(0.749)
$Q^2(18)$	13.285	15.610	17.265	14.553	12.584	12.997	14.665	12.189	25.365
	(0.774)	(0.657)	(0.505)	(0.692)	(0.816)	(0.792)	(0.684)	(0.837)	(0.115)

[a] Figures in brackets are p-values.

respectively, and the Schwarz information criterion[1] (SIC) is also used to rank the nine models because it allows a degree of freedom free comparison of the models' performance.

The residual tests for the supply response equation for each of the nine models are presented in Table 2 and indicate that the best performance belongs to NAGARCH model which presents no heteroskedasticity for all the examined lags at the 5% level of significance, no autocorrelation for 6 and 12 month lags at the 5% level of significance and no autocorrelation for 18 month lags at the 1% level of significance. With regard to the price equation residual tests presented in Table 3, all nine models present no heteroskedasticity and no autocorrelation for all the examined lags at the 5% level of significance. Thus, the residual tests in both supply and price equations indicate that NAGARCH model achieves the best performance. Finally, a comparison of SIC values, presented in Table 2 indicates that the NAGARCH model is the most appropriate one to describe the supply-price equation system for Greek pork production.[2]

Analyzing the estimated parameters of the NAGARCH model, presented in Table 3, it is apparent that the magnitude of b_2 is larger than the magnitude of b_1, that is, 0.513 and 0.321 respectively. The size of b_1 and b_2 parameters determines the short-run dynamics of price volatility. Since b_2 has a larger value, this indicates that volatility is persistent and shocks to conditional variance take a long time to die out. The asymmetry factor, b_3, although statistically significant, is very close to zero, that is, -0.00001, indicating the absence of asymmetric price volatility. This means that a negative shock causes equal price volatility with a positive shock of the same size. Pork producers seem to react the same way in case of "bad news" (which pushes them to decrease prices) as in case of "good news" (when they increase prices). The fact that producers respond equally to unexpected price increases and decreases, suggests that there is no evidence of market power. In other words, Greek pork producers appear to have a balanced position in the market chain and react symmetrically in case of "good" or "bad" news. This result is consistent with the structure of the Greek pork market where on the one hand there is a number of large Greek pork enterprises which are trying to dominate the market and control prices but on the other hand the high percentage of imports, that is, about 60% of total consumption, does not allow them to have any strong influence in the market. Unfortunately, there are no other studies examining the existence of asymmetric price volatility in the behavior of pork prices in order to cross-check the results of the present study. However, the asymmetric price volatility results of the present study can be compared to those by Rezitis and Stavropoulos (2007a) for the Greek broiler industry where a positive asymmetric effect was detected, that is, 0.005, and to those by Rezitis and Stavropoulos (2007b) for the Greek sheepmeat industry where a negative asymmetric effect was detected, that is, –0.221. These findings can be justified because the Greek broiler market is dominated by a small number of large producers with a strong influence in the market, while the lamb market is characterized by a large number of small size sheep breeding farms with a weak influence in the market.

Table 2 presents the estimated parameters of the supply response equation of the NAGARCH model. All the estimated coefficients have the theoretically expected signs and they are significant at all levels. Short-run supply price elasticity given by the estimated coefficient a_{14} is small but still positive, that is, 0.062, indicating that an expected pork price increase induces producers to slaughter pigs at present instead of holding them in the breeding flock in order to increase future production. This result is smaller than that obtained by Holt and Moschini with a magnitude of 0.172 and by Koo, Petry, and Anderson with a magnitude

[1] The Schwarz information criterion is given by SIC $= L - 0.5p^{*}\log(T)$, where L is the maximized value of the likelihood function, p is the number of the estimated parameters, and T is the number of the observations.

[2] Furthermore, the results of the J-test (Davidson and MacKinnon; MacKinnon) between NAGARCH and the rest of the symmetric and asymmetric models examined in this paper show that the NAGARCH is the most appropriate model.

between 0.206–0.270 with both of the studies referring to the U.S. pork industry. Furthermore, it is higher than the result obtained by Holt and Johnson with a magnitude of about –0.392 and by Hayenga and Hacklander with a magnitude of about –0.055 who estimated negative short-run supply price elasticity for the U.S. pork industry. The calculated long-run supply price elasticity of the present study is 0.315, which is inelastic, and smaller than the one obtained by Holt and Moschini with a magnitude of 1.982, by Holt and Johnson with a magnitude of –0.403 and by Kuiper and Meulenberg with a magnitude between 3.370–3.050. However, it is higher than the range 0.109–0.149 obtained by Koo, Petry, and Anderson.

The sign of the estimated coefficient for the expected price volatility is negative, that is, $a_{15} = -0.164$, as expected. Comparing this result to those obtained by Holt and Moschini (1992) for the U.S. hog industry (volatility effects between –0.003 and –0.029), it can be concluded that price volatility is a serious risk factor in the Greek pork production. Furthermore, Rezitis and Stavropoulos (2007a, 2007b) obtained results of –0.395 and –0.151 with regard to the Greek broiler and sheepmeat industry, respectively. The magnitude of the pork feed price coefficient, that is, $a_{16} = -0.105$, indicates that feed is a significant cost factor in the pork production. This result is in accordance with the fact that feed cost is the most important cost factor in Greek pork production. The effect of feed cost in the present study is smaller than the results obtained by Holt and Moschini with a magnitude of –0.189, by Koo, Petry, and Anderson with a magnitude of between –1.440 and –1.470, and by Kuiper and Meulenberg with a magnitude of –1.260. Veterinarian medicine cost estimated coefficient, that is, $a_{17} = -0.071$, is small indicating that this production cost is less important. The seasonal components are statistically significant, indicating the presence of a strong seasonal effect during December, and the estimates obtained for lagged production are high, which implies that production is adjusting slowly to the desired level.

Furthermore, the estimated supply response model provides out of sample forecasting of produced quantity (QPP), expected producer price (PPP) and price volatility (PCV) for the period 1/2006 to 12/2006. Actual and forecasted values are presented in Table 4 and Figures 2, 3, and 4 while the root mean square error (RMSE) for produced quantity and expected producer price is also presented in Table 4. The observation of the figures shows a good forecasting ability of the model, especially as far as produced quantity is concerned.

Relative marginal risk premium for pork supply is computed as $RRP_t = -(a_{15}/Supply\ price\ elasticity) \times (PCV_t/PPP_t^e)$, where a_{15}

Table 4. Forecasted Produced Quantity, Pork Price, and Price Volatility

	Produced Quantity		Price		Price Volatility	
	Actual	Forecast	Actual	Forecast	Actual	Forecast
1/2006	4.5200	4.5380	4.4548	4.3913	0.0446	0.0509
2/2006	4.3407	4.4032	4.4499	4.4276	0.0486	0.0480
3/2006	4.2224	4.2734	4.4571	4.4463	0.0483	0.0403
4/2006	4.2064	4.2274	4.4775	4.4752	0.0468	0.0383
5/2006	4.1959	4.2212	4.4766	4.4876	0.0409	0.0292
6/2006	4.2554	4.3033	4.4827	4.5245	0.0306	0.0241
7/2006	4.2681	4.3678	4.4830	4.5246	0.0286	0.0153
8/2006	4.2949	4.4331	4.5260	4.5754	0.0345	0.0315
9/2006	4.2416	4.3427	4.5494	4.6009	0.0320	0.0389
10/2006	4.2876	4.4016	4.5540	4.6021	0.0252	0.0345
11/2006	4.4322	4.4863	4.5715	4.6231	0.0230	0.0281
12/2006	5.0498	5.1497	4.5348	4.5861	0.0248	0.0195
RMSE (1/06–12/06)	0.0289		0.0418		0.0078	

[a] RMSE = Root mean square error.

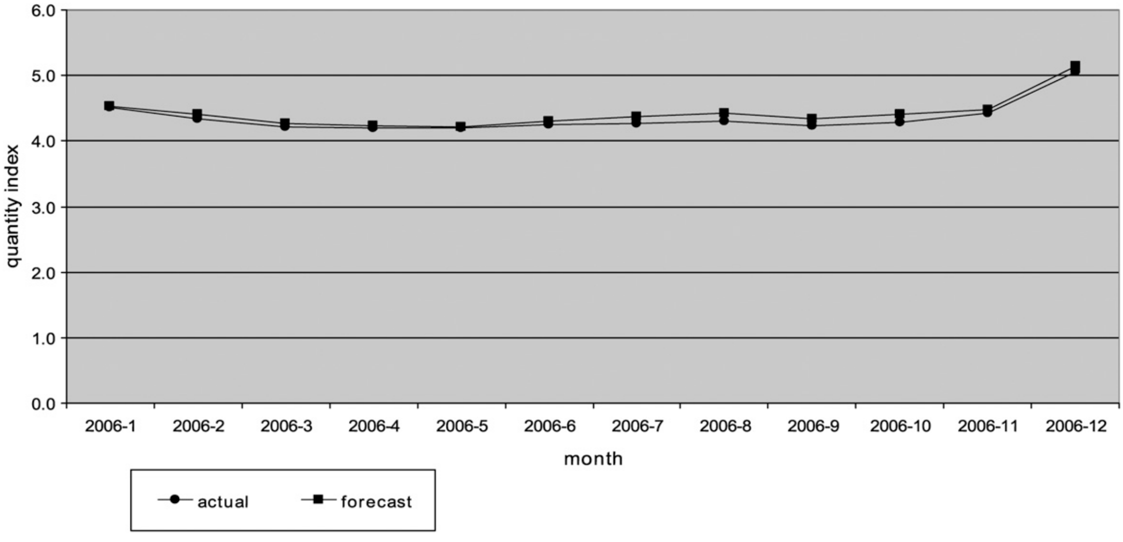

Figure 2. Forecast and Actual Values of Pork Produced Quantity Index (QPP) (1993 = 100)

is the estimated parameter of PCV_t, and it is presented in Figure 5. The time path for RRP_t reflects relative trend-cycle movements in actual pork price levels and volatility and it shows the percentage departure from marginal cost pricing, if $RRP_t > 0$ ($RRP_t < 0$, $RRP_t = 0$), producers are risk averse (risk lovers, risk neutral). It ranges from a peak of 0.22% in 2/2005 to a low of 0.05% in 3/1999 with an average of about 0.10%. These small positive values imply that there is no big departure from risk neutrality. This result is much lower than those obtained by Holt and Moschini for the U.S. pork production with an average RRP_t of about 6.7%.

Finally, dynamic adjustments in pork production are investigated in response to a change in producer price and price volatility. To measure

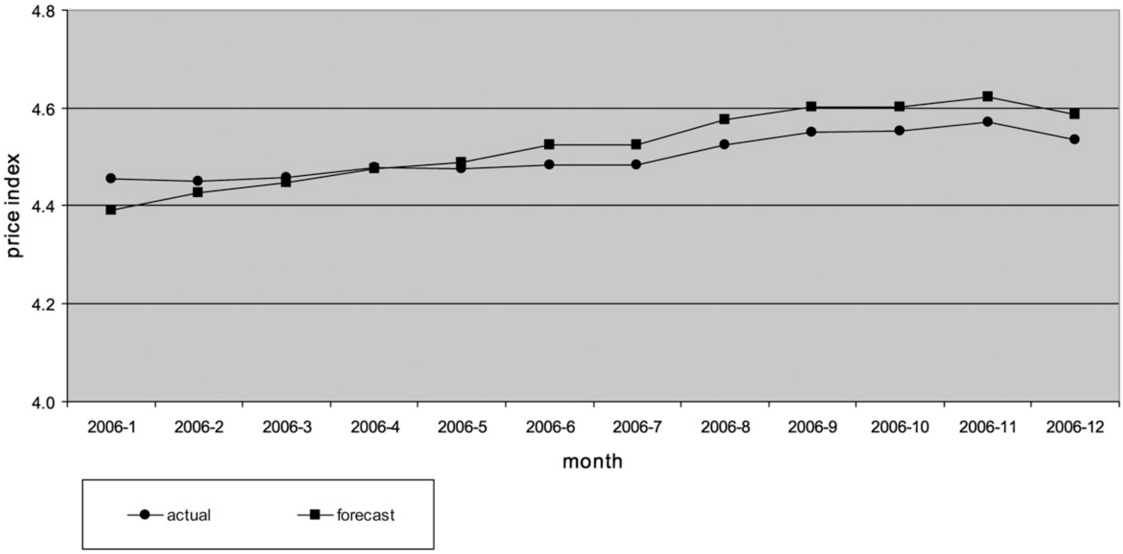

Figure 3. Forecast and Actual Values of Pork Price Index (PPP) (1993 = 100)

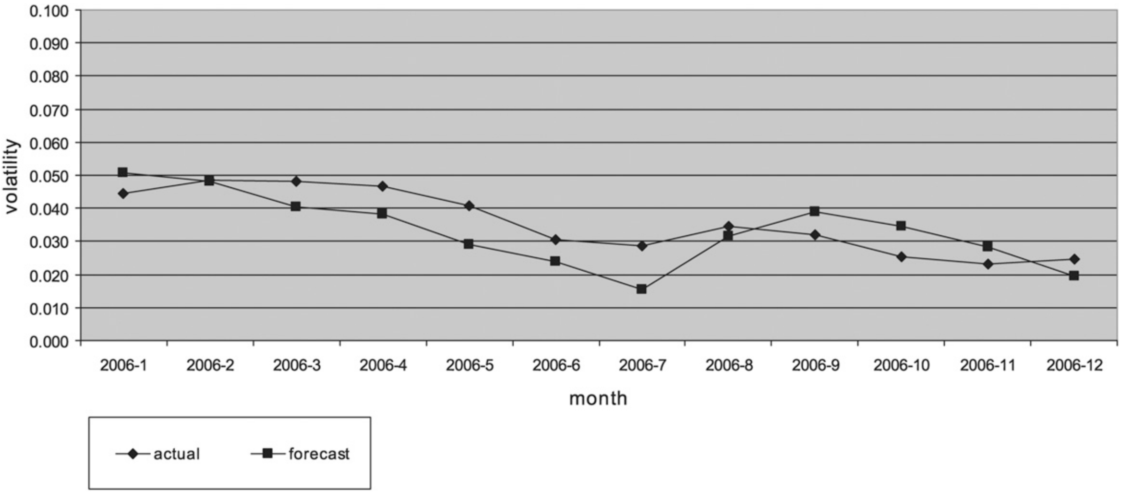

Figure 4. Forecast and Actual Values of Price Volatility

these effects, dynamic total elasticities of pork production are estimated with respect to a sustained 3% increase and decrease in producer price and price volatility, while the other variables are evaluated at the sample means of the data. The calculation of elasticities is for a forecast horizon of 120 periods, that is, 10 years. Table 5 reports the results smoothed on an annual base. For example, results reveal that a permanent 3% increase of price volatility causes a contemporaneous decrease in production, in the first year, of about 0.963% and an additional decrease of 0.626 in the second, while in the following years, the effect decreases monotonically and eventually converges to zero.

Conclusions

This study investigated the pork supply response in Greece. The empirical analysis used

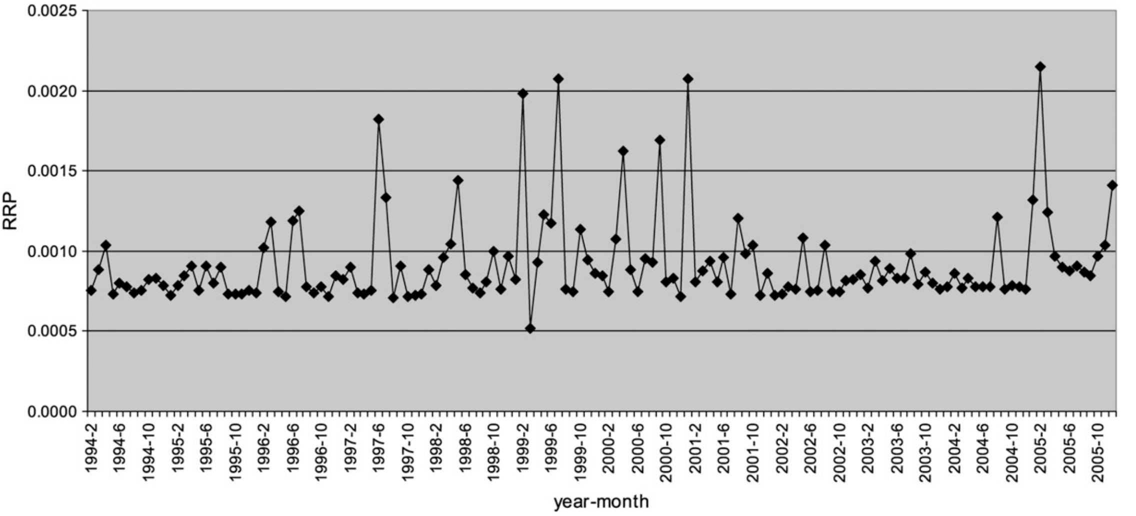

Figure 5. Relative Risk Premium (RRP) for Pork Supply

Table 5. Forecasted Response of Pork Quantity (*QPP*) to a 3% Percentage Changes in Price and Price Volatility (estimation at sample means)

	3% Increase of PPP_t^e	3% Decrease of PPP_t^e	3% Increase of PVC_t	3% Decrease of PVC_t
2006	0.0266	−0.0267	−0.0967	0.0913
2007	0.0190	−0.0212	−0.0629	0.0163
2008	0.0156	−0.0171	−0.0407	0.0099
2009	0.0107	−0.0147	−0.0262	0.0062
2010	0.0055	−0.0070	−0.0167	0.0040
2011	0.0035	−0.0044	−0.0106	0.0025
2012	0.0022	−0.0028	−0.0067	0.0016
2013	0.0014	−0.0018	−0.0042	0.0010
2014	0.0009	−0.0011	−0.0027	0.0007
2015	0.0006	−0.0007	−0.0017	0.0004

the GARCH process to model producers' expectations about expected price and expected price volatility and the supply response equation estimated jointly with the price equation using the FIML econometric approach. Several different symmetric and asymmetric GARCH models were tested and the NAGARCH model appeared to be particularly appropriate to describe the pork price response. Pork price volatility was found to have a negative effect on production, a result indicating that pork producers are risk averse. No asymmetric effect was detected on price volatility and producers responded equally to unexpected price increases and decreases, indicating a competitive behavior. Both, short and long-run supply price elasticities were found to be positive, while feed price had a stronger impact on pork production than veterinarian medicine, indicating that feed is the most important cost factor of pork production.

Price uncertainty appears to have a strong negative effect on Greek pig producers, which might be an important constraint in their attempt to expand their farm size and invest in more productive technologies. This high negative effect of price volatility in pork production is likely to affect production decisions and is probably an important reason why there is a decline in pork production during the last decade when Greek pork industry seems to be unable to compete with the rest of EU pork industry. It is characteristic that even though the pork sector experienced significant international growth during 2004 and 2005 due to BSE and Bird Flu, the Greek pork sector did not benefit from this expansion.

It seems that pork industry in a small country like Greece faces serious problems to adapt successfully to open market conditions and achieve high level performances in an increasing level of international competition. The Greek pork industry and policymakers should take this result into consideration and try to improve the industry's performance. An important necessity is to expand the use of hedging mechanisms (e.g., contracts to vertically coordinate the production process) in order to diversify away a portion of the risk and reduce uncertainty. In addition, Greek producers should upgrade the quality of their product and improve their performance in the level of providing standardized packing products in order to increase their competitiveness and get access to export markets. Finally, the Greek government should further assist pork producers to participate in specialized investment programs, financed jointly by the Greek government and the EU, providing them with subsidized capital appropriate for modernization and growth.

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