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Do hog breeds matter? Investigating the price volatility in the Taiwan's auction market

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Abstract: The study analyzes the dynamic differences between the prices of black hogs and white hogs in Taiwan and determines whether these two products should be viewed as homogeneous commodities by analyzing their price volatility. Previous studies have shown that the differences in auction prices stem from the traits of the individual hogs rather than certain breeds demanding a premium because of their superior meat quality. Methodologically, this study utilizes the multivariate GARCH and the constant conditional correlation models to analyze the average daily prices of the two breeds generated by random auction sequences. Data were collected from 1485 observations, from January 2009 to December 2013, of the Miaoli hog auction market of Taiwan. Based on the dissimilarity of price volatility structures and the low correlation factor between the black hogs and white hogs, this study concludes that these two hog breeds should be regarded as heterogeneous products. This conclusion should serve as a reference for the local hog producers when searching for the best economic traits of indigenous breeds in terms of rearing the potential as well as for the stakeholders when developing the breed-specific marketing strategies.

Key words: black hog, indigenous hog breeds, price actions, wholesale market

Breed has been shown to be an important reproduction consideration in relation to the consumption traits in the beef sector (Walburger 2002). For example, the consumers are willing to pay higher prices for the Angus and Wagyu (Japanese black cattle) breeds because of their distinctive meat quality (Wahl et al. 1995; Chung et al. 2012). However, in the pork industry, such a distinction based on taste is rarely made, even though the quality of pork has been found to have recognizable sensory differences from the perspectives of consumers (Melton et al. 1996a; Ngapo and Gariepy 2008). Indeed, only a few previous agricultural economics studies have considered breed to be a classification criterion for the differences in the meat quality of hogs. Similarly, the pork industry also pays less attention to specific hog breeds as brands or labels that may facilitate the consumer demand. However, regarding heterogeneous products as homogeneous not only makes it impossible to reflect the accurate information on prices, quantities, and quality, it also leads to market distortions and inefficiencies (Hudson et al. 1998). Case studies of the product demand (Baltagi et al. 2000) have also shown that homogeneous and heterogeneous value estimation produced by treating the data separately as "merged" or "not merged" results in distinct differences in the outcome forecasts.

This study analyzes whether the foreign and indigenous breeds of hogs (white hogs and black hogs herein) should be regarded as homogeneous, by using the data derived from the Taiwan's live hog auction markets rather than the observations of consumer behaviour. Auction prices are live and rapid indicators of the preferences of buyers towards products. If the price volatility between different breeds is insignificant, it implies that consumer demands for these two breeds are more likely to be independent on each other. The Taiwan's live hog auction market has been operating for 29 years and it accounts for over 80% of all hog slaughtering in the country (National Animal Industry Foundation 2008). The hog auctions provide unique price data on this topic because of two factors: (i) the obvious physical appearance of black hogs and the difference in their pork quality compared with that of the white hogs and (ii) the fact that the bidders in public auctions must be licensed and that the professional sales agents have a high level of sensitivity to market demand. Therefore, compared with the retail pork sector, the auction market provides an even a clearer understanding

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of the price differences of the black hogs and white hogs and the relationship between their different price volatilities. This feature can in turn be used to clarify the positional relationship between the black hogs and white hogs, the commodities that share a high degree of similarity but are not identical. Consequently, the objective of this study was to determine the potential value of diversity of the hog breeds from the perspective of consumers rather than that of livestock science.

Taiwan provides a valuable context for the empirical study of differentiation between hog breeds. In Taiwan, the terms "black hog" and "white hog" do not merely refer to hogs with a differently coloured skin, but to the completely different breeds. The indigenous black hog specifically refers to a breed that possesses the characteristics of the Taoyuan hog (or Meishan hog) strain. From the perspective of the livestock science, the black hog belongs to a breed and strain that is completely different to that of the white hog. Apart from its easily distinguishable appearance (i.e., black skin, largely pendulous ears, and noticeably wrinkled face), the black hog is significantly different to the white hog in terms of its functions such as breeding, growth, and rearing (Yen 1998). Moreover, the meat traits of black hogs, such as the lipid composition and dorsal adipose tissues, are also distinguishable scientifically because of their genotype (Gandemer et al. 1992). On the contrary, the ordinary pork is generally produced from the white hogs, which are bred and reared from the foreign strains such as the Duroc, Landrace, and Yorkshire as a three-way cross. The advantages of the ordinary pork include its conformation and carcass traits such as the average backfat thickness, the lean percentage, and the growth performance (Yen et al. 2001; Latorre et al. 2008). Nevertheless, the demand for the black hog pork from Taiwanese consumers has long been stable and the supply of the black hog pork has thus not been eliminated from the market.

Despite these clear differences, most previous agricultural economics studies of this topic have considered hogs to be homogeneous products, with almost no independent analyses of the different breeds. Data availability is one crucial reason for the lack of studies of the meat homogeneity related to specific breeds. For example, the official statistical data published by the Taiwan's Executive Yuan Council of Agriculture does not have independent columns for the prices and quantities of black hogs, making it almost impossible to obtain aggregate data on this breed. Given the foregoing limitation, this study examines the changes in the price and price volatility of black hogs and white hogs in real auction markets instead of in an experimental setting.

The transmission of the price volatility among different markets is also known as the volatility spillover effect, which typically occurs in markets with highly horizontal or vertical relationships. The previous studies have demonstrated that the incentive of arbitrage brings about a transmission of the price volatility in the price of beef in different auction markets (Natcher and Weaver 1999). Conversely, if the commodities exhibit distinct quality attributes or have a comparatively small scope for substitution, the transmission of the price volatility between commodities can be anticipated to have distinct restraints. Mintert et al. (1990), for instance, examine the factors governing the cattle price differences and show that during a single day's auctions, physical features, particularly the carcass-dressing percentage, the state of health, and weight, are the main factors responsible for the price differences.

The use of various types of the multivariate GARCH models in financial and banking markets is common for assessing the price volatility between markets. The multivariate GARCH models continue to be employed extensively in the empirical research (Li and Majerowska 2008), and they have been used in the empirical studies of general commodities because of the abundance of the available data on the transmission of prices and price volatility (see Worthington et al. 2005). Although the traditional analyses of agriculture-related commodity markets still predominantly use the extensions of the univariate GARCH model (Holt and Aradhyula 1990; Buguk et al. 2003; Oglend and Sikveland 2008), the applications of the multivariate GARCH models in agricultural analyses have recently risen. For example, Rezitis and Stavropoulos (2011) empirically study the price transmission and volatility in the Greece's wholesale and retail poultry markets. In addition, p the rice volatility and transmission can typically be detected by using the multivariate GARCH models among products with vertical relationships (Serra and Gil 2013) as well as factor relationships (Haigh and Bryant 2001; Apergis and Reztis 2003). Nevertheless, the previous empirical studies that have used the multivariate GARCH models to examine two seemingly homogeneous products are scarce.

In the large-scale, highly specialized hog-producing countries such as the United States, pork prices are mostly shaped by the negotiation between buyers

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and sellers, or else the prices are generated by the contract price terms governing the rearing of the animals, leading to few price differences in live hogs at the auction. Hence, there is a lack of a price analysis based on the primary influencing factors such as the hog breed and the non-physical attributes (e.g., local flavour, vein lines, leanness of the meat). Under a system of common agents with professional experience, Coatney et al. (2012) find that all prices generated by the common agent system auctions, whether in theory or in practice, possess pricing efficiency. Therefore, leveraging the Taiwan's hog auction bidders' understanding of market demand for black hogs and white hogs and evaluating the profit structure of their personal transactions with customers and bidding behaviour is highly likely to demonstrate an efficient and a favourable bidding strategy in terms of their attitude toward the specific differences between these two breeds. This study can thus inspire the local stakeholders about the merits of using the hog breeds with significant meat traits in terms of the product development and market segregation as well as prove the commercial value of preserving the native breed in Taiwan.

LITERATURE REVIEW

The previous research has commonly analyzed the pork attributes by directly observing the consumer choices in the laboratory (Melton et al. 1996b) or surveying the consumer's willingness to pay for specific levels of quality (Sanders et al. 2007). In Taiwan, from a consumer's perspective (Lü 2010b), notable differences between pork from the black hogs and white hogs in terms of the carcass-dressing percentage, quality, and sensory evaluation (succulence, tenderness, and degree of aroma) have been found both in the laboratory (Wu et al. 2007) and in stores (Lü 2010a). The significant palatability of pork related to the black hog gene has also received attention from the European scientists (Touraille et al. 1989), while the traditional oriental medicine and culinary culture has a specific preference for food that is black. Indeed, some Taiwanese consumers believe that the black-coloured food possesses more flavour and nutritional value. Hence, using the differences in the colour of merchandise to emphasize its cultural appeal for the market segmentation could create an additional value (Aslam 2006).

However, the preference for the food colour is a factor that causes inconsistencies in the consumers' perceptions of food quality. The most commonly cited example is the inconsistency in the consumer perception of white and brown eggs and the belief that the latter are more nutritious.[1] Another example is the colour of salmon, with consumers willing to pay more for salmon with more pink/red colour that comes from pigment added to their feed (Steine et al. 2005). The concepts of food quality are complex: not only are the inconsistencies produced by the objective and specific sensory perceptions, but subjective factors also relate to the consumers' conceptual perceptions (Moskowitz 1995). Although some believe that, scientifically speaking, the colour of food does affect its taste and quality (e.g., the sweetness of mandarin oranges), others state that it merely represents an inconsistency in the consumers' subjective cognition and lacks a substantive effect. In the context of the present study, therefore, the difference between black hogs and white hogs may not only be one of breed; the difference might also relate to the distinctive features represented by the food colour.

DATA

This study takes the daily per-batch average auction price per head of black hogs and white hogs at the Taiwan's Miaoli hog auction market (abbreviated hereafter as "the market") as its sample for analysis, covering the period from January 2009 to December 2013. The number of auction days totals 1485 observations. These values consist of the average daily prices derived from the price data of 27 259 batches of hogs, including 17 321 and 9938 batches of white hogs and black hogs, respectively. This market is representative for the subject under study because it is one of the few public auctions that conduct transactions for both black hogs and white hogs. In addition, it is noteworthy that the number of black hogs traded daily at the market is the largest in Taiwan (Hu 2010) and that the black hog transactions accounted for 37% of all hog transactions during the observation period.

Black hogs are supplied at a fixed proportion, and the daily supply of black hogs is stable; therefore, the

[1]The empirical findings of Chang et al. (2010) also demonstrate that the sales price of brown eggs is higher than that of white eggs.

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integrity of the data can be guaranteed. In addition, any systematical bias that may affect the data has been avoided because of the stochastic process of the auction orders. The sequence of the black hog and white hog auctions is determined through a public lottery in advance in accordance with the Taiwanese regulations on the wholesale market management of agricultural products. Further, the auction of each batch of black hogs and white hogs is conducted in an alternating order. Such a random transaction order should reduce the influence of diminishing prices, as generally occurs in a sequential auction (Engelbrecht-Wiggans 1994; Jeitschko 1999). This random ordering assures the data quality and allows the pricing information on black hogs and white hogs to be supplied directly and immediately to the professional sales agents, who can refer to such information when deciding on their next bids, thereby continually and consistently affecting the mutual price volatility transmission of these breeds.

Table 1. Descriptive statistics for black hog and white hog auctions in the Taiwan's Miaoli meat products market (N = 1485)

	Black hogs	White hogs
Avg. daily price (per head)	**8 920**	**8 400**
Standard deviation	736.27	641.31
Maximum value	10 750	10 033
Minimum value	6 275	6 013
Skewness	–0.120	–0.460
Kurtosis	2.716	3.691
JB test	8.5453	81.972
JB test p-value	0.0139**	0.000***
Avg. daily price (per kg)	**68.09**	**67.39**
Standard deviation	5.245	5.55
Maximum value	80.83	79.94
Minimum value	48.70	47.28
Skewness	–0.191	–0.588
Kurtosis	2.726	3.596
JB test	13.698	107.597
JB test p-value	0.001***	0.000***
Average weight (kg/head)	**131.00**	**124.72**
Standard deviation	3.719	3.449
Average no. auctioned (day)	**307**	**485**
Standard deviation	70	106

Survey period: January 2009 to December 2013 (all trading days)
The proportion of trading volume represented by black hogs varied between 37% and 42% of the total hog trading volume
Calculation results are rounded up to the nearest integer
***p < 0.01; **p < 0.05
Pearson's linear correlation coefficients of the black hog and white hog average price (per head and per kilo) are ρ = 0.3415 and 0.4136, respectively.

Source: Miaoli Meat Products Market Co.

The descriptive statistics for the black hog and white hog auctions are shown in Table 1, illustrating that in the period of observation, the average per-head price for black hogs was about 5% (NT$418) higher than that for white hogs. Furthermore, the standard deviation in the average price of each black hog is also higher than that of each white hog, indicating that the price volatility of black hogs is greater than that of white hogs. With regard to the outcome of *the coefficient of kurtosis*, the distribution of the black hog prices seems to be *platykurtic*, whereas the distribution of the white hog prices seems to be *leptokurtic*. Generally, this fact shows that the price of white hogs has a higher degree of stability than that of black hogs. In addition, from the observation of the *skewness coefficient*, it is evident that the pricing distributions of black hogs and white hogs demonstrate an inclination to the left; however, the degree of left skewing is distinct. In terms of whether the data composition conforms to the normal distribution, the black hog and white hog pricing uniformly rejects the Jarque–Bera (JB) null hypothesis test in that neither conforms to the normal distribution. Figures 1 and 2 show that the average daily auction prices of black hogs and white hogs in the research period were inconsistent.

Before the empirical analysis of time series data, it is first necessary to establish whether there exists a unit root in the data to prevent estimation errors caused by a non-steady-state data structure. This study estimated two sets of price data. One was based on the unit per head and the other per kilo. Because the agents evaluate hogs through their external features, an animal is priced as a whole instead of based on its internal and implicit value, such as per kilogram. However, the results of the price per kilo can probably strengthen and support the consistency of the different species of hog value regardless of the units on which pricing is based. The present study employed the commonly used unit root tests for the

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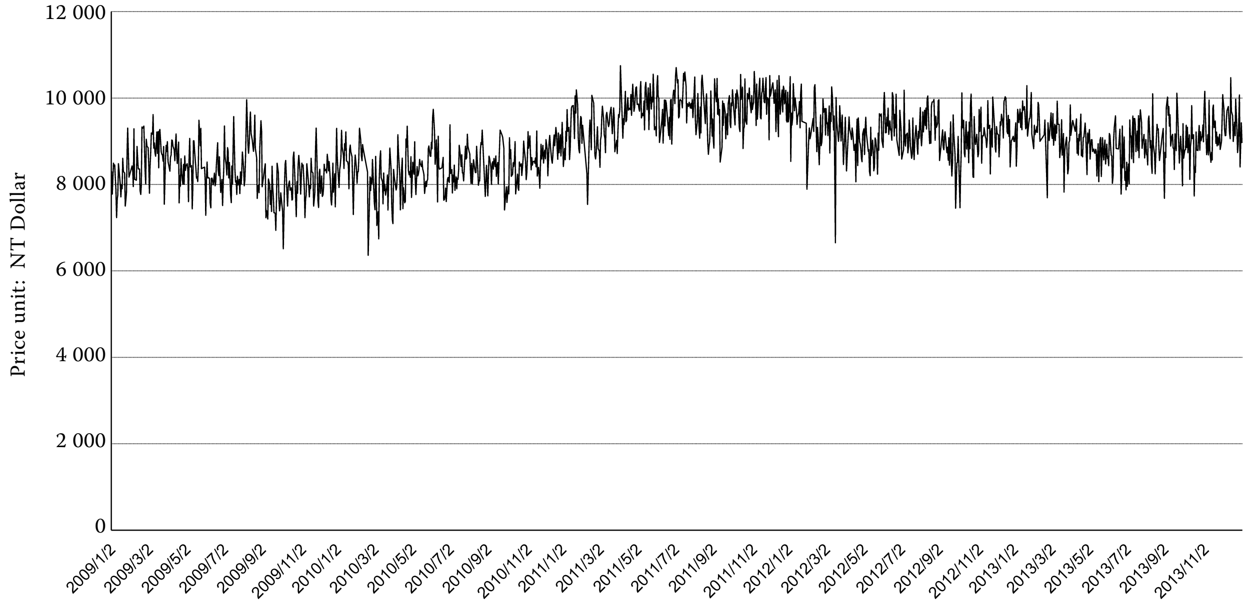

Figure 1. Average daily auction prices per head of black hogs during the study period (2009–2013)

time series data analysis – the Augmented Dickey-Fuller (ADF) test, the Phillips-Person (PP) test, and the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test – to conduct the stationary state testing. The KPSS, ADF, and PP tests have complementary characteristics and can strengthen the conclusions of the ordinary unit root tests in an exposition (Kwiatkowski et al. 1992). The results of the tests are shown in Table 2. None of the variable original time series data has a unit root, and all can be econometrically regarded as a stationary state sequence.

Next, the study tested the effect of ARCH to verify whether it was applicable to the model selected. The test results for the ARCH effect are shown in Table 3.The price sequence data for all black hogs and white hogs were subject to the ARCH effect. Additionally, the study used the Q-Stat to inspect each price sequence and its respective lag period number's self-related phenomena. Similarly, it also inspected each price square sequence and its respective lag period number's heterogeneous variation. When the number of lag periods was set at 10, the

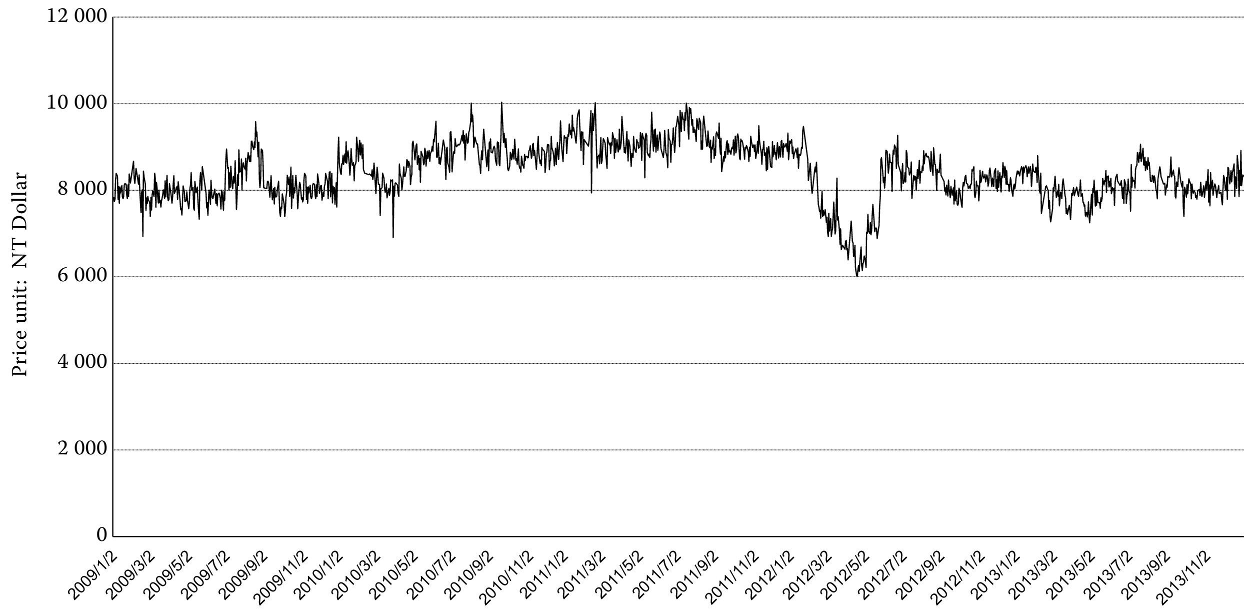

Figure 2. Average daily auction prices per head of white hogs during the study period (2009–2013)

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Table 2. Unit root test results

Variable	ADF test	PP test	KPSS test
B_avg_price	−3.102**	−18.915***	2.815
W_avg_price	−2.938**	−8.890***	0.586
B_avg_price_kilo	−3.376**	−17.373***	2.645
W_avg_price_kilo	−2.734*	−4.286***	0.570

The model features an intercept term and an unconfirmed trend
Newey-West bandwidth criteria were used to select the number of lags in each period for the PP and KPSS tests
The null hypothesis (H_0) for the KPSS test is that the variable is stationary
*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

Table 3. Test results for the ARCH effect for the average daily prices of black hogs and white hogs

Variable	*F*-statistic	*p*-value
B_avg_price	9.5824	0.0000***
W_avg_price	25.3499	0.0000***
B_avg_price_kilo	45.2173	0.0000***
W_avg_price_kilo	45.8998	0.0000***

The ARCH-LM test was adopted as the test procedure
The number of lag periods was set at 5 during the test
The *F*-statistic null hypothesis was the residual has no ARCH effect
*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

Q statistical test results revealed that the autocorrelation and heterogeneous variation in every price sequence were statistically significant. Based on the characteristic results of the analysis data, the study selected the multivariable GARCH model.

METHODOLOGY

This study adopted the multivariable GARCH model to construct the properties of the black hog and white hog price volatility and its interaction characteristics in order to determine the possible existence of co-integration. By comparing the GARCH model adopted in this study with the ARCH models, we find that the conditional variance in the former is affected by its own preceding period, which is more in line with the hypothesis of the actual market volatility. The GARCH model also surpasses the ARCH model in terms of simplicity (Li et al. 2011). In addition, by setting a covariance, the multivariate GARCH model can more clearly demonstrate an inferred co-integrated correlation between two probably related market prices than can the univariate GARCH model.

The multivariate GARCH model used in this study is presented next. First, the explained variables in the mean equation were separated into the average daily auction price of each black hog ($P_{B,T}$) and each white hog ($P_{w,T}$). The AIC test is typically used to determine the GARCH (*p*,*q*) process. Nonetheless, most empirical studies of agricultural products (Rezitis and Stavropoulos 2012) generally consider a single lag period to be sufficient. Hence, for concision, the study design was based on a model with two variables: the GARCH (1,1). Since these two types of commodities (they can also be treated as two markets) are possible substitutes for each other, the auction prices may be interactive and interdependent. The study thus hypothesizes a model based on the structure of VAR(1) simultaneous equations; therefore, in addition to the respective preceding period auction prices ($P_{w,T} - 1$ and $P_{B,T} - 1$) acting as self-explanatory variables, they also become explanatory variables for each other's mean equations. The model structures are shown in equations (1) and (2):

$$P_{B,t} = \mu_B + \alpha_{BB} P_{B,t-1} + \alpha_{BW} P_{w,t-1} + \varepsilon_{B,t} \tag{1}$$

$$P_{w,t} = \mu_w + \alpha_{wW} P_{w,t-1} + \alpha_{WB} P_{B,t-1} + \varepsilon_{w,t} \tag{2}$$

The multivariate GARCH model requires establishing a covariance equation. Several options are commonly used for estimating the conditional covariance matrix, with the flexibility of variability and parsimony of the model often the main considerations for selection (Bauwens et al. 2006). After comparing the estimation of the conditional covariance matrix using the diagonal VECH, BEKK, and CCC (constant conditional correlation) models, this study targeted the BEKK as its primary model and the estimation method for the multivariate GARCH owing to its simplicity (Engle and Kroner 1995). The key characteristic of this model is that it enables the conditional covariance matrix Ω_t (refer to Equation 4) to comply with the positive definite requirements while effectively meeting the simplicity requirements of reducing the number of parameters. The matrix form of the BEKK model conditional covariance equation is

$$VECH(H_t) = CC' + \beta U_{t-1} U'_{t-1} \beta' + g H_{t-1} g' \tag{3}$$

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$$\Omega_t = \begin{bmatrix} \sigma_{BB,t} & \sigma_{BW,t} \\ \sigma_{WB,t} & \sigma_{WW,t} \end{bmatrix} \quad (4)$$

Engle (2002) also develops a more advanced multivariate GARCH model that allows the time-varying conditional correlation. This type of GARCH model is called the dynamic conditional correlation (DCC)-GARCH. The conditional covariance matrix with time-varying conditional correlation in Equation 4 is thus revised to Equation 5:

$$\Omega_t = \begin{bmatrix} \sigma_{B,t}^2 & \rho_{BW}\sqrt{\sigma_{B,t}^2\sigma_{W,t}^2} \\ \rho_{WB}\sqrt{\sigma_{W,t}^2\sigma_{B,t}^2} & \sigma_{W,t}^2 \end{bmatrix} \quad (5)$$

The construction of the variance equations in the DCC-GARCH(1,1) process runs as follows:

$$h_{BB,t} = \alpha_{B0} + \alpha_{BB}\varepsilon_{B,t-1}^2 + \beta_{BB}h_{BB,t-1} \quad (6)$$

$$h_{WW,t} = \alpha_{W0} + \alpha_{WW}\varepsilon_{W,t-1}^2 + \beta_{WW}h_{WW,t-1} \quad (7)$$

If white and black hogs are heterogeneous, not only will the estimated results of the coefficients in variance equations be significantly larger than 0, but the structures of the unexpected shocks and the interpretable volatility among black and white hogs will also be inconsistent. The disparity of price volatility between white and black hogs indicates that the demands for these products are uniform.

RESULTS

By using the estimation procedures of the ARCH maximum likelihood method, the estimation results based on the BEKK model's mean equation and variation–covariation equation coefficients can be derived (Table 4).

Although the coefficients (R^2) are reasonably acceptable, there is a considerable difference between those for black hogs and those for white hogs. The prices (including both black hog and white hog prices) from

Table 4. Coefficient estimation results using the mean equation and variance equation: price per head of live hogs

Coefficient		Black hogs (i = B)			White hogs (i = W)		
		estimated value	standard deviation	p-value	estimated value	standard deviation	p-value
α_i		1 956.100	198.985	0.000**	739.706	111.709	0.000**
α_{iB}		0.728	0.021	0.000**	0.012	0.010	0.2536
α_{iW}		0.056	0.021	0.008**	0.900	0.012	0.000**
Variance equation							
M_i		25 3326.7	24 512.4	0.000**	46 577.6	11 800.8	0.000**
β_{BB}		0.062	0.047	0.000**	–	–	–
β_{WW}		–	–	–	0.152	0.043	0.000**
g_{BB}		0.008	0.446	0.839	–	–	–
g_{WW}		–	–	–	0.352	0.114	0.000**
Covariance equation							
M_{BW}	33 776.081						
β_{BW}	0.097						
g_{BW}	0.054						

** $p < 0.01$; * $p < 0.05$

Black hogs: R^2 = 0.4909($\bar{R}^2$ = 0.4902); white hogs: R^2 = 0.7652 ($\bar{R}^2$ = 0.7649)

Convergence achieved after 419 iterations under the error term is the assumption of the Student's distribution; convergence not achieved after 500 iterations under the error term is the assumption of the normal distribution. Therefore, the latter situation is not reported. This result indirectly supports that of Onour and Sergi (2011), who report that the normal distribution assumption is not always the priority for the empirical studies of the price volatility of food commodities

Autocorrelation test is not valid with lagged endogenous variables

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the previous period explain approximately 54% of the black hog prices in the current period, while those from the previous period explain more than 77% of the white hog prices in the current period. The range is 23%. These disparities imply that (1) the unobservable non-price factors have a comparatively significant impact on the black hog prices relative to the white hog prices and (2) the prices of white hogs are easier to predict from the prices in the previous period. This result indicates that the stability of demand and supply of white hogs is higher than that for black hogs.

The estimation results of the variance equation meet the criteria, too. The variance equation consists of two explanatory variables: the unexpected shocks and the interpretable volatility. An inspection of the suitability of the conditional covariance equations of black hogs and white hogs revealed that the values of all coefficients are greater than zero and conform to the results of their respective equations in which, apart from the constant terms, the sums of all coefficients ($\beta_{BB} + g_{BB}$ and $\beta_{WW} + g_{WW}$) are less than one. In addition, the changes that reflect the variances all present a stable state; in other words, with the passage of the estimation time, the estimated conditional covariance value converges toward the long-term average value of the variance. This result implies that the long-term stability of price volatility sustains.

Based on the econometrical results, in terms of the respective time series price correlations, we first find that the number of lag periods for the black hog prices has a significant effect on the prices of black hogs in the current period. Likewise, the white hog prices from the previous day also explain the same day's white hog prices. In short, hog prices in the previous auction (normally on the previous day) significantly influence the auction prices of hogs in the current period. In addition, in terms of the correlation between the prices of black hogs and white hogs, the coefficient α_{BW} is a positive value with statistically significant estimation outcomes. This finding suggests that the per-head price of white hogs during the previous period positively affects the per-head price of black hogs in the current period (i.e., it raises the price of black hogs). On the contrary, the value of the coefficient α_{WB} indicates no statistical significance, implying that the auction price for black hogs in the previous period has a limited influence on the price of white hogs in the current period (i.e., no such significant uplifting effect). Hence, the price influence between these two breeds is asymmetric: only white hogs are able to exert a unilateral effect on black hogs. This result clearly indicates that the sales agents treat the two breeds of hog differently based on their bidding behaviours. Accordingly, the customers are also highly likely to have heterogeneous preferences toward these two breeds of hog.

The study further analyzed the correlation between the price volatility of white hogs and black hogs (i.e., the spillover effect). In particular, there is presumably a great opportunity to generate an immediate price parity effect between the two hog breeds on the same day and in the same auction location. If black hogs and white hogs are classified as homogeneous (heterogeneous) commodities, the price volatility between them will tend to converge or synchronize (be non-identical).

By comparing the magnitude of the individual coefficients, we find that the proportion of the interpretable price volatility of white hogs (g_{WW} = 0.352) is greater than the proportions that cannot be explained (β_{WW} = 0.152). The price volatility of black hogs shows the exact opposite trend: the effect of unexpected shocks (β_{BB} = 0.062) on the price volatility is greater than the interpretable volatility (g_{BB} = 0.008). This result indicates a significant difference in the relative importance and intensity of factors that influence the price volatility of black hogs and white hogs. Most unexpected shock elements arise from the changes in demand, whereas the important factors affecting the stability of auction prices, which are classed as interpretable volatility elements, arise from the quantity of the hog supply, while the changes in the quantity of supply are mainly influenced by the hog farmers' willingness to raise hogs. One of the most important factors affecting the hog farmers' willingness to raise hogs are the changes in production costs, with feed costs having the greatest proportion. The most important ingredients for the hog feed are corn and soybean dregs, which account for 60% to 70% of the hog production costs. Therefore, as their prices fluctuate in the international markets, the costs of hog production in Taiwan change accordingly (Saengwong et al. 2011).

Feed costs for black hogs show distinct differences compared with those for white hogs. As black hogs can tolerate coarse feed, their main source of food is essentially the kitchen waste in Taiwan; therefore, their feed costs are relatively stable and do not fluctuate with changes in the price of the imported feed. Moreover, the black hog and white hog breeders are of sharply distinct communities: there is no practice of alternating poly-culture or switching at will. One

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possible explanation is that the growth performance of these two breeds is fundamentally different. In addition, there are notable differences in the scale of the black hog and white hog rearing, again meaning that changes in the hog farmers' willingness to raise hogs are different. Differences in the substance of the variance equations pertaining to black hogs and white hogs can also therefore be substantiated.

Further, when comparing the post-summation magnitude of the coefficient of the variable equations for black hogs and white hogs, we find that the value of the former ($\beta_{BB} + g_{BB}$) is 0.103, while that of the latter ($\beta_{WW} + g_{WW}$) is 0.593. Aside from indicating a significant difference between the shock coefficients of black hogs and white hogs, this fivefold increase also reveals that shocks have a relatively great influence on the volatility, implying that the response period for the short-term price volatility for white hogs is longer. This result shows that experimentally verifying the notion of the hog farmers' willingness to raise hogs is also possible.

Since live hogs instead of carcasses are used for auctions, the professional sales agents generally conduct bidding by assessing each hog's external attributes such as the body shape (degree of fatness), the degree of activity (state of health), and the size (weight). Likewise, they may even refer to the background information on the supplier in order to reduce the impact of the meat quality traits such as the body fat ratio on prices and to use weight (quantity) as the principal consideration. To gain a greater understanding of black hog and white hog price differences, the weight of each batch of hogs is therefore converted into a per-kilo unit price. Once again, the exact procedure is based on the BEKK model within the multivariate GARCH model. The estimation results are shown in Table 5 as an auxiliary and supportive explanation of the above-mentioned result.

The estimation results in Table 5 are comparable with those based on the average price per-head of black hogs and white hogs in terms of the coefficient significance. Therefore, apart from any mitigating errors caused by different attributes such as the possible differences in the body type and size of black hogs and white hogs, the aforementioned results are confirmed: the auction prices of both black hogs and white hogs are affected by their respective auction prices in the preceding period. Specifically, the price of black hogs is significantly affected by the price of white hogs in the preceding period, whereas the price of white hogs is not affected by the price of black hogs in the preceding period.

Further, the characteristics of the price volatility between black hogs and white hogs are inconsistent.

Table 5. Coefficient estimation results for the mean equation and variance equation: per-kg price

Coefficient	Black hogs ($i = B$)			White hogs ($i = W$)		
	estimated value	standard deviation	p-value	estimated value	standard deviation	p-value
μ_i	7.495	1.025	0.000**	2.373	0.530	0.000**
α_{iB}	0.851	0.015	0.000**	0.000[a]	0.007	0.972
α_{iW}	0.040	0.015	0.006**	0.965	0.007	0.000**
Variance equation						
M_i	0.724	0.226	0.001**	0.664	0.129	0.000**
β_{BB}	0.061	0.031	0.000**	–		
β_{WW}	–			0.158	0.037	0.000**
g_{BB}	0.859	0.018	0.000**	–		
g_{WW}	–			0.581	0.042	0.000**
M_{BW}	0.375					
β_{BW}	0.098					
g_{BW}	0.707					

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$, [a]estimation value is 0.000254

Black hogs: $R^2 = 0.546$ ($\bar{R}^2 = 0.545$); white hogs: $R^2 = 0.905$ ($\bar{R}^2 = 0.905$)

Convergence achieved after 25 and 12 iterations under the assumptions of normal and Student's distributions, respectively

Autocorrelation test is not valid with the lagged endogenous variables

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The mechanism of the Taiwan's hog auction market adopts the "auction first, slaughter later" approach instead of the "slaughter before auction" method. Under such a method, the internal features that are unobservable before slaughter, such as the pork's fatness or leanness, marbling, colour, and lustre, have no influence on the agreed price. Hence, the analysis result derived from data using each hog as a unit should have a reasonable reference value. Consequently, the study confirms that the hog bidders evaluate these two breeds differently.

Finally, this study reports the estimated CCC results through the constant conditional correlation model in the GARCH model. This coefficient is able to explain the correlation between black hog and white hog prices, and it is not affected by changes over time. The CCC value (ρ_{BW}) for the average daily price per head of black hogs and white hogs calculated during the entire observation period was 0.239; however, the CCC value for the average daily price per kg of black hogs and white hogs was 0.313. Both values indicate a relatively low correlation between the black hog and white hog price volatility that does not exceed 50%. Hence, the price volatility of black hogs and white hogs does not display a high degree of consistency or an opposite trend, which indirectly implies the lack of a distinctive substitutive or complementary relation between the two commodities at auction. In other words, black hogs and white hogs can be viewed as separate and distinct commodities for consumers. This finding is the key discovery of the present study.

DISCUSSION AND CONCLUSION

This study assessed whether black hogs and white hogs should be viewed as heterogeneous commodities by analyzing the correlation between their prices as well as the characteristics and relation of their price volatility during a randomly sequenced auction. The presented analysis allows us to draw three major conclusions: (i) there is no prominent mutual uplifting effect between the prices of black hogs and white hogs; (ii) the relation between the price volatility of black hogs and white hogs is low; and (iii) the structures of their price volatility are significantly different. Based on these three conclusions, this study proposes that the statistical data on black hogs such as price and supply quantity should be collected and segmented separately from those for white hogs. This separation would allow the price volatility of and supply and demand trends in the market for black hogs to be presented more realistically, thereby reducing errors when forecasting the black hog prices. More importantly, since the study's salient feature is the employment of high frequency hog auction price data through public bidding by the professional sales agents, it is therefore easier to understand the changes in supply and demand arising from the changes in the transactions and prices of black hogs compared with white hogs.

The results of this study provide a certain reference value for the stakeholders that leverage the distinctions between different hog breeds as a means of promoting production and diversifying market demand for the meat quality. The specific methods proposed are twofold. First, the stakeholders should encourage local producers, especially the smaller ones, to search out hog breeds with distinguishing meat qualities that would enable the pork market to be segregated, thereby increasing the value and strengthening competition. Second, we should enlighten the stakeholders that may wish to focus on the genetic traits of hogs in order to develop diverse instead of homogeneous pork. Another purpose of this study was to confirm that both conserving the native livestock breeds and diversifying the animal genetic banks are feasible approaches in parallel to the promotion of commercialized products and economic value (Ruto et al. 2008; Tienhaara et al. 2013).

In terms of the policy implications, it is essential that the production and marketing units can control the production and sales of different breeds of hog more precisely and comprehensively. Taking Taiwan's black hogs and white hogs as an example, from the perspective of the characteristics of price volatility and price correlations, these two breeds possess distinct conditions and market segmentation possibilities. Therefore, to strengthen the competitiveness of the hog industry, one tangible strategy would be to ameliorate and diversify the sensory meat traits of pork that emphasize the market segmentation based on diverse foreign and indigenous hog breeds or even encourage greater crossbreeding.

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