On the Nature and Magnitude of Cost Economies in Hog production

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Abstract

In this paper, we assess the impact of farm size on production cost and evaluate the marginal costs and margins by considering that input prices may change with the scale of production. By using French hog farm data, we estimate a system of equations including a feed price function, input demand functions, and an output supply function based on a technology approximated by a combined generalized Leontief-Quadratic form. Our results suggest that the marginal costs are over-estimated when the adjustment of the feed unit prices to a change in farm size is not controlled for.

Keywords: Marginal cost; Farm size; Scale economies; Input prices; Price-cost margin;

JEL Classification: Q12; D24

1. Introduction

For many countries, organization of the livestock sector is high on the agenda. Increasing international competition in this sector raises the question of evaluating the optimal structure of livestock farms, being aware that the optimal farm structure might vary over time and according to production systems. A key question concerns the relationship between farm size and its economic efficiency. In the last decades, we observed the development of large specialized production units in many developed countries in various livestock sectors (MacDonald *et al.*, 2010). This transformation suggests the presence of cost economies associated with farm size. However, in the empirical literature on the nature and magnitude of cost economies, much attention has been paid to technological factors, but little attention has been afforded to the role of market mechanisms. This paper argues that increasing the output size also enables farmers to pay a lower *unit* price of variable input when buying larger input quantities.

Traditionally, the fall in unit costs associated with the rise in production scale is explained by technological factors such as fixities imbedded in the technology or internal scale relationships. Indivisibilities in the production process imply fixed costs and hence economies of scale. Larger production provides an opportunity for spreading the fixed costs to more product units and, in turn, lowering unit costs. In addition, the large scale of operations may induce the better use of existing inputs. For example, an increasing level of operation may allow the farmer to improve the use of labour. More generally, the output may increase greater than in proportion to the inputs. Several earlier studies have analyzed scale economies in livestock farms in the U.S. (Key *et al.*, 2008; Kumbhakar, 1993; Moschini, 1988; Mosheim and Lovell, 2009; Nehring *et al.*, 2009; Tauer and Mishra, 2006) as well as in Europe (Alvarez and Arias, 2003; Fernandez-Cornejo *et al.*, 1992; Rasmussen, 2010). The evidence supporting scale economies is rather mixed–strong for livestock production (MacDonald and McBride, 2009).

However, average costs may also decrease as the production scale increases because of lower *unit prices* of variable inputs. Several reasons may explain why the unit price of many products decreases with the purchased quantity (Beard *et al.*, 2007; Calzori and Denicolo, 2011). On the one hand, the input provider can supply progressive rebates on quantity to reduce some of the transaction costs in writing a contract and delivering the product. In addition, the supplier's technology may exhibit scale economies and pass them on to buyers through a lower unit price. Furthermore, such a price discrimination enables input providers to better extract purchaser surplus. Under these circumstances, there exists a menu of tariffs from which a customer can choose depending on his purchased volume. On the other hand, large buyers may also bargain to obtain a lower price. The possibility of achieving lower unit input prices depends not only on the ability of farmers to negotiate prices also on the gains that the supplier reaches from a larger individual demand.[1]

Once it is recognized that input suppliers practice non-linear pricing and/or a large producer may be able to bargain over the input price to take advantage of pecuniary economies, cost economies may be related not only to technology but also to market mechanisms. When cost economies are estimated, we should consider that the unit input price can vary with the output size.

In this paper, we evaluate the impact of the output size on the short-run production cost taking into account that the prices of some inputs may differ among farmers. More precisely, using a unique data set on French hog farms at the feeder-to-finish operation level, we estimate a system of equations based on a generalized Leontieff cost function developed by Morrison Paul (2001) to evaluate the nature and magnitude of cost economies in hog production. Our system includes inputs demand and output supply functions as well as a unit feed input price equation to capture the ability of farmers to enjoy a lower unit price with respect to the quantity

[1] It is worth stressing that we consider here that the buyer has no market power, *i.e.* he cannot manipulate the market price by changing his level of production (as under an oligopsonic market structure).

of purchased feed. We must stress here a major difference between our approach and the analysis in Morrison Paul (2001). She considers large firms producing under imperfect competition and holding a market power (her study concerns the meat industry in the United States). In other words, in Morrison Paul, firms may manipulate the market price, and this price is the same for all firms. In our case, we do not consider that the existing farms can manipulate the market price by changing their production level, regardless of their size. We assume that farmers face different unit input prices with respect to the quantity of purchased input. Hence, the input prices paid by farmers may differ and are affected by the level of hog production.

The literature in agricultural economics estimating cost economies neglects the pecuniary externalities affecting unit input prices. The literature estimating profit or cost functions considers that farmers do not purchase their factor inputs in bulk at discounted prices or do not bargain over the input price. If such an assumption is realistic concerning the output market, it is discussed for some of the inputs, such as feeds and fertilizers (Debertin 1986). and is related to the organization of the agricultural sectors. Even though French hog producers sell their production through producer organizations (Roguet and Rieu, 2011), they offer a wide diversity of coordination schemes in their upstream and downstream partnerships which may influence how hog farmers take their decision on feed input Furthermore, French hog producers keep a strong managerial autonomy in their production choices and may negotiate their input prices. More generally, Key (2005) showed that hog producers reveal a strong preference for autonomy.

From a methodological standpoint, our results suggest that the marginal costs are over-estimated when we do not account for the adjustment of the unit feed prices to a change in the output size. In other words, the cost economies associated with the scale of operation and price-cost margins might be under-estimated in the current literature on scale economies in agricultural production. Although our work cannot be generalized to other agricultural sectors, we believe that our results are sufficiently convincing to warrant a greater focus on the difference in unit inputs prices among farms with respect to their size in assessing cost economies.

Our study also provides a better understanding of the nature and magnitude of cost economies at the hog farm level. We show that hog farms face cost economies in the short run due to technological factors and to market mechanisms. Most farms face decreasing average costs even if their short-run marginal costs increase in hog production; hog farms are closed to their minimum average costs. More precisely, the cost economies associated with the output size are related to lower feed prices and not to a fall in the relative use of labour, regardless of estimations. The only source of scale economies in hog production seems to be related to feed input utilization. The gains associated with a better use of feed are stronger for the farms with no hired labour. These hog farms also reach higher price-cost margins than larger farms. *In fine*, there are technological scale economies, but the magnitude of the cost economies associated with the scale of operation in hog production due to lower feed prices is significant. The negative effect of an increasing size on the unit feed price paid by the farmers allows them to significantly reduce their marginal costs by an average 2.4 € per head, which represents on average of approximately 7735 € per year and per farm.

This paper is also related to the empirical studies using data on hog producers. These contributions offer limited evidence on cost economies in this sector. From a stochastic frontier analysis, Key *et al*. (2008) show that the changes in total factor productivity growth in US hog farms can be explained by technical progress and improvements in scale efficiency. By testing the existence of stage-specific scale economies, Azzam and Skinner (2007) conclude that it is not cost effective to expand finished hog production for small farms while there are scale economies specific to the feeder-to-finish stage for large farms. However, as recognized by the authors, this study suffers from several caveats (the non-randomness of the sample, no farm-specific input prices, no control for heterogeneity ...). Furthermore, when assessing the impact of farm size on production cost, the existing literature fails to address the reaction of unit input price at the farm level to a change in production.

The paper is organized as follows. We develop in the next section the model that we test. We present data in section 3 whereas section 4 provides the results as well as a set of additional estimations to test the robustness of our results. The last section concludes.

2. A cost function-based model

In this section, we present the full decision process allowing us to identify cost economies when the level of input prices is not exogenous. First, as in the standard approach, farmers choose inputs to minimize costs under the technology constraint. As usual, we obtain the farm's conditional input demand functions where the levels of output, quasi-fixed inputs, and input prices are taken as given. Note that this cost minimization problem is the same regardless of whether the markets for the output good and for the inputs is competitive or if there are some market imperfections (see Morrison Paul, 1988, 2001, for more details). Under these circumstances, the profit function of a hog producer is given by

$$\pi = \mathrm{pY} - \mathrm{C}(\mathrm{w}, \mathrm{Y}, .) \quad (1)$$

where p is the unit price of hogs, Y is the number of hogs sold on the market, and $C(\mathrm{w}, \mathrm{Y}, .)$ is the short-run production cost function with w is a vector of I variable inputs prices.

Second, we have to adapt the output supply decision. Traditionally, the producer chooses its output level by maximizing its profit π so that the equilibrium output is such that $p = \partial C/\partial Y$. However, as mentioned in the introduction, the unit price of inputs can depend on the level of production Y so that w can negatively react to a change in Y. Hence, the farmer can adjust its level of production by taking into account the impact of Y on input prices and, in turn, on its profit.[2] Under this configuration, the equilibrium output is such that $p = \partial C/\partial Y + \sum_i (\partial C/\partial w_i)(\partial w_i/\partial Y)$. Clearly, if we do not consider the input price adjustments to a change in the level of production, the marginal costs may be overestimated.

2.1 Technology and input demand

We assume that the farm's minimum cost of producing the output Y is characterized by a general form given by

$$\mathrm{C} = \mathrm{G}(\mathrm{w}, \mathrm{Y}, \mathrm{x}, \mathrm{d}) \quad (2)$$

where w is a vector of I variable inputs prices (feed, labour and piglets with $i = f, l, p$ respectively), x is a vector of K quasi-fixed inputs (sows and capital with $k = \mathrm{s}, \mathrm{c}$ respectively), and d is a vector of control variables. The choice of these control variables is discussed when we present the equations we estimate. Note that we consider that labour is a variable input because we know the number of hours of labour at different stages of the production sequence. We consider that G can be approximated by a combined generalized Leontief-Quadratic form (Morrison Paul 2001) given by

$$\mathrm{G}(\mathrm{w}, \mathrm{Y}, \mathrm{x}, \mathrm{d}) = \sum_i \sum_j \alpha_{ij} w_i^{0.5} w_j^{0.5} + \sum_i \beta_i w_i Y + \sum_i \gamma_i w_i Y^2 + \sum_i \sum_k \delta_{ik} w_i x_k + \sum_i \sum_k \eta_{ik} w_i x_k Y + \sum_i \sum_k \sum_l \rho_{ikl} w_i x_k x_l + \sum_i \sum_r \mu_{ir} w_i d_r \quad (3)$$

where α_{ij}, β_i, γ_i, δ_{ik}, η_{ik}, ρ_{ikl}, and μ_{ir} are the coefficients to be estimated (with

[2] Note that if the level of production affects the input price, the input demand can be obtained for a given input price as the input demand functions are determined by considering the production level as given.

$\alpha_{ij} = \alpha_{ji}, \delta_{ik} = \delta_{ki}, and\ \rho_{ikl} = \rho_{ilk})$ and d_{ir} represents the control variables (that we specify below). This flexible form can capture many aspects of cost economies through input substitutability, utilization rate of quasi-fixed input and scale economies. Apart from the advantages presented in Morrison (1988), this functional form allows us to deal with zero quasi-fixed input values. It is worth noting that such a flexible functional form captures the cross-effects among all arguments of the cost function while the linear homogeneity in price is satisfied $\left(G(\lambda w,.) = \lambda G(w,.)\right)$. In addition, there are no a priori restrictions on the shapes of curves representing technology. Because $\partial^2 G/\partial w_i^2$ is not ensured to be negative or, equivalently, $\alpha_{ij} > 0$ (global concavity) and $\partial^2 G/\partial x_k^2$ is not ensured to be positive or equivalently, $\rho_{ikk} > 0$ (convexity), we check *ex post* if $\alpha_{ij} > 0$ and $\rho_{ikk} > 0$.

We also characterize optimization decisions for the inputs and the output. By using Shepard's lemma, at the given level of output, the demand for each of the three variable inputs $\upsilon_i (= \partial G/\partial w_i)$ expressed as

$$\upsilon_i = \alpha_{ii} + \alpha_{ij} w_i^{-0.5} \sum_{j \neq i} w_j^{0.5} + \beta_i Y + \gamma_i Y^2 + \sum_k \delta_{ik} x_k + \sum_k \eta_{ik} x_k Y + \sum_k \sum_l \rho_{ikl} x_k x_l + \sum_r \mu_{ir} d_{ir} \quad (4)$$

We now clarify the control variables used in each input demand. As feed input represents over 60 percents of the hog production cost, hog producers develop several strategies. Some farmers produce their feed input on farm. Thus, we introduce dummy variables to control for *On-Farm Feed* by using three categories: with only on-farm feed, with only purchased feed and both on-farm and purchased feed).

Second, hog farms can use different types of feed diets, they decide whether they use a unique feed input or they adapt feed to the hog production stage in order to adjust feed composition (net energy and crude proteins) to each stage. To take into account feed quality, we use the *Feed Conversion Ratio* which is the total feed consumption over the gain in weight during the fattening duration as a proxy of feed quality. A low feed conversion ratio means that pigs from a farm consume less feed than pigs from another farm to reach the same weight. Thus the feed used to get a lower feed conversion ratio contains either higher nutritional contents or attributes that facilitate feed intake.

Third, we control for the *Producer Organizations* hog farmers belong to by using dummy variables. For each farmer we know his/her producer organization. We introduce 24 dummy variables. About 90 percents of all hog farms are members of a producer organization. And each producer organization develops its own strategy as far as members services (feed, genetic, processing activities ...) are regarded. Some producer organizations favour low feed prices, others prefer to give advises to better manage feed intake and get better technical results on hog farms.

In the labour input demand function, we mainly control for *Hired Labour* by introducing a dummy variable. In the piglet input demand function, we control for the *Specialization* of hog farms. Four types of hog farms according to their specialization stage are identified in the survey. We include them as control variables. We are more specifically interested in hog farms with sows as this production system is dominant in France. Finally in all input demand functions, we include dummy variables for the main hog production *Regions*.

2.2 Input prices and output supply

To determine whether input prices depend on the level of production, we first test whether the farm size affects each input price through a simple OLS regression procedure by estimating the following equation for each input *i* price:

$$w_i = \sigma_{i0} + \sigma_{i1}Y + \sigma_{i2}Y^2 + \sum_r \mu_{ir} d_{ir} + \varepsilon_i \qquad (5)$$

where σ_{i0}, σ_{i1}, σ_{i2}, μ_{ir} are coefficients to be estimated and ε_i is an error term which independently and normally distributed. It is worth noting that we could consider in equation (5) the quantity of purchased input (v_i) instead of the output size (Y). However, we take into account the potential endogeneity bias related to the simultaneity between variables. Indeed, reverse causality could bias the estimated coefficients because the demand for inputs depends on their price. To address this endogeneity concern, we use the output size instead of the quantity of purchased input.

For the feed price equation, it also is important to control for three main potential biases. First, hog producers get different feed prices because some of them produce their *On Farm Feed*, thus we include dummy variables to control for the hog producer's strategy. Second, the difference between feed prices paid by the farmers may reflect the difference in quality (difference in protein contents for example). As a result, we include the *Feed Conversion Ratio* as a proxy of feed quality. We expect this control variable is negatively correlated to feed input price as a low conversion feed ratio means a better feed intake and as a result a higher quality of feed.[3] Third, farmers may form purchasing alliances through producer organizations that buy in bulk to obtain quantity discounts. To control for this effect, we introduce a dummy variable indicating the *Producer Organization* to which a farmer belongs. For each farmer we know his/her producer organization. Finally, the feed prices may differ across regions because the regional demand for feed varies so that feed suppliers may benefit more and less from scale economies in feed production. In order to control for this potential bias, we have introduced a dummy for the main hog production *Regions* (*Bretagne*, *Normandie*, *Pays de la Loire*).

The results are reported in Table 1. Our findings show that the parameters associated with the output size are not significant in the piglet price and in the labour price equations. However, the level of production has a significant effect on the feed unit price. It appears that $dw_f/dY = \sigma_{f1} + 2\sigma_{f2}Y < 0$. This suggests that the feed providers offer price reductions for bulk purchases. Because feed providers have market power due to scale economies and transport costs to reach farmers, they can charge customers with more elastic demands a lower price. In addition, the transaction costs incurred by feed suppliers are lower as farmers' purchases become larger, hog producers may negotiate lower feed unit prices according to their production scale. As a result, we append to the model a feed price equation to capture the impact of farm size on feed unit price, while the other input prices are considered exogenous.

Table 1. Input price and output size (Y)

	Feed Price	**Labor price**	**Piglet price**
Constant	166.7*** (73.3)	15.3*** (26.6)	10.09*** (8.4)
Y	-0.0035*** (-5.3)	0.0003* (1.7)	0.0003 (0.8)
$\mathbf{Y^2}$	$1.32 \times 10^{-7**}$ (2.4)	-1.98×10^{-8} (-1.4)	-2.04×10^{-8} (-0.71)
R2	*0.43*	*0.11*	*0.81*

All farms (772 obs) Note: t-statistics are in parentheses. The significance thresholds are respectively 1%(***), 5%(**) and 10%(*). We use the same control variables as in the system regression, we do not report them but they are available upon request.

In addition, we estimate the short-run supply function given by the maximization of the

[3]We are aware that a low feed conversion ratio might also be reached by a combination of other factors such as farmer's skills and the management of sanitary conditions in hog farms.

profit equation (1) under technological constraint (3) and by considering how the unit feed prices react to a change in hog production. The equilibrium output is implicitly given by $p = \partial C/\partial Y + (\partial C/\partial w_f)(\partial w_f/\partial Y)$. By using (5) and (3), we obtain

$$p = \sum_i \beta_i w_i + 2\sum_i \gamma_i w_i Y + \sum_i w_i \left(\sum_k \eta_{ik} x_k\right) + \sum_i \sum_r \mu_{ir} w_i d_{ir} + \nu_f\left(\sigma_{f1} + 2\sigma_{f2} Y\right) \quad (6)$$

In the supply equation, we control for the *Specialization* of hog farms, the *Producer Organization* the hog farm belongs to, the *Region* where the farm is located and the *Meat Quality* at the farm level through the lean meat percentage. We create a dummy for hog farmers who get a lean meat percentage greater than 61, that is to say when they obtain the highest premium.

2.3 Marginal costs, margins, and cost elasticities

The equations including the three derived demand equations (4), the supply function (6), and the feed price equation (5) are jointly estimated by full information. Using parameters α_{ij}, β_i, γ_i, δ_{ik}, η_{ik}, ρ_{ikl}, and μ_{ir} as well as σ_{f1} and σ_{f2}, we can evaluate the marginal costs and margins as well as the cost-output relationship and the margin-output relationship.

It is both relevant and convenient to distinguish between the case under which feed prices paid by farmers do not react to a change in her/his operation scale and the configuration whereby unit feed prices adjust to farm size. Let *MC* be the short-run marginal cost for a given feed price with

$$MC = \partial G/\partial Y = \sum_i w_i\left(\beta_i + 2\gamma_i Y + \sum_k \eta_{ik} x_k\right) \quad (7)$$

whereas the short-run margin is expressed as $p - \mathrm{MC}$. We also use the short-run cost elasticity to a change in output $\varepsilon_{CY} (= d\, lnC/dlnY)$ along the long-run cost curve where $\varepsilon_{CY} < 1$ means that average costs decrease with output.

In addition, let MC^e be the short-run marginal cost with an adjustment in unit feed price to a change in production, given by

$$MC^e = \mathrm{MC} + \frac{\partial G}{\partial w_f}\frac{\partial w_f}{\partial Y} = \sum_i w_i\left(\beta_i + 2\gamma_i Y + \sum_k \eta_{ik} x_k\right) + \nu_f\left(\sigma_{f1} + 2\sigma_{f2} Y\right) \quad (8)$$

3. Data

We use data from a technical survey and a bookkeeping survey of hog farms conducted in 2006 by the French Institute of the Hog Sector (IFIP). These databases are unique as we get precise data on each *production stage* including technical and economic information. Furthermore, they are widely used as technical support for hog farms and widely widespread among producer organizations in France.

Both surveys include a broad range of data on outputs, inputs, and management, as well as technical and social variables at the farrowing and finishing stages. Because we focus on scale economies in hog production, we only selected hog farms that operate the finishing stage of hog production and we excluded all farms that are specialized in the farrowing stage. In addition, only farms that had complete and reliable information for the selected outputs and inputs at the finishing stage are included in our database. Our sample has 772 French hog farms. For each farm, the survey provides the output quantity and hog price, the average feed price and quantity used at each stage as well as the feed cost when farmers make their own on-farm feed. We also get information on the number of sows, the piglet price when purchased by feeder-to-finish farms, and piglet production costs for farrow-to-finish farms. We also know the labour cost (family and hired labour) and the number of hours associated with hog production for each stage as well as whether the farm has hired labour. As a result, we can determine the unit labour cost (in € per hour). In addition, we know if the farm produces on-farm feed as well as the cost and quantity of on-farm feed.

Table 2 provides some descriptive statistics on input prices (feed, labour and piglets) and output. The average price of hog is approximately 118 € per head, or 1.38 € per kilogram, which is close to the average price observed in France in 2006. The hog farms in our sample are heterogeneous in size, and the input prices differ among farms.

Table 2. Summary statistics – all farms (772 obs.)

	Mean	Std. Dev.	Q_1	Median	Q_3
Feed price (€/ton)	169.19	16.34	159.46	169.00	178.79
Labour price (€/hours)	16.12	3.30	14.35	16.14	17.10
Piglet price (€/head)	18.30	14.97	8.62	9.98	33.02
Output price (€/head)	118.35	13.46	111.73	119.94	126.01
Output (head)	2,426	1,868	1,214	1,913	2,853

Source: IFIP – GTE-TB databases

Most farms in our sample combine all the hog production stages, there are 581 farrow-to-finish farms (75% of farms in our sample), which is representative of the French hog sector. In addition, 494 farms buy all feed input to feed mills at an average price of 178 *€/T*, 186 farms exclusively produces on-farm feed at an average cost of 164 *€/T*, the remaining farms use both on-farm and purchased feed at an average price of 170 *€/T*. Furthermore, 443 farms do not employ any hired labour, their labour average price is 15.9 *€/hour* whereas the labour average price is 16.4 *€/hour* when hog farms use hired labour. Only 297 hog farms are located in the western part of France, the main hog production region including *Bretagne*, *Pays-de la Loire* and *Normandie*, which accounts for only 38% of all farms in our sample.

Table 3. Summary statistics – all farms (772 obs.)

	Mean	Std. Dev.	Q_1	Median	Q_3
Variable cost[(a)] (€)	211,190	158,472	113,310	163,048	246,880
Total cost (€)	276,506	196,965	149,553	220,244	330,199
Average cost (€)	120.70	34.61	105.11	113.98	128.43
Total profit (€)	8,518	69,404	-16,548	7,503	36,775
Average profit (€)	-2.35	37	-10.19	4.80	15.42

(a) variable cost corresponds to the sum of variable input costs (G)

Source: IFIP – GTE-TB databases

Table 3 reveals information about hog production costs and profits given by our databases, it shows that the average cost also varies greatly among farms. The average cost function has a *L* shape, which is common in the agriculture of developed countries (Chavas, 2001). The average cost declines with the production for small farms and, from a threshold value of hog production, remains relatively constant.

4. Estimation and results

We estimate a system of five equations including the three input demand equations (4), the unit feed price equation (5), and the output supply equation (6) simultaneously. Equation (5) and the last term in the right hand side (RHS) of equation (6) allow us to highlight the importance of the adjustment of input prices to a change in the output size in assessing cost economies. In addition, because the error terms of these equations may be correlated and because the demand for feed and the unit feed price are not only a dependent variable (equations (4) and (5) respectively) but also are introduced in the RHS of equation (6) and equation (4) respectively, we estimate the model using the three-stage least squares estimation method (as in Morrison Paul, 2001). We also use the control variables defined in Section 2 to take into account hog farm heterogeneity. The generalized R^2 shows an excellent fit for the equation system (0.98). Despite the cross sectional nature of our data, the model provides a significant explanation of farmers' choices.

4.1 Regularity conditions and price effects

We first check whether our results are consistent. The estimated parameters must involve a cost function that satisfies the standard regularity conditions. Note that we check the regularity conditions at every data point and not at the sample mean. We must have $\partial^2 G/\partial w_i^2 < 0$ or, equivalently, $\partial v_i/\partial w_i = -0.5 w_i^{-1.5} \sum_{j \neq i} (\alpha_{ij} w_j^{0.5}) < 0$. All significant estimates $\hat{\alpha}_{ij}$ being positive and $w_i > 0$, the variable cost function is concave in w_i. In other words, at any given hog production, derived input demands are elastic to own-price changes. Further, we check that $\partial v_i/\partial Y > 0$, or equivalently, $\hat{\beta}_i + 2\hat{\gamma}_i Y + \sum_k \hat{\eta}_{ik} x_k > 0$. By inspection, we have $\partial v_i/\partial Y > 0$ for each observation. Hence, at any given input price, increasing the hog production involves a rise in input demands, as expected.

We check that an increasing output price leads to a rise in the output supply $(\partial Y/\partial p > 0)$ and that an increase in input prices decreases the output supply$(\partial Y/\partial w_i < 0)$. Using (6) and applying the envelop theorem gives

$$\frac{\partial Y}{\partial p} = \frac{1}{\partial^2 G/\partial Y^2} = \frac{1}{2\sum_i \hat{\gamma}_i w_i} \text{ and } \frac{\partial Y}{\partial w_i} = -\frac{\partial^2 G}{\partial w_i \partial Y}\frac{\partial Y}{\partial p} = -\frac{\partial v_i}{\partial Y}\frac{\partial Y}{\partial p} \quad (9)$$

Given the values of $\hat{\gamma}_i$ and w_i, we have $\sum_i \hat{\gamma}_i w_i > 0$ for each farm so that $\partial Y/\partial p > 0$. In addition, because $\partial v_i/\partial Y > 0$ and $\partial Y/\partial p > 0$, we have $\partial Y/\partial w_i < 0$. Hence, demand and supply functions satisfy the conditions required by the theory.

4.2 Marginal costs, price-cost margins and cost economies

Table 4 reports the estimates of cost economies, marginal costs and profit margins. We first examine cost economies without taking into account the feed input price adjustment. By inspection, it appears that the estimated short-run marginal cost (given by *MC*) is positive at each observation. These results show that the short-run marginal cost is estimated at approximately 103.7 € per head whereas the average short-run margin is approximately 14.7 € per head (see Table 4) or 0.16 € per kg (the average hog weight being equal to 86 kilograms, see Table 2).

Table 4. Cost elasticities, marginal costs and margins – all farms (772 obs.)

	Mean	**Std. Dev.**	**Q_1**	**Median**	**Q_3**
	without adjustment in unit feed price to a change in production				
ε_{CY}	0.89	0.19	0.78	0.89	1.01
Marginal cost (MC)	103.7	15.4	92.8	98.6	114.7
Margin	14.7	18.4	2.0	17.3	28.1
	with adjustment in unit feed price to a change in production				
$\varepsilon_{CY}+\varepsilon_{wfY}.w_f v_f/C$	0.87	0.19	0.76	0.87	0.99
$MC^e = MC + v_f.\partial w_f/\partial Y$	101.2	16.0	90.1	96.1	112.8
$MC - MC^e$	2.41	1.52	1.27	2.04	3.15

At the sample mean of the data estimated, the cost elasticity e_{CY} is 0.89, suggesting the presence of cost economies associated with the output size. Some statistical tests indicate that the short-run cost elasticity is significantly below one for a wide range of observations. Thus, hog production is characterized by increasing returns to scale. Hence, we confirm the findings in Azzam and Skinner (2007) and Rasmussen (2010) from a different approach. By inspection, the estimated short-run marginal cost decreases with hog production. More precisely, the short-run marginal cost declines strongly for low values of hog production and slightly for high values of output. These estimates suggest a flattening of the average cost curve for high levels of production (a *L*-shaped cost curve).

We now analyze the nature of cost economies. The fall in the marginal costs with the output size may be due to a better input use or a decrease in unit feed price linked to a price rebate on input quantity between the largest hog farms and feed producers. We explore the cost economies that are related to the input use. Using (7), the impact of hog production on short-run marginal cost at constant input prices is given by $\partial MC/\partial Y = 2\sum_i \gamma_i w_i$, where $\gamma_i = \partial^2 v_i/\partial Y^2$.[4] It appears that farmers do not use less labour or less feed for each additional hog unit. In addition, they use relatively more piglets with the output size ($\hat{\gamma}_p > 0$). The estimated value of$\partial MC/\partial Y$ is positive for all farms and statistically different from zero. The values achieved by $\partial MC/\partial Y$ are low (0.0025 on average ranging from 0.0013 to 0.0063). Most farms face decreasing average costs, the cost elasticity ε_{CY} is less than one even if their short-run marginal costs are increasing in hog production. Thus, the size of hog production in each farm is closed to the hog production value that generates the minimum average costs.

The cost economies are also related to the negative relationship between the unit feed price and the output size. Indeed, as expected, we have $\partial w_f/\partial Y = -0.026 + 7.66 \times 10^{-7} Y$, which is negative by inspection for most observations. The feed price falls with hog production at a decreasing rate even if we control for the *Producer Organization* the hog farm belongs to, the *Region* where the farm is located, and the *Feed Conversion Ratio*. As expected, the estimated coefficient of the *Feed Conversion Ratio* is significantly negative which means that the feed unit price increases when the ratio decreases. The *Feed Conversion Ratio* seems to capture the feed quality effect. We also find that the hog farms from the Regions of Bretagne and Pays de la Loire, that are the French regions specialized in hog production, get a lower feed unit price than the hog farms located elsewhere in France. Furthermore, we also note that some *Producer Organisations* influence the feed unit price. We will explore in more details how producer organisations influence cost economies in future research. In addition, we can now evaluate the global impact of output supply on marginal costs by taking into account the adjustments in unit feed prices. The results are reported in Table 4. The marginal cost when the unit feed price reacts to hog production is estimated at approximately 101.2 € per head (1.19 € per kg). The average wedge between both short-run marginal costs is at approximately 2.4 € per head, an average of approximately 7735 € per year and per farm. It appears that the negative effect of an increasing size on feed price paid by the farmers (the elasticity $\varepsilon_{w_f Y}$ is negative and around -0.03) allows them to significantly reduce their marginal costs.

In other words, the cost economies associated with farm size are related to both scale economies and lower feed prices. Although feed price has a lower effect on cost economies than technology does, the impact of feed price is substantial. A mean comparison test between the short-run marginal cost (MC) and the short-run marginal cost with the feed price input adjustment (MC^e) indicates a significant difference between the means at the 0.01 level. On average, the feed price effect on marginal cost which is given by the derivative $\partial(MC^e - MC)/\partial Y$ accounts for 7.8% of the total cost economies generated by farm size

[4] The coefficients associated with γ_i are available upon request.

which is given by the derivative $\partial MC^e/\partial Y$. Moreover, for few farms (1% in our sample), it represents approximately 32% of the total cost economies associated with farm size.

It is also worth stressing that the marginal costs and margins differ among farms according to their location. On average, the farms located in *Bretagne* (the Region specialized in hog production) exhibit lower marginal costs and higher margins than the other farms. This result seems to confirm the presence of agglomeration economies in the hog sector (Gaigné *et al.*, 2012) at the farm level. However, the nature and the magnitude of agglomeration economies at the farm level merit more attention. Exploring this question is beyond the scope of our analysis. This is an area for future research.

5. Conclusion

Our study provides a better understanding of the nature and magnitude of cost economies at the hog farm level based on a system of equations including a feed price equation, input demands and output supply. Our hypothesis is that cost economies are not only related to the technology and the relative use of input, but also to the market mechanism in the sense, that unit input prices decreases with the level of production. Indeed, for a given technology, farms may lower their average costs by increasing output in two ways. First, the unit cost can fall as the scale of production increases, given factor prices. Second, by increasing the scale of production, the farmer may obtain a lower input price. Indeed, the unit input prices paid by farmers may differ significantly between them due to the transaction costs or bargaining power associated with the output size. For example, purchasing a larger quantity of feed may reduce transaction costs incurred by the feed supplier (because of lower unit transport costs or a lower number of customers) and allows the feed producers to exploit scale economies.

Our results suggest that the marginal costs are over-estimated when the unit feed prices adjustments to a change in the output size are not controlled for. Our study also provides new findings on the nature and magnitude of cost economies at the hog farm level. We have shown that the cost economies associated with the output size are due to lower feed prices and not to a fall in the relative use of inputs. However, from a certain threshold of the output size, the marginal cost and the marginal profit become non-decreasing and non-increasing, respectively. Furthermore, the farms with no hired labour exhibit scale economies due to their technology and reach higher marginal operating profits than the other types of farms.

We hope that our contribution will motivate further research on economies of size in different livestock sectors as well as in crop sectors where the prices of seed or fertilizer may also be negotiated by farmers. The main challenge lies in the structural estimation of the bargaining power of farmers according to their size.

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