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Cost Economies in Hog Production: Feed prices matter

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Abstract

In this paper, we assess the impact of farm size on the production cost and evaluate the marginal costs and margins by taking into account that input prices may change with the scale of production. By using French data at the hog farm level, we estimate a system of equations including feed price equation, input demand functions, a output supply function based on a technology approximated by a combined generalized Leontief-Quadratic form. Our results suggest the marginal costs are over-estimated whether the endogeneity of feed prices is not controlled for. We show also that cost economies associated with output size are related to lower feed prices and not to a better use of labor. More specifically, cost economies for large farms (enjoying highest levels of profits) arise from feed prices and not by technological scale economies. In contrast, farms with no hired labor exhibit technological scale economies and reach higher price-cost margins than the larger farms.

Résumé

Dans cet article, nous mesurons l'impact de la taille des exploitations porcines sur le coût de production et évaluons les coûts marginaux et marges en tenant compte du fait que les prix de l'alimentation peuvent changer avec l'échelle de production. A partir de données françaises au niveau des ateliers d'exploitations porcines, nous estimons un système d'équations incluant non seulement des équations de demande d'inputs et d'offre basée sur une technologie de type Léontief généralisée mais aussi une équation de prix de l'alimentation. Nos résultats suggèrent que les coûts marginaux de production sont surestimés si l'endogénéité des prix des aliments n'est pas contrôlée. Nous montrons aussi que les économies de coûts associées au niveau de la production sont liées à des prix des aliments plus faibles et non pas à une meilleure utilisation de la main-d'œuvre. Pour les grandes exploitations, les économies de coûts proviennent des prix des aliments et non des économies d'échelle technologiques. En revanche, les fermes sans main-d'œuvre salariée sont caractérisées par des économies d'échelle technologiques et dégagent en moyenne des plus hautes marges prix-coût que les plus grandes fermes.

Keywords: *Marginal cost; Farm size; Scale economies; Input prices, Price-cost margins*

JEL Classification: *Q12; D24*

1 Introduction

The organization of the livestock sector is high on the agenda of many countries. Indeed, agricultural markets liberalization raises the question of optimal structure of livestock farms. One of 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 different livestock sectors (MacDonald, O'Donoghue, and Hoppe 2010). This transformation suggests the presence of cost economies associated with the size of farms. However, there is a lack of empirical evidence on the nature and the magnitude of cost economies.

For a given technology, there are two possible reasons for farms facing costs economies. First, unit cost at the farm level can fall as the scale of production increases, given factor prices. In this case, scale economies arise from technological factors due to fixities imbedded in the technology or internal scale relationships. Better utilisation of existing inputs is often of key importance. For example, an increasing level of operation may allow the farmer a better use of own labor. More generally, output may increase more than in proportion to inputs. In addition, larger production gives the opportunity of spreading the fixed costs to more product units and, in turn, achieve lower unit costs.

Second, by increasing the scale of production, the farmer may obtain a lower input price. As the size of the operation rises, the farmer may pay a lower unit price of variable input because inputs can be bought in larger quantities. In this case, cost economies are not related to technology but to market mechanisms. The possibility to achieve lower input prices depends on the ability of the farmer to negociate the prices and the gains obtained by the supplier from a larger individual demand. In other words, the larger producer may be able to take advantage of pecuniary economies. Yet, the literature in agricultural economics estimating cost economies neglects these pecuniary economies.

The literature estimating profit or cost functions considers that farmers are price takers. If such an assumption is realistic concerning the output market, this assumption may be rejected for some inputs, such as feeds and fertilizers (Debertin, 1986). Indeed, input prices paid by the farmers may differ significantly between them due to transaction costs or bargaining power associated with the output size. For example, purchasing large 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. Hence, the estimates may be biased when the estimations are based on input demands and cost functions, because input prices may be correlated with the error term in the input demand equation.

In this paper, we propose to evaluate the impact of the output size on production cost by taking into account that prices of some inputs may be changed with the scale of production. 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 developped by Morrison Paul (2001). Our system includes not only inputs demand and output supply functions but also a input price equation (for feed) in order to capture the abality of farmers to negociate a lower price with respect to the quantity of purchased feed.

From a methodology standpoint, our study differs from the literature on scale economies in agricultural activities. Several earlier studies have analyzed scale economies in livestock farms (Alvarez and Arias, 2003; Kumbhakar, 1993; Moschini, 1988; Mosheim and Lovell, 2009; Tauer and Mishra, 2006; Key, McBride, and Mosheim 2008; Azzam and Skinner 2007). The evidence for scale economies is rather mixed–strong for livestock production in Europe and in the North America (MacDonald and McBride, 2009). However, these studies neglict the role played by input prices in cost economies and do not control for the endogeneity of input prices.

Note also that our approach differs from Morrison Paul (2001a) because she considers large firms producing under imperfect competition and having 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 level of production, regardless of their size. We assume that the farmers may negociate their input prices with respect to the quantity of purchased input due to transaction costs incurred by the input suppliers. Hence, the input prices paid by the farmers may differ.

Our contribution can be summarized as follows. From a methodology standpoint, our results suggest the marginal costs are over-estimated whether the endogeneity of feed prices is not controlled for. In other words, cost economies associated with the scale of operation and price-cost margins might be under-estimated in the current litterature on scale economies in agricultural production. Although our work cannot be generalized, we believe that our results are sufficiently convincing to pay more attention to input price endogeneity in assessing cost economies.

Our study provides a better understanding of the nature and magnitude of cost economies at the hog farm level. Indeed, the studies from data on hog producers offers 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) concludes 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 nonrandomness of the sample, no farm-specific input prices, no control for heterogeneity, ...).

We show cost economies associated with output size are related to lower feed prices and not to a fall in the relative use of labor, regardless of estimations. The source of scale economies in hog production seems to be related to feed input utilization. Increasing hog production at the farm level generates a less than proportional increase of the use of feed. The gains associated with a better use of feed are strong. *In fine*, there are technological scale economies. In addition, the magnitude of 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 feed price paid by the farmers allow them to reduce significantly their marginal costs, in average 2.5 euros per head which represents in average about 6110 euros per year and per farm. More specifically, concerning the large farms (enjoying highest levels of profits), cost economies arise from feed prices and not by technological scale economies. The gains associated with lower feed prices offset the losses due non-increasing returns when hog production increases. In contrast, farms with no hired labor exhibit technological scale economies and reach higher price-cost margins than the larger farms.

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 additionnal 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. We assume that the profit function of a hog producer is given by

$$\pi = pY - C(Y) \tag{1}$$

where p is the unit price of hogs, Y is the number of hogs sold on the market, C is the production cost function. We assume that C is characterized by a general form given by:

$$C = G(\mathbf{w}, Y, \mathbf{x}, \mathbf{d}) + \mathbf{rx} \tag{2}$$

where $\mathbf{w}$ is a vector of I variable inputs prices (piglets, feed and labor with $i = p, f, l$ respectively), $\mathbf{x}$ is a vector of K quasi-fixed inputs (sows and capital with $k = s, c$ respectively), and $\mathbf{d}$ is a vector of control variables. Note that we consider that labor is a variable input because we know the quantity of hours of labor at the finishing stage. We consider that G can be approximated by a combined generalized Leontief-Quadratic form (Morrison-Paul, 2001b) given by

$$\begin{aligned} G(\mathbf{w}, Y, \mathbf{x}, \mathbf{d}) &= \sum_i \sum_j \alpha_{ij} w_i^{0.5} w_j^{0.5} + \sum_i \beta_i w_i Y + \sum_i \gamma_i w_i Y^2 + \sum_i \sum_k \delta_{ik} w_i x_k \\ &+ \sum_i \sum_k \eta_{ik} w_i x_k Y + \sum_i \sum_k \sum_l \rho_{ikl} w_i x_k x_l + \sum_i \mu_i w_i d_i \end{aligned} \quad (3)$$

where α_{ij}, β_i γ_i, δ_{ik}, η_{ik}, and ρ_{ikl}, and μ_i are the coefficients to be estimated (with $\alpha_{ij} = \alpha_{ij}$, $\delta_{ik} = \delta_{ki}$, and $\rho_{ikl} = \rho_{ilk}$) and d_i is a dummy variable for $d_p = 1$ if the farm has also farrow-to-feeder operations, $d_f = 1$ if the farm produces on-farm feed, and if $d_l = 1$ if the farm has hired labour. This flexible form can capture many aspects of cost economies through input substituability, utilization rate of quasi-fixed input and scale economies. It is worth noting that such a flexible functional form captures the cross-effects among all arguments of the cost function while linear homogeneity in price is satisfied ($G(\lambda\mathbf{w}, .) = \lambda G(\mathbf{w}, .)$). In addition, there is 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), we check ex post whether $\alpha_{ij} > 0$.

A. Input demand and output supply. We also characterize optimization decisions for the inputs and the output. By using Shepard's lemma, at the given prices of input, the demand for each of the three variable inputs v_i ($= \partial G/\partial w_i$) is expressed as follows:

$$\begin{aligned} v_i &= \alpha_{ii} + \alpha_{ij} w_i^{-0.5} \sum_{j \neq i} w_j^{0.5} + \beta_i Y + \gamma_i Y^2 + \sum_k \eta_{ik} x_k Y \\ &+ \sum_k \delta_{ik} x_k + \sum_k \sum_l \rho_{kl} x_k x_l + \mu_i d_i \end{aligned} \quad (4)$$

In addition, we estimate the short-run supply function given by the maximisation of the profit equation (1) under technology constraint (3). The equilibrium output is implicitly given by $p = \partial C/\partial Y$ or, equivalently, by

$$p = \sum_i \beta_i w_i + 2 \sum_i \gamma_i w_i Y + \sum_i w_i \left(\sum_k \eta_{ik} x_k\right) \quad (5)$$

B. Input prices. We append to the model a feed price equation to capture the impact of farm size on feed price, while the other input prices are considered as exogenous. Indeed, we performed the following simple regression $w_i = f(Y) + \mathbf{d} + \boldsymbol{\varepsilon}_i$ for each variable input price (see Appendix A.1). Our findings show that the parameters associated with the output size are not significant in the labour price and piglet price equations whereas they are significant in the feed price equation. This suggests that the farmers in our sample may negociate the feed prices according to their scale of production. Indeed, from the feed producer viewpoint, the smaller the number of buyers and the bigger their purchases, the lower their transaction costs.

By considering the feed prices as endogenous, we must precise the sequent of events. We follow the literature on imperfect competition with wage bargaining (López and Naylor 2004). The timing is as follows. In the first stage, each farm independently bargains over its feed price with a feed producer. In the second stage, each farmer sets its output and input demand to maximize profits by considering the feed price as given (equations (5) and (4)). Ideally, we would consider the Nash outcome of the bargaining process involving two parties (the feed producer and the farmer). However, our database does not allow to implement such a strategy like in Draganska, Klapper and Villas-Boas (2010) because we cannot identify the feed suppliers of each farm and we have no information on the potential feed suppliers. As a result, to take into account the fact the farmer may negociate the feed price with respect to the level of feed demand v_f, the feed price equation is assumed to be a simple square root functional form, given by

$$w_f = \sigma_0 + \sigma_1 v_f + \sigma_2 v_f^2 + \mathbf{d} + \boldsymbol{\varepsilon}_f. \tag{6}$$

We expect $\mathrm{d}w_f/\mathrm{d}v_f < 0$.

C. Marginal costs, margins, and cost elasticities. The equations including the three derived demand equations (4), the supply function (5), and the feed price equation (6) are jointly estimated by full information. Knowing paramaters α_{ij}, β_i γ_i, δ_{ik}, η_k, and ρ_{kl} as well as σ_1 and σ_2, 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 what we call a *short-run* analysis, in which feed prices paid by farmers do not react to a change in her/his operation scale, and a *long-run* analysis where feed prices adjust to farm size. Hence, the short-run marginal cost MC^s is given by

$$MC^s = \partial G/\partial Y = \textstyle\sum_i w_i(\beta_i + 2\gamma_i Y + \sum_k \eta_{ik} x_k) \tag{7}$$

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

In addition, the long-run marginal cost MC^l is given by

$$MC^l = MC^s + \frac{\partial G}{\partial w_f}\frac{\partial w_f}{\partial v_f}\frac{\partial v_f}{\partial Y}$$

or, equivalently, by

$$MC^l = MC^s + v_f(\sigma_1 + 2\sigma_2 v_f)\left(\beta_f + 2\gamma_f Y + \sum_k \eta_{fk} x_k\right). \tag{8}$$

3 Data

We use farm-level data from a technical survey and a bookkeeping survey of pig farms carried out by the French Institute of the Hog Sector (IFIP) in 2006. Both surveys included a large range of data about outputs, inputs, management, as well as technical and social variables at the farrowing stage and the finishing stage (IFIP, 2006). Because we focus on scale economies in hog production, we have selected farrow-to-finish farms and feeder-to-finish farms. In other words, we exclude farrow-to-feeder farms. In addition, only farms that had nonmissing and reliable information for the selected outputs and inputs at the finishing stage are included in our database. Our sample has 772 hog farms. The large majority of farms in our sample are farrow-to-finish farms (581 farms), what is representative of the French hog sector. In addition, there are 494 farms with no on-farm feed and 443 farms using no hired labour.

Table 1 about here

For each farm, we know the cost and quantity of feed used at the finishing stage as well as the average price perceived by each farmer and the quantity of hog at the finishing stage. Information on the number of sows, the piglet prices (euros per unit or per kilogram) purchased by feeder-to-finish farms, and production costs of piglets (euros per unit or per kilogram) for farrow-to-finish farms are available. We know the labor cost (family and hired labor) and the number hours associated with hog production as well as whether the farm has hired labor. As a result, we can determine the unit labor cost (euros per hour). In addition, we know whether the farm produces on-farm feed as well as the cost and quantity of on-farm feed. Table 1 provides some descriptive statistics on input prices (feed, labor and piglets) and output. The average price of hog is about 118 euros per head, that is 1.38 euro per kilogram, which is close to the average price observed in France in 2006. The hog farms in our sample are heterogenous in size and the input prices differ among farms.

Table 2 about here

Table 2 shows that the average cost varies also greatly among farms whereas 1 reveals the average cost function has a L shape which is common in agriculture of developed conutries (Chavas, 2001). The average cost declines with production for small farms and, from a threshold value of hog production, remains relatively constant.

Figure 1.

4 Estimation and results

We estimated a system of five equations that includes the three input demand equations (4), the output supply equation (5) and the feed price equation (6) simultaneously. The last equation allows us to highlight the importance of endogeneity of input prices in assessing cost economies. In addition, because the error terms of these equations may be correlated and the feed demand and price are endogenous, we estimated the model using the three-stage least squares estimation method. We controled for the type of hog farm (with or without sows, with or without hired labor, with or without on-farm feed) as mentionned in Section 2, for the average quality of meat at the farm level and for the farm location (by including a Region dummy). The results on the estimated coefficients are reported in Appendix A.2. The generalized R^2s show an excellent fit for the equation system (0.98). Despite the cross section nature of our data, the model provides a significant explanation of farmers' choices.

A. Regularity conditions and price effects. We first check whether our results are consistent. The estimated parameters must involve a cost function which 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 $\widehat{\alpha}_{ij}$ being positive (see Appendix A.2) 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 (see Table 3). Further, we check that $\partial v_i/\partial Y > 0$, or equivalently, $\widehat{\beta}_i + 2\widehat{\gamma}_i Y + \sum_k \widehat{\eta}_{ik} x_k > 0$. By inspection, we have $\partial v_i/\partial Y > 0$ for each observation (see Table 3 for the magnitude of the output supply elasticity of input demands). Hence, at any given input prices, increasing hog production involves a rise in input demands, as expected.

Table 3 about here

We check that an increasing output price leads to a rise in output supply ($\partial Y/\partial p > 0$) and that an increase in input prices decreases ouput supply ($\partial Y/\partial w_i < 0$). Using (5) and applying the envelop theorem give

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

Given the values of $\widehat{\gamma}_i$ (see Appendix A.2) and w_i, we have $\sum_i \widehat{\gamma}_i w_i > 0$ 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, the variable cost, demand, and supply functions satisfy the conditions required by theory.

B. Marginal costs, price-cost margins and cost economies. Table 4 reports the estimates of cost economies, marginal costs and profit margins. By inspection, it appears that the short-run marginal cost (given by MC^s) is positive at each observation. The results show that the short-run marginal cost is estimated to be around 95 euros per head whereas the average short-run margin is around 23 euros per head (see Table 4) or around 0.27 euro per kg (the average hog weight being equal to 86 kilograms, see Table 1). At the sample mean of the data estimated, the cost elasticity ε_{CY} is 0.82, suggesting the presence of cost economies associated with output size. Some statistical tests reveal that the short-run cost elasticity is significantly below one for a large range of observations. This means that increasing hog production allows farmers to realise cost economies. The estimated short-run marginal cost decreases with hog production (see Appendix A Table A.4). More precisely, the short-run marginal cost declines strongly for low values of hog production and slightly for high values of output as illustrated by Figure 2. These estimates suggest a flattening of the average cost curve for high levels of production (a L-shaped cost curve).

Table 4 about here

We now analyze the nature of cost economies. The fall in the marginal costs with output size may be due to a better use of inputs or decrease in feed price linked to a bargaining process between the largest hog farms and feed producers. Our results reveal that the cost economies are related to the technology used. Using (7), the impact of hog production on short-run marginal cost at constant input prices is given by $\partial MC^s/\partial Y = 2\sum_i \gamma_i w_i$ where $\gamma_i = \partial^2 v_i/\partial Y^2$. The coefficients associated with γ_i are given in Appendix A.2. It appears that farmers do not use less labor for each additionnal hog unit. Although the coefficient $\widehat{\gamma}_l$ is negative, it is not significant. In addition, whether larger hog operation enables farmers to purchase relatively less feed at given feed prices ($\widehat{\gamma_f} < 0$), they use relatively more piglets with the output size ($\widehat{\gamma_p}$). Thus, the effect of the scale of operation on marginal costs is ambiguous. However, we can check by inspection the former effect dominates the latter effect because the estimated value of $\partial MC^s/\partial Y$ is negative for most of the farms. Some calculations reveal that the mean $2\sum_i \widehat{\gamma}_i w_i$ is negative and statistically different from zero. In other words, given input prices, there is economies of scale related to a better use of feed. However the values achieved by $\partial MC^s/\partial Y$ are low (-0.0017 in average and vary from -0.003 to 0.002).

Figure 2 about here avec nouveau system (MC^{s}et MC^l)

The cost economies are also related to the negative relationship between feed price and output size. Indeed, as expected, we have $\partial w_f/\partial v_f = -0.007 + 10.1\text{x}10^{-7} v_f$ which is negative by inspection for all observations. The feed price decreases with the quantity of purchased feed even if we control for on-farm feed and the location of farms. In addition, we now can evaluate the global impact of output supply on marginal costs by taking into account the adjustments in feed prices. The results are reported in Table 4. The long-run marginal costs is estimated around 93 euros per head (1.08 euro per kg). The average wedge between the short-run and the long-run marginal cost is around 2.5 euros per head which represents in average about 6110 euros 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 -0.032) allow them to reduce significantly their marginal costs (see Table A.4).

In other words, the cost economies associated with farm size are related to both scale economies through a better feed utilization and lower feed prices. Although feed price has a lowest effect on cost economies than technology, the impact of feed price is substantial. The derivative $\partial(MC^l - MC^s)/\partial Y$,which represents the feed price effect on marginal cost, accounts for 22.8% on average of the technology effect ($\partial MC^s/\partial Y$). Moreover, for few farms (1% in our sample), it can be four times higher than the technology effect.

It is also worth stressing that the marginal costs and margins differ among farms according their location. The farms located in Bretagne (the Region specialized in hog production) exhibit in average lower marginal costs and higher margin than the other farms (see Table 5). 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 merits more attention. Exploring this question is beyond the scope of our analysis. This is an area for future research.

Table 5 about here (court et long terme)

C. Robustness checks. Our results reveal that it is cost effective to expand finished hog production. These cost economies are not only related to technology allowing farmers to use less inputs but also seem associated with lower feed price. We test whether such findings are robust. Technology may differ among hog farms. Whether heterogeneity among farms is not sufficiently controlled for, our results may be biased. In this section, we implement the same estimations from more homogeneous samples. We perform four types of subsample for which the number of farms is high enough. We select only (i) the farrow-to-finish farms; (ii) the farms with no hired labour; (iii) farms with no on-farm feed; (iv) larger farms.

(i) farrow-to-finish farms. We first focus on the farrow-to-finish farms. Some summary statistics are reported in Table 6. In our sample, the farrow-to-finish farms are, in average, larger than the other farms (2642 heads on average). However, they face similar prices of input and output, except for the prices of piglets, which is lower for the farrow-to-finish farms (as expected). The estimated coefficients associated with this subsample are given in Appendix B.1. It appears that the marginal costs are significantly lower and thus the margins higher than the results obtained with the full sample. Standard calculations show that the estimated value of $\partial MC/\partial Y$ is positive for all observations. The farrow-to-finish farms exhibit no scale effect due to input utilization. In addition, we have $\partial^2 v_f/\partial Y^2 = 0$, $\partial^2 v_l/\partial Y^2 > 0$ and $\partial^2 v_p/\partial Y^2 > 0$ (see Appendix B.1) so that the farrow-to-finish farms use relatively more labor and piglets when hog production increases. Again estimated marginal costs and feed prices decrease with output size. Hence, the cost economies are related to lower feed prices, the elasticity $\varepsilon_{w_f Y}$ is negative and about -0.036. The wedge between the short-term marginal costs and the long-term marginal costs is much higher than in the full sample (around 2.9 euros that is to say around 7660 euros per year and per farm). It thus seems that the farrow-to-finish farms bargains more over feed price than the full sample. Note the estimates lead to results which are in accordance with regularity conditions.

Table 6

(ii) Farms with no on-farm feed. The results concerning the farms with no on-farm feed are reported in Table 7 whereas the estimates are given in Appendix B.2. It appears these farms are smaller than the full sample. The cost economies associated with output

size are slightly higher than in the full sample. The marginal cost appears to be lower while the margin is higher than the other farms. We have $\partial^2 v_f / \partial Y^2 < 0$, $\partial^2 v_l / \partial Y^2 = 0$ and $\partial^2 v_p / \partial Y^2 > 0$ (see Appendix B.2) and, by inspection, the estimated value of $\partial MC^s / \partial Y$ is negative for a large range of farms with no on-farm feed. Thus, we obtain similar conclusions with this subsample and the full sample concerning the nature of cost economies

Table 7

(iii) Farms with no hired labor. With a subsample excluding farms with hired labor, the results change significantly (see Table 8 and Appendix B.3). The average output supply is in average much lower for farms with no hired labor. The cost economies seem to be higher. In addition, the farms with no hired labor have lower marginal costs and higher margins. Our estimations reveal also that $\partial^2 v_f / \partial Y^2 < 0$, $\partial^2 v_l / \partial Y^2 = 0$ and $\partial^2 v_p / \partial Y^2 = 0$ so that the estimated value of $\partial MC^s / \partial Y$ is negative for all farms with no hired labor. In other words, the farms with no hired farms seem to exhibit scale economies associated with technology, mainly through feed utilization while the relative number of piglets does not increase with output size. Because the estimated marginal costs and feed prices decrease with output size (see Appendix B.3), the larger farms with no hired farms enjoy lower marginal costs and higher margins due to both scale economies and lower feed prices. However, the no hired labor farms seem to be less able to bargain over feed price, the elasticity $\varepsilon_{w_f Y}$ is about -0.024.

Table 8

(iv) larger farms. Finally, we focus only on larger farms (superior to median output). A high majority of these farms are farrow-to-finish farms and farms with hired labor. The results are reported in Table 9 and Appendix B.4. It appears the average cost is lower for this subsample and the estimated marginal costs are lower than the marginal costs for the full sample. However, the cost economies are similar to the results obtained from the full sample. In addition, our result about the absence of scale economies due to technology holds with this subsample. From Appendix B.4, we have $\partial^2 v_f / \partial Y^2$ and $\partial^2 v_l / \partial Y^2$ which are non significant while $\partial^2 v_p / \partial Y^2$ is significantly positive. As a result, $\partial MC^s / \partial Y > 0$ at every data point when we consider only the significant coefficients. In addition, from Appendix B.4, it appears the marginal impacts of output size on feed price is significantly negative $(\partial w_p / \partial v_p < 0)$. However, whether the margin is lower for the larger farms, it appears that the profits and average profits are higher (see Table 9).

Table 9

To sum up, regardless of subsample, larger scale of operation does not induce a fall in the relative use of labor. The only source of scale economies in hog production seems to be related to feed input utilization. An increase in hog production generates a less than proportional increase of the use of feed. However, this advantage may be compensated for by diseconomies of scale in the number of piglets to be raised. Indeed, more hog production at the farm level may lead to an increase in the relative use of piglets (except for farms with no hired labor). However, *in fine*, there is technological scale economies. These different regressions show that, whether large hog operations hold cost advantages over smaller farms, this is related to their ability to enjoy lower feed price. Only the farms with no hired labor seem to exhibit technological scale economies through a better use of feed. Hence, feed plays a significant role in cost economies in the hog sector.

5 Conclusion

In this paper, we have evaluated the nature and the magnitude of cost economies in the hog sector based a system of equations including a feed price equation, inputs demand and output supply. For a given technology, the farms can lower their average costs by increasing output in two ways. First, 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. When assessing the impact of farm size on production cost, the existing literature does not address the second effect. Hence, the estimates may be biased when the estimations are based on input demands and cost functions, because input prices may be correlated with the error term in the input demand equation. Our results suggest the marginal costs are over-estimated whether the endogeneity of feed prices is not controlled for.

Our study also provides new findings on the nature and magnitude of cost economies at the hog farm level. We have showed cost economies associated with output size are due to lower feed prices and not to a fall in the relative use of inputs. In addition, the gains associated with lower feed prices offset the losses due non-increasing returns when hog production increases. However, from a certain threshold of output size, the marginal cost and the marginal profit become non-decreasing and non-increasing respectively. Furthermore, farms with no hired labour exhibit scale economies due to their technology and reach higher marginal operating profits than the other type of farms.

We hope that our contribution will motivate further research in economies of size in different livestock sectors but also in crop sectors because the prices of seed or fertilizer may be negociated by farmers. The main challenge lies in the structural estimation of bargaining powers of farmers according to their size.

References

Allen, D., and D. Lueck, (2001) The Nature of the Farm: Contracts, Risk, and Organization in Agriculture. Cambridge, MA: The MIT Press.

Alvarez, A., and C. Arias (2003) Diseconomies of Size with Fixed Managerial Ability. American Journal of Agricultural Economics 85(1):134–142.

Azzam ,A., Skinner C. (2007) Vertical economies and the structure of US hog farm. Canadian journal of agricultural Economics 55: 349-364.

Chavas, J.P. (2001) Structural change in agricultural production: economics, technology and policy, in Gardner, B. and Rausser, G. (eds), Handbook in Agricultural Economics , Vol. 1. Elsevier Science, Amsterdam, 263–285.

Debertin, D. L., (1986) Agricultural Production Economics. Macmillan Publishing Co, New York.

Draganska, M., Klapper D., and Villas-Boas, S. B. (2010) A larger slice or a larger pie? An empirical investigation of bargaining power in the distribution channel. Marketing Science 29(1), 57–74.

Gaigné, C., J. Le Gallo, S. Larue, and B. Schmitt (2012) Does regulation of manure land application work against agglomeration economies? Theory and evidence from the French hog sector. American Journal of Agricultural Economics 94(1), 116-132.

Key, N., W. McBride, and R. Mosheim (2008) Decomposition of Total Factor Productivity Change in the U.S. Hog Industry, Journal of Agricultural and Applied Economics, 40(1): 137-149.

Kumbhakar, S.C. (1993) Short-Run Returns to Scale, Farm-Size, and Economic Efficiency. Review of Economics and Statistics 75(2):336-341.

López, M.C. and Naylor, R.A. (2004). The Cournot-Bertrand profit differential: a reversal result in a differentiated duopoly with wage bargaining, European Economic Review 48, pp. 681–96.

MacDonald, James M., and William D. McBride (2009) The Transformation of U.S. Livestock Agriculture: Scale, Efficiency and Risks. U.S. Department of Agriculture, Economic Research Service. EIB-43. January.

MacDonald, James M.; Eric O'Donoghue, and Robert A. Hoppe (2010) Reshaping Global Agricultural Production: Geography, Farm Structure, and Finances. A symposium sponsored by the Federal Reserve Bank of Kansas City.

Morrison Paul, C.J. (2001a) Cost Economies and Market Power: The Case Of The U.S. Meat Packing Industry. The Review of Economics and Statistics 83(3): 531-540.

Morrison Paul, C.J. (2001b) Market and Cost Structure in the U.S. Beef Packing Industry: A Plant-Level Analysis. American Journal of Agricultural Economics 83(1): 64-76

Morrison Paul, C.J., R.F. Nehring, D. Banker, and A.L. Somwaru (2004) Scale Economies and Efficiency in U.S. Agriculture: Are Traditional Farms History? Journal of Productivity Analysis 22(3):185–205.

Moschini, G. (1988) The Cost Structure of Ontario Dairy Farms: A Microeconomic Analysis. Canadian Journal of Agricultural Economics 36(2):187–206.

Mosheim, R., and C.A. Knox Lovell (2009) Scale Economies and Inefficiency of U.S. Dairy Farms. American Journal of Agricultural Economics 91:777–794.

Tauer, L.W., and A.K. Mishra (2006) Can the Small Dairy Farm Remain Competitive in U.S. Agriculture? Food Policy 31(5):458–68.

Table 1. Summary statistics – All farms (772 obs.)

	Mean	S D	Q1	Q2	Q3
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

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

	Mean	S D	Q1	Q2	Q3
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)

Table 3. Elasticities of input demand – All farms (772 obs.)

	Elasticities of input demand		Morishima elasticities		
	output supply	input price	Feed	Labour	Piglet
	$\partial v_i/\partial Y_i . Y_i/v_i$	$\partial v_i/\partial w_i . w_i/v_i$			
Feed	1.07 (0.42)	-0.13 (0.11)		0.76 (0.62)	0.14 (0.11)
Labour	0.37 (0.25)	-0.63 (0.55)	0. 75 (0.62)		0.63 (0.55)
Piglet	0.84 (0.20)	-0.004 (0.003)	0.01 (0.01)	0.009 (0.007)	

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

	Mean	S D	Q1	Q2	Q3
			short-run		
$\varepsilon_{C,Y}$	0.82	0.19	0.70	0.81	0.94
Marginal cost (MC)	95.3	19.4	82.3	91.1	109.1
Margin	23.1	21.3	7.5	24.9	38.5
			long-run		
$\varepsilon_{C,Y}+\varepsilon_{wf,Y} . w_f v_f / C$	0.79	0.19	0.68	0.79	0.92
$MC_T = MC + v_f . \partial w_f / \partial Y$	92.7	20.0	79.3	88.7	106.9
$MC - MC_T$	2.52	1.24	1.56	2.43	3.43

Table 5. Short-run cost elasticities, marginal costs and margins by Region – All farms (772 obs.)

	Mean	S D	Q1	Q2	Q3
			Bretagne		
$\varepsilon_{C,Y}$	0.77	0.13	0.70	0.76	0.85
Marginal cost	85.6	12.0	79.2	83.6	88.9
Margin	31.1	16.6	17.9	37.2	42.9
			Pays-de-Loire		
$\varepsilon_{C,Y}$	0.80	0.17	0.71	0.78	0.89
Marginal cost	91.7	16.4	81.1	87.3	96.7
Margin	25.6	21.1	9.0	32.4	40.4
			Normandie		
$\varepsilon_{C,Y}$	0.80	0.22	0.68	0.79	0.96
Marginal cost	90.5	16.8	81.5	87.2	97.7
Margin	23.4	20.3	5.4	26.3	36.8

Figure 1. Average cost and output size

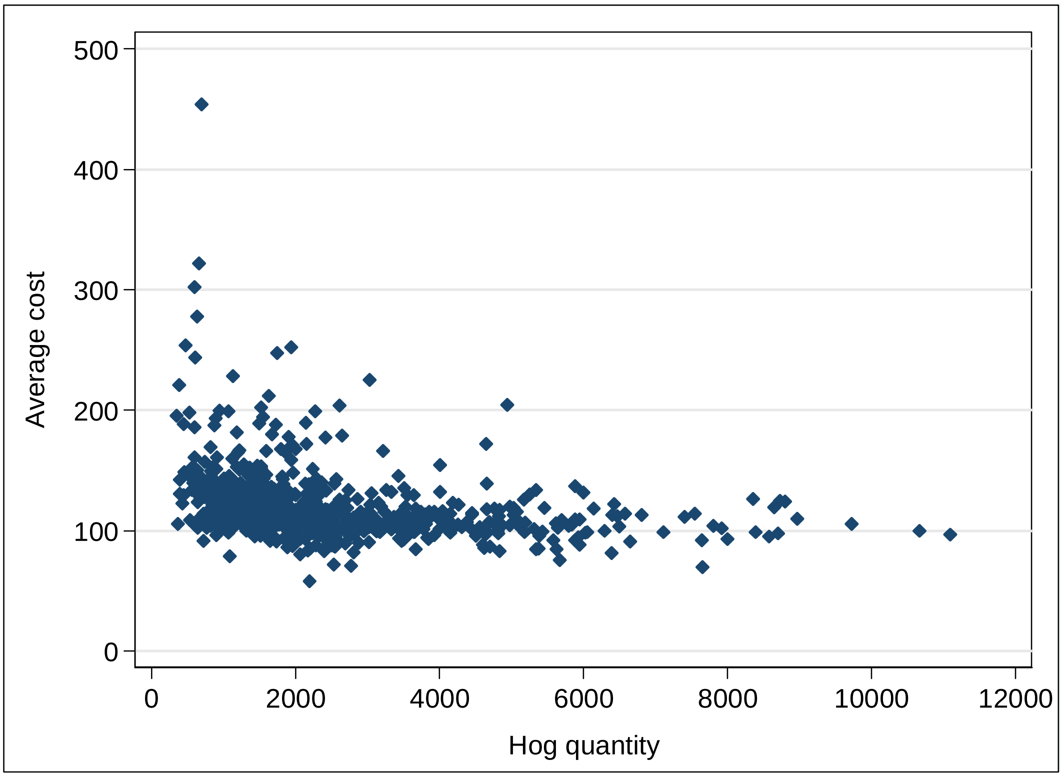

Figure 2. Marginal cost and output size

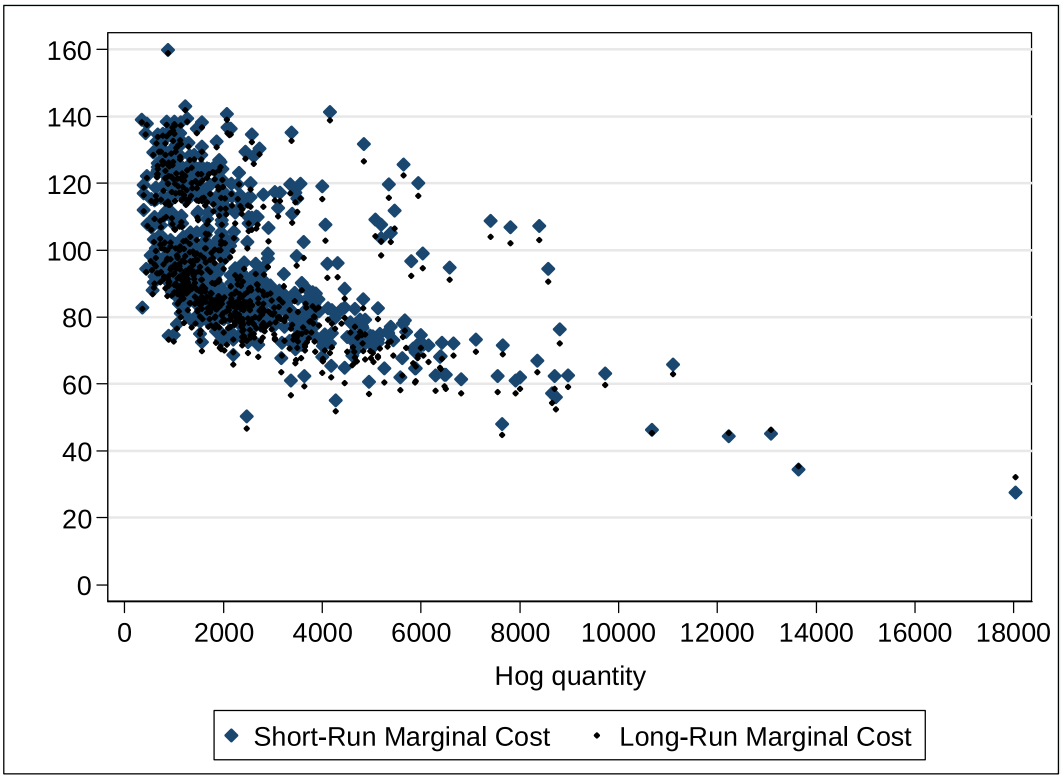

Table 6. Cost elasticities, marginal costs and margins – Farrow-to-finish farms (581 obs)

	Mean	S D	Q1	Q2	Q3
Output	2,642	1,945	1,421	2,152	3,156
Average cost	120.47	38.06	103.15	111.90	128.50
Profit	8,711	76,131	-20,791	9,279	44,864
Average profit	-3.25	40.36	-11.56	4.72	16.44
			short-run		
$\varepsilon_{C,Y}$	0.70	0.16	0.62	0.71	0.79
Marginal cost	80.5	11.9	74.4	80.6	86.9
Margin	36.7	16.7	26.1	38.0	47.3
			long-run		
$\varepsilon_{C,Y}$	0.68	0.16	0.59	0.68	0.76
Marginal cost	77.6	12.4	72.9	77.8	84.5
Margin	39.6	17.0	28.5	40.6	50.6

Table 7. Cost elasticities, marginal costs and margins – No on-farm feed (494 farms)

	Mean	S D	Q1	Q2	Q3
Output	2,197	1,637	1,137	1,739	2,613
Average cost	122.8	37.71	106.8	115.8	129.4
Profit	2,526	67,646	-19,154	4,317	27,028
Average profit	-4.84	40.15	-12.26	2.92	13.33
			short-run		
$\varepsilon_{C,Y}$	0.79	0.20	0.67	0.78	0.92
Marginal cost	93.7	20.6	80.6	90.3	109.4
Margin	24.3	21.9	8.5	24.5	39.2
			long-run		
$\varepsilon_{C,Y}$	0.77	0.20	0.65	0.76	0.91
Marginal cost	91.6	21.0	77.7	88.0	107.3
Margin	26.4	22.2	10.6	27.0	41.7

Table 8. Cost elasticities, marginal costs and margins – No hired labour (443 farms)

	Mean	S D	Q1	Q2	Q3
Output	1,793	1,150	1,066	1,545	2,244
Average cost	120.3	26.26	105.9	115.8	129.1
Profit	9,271	47,180	-14,610	5,454	28,075
Average profit	-0.88	29.05	-10.22	4.24	14.76
			short-run		
$\varepsilon_{C,Y}$	0.74	0.25	0.59	0.73	0.92
Marginal cost	87.7	30.0	69.7	88.2	109.8
Margin	31.7	31.1	9.8	30.5	50.8
			long-run		
$\varepsilon_{C,Y}$	0.719	0.245	0.578	0.715	0.908
Marginal cost	85.9	30.0	66.6	86.1	108.1
Margin	33.6	31.0	11.0	32.4	53.7

Table 9. Cost elasticities, marginal costs and margins – Larger farms (386 obs)

	Mean	S D	Q1	Q2	Q3
Output	3,619	1,996	2,356	2,853	4,256
Average cost	111.12	21.01	99.86	107.87	115.99
Profit	25,993	84,434	-9,904	33,041	66,521
Average profit	5.71	24.24	-3.74	11.06	20.40
			short-run		
$\varepsilon_{C,Y}$	0.82	0.17	0.72	0.81	0.93
Marginal cost	89.0	15.7	79.9	85.9	94.4
Margin	27.8	19.0	16.2	31.0	41.1
			long-run		
$\varepsilon_{C,Y}$	0.80	0.17	0.70	0.78	0.90
Marginal cost	86.5	16.0	76.7	83.7	92.1
Margin	30.4	19.3	18.6	33.5	43.9

Appendix A.

A.1. Input Price and output size.

Table A.1. Input price and output size (Y)

	Feed Price	Labor price	Piglet price
Constant	169.4*** (92.52)	15.93*** (36.48)	10.55*** (11.82)
Y	-0.0036*** (-5.26)	0.0002 (1.51)	0.0002 (0.55)
Y^2	$1.28 \times 10^{-7***}$ (2.21)	-1.73×10^{-8} (-1.25)	-1.43×10^{-8} (-0.51)
d^b	yes	yes	yes
R2	*0.32*	*0.06*	*0.81*

All farms (772 obs) Note: t-statistics are in parentheses.

A.2 Parameter estimates for all farms (772 obs)

	Estimate	t-statistics		Estimate	t-statistics
$\alpha_{F,F}$	-217.9***	(-4.33)	$\alpha_{P,P}$	-279.3**	(-2.92)
$\alpha_{F,L}$	534.4***	(7.54)	$\alpha_{P,F}$	36.29	(1.24)
$\alpha_{F,P}$	36.29	(1.24)	$\alpha_{P,L}$	11.40	(0.17)
β_F	0.491***	(30.61)	β_P	0.805***	(25.97)
γ_F	-0.00000843*	(-2.30)	γ_P	0.0000382***	(7.68)
$\eta_{F,K}$	0.000000692	(1.56)	$\eta_{P,K}$	-0.00000192**	(-3.24)
$\eta_{F,S}$	-0.000201	(-1.70)	$\eta_{P,S}$	-0.00168***	(-14.21)
$\delta_{F,K}$	0.00157	(0.80)	$\delta_{P,K}$	0.00568***	(3.60)
$\delta_{F,S}$	0.209	(0.47)	$\delta_{P,S}$	6.416***	(8.29)
$\varrho_{F,K,K}$	-2.28e-08	(-0.78)	$\varrho_{P,K,K}$	6.18e-08**	(2.69)
$\varrho_{F,S,S}$	0.00703***	(4.37)	$\varrho_{P,S,S}$	0.0231***	(15.93)
$\varrho_{F,K,S}$	-0.00000487	(-0.36)	$\varrho_{P,K,S}$	-0.00000656	(-0.54)
μ_{ACH}	-49.75	(-1.33)	μ_{ME}	529.4***	(14.47)
μ_{MIX}	57.59	(1.08)	μ_{PE}	490.6***	(6.44)
μ_{BT}	20.69	(0.39)	μ_{EN}	480.1***	(5.33)
μ_{PL}	146.3**	(3.16)	μ_{BT}	41.86	(1.07)
μ_{BN}	-283.1***	(-5.96)	μ_{PL}	15.26	(0.45)
$\alpha_{L,L}$	-1389.9***	(-5.93)	μ_{BN}	15.02	(0.43)
$\alpha_{L,F}$	534.4***	(7.54)	σ_0	166.3***	(123.59)
$\alpha_{L,P}$	11.40	(0.17)	σ_1	-0.00710***	(-6.80)
β_L	0.330***	(5.92)	σ_2	0.000000505**	(3.06)
γ_L	-0.00000621	(-0.58)	σ_{ACH}	16.80***	(13.63)
$\eta_{L,K}$	-0.000000817	(-0.60)	σ_{MIX}	10.29***	(5.86)
$\eta_{L,S}$	0.000336	(1.25)	σ_{BT}	-6.874***	(-4.07)
$\delta_{L,K}$	0.00479	(1.27)	σ_{PL}	-6.088***	(-4.09)
$\delta_{L,S}$	8.661***	(7.99)	σ_{BN}	-2.977*	(-2.01)
$\varrho_{L,K,K}$	0.000000157**	(2.83)			
$\varrho_{L,S,S}$	0.0112***	(3.59)			
$\varrho_{L,K,S}$	-0.0000997***	(-3.44)			
$\mu_{Travsal}$	152.2*	(2.49)			
μ_{BT}	208.4*	(2.20)			
μ_{PL}	-1.027	(-0.01)			
μ_{BN}	-38.37	(-0.46)			

A.3 Marginal costs, margins and output supply

Table A.4. Long-run Marginal costs, margins and output size (Y)

	estimated marginal cost	estimated margin
Constant	93.51*** (80.50)	26.42*** (13.15)
Y	-0.005*** (-11.46)	0.004*** (5.78)
Y^2	9.16×10^{-8} (2.49)	-6.52×10^{-8} (-1.02)
d^b	yes	yes
R2	*0.82*	*0.54*

All farms (772 obs)

Appendix B

B.1 Parameter estimates for farrow-to-finish farms (581 obs)

	Estimate	t-statistics		Estimate	t-statistics
$\alpha_{F,F}$	-141.3	(-1.89)	$\alpha_{P,P}$	-290.7**	(-3.06)
$\alpha_{F,L}$	607.7***	(6.84)	$\alpha_{P,F}$	26.81	(0.85)
$\alpha_{F,P}$	26.81	(0.85)	$\alpha_{P,L}$	30.95	(0.40)
β_F	0.457***	(17.28)	β_P	0.688***	(16.09)
γ_F	-0.00000714	(-0.73)	γ_P	0.000131***	(11.94)
$\eta_{F,K}$	0.000000404	(0.62)	$\eta_{P,K}$	-0.00000300***	(-3.74)
$\eta_{F,S}$	-0.000218	(-0.68)	$\eta_{P,S}$	-0.00438***	(-12.91)
$\delta_{F,K}$	0.00171	(0.70)	$\delta_{P,K}$	0.00343*	(1.99)
$\delta_{F,S}$	-0.257	(-0.29)	$\delta_{P,S}$	9.439***	(9.75)
$\varrho_{F,K,K}$	-3.33e-08	(-1.03)	$\varrho_{P,K,K}$	5.59e-08*	(2.46)
$\varrho_{F,S,S}$	0.00799**	(2.63)	$\varrho_{P,S,S}$	0.0374***	(13.56)
$\varrho_{F,K,S}$	0.00000565	(0.30)	$\varrho_{P,K,S}$	0.0000239	(1.33)
μ_{ACH}	-38.44	(-0.83)	μ_{ME}	448.5***	(11.99)
μ_{MIX}	103.9	(1.64)	μ_{PE}	-	-
μ_{BT}	33.67	(0.57)	μ_{EN}	-	-
μ_{PL}	200.8***	(3.70)	μ_{BT}	12.78	(0.32)
μ_{BN}	-302.9***	(-5.22)	μ_{PL}	22.51	(0.62)
$\alpha_{L,L}$	-1553.9***	(-4.98)	μ_{BN}	3.891	(0.10)
$\alpha_{L,F}$	607.7***	(6.84)	σ_0	169.4***	(105.67)
$\alpha_{L,P}$	30.95	(0.40)	σ_1	-0.00830***	(-7.06)
β_L	0.371***	(3.67)	σ_2	0.000000618***	(3.53)
γ_L	0.0000747**	(2.64)	σ_{ACH}	15.46***	(10.80)
$\eta_{L,K}$	-0.00000238	(-1.14)	σ_{MIX}	10.17***	(5.17)
$\eta_{L,S}$	-0.00230**	(-2.59)	σ_{BT}	-7.159***	(-4.08)
$\delta_{L,K}$	0.00505	(1.08)	σ_{PL}	-5.539***	(-3.35)
$\delta_{L,S}$	7.043**	(2.93)	σ_{BN}	-2.515	(-1.50)
$\varrho_{L,K,K}$	0.000000146*	(2.36)			
$\varrho_{L,S,S}$	0.0315***	(4.30)			
$\varrho_{L,K,S}$	-0.0000634	(-1.33)			
$\mu_{Travsal}$	177.6*	(2.41)			
μ_{BT}	189.6	(1.76)			
μ_{PL}	0.889	(0.01)			
μ_{BN}	-97.27	(-0.91)			

B.2 Parameter estimates for farms with no on-farm feed (494 obs)

	Estimate	t-statistics		Estimate	t-statistics
$\alpha_{F,F}$	-	-	$\alpha_{P,P}$	-270.9**	(-2.74)
$\alpha_{F,L}$	555.9***	(6.43)	$\alpha_{P,F}$	-20.78	(-0.66)
$\alpha_{F,P}$	-20.78	(-0.66)	$\alpha_{P,L}$	80.91	(1.05)
β_{F}	0.478***	(23.98)	β_{P}	0.867***	(24.81)
γ_{F}	-0.0000162**	(-2.87)	γ_{P}	0.0000546***	(8.40)
$\eta_{F,K}$	-0.000000222	(-0.36)	$\eta_{P,K}$	-0.00000586***	(-8.55)
$\eta_{F,S}$	0.0000844	(0.44)	$\eta_{P,S}$	-0.00190***	(-10.64)
$\delta_{F,K}$	-0.00619	(-1.91)	$\delta_{P,K}$	0.00494*	(2.26)
$\delta_{F,S}$	1.926***	(3.31)	$\delta_{P,S}$	7.504***	(8.81)
$\varrho_{F,K,K}$	0.000000214***	(3.63)	$\varrho_{P,K,K}$	0.000000127**	(3.23)
$\varrho_{F,S,S}$	0.000982	(0.32)	$\varrho_{P,S,S}$	0.0175***	(7.27)
$\varrho_{F,K,S}$	-0.0000283	(-1.37)	$\varrho_{P,K,S}$	0.0000522**	(3.27)
μ_{ACH}	-233.8***	(-4.74)	μ_{ME}	501.3***	(13.47)
μ_{MIX}	-	-	μ_{PE}	450.7***	(5.81)
μ_{BT}	71.07	(1.19)	μ_{EN}	437.2***	(4.76)
μ_{PL}	162.1**	(3.18)	μ_{BT}	10.43	(0.27)
μ_{BN}	-266.6***	(-5.25)	μ_{PL}	-5.148	(-0.15)
$\alpha_{L,L}$	-1716.6***	(-5.83)	μ_{BN}	-1.315	(-0.04)
$\alpha_{L,F}$	555.9***	(6.43)	σ_{0}	-	-
$\alpha_{L,P}$	80.91	(1.05)	σ_{1}	-0.00829***	(-5.67)
β_{L}	0.394***	(5.48)	σ_{2}	0.000000952**	(3.18)
γ_{L}	-0.0000150	(-0.96)	σ_{ACH}	184.5***	(157.18)
$\eta_{L,K}$	-0.00000408*	(-2.32)	σ_{MIX}	-	-
$\eta_{L,S}$	0.000900*	(2.01)	σ_{BT}	-8.909***	(-5.12)
$\delta_{L,K}$	-0.00440	(-0.76)	σ_{PL}	-8.290***	(-5.44)
$\delta_{L,S}$	11.62***	(8.61)	σ_{BN}	-4.385**	(-3.01)
$\varrho_{L,K,K}$	0.000000584***	(5.65)			
$\varrho_{L,S,S}$	-0.00591	(-0.99)			
$\varrho_{L,K,S}$	-0.000115**	(-2.74)			
$\mu_{Travsal}$	227.9**	(3.19)			
μ_{BT}	178.7	(1.74)			
μ_{PL}	27.42	(0.31)			
μ_{BN}	42.54	(0.49)			

B.3 Parameter estimates for farms with no hired labour (443 obs)

	Estimate	t-statistics		Estimate	t-statistics
$\alpha_{F,F}$	-184.6***	(-3.83)	$\alpha_{P,P}$	-172.0	(-1.80)
$\alpha_{F,L}$	392.2***	(4.78)	$\alpha_{P,F}$	10.09	(0.35)
$\alpha_{F,P}$	10.09	(0.35)	$\alpha_{P,L}$	-43.07	(-0.57)
β_{F}	0.563***	(29.59)	β_{P}	0.966***	(23.65)
γ_{F}	-0.0000546***	(-9.62)	γ_{P}	0.0000119	(1.31)
$\eta_{F,K}$	0.000000784	(1.14)	$\eta_{P,K}$	-0.00000139	(-1.17)
$\eta_{F,S}$	-0.000291	(-1.33)	$\eta_{P,S}$	-0.00200***	(-7.47)
$\delta_{F,K}$	0.00285	(1.18)	$\delta_{P,K}$	0.00477*	(2.07)
$\delta_{F,S}$	-2.023***	(-3.56)	$\delta_{P,S}$	4.617***	(3.97)
$\varrho_{F,K,K}$	-1.22e-08	(-0.15)	$\varrho_{P,K,K}$	3.42e-08	(0.49)
$\varrho_{F,S,S}$	0.0330***	(6.44)	$\varrho_{P,S,S}$	0.0401***	(7.82)
$\varrho_{F,K,S}$	-0.0000209	(-0.66)	$\varrho_{P,K,S}$	-0.0000246	(-0.95)
μ_{ACH}	-18.60	(-0.56)	μ_{ME}	445.3***	(12.21)
μ_{MIX}	7.888	(0.15)	μ_{PE}	318.8***	(3.90)
μ_{BT}	-36.43	(-0.75)	μ_{EN}	314.7***	(3.55)
μ_{PL}	66.43	(1.65)	μ_{BT}	-1.619	(-0.04)
μ_{BN}	-209.3***	(-4.55)	μ_{PL}	-30.09	(-1.00)
$\alpha_{L,L}$	-672.1*	(-2.27)	μ_{BN}	-14.51	(-0.42)
$\alpha_{L,F}$	392.2***	(4.78)	σ_{0}	167.6***	(93.92)
$\alpha_{L,P}$	-43.07	(-0.57)	σ_{1}	-0.00886***	(-4.78)
β_{L}	0.190*	(2.03)	σ_{2}	0.000000528	(1.43)
γ_{L}	0.0000311	(1.29)	σ_{ACH}	18.09***	(11.57)
$\eta_{L,K}$	-0.00000959**	(-2.87)	σ_{MIX}	10.17***	(4.10)
$\eta_{L,S}$	0.00281***	(4.04)	σ_{BT}	-7.863***	(-3.68)
$\delta_{L,K}$	0.00660	(1.07)	σ_{PL}	-7.483***	(-4.08)
$\delta_{L,S}$	8.614***	(5.40)	σ_{BN}	-7.526***	(-3.60)
$\varrho_{L,K,K}$	0.000000407*	(2.04)			
$\varrho_{L,S,S}$	-0.0332**	(-2.68)			
$\varrho_{L,K,S}$	-0.0000435	(-0.59)			
$\mu_{Travsal}$	-	-			
μ_{BT}	63.26	(0.60)			
μ_{PL}	-63.23	(-0.73)			
μ_{BN}	1.297	(0.01)			

B.4 Parameter estimates for larger farms (386 obs)

	Estimate	t-statistics		Estimate	t-statistics
$\alpha_{F,F}$	-321.6**	(-3.04)	$\alpha_{P,P}$	-175.8	(-1.12)
$\alpha_{F,L}$	595.6***	(5.20)	$\alpha_{P,F}$	26.92	(0.59)
$\alpha_{F,P}$	26.92	(0.59)	$\alpha_{P,L}$	43.18	(0.41)
β_F	0.490***	(17.24)	β_P	0.704***	(11.71)
γ_F	-0.00000627	(-1.17)	γ_P	0.0000358***	(4.57)
$\eta_{F,K}$	0.000000952	(1.64)	$\eta_{P,K}$	-0.000000420	(-0.50)
$\eta_{F,S}$	-0.000229	(-1.38)	$\eta_{P,S}$	-0.00152***	(-9.50)
$\delta_{F,K}$	0.00183	(0.62)	$\delta_{P,K}$	0.00447	(1.92)
$\delta_{F,S}$	0.815	(1.06)	$\delta_{P,S}$	7.688***	(5.51)
$\varrho_{F,K,K}$	-2.14e-08	(-0.57)	$\varrho_{P,K,K}$	5.73e-08*	(2.00)
$\varrho_{F,S,S}$	0.00709***	(3.38)	$\varrho_{P,S,S}$	0.0211***	(10.05)
$\varrho_{F,K,S}$	-0.0000150	(-0.85)	$\varrho_{P,K,S}$	-0.0000302	(-1.90)
μ_{ACH}	-111.4	(-1.60)	μ_{ME}	716.6***	(9.28)
μ_{MIX}	43.87	(0.52)	μ_{PE}	768.1***	(4.29)
μ_{BT}	55.00	(0.68)	μ_{EN}	795.3***	(3.77)
μ_{PL}	241.7**	(2.86)	μ_{BT}	54.80	(0.98)
μ_{BN}	-466.8***	(-5.51)	μ_{PL}	13.01	(0.22)
$\alpha_{L,L}$	-1899.9***	(-4.91)	μ_{BN}	17.87	(0.30)
$\alpha_{L,F}$	595.6***	(5.20)	σ_0	162.1***	(75.26)
$\alpha_{L,P}$	43.18	(0.41)	σ_1	-0.00479***	(-3.44)
β_L	0.414***	(4.24)	σ_2	0.000000271	(1.42)
γ_L	-0.0000149	(-0.90)	σ_{ACH}	16.26***	(9.52)
$\eta_{L,K}$	-0.00000103	(-0.54)	σ_{MIX}	7.953***	(3.87)
$\eta_{L,S}$	0.000545	(1.47)	σ_{BT}	-4.582*	(-2.38)
$\delta_{L,K}$	0.00911	(1.62)	σ_{PL}	-3.034	(-1.51)
$\delta_{L,S}$	7.383***	(4.31)	σ_{BN}	0.0875	(0.04)
$\varrho_{L,K,K}$	0.000000133	(1.91)			
$\varrho_{L,S,S}$	0.0110**	(2.80)			
$\varrho_{L,K,S}$	-0.0000993**	(-2.65)			
$\mu_{Travsal}$	261.0*	(2.57)			
μ_{BT}	256.4	(1.89)			
μ_{PL}	6.818	(0.05)			
μ_{BN}	-114.1	(-0.80)			