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Abstract

In this paper, we present a theoretical model for adjustment costs and investment utilisation that illustrates their causes and types and shows in which phases of an investment they occur. Furthermore, we develop an empirical framework for analysing the size and the timing of adjustment costs and investment utilisation. We apply this methodology to a large panel data set of Danish pig producers with 9,281 observations between 1996 and 2008. The paper further contributes with a thorough discussion of the calculation and deflation of capital input from microeconomic data. We estimate an output distance function as a stochastic frontier model and explain the estimated technical inefficiencies with lagged investments, farm size and age of the farmer. We allow for interaction effects between these variables and derive the formula for calculating the marginal effects on technical efficiency. The results show that investments have a negative effect on farm efficiency in the year of the investment and the year after accruing from adjustment costs. There is a large positive effect on efficiency two and three years after the investment. The farmer's age and the farm size significantly influence technical efficiency, as well as the effect of investments on adjustment costs and investment utilisation. These results are robust to different ways of measuring capital.

JEL codes: Q12, D22, D24, D92

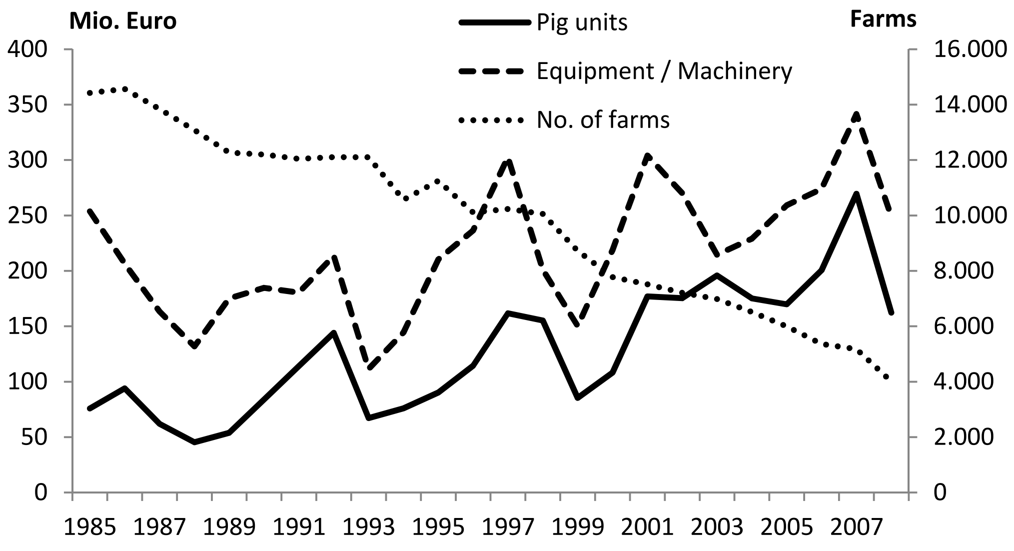
Key words: investment utilisation, adjustment costs, stochastic frontier analysis, technical efficiency, pig production, Denmark

1. Introduction

Farmers' investments are usually aimed at maintaining capital capacity by reinvesting, or expanding farm capacity. Expanding strategies can be grounded in multiple reasons, but even if the reasons are non-pecuniary, it is desirable if the investment contributes to increased profit. As new technologies are often associated with investments in new production units, equipment, or machinery, it is expected that investments increase productivity. Furthermore, in an industry with increasing returns to scale, higher productivity is expected when firms invest and become larger. Increasing returns to scale have been found in Danish pig farming (Rasmussen, 2010), but diseconomies of scale have also been found when controlling for constant managerial ability (Alvarez & Arias, 2003).

Cochrane (1958) formulated the agricultural treadmill, which states that farmers constantly strive to make a profit by being early adopters of new technology, thereby lowering their unit costs. This theory clearly states that the farmers who make investments will have an economic advantage over producers who utilise older technology. Levins & Cochrane (1996) revisited the theory, because government support for farm income did not squeeze out the "laggard" farmers as a consequence of low product prices. Instead, these subsidies have driven up land prices and the rent for land, i.e. the goal of making investments in new technology is still to strive for profit. The Danish pig farming sector has experienced a rapid structural change in recent decades. Although the number of pig farms dropped dramatically from more than 14,000 in 1985 to about 4,000 in 2008, the total investment in pig units and other buildings, equipment, and machinery increased considerably during the same period, totalling more than €600 million in 2007 (see figure 1). As a result, the average annual investment of pig farms in the mentioned assets increased from €23,000 in 1985 to €118,000 in 2007.

Figure 1. Investment in pig units, equipment and machinery for pig producers from 1985 to 2008



Source: Statistics Denmark (2010)

Pig production is capital intensive and capital costs, as well as other fixed costs, make up a large share of total costs, which makes the utilisation of investments and the minimisation of adjustment costs important. Lucas (1967) introduced adjustment costs into the economic theory of investment to overcome the assumption that the adjustment of production is costless and occurs immediately after an investment. The adjustment cost term covers a range of costs associated with the investment process such as installation costs, gestation lags (Jorgenson, 1972), and time to build (Pindyck, 1993), and depends on the manager's skills and motivation (Gardebroek & Oude Lansink, 2004).

In the theory of investment and production, the optimal level of investment and production given the current level of accumulated capital and given a set of prices depends on adjustment[1] costs. The theory of investment and production further assumes that the marginal adjustment costs increase with increasing investments (Jorgenson, 1972). The specification of adjustment cost functions has been intensively investigated in the literature (Gould, 1968; Chang & Stefanou, 1988; Hsu & Chang, 1990; Lundgren & Sjöström, 2001; Cooper & Haltiwanger, 2006) as this is a central element in determining the optimal investment level. This literature shows that the optimal specification of the adjustment cost function depends on the type of adjustment costs and empirical considerations, and varies over industries (Gould, 1968) and between individual decision-makers (farmers) (Gardebroek and Oude Lansink, 2004).

However, factors other than adjustment costs can cause the capital input to be at an inoptimal level. Auerbach and Hassett (1991) develop a model for analysing the relationship between investment and the determinants of Tobin's *q* and find that tax changes have a significant effect on the level and pattern of investments[2]. Pindyck (1993) questions the role of adjustment costs when determining the optimal investment level and argues that adjustment costs are unimportant under perfect competition and constant returns to scale and that uncertainties rather than adjustments costs are the primary cause of lower than optimal investment levels.

In Abel and Eberly's (1994) Unified Model of Investment under Uncertainty, the authors combine the specification of adjustment costs with investment under uncertainty as a reason for the capital adjustment not taking place instantly. The adjustment costs are a function of the size of investments and of the capital stock. Abel and Eberly use a dynamic stochastic model to investigate the optimal investment with several different specifications of adjustment costs, which include the fixed costs of investments (i.e. costs associated with the investments that do not depend on the amount of the

[1] Also referred to as installation costs (Jorgenson, 1972)

[2] Tobin's q is a measure of the market value of a firm divided by the book value of the firm. If the market value of a firm is higher than its book value, the market has identified investment opportunities for the specific firm. This quotient is also known as the average q. Marginal q is, loosely speaking, the value of an additional investment divided by the cost of capital for this investment. Tobin's q is described in Bond and van Reenen (2007, p. 4431).

investment) and lower sales prices than purchase prices (resulting in an irreversibility of the investment). The authors conclude that the adjustment costs are important for the investment decision and that there is a range of possible investment inactions which depend on the shadow price of installed capital and the size of the adjustment costs. Hüttel *et al.* (2010) extended the model of Abel and Eberly (1994) with a term that captures the additional costs associated with imperfect capital markets. Investment under uncertainty and dynamic adjustment is investigated in, e.g. Pietola and Myers (2000). Oude Lansink and Stefanou (1997) developed a model with asymmetric adjustment costs in expanding and contracting regimes.

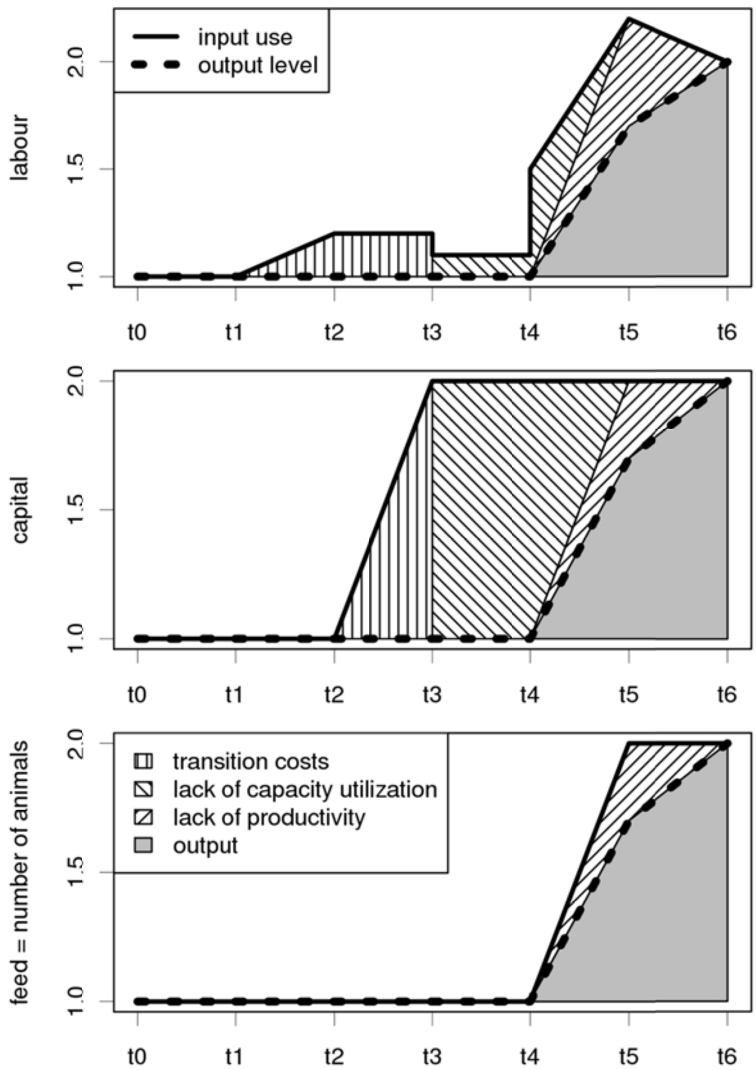
We employ a different method for estimating farmers' adjustment costs by analysing the effect of investments and lagged investments on technical efficiency. Our model estimates the adjustment costs after the investment has been completed, whereas the above-mentioned models all estimated the adjustment costs based on the investment decision and on the assumption that the decision maker invests according to theory. Danish pig farms are constrained by legal restrictions which might discourage them from making investments, even though the investments are profitable, or which might force them to delay an investment because, e.g. they have to wait for permission to expand the farm. In the neoclassical structural investment model, the adjustment costs are estimated as the difference between the optimal level of investments according to the theoretical model and the observed investment behaviour. However, whether this difference is due to legal restrictions and not adjustment costs in the classical sense cannot be analysed with this model. In contrast, we are interested in the adjustment costs *per se* and hence, our model investigates the adjustment costs after the investment.

Studies on the length of construction or promptness of investment utilisation are rare. However, Mayer (1960) found plant lead times for various types of manufacturing plants of over 12 months from the start of construction to completion, whereas over 6 months elapsed from the decision to undertake the project to the start of construction. The lag of the output response after an investment by Danish pig producers depends on the management and the production type. As changes in the value of the livestock are included in the output, the lag of the output response does not directly originate from the duration of the biological production, but from an incomplete capacity utilisation. All-in/all-out slaughter pig production does not have a lagged output response as the pig unit is filled immediately, which is in contrast to a sow unit in which the flow of livestock means that the sows have to be continually mated, which results in less than full capacity utilisation.

The adjustment costs of an investment in a continual slaughter pig production unit are illustrated in figure 2. The figure shows the input use and output production in different phases of an investment. In order to make the figure more accessible, we have made a few simplifying assumptions: (a) constant returns to scale; (b) inputs and output are doubled after expanding with a new unit; (c) the age of the slaughter pigs does not influence the amount of feed and labour required; (d) all phases are of the same duration. For space reasons, the intermediate pig input and general costs are not shown in figure 2. The intermediate pig input is proportional to the number of animals and its level depends on management. The increase in general costs is only partly determined by the scale of production. The initial input and output quantities at time t0 are all normalised to one. At time t1, the farm manager starts planning the investment, which requires extra labour, but has no (relevant) influence on the other inputs or the output. At time t2, the actual investment, i.e. the construction of the new pig unit, starts. This usually also requires additional labour to coordinate and monitor the investment. Moreover, the capital input increases with the investment. At time t3, the new pig unit is finished and the capital input is twice as large as it was in the beginning. At time t4, the farmer starts to fill the new pig unit and it is assumed that the number of pigs increases linearly; the use of feed increases in proportion to the number of animals; the output (line above the solid gray area) increases less than proportionally to the number of animals due to “teething problems”; the use of labour escalates with the first pig in the new unit and then increases linearly with the number of pigs. At time t5, the pig unit is completely filled; the number of animals and the use of feed inputs have doubled; the use of labour is greater than double the initial level, whereas the output is less than double the initial output because the farmer has to learn and fine-tune production in the new unit. At time t6, the adjustment is finished, i.e. all input and output quantities are twice as large as they were initially. The increases in input use, which are not off-set by an equivalent increase in output, are considered to be adjustment costs and are indicated by the shaded areas in figure 2. These adjustment costs can be divided into transition costs and start-up costs, so that the former are losses incurred before the investment is finished (areas shaded with vertical lines in figure 2), whilst the latter are costs that occurred after the investment is finished (areas shaded with diagonal lines in figure 2) (Maegaard, 1981). The start-up costs can be further divided into lack of capacity utilisation (areas shaded with downward sloping lines in figure 2), and lack of productivity (areas shaded with upward sloping lines in figure 2). The lack of productivity occurs because it takes time to become accustomed to new technology, to identify weak spots, and other uncertainties which stem from handling animals when biology is important. This learning process is rather complex because optimisation is multifaceted and unintended negative side effects can follow optimisation.

A good and experienced farm manager can reduce the adjustment costs by, (a) decreasing the additional labour used for planning, coordinating, and monitoring the investment (transition costs), (b) reducing/eliminating the time between finishing and using the new investment (costs due to a lack of capacity utilisation), and (c) becoming familiar with the new technology quicker thereby reducing the extra labour input and the lack of output compared to the capacity utilisation (costs due to lack of productivity). In figure 2, it is assumed that the farmer can maintain his management focus on production on the existing farm during the expansion phase and that the expansion does not interfere with current production or reduce output.

Figure 2: Inputs and outputs during different phases of an investment



Note: t0 = initial production where all input and output quantities are normalised to one; t1 = start of planning the investment; t2 = start constructing the new pig unit; t3 = pig unit construction finalised; t4 = begin filling the new pig unit; t5 = new pig unit is completely full, t6 = end of adjustment. The legends in the upper and lower panel apply to all three panels. All shaded areas together indicate total adjustment costs.

Given the high capital intensity and large investments of Danish pig farms, our considerations about adjustment costs suggest that they are an important determinant of the profitability of investments in pig units. However, given the various types of transition costs and start-up costs, it is difficult in practice to evaluate investment proposals using discounted cash flow methods in which all the positive and negative effects of a new investment on the current operation are taken into account. Usually, the size and the promptness of acquiring the effects are unknown, whilst the transition and start-up costs can only be roughly estimated.

Adjustment costs and a lack of investment utilisation can also be seen as sources of (seemingly) excess capital capacity. This has been investigated in Dutch cash crop farming by Guan *et al.* (2009). The authors found that the farmers in the analysis had an average of 22 percent excess capital capacity. The model in Guan *et al.* (2009) addresses all deviations from the production frontier to the existence of excess capital. However, our theoretical framework (figure 2) indicates that deviations from the production frontier are not only caused by a lack of capital utilisation, but also by an excessive use of labour. Furthermore, we claim that other factors such as land quality, education and the experience of the farm manager and the farm workers, and problems in measuring capital input also influence technical efficiency.

A lack of investment utilisation can be caused by a lower than expected demand for the output. However, Danish farms sell their outputs primarily via cooperative companies, in which the members have the right to deliver the entire production to the company. Hence, farmers usually have no incentive to utilise their capacity less than optimally. Hence, we can ignore a lack of capacity utilisation in this study (Färe *et al.*, 1989).

The objective of this paper is to empirically investigate the size and timing of adjustment costs, as well as investment utilisation in Danish pig production. Given that the average investment of Danish pig producers is rather large, we expect adjustment costs to be of a considerable size. Based on our theoretical model for adjustment costs and investment utilisation (figure 2), we estimate a stochastic frontier output distance function and measure the size and timing of adjustment costs jointly as the effect on technical efficiency. Given our above considerations, we expect that farms experience adjustment costs during the year of the investment and in the year after the investment because of transition costs, lack of capacity utilisation, and a lack of productivity, and hence have a lower technical efficiency than farms that have not recently invested. Therefore, we analyse the effect of lagged investments on the farms' technical efficiencies and we allow for interaction effects between lagged investments and other variables such as farm size and the farmer's age. Finally, we derive the marginal effects of these variables on efficiency and develop a method for calculating the adjustment costs as foregone profit. Given the importance of measuring capital input correctly, we thoroughly discuss the calculation and deflation of capital and derive a new methodology for deflating capital. We expect that in the short run, adjustment costs lower the firm's technical efficiency, but in the medium run, investments in new (modern) assets increase technical efficiency. We test the following hypothesis:

- *Hypothesis 1: During the current year, farmers who have made large investments are less efficient than farmers who have not invested.* Given our explanations above, we expect that farmers who have invested in the same year experience adjustment costs and, hence, are less technically efficient.

- *Hypothesis 2: Farmers who made substantial investments two or three years before the current year have a higher efficiency than farmers who did not invest in the previous years:* One or two years after the investment, the adjustment costs are negligible, the maintenance costs of the new asset are usually still rather low, whilst the relatively new (modern) asset facilitates more efficient production compared to farms on which no investment has taken place. Hence, the technical efficiency should be relatively high two to three years after the investment.
- *Hypothesis 3: Age is relevant regarding the effect of investments on farm inefficiency:* Brown (1995) showed that individuals use their past experience as a learning resource and hence we expect that the middle-aged farmers will be better at improving their farm efficiency after having made investments than inexperienced young farmers. Furthermore, we expect that old farmers will be less efficient than middle-aged farmers, because we assume that they are on average less energetic, and less ambitious compared to young and middle-aged farmers.

2. Data

We use accounting data collected from Danish pig producers for 13 years (1996 to 2008) by the Danish Knowledge Centre for Agriculture to test the above hypotheses. These farm accounts are audited and the total number of observations in the dataset is 30,218. However, the dataset is unbalanced and the inclusion of three years of lagged investments requires the removal of several observations so that the final dataset used for the estimation contains 9,281 observations. The largest cross-section is during the year 1999 with 1,171 farms in the dataset and this number declines to 611 in 2008.

Many variables are measured in monetary units and hence deflation with a price index is required to achieve a measure of production in quantity. We use official national price indices to deflate the inputs and outputs as we assume that price differences between individual farms are mainly due to quality differences (Statens Jordbrugs- og Fiskeriøkonomiske Institut, 1994-2000; Fødevareøkonomisk Institut, 2001-1009). The Törnqvist price index is used for the deflation, which is defined as:

$$P^{t+1} = \left[\prod_{i=1}^{n} \left\{ \frac{p_i^{t+1}}{p_i^t} \right\}^{½(s_i^{t+1}+s_i^t)} \right] P^t, \tag{1}$$

in which P^t is the price of the aggregate input/output in year t, and P_i^t is the price of the individual input/output in year t. Finally, s_i^t is the cost/revenue share of the individual inputs/outputs in year t.

Our model has multiple inputs and outputs. The inputs are: feed, intermediate crop input, intermediate pig input, land, labour, capital, and general inputs. Intermediate crop input includes fertiliser, pesticides, seed and miscellaneous crop inputs. Intermediate pig input includes veterinary costs, costs of medicine, and other miscellaneous pig inputs. Capital is measured as the consumption of capital and is further described below. General inputs are other inputs not readily allocated to either crop or pig production. All inputs are measured in thousand Euros and deflated to 1996 prices, except for land, which is measured in hectares, and labour, which is measured in hours. The outputs are animal outputs (mainly pigs) and crop outputs (mainly cereals) measured in thousand Euros deflated to 1996 prices. Summary statistics are presented in table 1.

Table 1. Summary statistics of Danish pig farms from 1996 to 2008

Variable name	Variable	Unit	Mean	Std Dev.
Animal output	Y_1	Thousand Euro (1996)	459	362
Crop output	Y_2	Thousand Euro (1996)	123	97
Feed	X_1	Thousand Euro (1996)	201	149
Intermediate pig input	X_2	Thousand Euro (1996)	28.3	24.5
Intermediate crop input	X_3	Thousand Euro (1996)	19.2	15.0
Land	X_4	Hectare	104.1	72.9
Labour	X_5	Hours	4,356	2,292
Capital	X_6	Thousand Euro (1996)	93.4	68.1
General input	X_7	Thousand Euro (1996)	40.4	29.6
Only piglet production	H_1	Product dummy	0.39	0.49
Only slaughter pig production	H_2	Product dummy	0.20	0.40
Soil quality	H_3	Share of land, clay	0.48	0.45
Net investments	I_t^r	Thousand Euro (1996)	30.1	147.9
Net investments	I_{t-1}^r	Thousand Euro (1996)	29.3	133.2
Net investments	I_{t-2}^r	Thousand Euro (1996)	32.1	120.7
Net investments	I_{t-3}^r	Thousand Euro (1996)	37.2	118.6
Age	Age	10 years	4.61	0.87
Size	Size	Standard gross margin, Thousand Euro (1996)	25.6	18.6

The investments are measured in thousand Euros and are calculated as the net investments, i.e. they do not include reinvestments, which are defined as being equal to the depreciation.

3. Capital input

Special attention is paid to capital input in this paper because investments affect the capital input and hence it is particularly important to measure this variable in a theoretically sound manner. Other inputs, except for land, are consumed within the year. The analogous measure of capital input is the user cost of capital, because it measures the cost of utilising the capital goods in the production process and can be considered an appropriate measure of the capital (Coelli *et al.2005*; Klein 1960).

Practically speaking, the measurement of capital has some limitations, which are impossible to overcome. One limitation is that when new technologies are introduced which have the same price as the old technology, the price of the existing asset with the old technology should be optimally reduced, because the new asset is able to produce more output than the old. The price index for the asset should optimally be for assets of equal quality, but calculating a constant quality index is practically impossible (OECD, 2001, p. 22). Another limitation is that the valuation is based on historical prices because the values are taken from farm accounts. The optimal value is the future rental value of fixed capital. Depreciation is defined as the estimated decline in the value of the asset due to wear and tear, which is estimated by the farmer with the help of an economic consultant, but within bookkeeping regulations.

We label the flow of capital used in the production capital consumption. This is a measure of the flow of capital used, which is independent of interest rate, price appreciation, and tax rules. The book value of buildings and equipment in the accounts is determined by usual accounting conventions, which implies that they are based on historical prices. If the price of capital goods increases, an investment in the same physical asset results in a higher investment value and a higher book value for the new asset, so that the book value of the new asset has to be deflated to get a measure of the quantity of the capital input. In contrast, book values of investments made in previous years and their depreciations are unaffected by the current year's price increase. This has implications for the price index that should be used to deflate the capital stock and the depreciations. Of course, the depreciation method affects the method used to deflate capital stock and depreciations.

If a type of capital good is linearly depreciated over T years, the (nominal) capital stock shown in the accounts at the end of year t is:

$$C_t = \sum_{i=0}^{T-2} I_{t-i} \cdot \frac{T-i-1}{T}, \tag{2}$$

in which I_t is the (nominal) gross investment in year t. As our capital variable should measure the quantity of capital goods and should not be affected by price changes, we have to deflate the investments by a suitable price index (P_t) so that we get the real gross investment of year t:

$$I_t^r = \frac{I_t}{P_t}. \tag{3}$$

Hence, assuming the same depreciation as before, the real capital stock at the end of year t is:

$$C_t^r = \sum_{i=0}^{T-2} I_{t-i}^r \cdot \frac{T-i-1}{T} \tag{4}$$

and the nominal capital stock at the end of year t can be rewritten as:

$$C_t = \sum_{i=0}^{T-2} I_{t-i}^r \cdot P_{t-i} \cdot \frac{T-i-1}{T}. \tag{5}$$

As T is up to 30 years for buildings and we usually do not have data on investments in each of the previous $T-2$ years, we have to make the simplifying assumption that the real investments were made equally in the current year and the previous $T-2$ years, i.e.:

$$I_m^r = I_s^r \; \forall \; s = t, \dots, t-(T-2), \tag{6}$$

in which I_m^r is the annual real investment. Hence, we can rewrite the nominal and real capital stock at the end of year t as:

$$C_t^r = \frac{I_m^r}{T} \cdot \sum_{i=0}^{T-2} (T-i-1) \tag{7}$$

and,

$$C_t = \frac{I_m^r}{T} \sum_{i=0}^{T-2} P_{t-i} \cdot (T-i-1). \tag{8}$$

Hence, the price index for deflating the nominal capital stock must be:

$$P_t^S = \frac{\sum_{i=0}^{T-2} P_{t-i} \cdot (T-i-1)}{\sum_{i=0}^{T-2} (T-i-1)} \tag{9}$$

so that:

$$C_t^r = \frac{C_t}{P_t^S}. \tag{10}$$

Similarly, the nominal depreciation of these capital goods in year t is shown in the accounts as:

$$G_t = \sum_{i=0}^{T-1} \frac{I_{t-i}}{T}; \tag{11}$$

hence, the real depreciation of capital goods in year t should be:

$$G_t^r = \sum_{i=0}^{T-1} \frac{C_{t-i}^r}{T} = I_m^r \tag{12}$$

and the nominal depreciation in year t can be rewritten as:

$$G_t = \sum_{i=0}^{T-1} I_{t-i}^r \cdot \frac{P_{t-i}}{T} = \frac{I_m^r}{T} \cdot \sum_{i=0}^{T-1} P_{t-i}. \tag{13}$$

Hence, the price index for deflating the nominal depreciation must be:

$$P_t^G = \left(\frac{1}{T}\right) \sum_{i=0}^{T-1} P_{t-i} \tag{14}$$

so that,

$$G_t^r = \frac{G_t}{P_t^G}. \tag{15}$$

In the calculation of capital consumption, a depreciation period of 12 years was selected for machinery and equipment and 25 years for buildings. The capital consumption is calculated as in the following equation:

$$Capital\ \ consumption = \frac{Capital\ stock_t}{P_t^S} \cdot i + \frac{depreciation_t}{P_t^G} + \frac{Maintenance_t}{P_t^M}, \tag{16}$$

in which i is the average of the nominal interest rates in the 13-years period, and P_t^s, P_t^G, and P_t^M are the price indices for capital stock, depreciation, and maintenance, respectively, with the former two being calculated as described above. Maintenance is included in the consumption of capital because the maintenance costs affect the capital deterioration (Schworm 1979). The aggregated index from one period to the next is calculated by use of the Törnqvist index as shown in equation (1).

4. Methods

We estimate a stochastic frontier output distance function, in which the inefficiency is explained by variables deduced from the hypotheses about inefficiency at the farm level.

Let $\boldsymbol{S}(\mathbf{x})$ represent the set of all output vectors, $\mathbf{y}$, that can be produced using the input vector, **x:**

$$\boldsymbol{S}(\mathbf{x}) = \{\mathbf{y}: \mathbf{x}\ can\ produce\ \mathbf{y}\} \tag{17}$$

The corresponding output distance with $0 < D_o \leq 1$ is defined as (Coelli *et al.* 2005):

$$D_0(\mathbf{x}, \mathbf{y}) = \min\{\delta: \mathbf{y}/\delta \in \mathbf{S}(\mathbf{x})\} \tag{18}$$

Several properties can be derived from microeconomic theory. For instance, the output distance function should be non-decreasing in output quantities, non-increasing in input quantities, and linearly homogeneous in output quantities (Coelli *et al.* 2005, p. 47). Henningsen & Henning (2009) show that the monotonicity condition is particularly important in efficiency analyses. Assuming that $D_0(\mathbf{x},\mathbf{y})$ is of the Translog second-order flexible functional form, replacing $-\ln D_0(\mathbf{x},\mathbf{y})$ by the inefficiency term $u_{it} \geq 0$, adding a stochastic error term v_{it}, and imposing linear homogeneity in outputs by normalising the outputs by the animal output $\mathbf{y}_1$, results in the following equation for the estimation with panel data:

$$\begin{aligned}
-\ln y_{1it} = {} & \alpha_0 + \alpha_1 \ln\left(\frac{y_{2it}}{y_{1it}}\right) + ½\alpha_{11} \ln\left(\frac{y_{2it}}{y_{1it}}\right)^2 \\
& + \sum_{k=1}^{7} \beta_k \ln x_{kit} + ½ \sum_{k=1}^{7}\sum_{l=1}^{7} \beta_{kl} \ln x_{kit} \ln x_{lit} \\
& + ½ \sum_{k=1}^{7} \varphi_k \ln x_{kit} \ln\left(\frac{y_{2it}}{y_{1it}}\right) + \omega_0 t + ½\omega_{00} t^2 \\
& + \sum_{k=1}^{7} \omega_k t \ln x_{kit} + \omega_{01} t \ln\left(\frac{y_{2it}}{y_{1it}}\right) + \sum_{m=1}^{3} \rho_m H_{mit} + u_{it} + v_{it}
\end{aligned} \tag{19}$$

In this equation, the subscript i indicates the farm, the subscript t indicates the time period, and α, β, φ, ρ, and ω are parameters to be estimated. We assume that the residuals in the model can be decomposed into an inefficiency term u_{it}, which follows a truncated normal distribution ($N^+(\mu_{it}, \sigma_u^2)$), and a stochastic error term v_{it}, which follows a normal distribution ($N(0, \sigma_v^2)$). It is further assumed that the error term (v_{it}) is homoskedastic and is uncorrelated between observations. Inefficiencies are uncorrelated between observations and are homoskedastic and v_{it} and u_{it} are uncorrelated (Coelli *et al.* 2005). Given our hypothesis stated above, we allow the inefficiency term u_{it} to depend on lagged investments, age, and farm size, as well as interactions between these variables (Battese & Coelli 1993, 1995). We assume the following specification for the expectation of the truncated normal distribution:

$$\begin{aligned}
\mu_{it} = {} & \delta_1 I_{it}^r + \delta_2 I_{it-1}^r + \delta_3 I_{it-2}^r + \delta_4 I_{it-3}^r + \delta_5 Age_{it} + \delta_6 Age_{\mathrm{it}}^2 + \delta_7 Size_{it} \\
& + Age_{it}(\delta_8 I_{it}^r + \delta_9 I_{it-1}^r + \delta_{10} I_{it-2}^r + \delta_{11} I_{it-3}^r) \\
& + Age_{\mathrm{it}}^2(\delta_{12} I_{it}^r + \delta_{13} I_{it-1}^r + \delta_{14} I_{it-2}^r + \delta_{15} I_{it-3}^r) \\
& + Size_{it}(\delta_{16} I_{it}^r + \delta_{17} I_{it-1}^r + \delta_{18} I_{it-2}^r + \delta_{19} I_{it-3}^r).
\end{aligned} \tag{20}$$

In the following, the variables which are assumed to explain inefficiency are labelled “z-variables”. When the farmer makes an investment, it is designed to increase production because the demand for the farm products is unconstrained. Hence, we can assume that farmers maximise revenue or expected profit so that the estimation of an output distance function provides consistent estimates (Coelli 2000).

Furthermore, this applied study should also be communicated to farmers who focus on output expansions and, therefore, we consider an output-oriented model to be easier to comprehend.

An endogeneity problem could be present in the model because some of the inputs are jointly determined with the output. Guan *et al.* (2009) developed a model to deal with the endogeneity problem encountered when energy consumption in cash crop production in The Netherlands co-determines the output level. The farmers who used more energy could obtain a better quality and price for the output. Guan *et al.* (2009) used the Generalized Method of Moments (GMM) approach to estimate the model in the first step and the ML-method in the second step to overcome the endogeneity problem. The correction for potential endogeneity is not pursued in this paper, because the variables which have the highest potential for endogeneity are of minor importance to the total production on the farm. It is mainly the general costs, which have the highest potential endogeneity because energy consumption/input is codetermined with output.

We calculate the technical efficiencies by the formula:

$$TE = E[e^{-u}] = \frac{\Phi\left(\frac{\mu_*}{\sigma_*} - \sigma_*\right)\ e^{-\mu_* + \frac{1}{2}\sigma_*^2}}{\Phi\left(\frac{\mu_*}{\sigma_*}\right)}, \tag{21}$$

in which $\Phi(.)$ denotes the cumulative distribution function of the standard normal distribution, $\mu_* = (1-\hat{\gamma})\,\hat{\mu}\ + \hat{\gamma}\,\epsilon$, $\sigma_* = \sqrt{\hat{\gamma}(1-\hat{\gamma})\hat{\sigma}}$, $\hat{\sigma} = \hat{\sigma}_u + \hat{\sigma}_v$, $\hat{\gamma} = \hat{\sigma}_u/\hat{\sigma}$, $\hat{\sigma}_u$ is the estimated variance of the inefficiency term u, $\hat{\sigma}_v$ is the estimated variance of the stochastic error term v, $\epsilon = u + v$ is the total residual, and μ is the expectation of the truncated normal distribution for the inefficiency term based on the estimated δ coefficients (see equation 20). These formulas are almost identical to the formulas in Battese and Coelli (1993, p. 20), the only difference being that our formulas are derived so that the inefficiency term u is added to the frontier, whereas in the formulas of Battese and Coelli (1993), the inefficiency term u is subtracted from the frontier. The resulting technical efficiency estimates are between 0 and 1, where a higher efficiency is interpreted as indicating a more efficient farm.

We calculate the marginal effect of a *z*-variable on the technical efficiency by the formula:

$$\begin{aligned}\frac{\partial TE}{\partial z} = (1-\hat{\gamma}) \Bigg(& \frac{\phi\left(\frac{\mu_*}{\sigma_*} - \sigma_*\right)\ e^{-\mu_* + \frac{1}{2}\sigma_*^2}}{\sigma_*\ \Phi\left(\frac{\mu_*}{\sigma_*}\right)} - \frac{\Phi\left(\frac{\mu_*}{\sigma_*} - \sigma_*\right)\phi\left(\frac{\mu_*}{\sigma_*}\right)\ e^{-\mu_* + \frac{1}{2}\sigma_*^2}}{\sigma_*\left(\Phi\left(\frac{\mu_*}{\sigma_*}\right)\right)^2} \\ & - \frac{\Phi\left(\frac{\mu_*}{\sigma_*} - \sigma_*\right)\ e^{-\mu_* + \frac{1}{2}\sigma_*^2}}{\Phi\left(\frac{\mu_*}{\sigma_*}\right)} \Bigg) \frac{\partial \mu}{\partial z},\end{aligned} \tag{22}$$

in which $\phi(.)$ denotes the probability density function of the standard normal distribution and $\partial\mu/\partial z$ is the marginal effect of a z-variable on the term μ as defined in equation (20), e.g. for the current year's investments it is $\partial\mu/\partial I_{it} = \delta_1 + \delta_8 Age_{it} + \delta_{12} Age_{\text{it}}^2 + \delta_{16} Size_{it}$.

This derivative of investments on the term μ is based on the assumption that investments do not affect any other z variable. However, it is expected that investments usually increase the size of the farm. Hence, beyond the direct effect of investments on efficiency, there is also an indirect effect: investments affect the size of the farm, which in turn affects the efficiency of the farm via μ, so that the total effect is:

$$\frac{\partial\mu}{\partial I_{it-k}} = \delta_{1+\text{k}} + \delta_{8+\text{k}} Age_{it} + \delta_{12+\text{k}} Age_{\text{it}}^2 + \delta_{16+\text{k}} Size_{it} + \delta_7 \frac{\partial Size_{it}}{\partial I_{it-k}}. \tag{24}$$

We decompose the effect of investments on farm size into two parts:

$$\frac{\partial Size_{it}}{\partial I_{it-k}} = \frac{\partial Size_{it}}{\partial Cap_{it}} \cdot \frac{\partial Cap_{it}}{\partial I_{it-k}}, \tag{25}$$

where Cap_{it} is the capital stock and the first part is:

$$\frac{\partial Cap_{it}}{\partial I_{it-k}} = 1 - (k+1)\delta, \tag{26}$$

with δ being the depreciation rate. We analyse the second part, the effect of capital on size, by the quadratic model:

$$Size_{it} = \alpha_t + \alpha_1 Cap_{it} + \frac{1}{2}\alpha_2 Cap_{it}^2 + \mu_i + \eta_t + \epsilon_{it} \tag{27}$$

which we estimate as a two-ways fixed effects panel data model.[3] From these estimation results, we can calculate effect of capital on size by:

$$\frac{\partial Size_{it}}{\partial Cap_{it}} = \alpha_1 + \alpha_2 Cap_{it} \tag{28}$$

so that the total effect becomes:

$$\frac{\partial\mu}{\partial I_{it-k}} = \delta_{1+\text{k}} + \delta_{8+\text{k}} Age_{it} + \delta_{12+\text{k}} Age_{\text{it}}^2 + \delta_{16+\text{k}} Size_{it} + \delta_7 (1-(k+1)\delta)(\alpha_1 + \alpha_2 Cap_{it}). \tag{29}$$

[3] An F-test revealed that both individual effects and time effects are statistically significant so that a two-ways model should be used. A Hausman test rejects a random-effects model in favour of our fixed-effects model. As our model should capture the short-run effects of a changing capital stock on farm size, we chose to use the fixed-effects ("within") estimator, which focuses on changes within each farm over time, rather than the "between" estimator, which focuses on differences between farms and captures the long-run relationship.

We measure adjustments costs in terms of reduced output, whilst assuming radial changes of the output vector. Hence, we can calculate the marginal effect of a z-variable (e.g. current year's investments) on profit by:

$$\frac{\partial \pi}{\partial z} = R\left(\frac{\partial TE}{\partial z}\right), \qquad (30)$$

where $R = p_1 \cdot y_1 + p_2 \cdot y_2$ is total revenue. A detailed derivation of this formula is provided in the appendix.

5. Results and discussion

Given our model specification with investments lagged up to three years, a farm has to be in the data set for at least four continuous years to be included in the estimation, because the first three years have to be used to construct the lagged variables. Given that our data set covers 13 years, a maximum number of 10 years for each farm can be used for the estimation. A total of 9,281 observations are used to estimate this model. The estimation is performed by the add-on package "frontier" (Coelli & Henningsen 2010) for the statistical environment "R" (R Development Core Team 2010). Parameter estimates for this model are shown in table 2.

Positive parameter estimates for the z-variables are to be interpreted as a positive relationship between the z-variables and the inefficiency term u. Hence, higher values of the z-variable are associated with less efficient farms. A likelihood ratio test clearly rejects (p<0.001) the model without inefficiency (OLS model).

The distance function is monotonically decreasing in six out of seven inputs at 83 – 100 percent of the observations and at 55 percent of the observations for the remaining input, intermediate pig input. The intermediate pig input includes veterinary and medicine costs, and hence, depends on the management and might indicate problems in management and pig health. Therefore, it is not evident that higher input use leads to higher output. Furthermore, the distance function is increasing in animal output in all observations and increasing in crop output in 99.8 percent of the observations. Finally, the distance function is increasing in time (year) for 84 percent of the observations, which indicates that a large share of the farms experienced technological regress. A likelihood ratio test confirms that time has a statistically significant effect on the model (P<0.001). The mean of the estimated distance elasticities of time is 0.038, which indicates an annual decrease in the frontier output of 3.8 percent when the same input quantities are used. The technological regress seems counterintuitive and is a topic for further research. An explanation for the occurrence of technological regress could be the ban on growth-promoting antibiotics in 2000, which led to a decrease in feed efficiency (Jultved & Nielsen 2000). The use of nitrogen fertiliser was restricted in the period and animal welfare legislation, which prohibited the tying of sows, has resulted in higher capital use in recent years. The bookkeeping standards were changed in 2006, which caused price changes in the capital stock to be recorded as income. The data have been cleaned for this effect by using average prices, but it opens up a source of error, as the actual prices in the accounts are not necessarily equal to national price statistics. Finally, farm size has increased over time and our estimation results show that the technology has increasing returns to scale and large farms are technically more efficient than small farms so that the actual productivity probably decreases less, or might even increase over time. Rasmussen (2010, p. 352) found a significant annual 2.3 percent decrease in efficiency over time (1985 – 2006) in an analysis of Danish pig producers using a different data set and modelling approach. The estimated technical change and input scale efficiency in Rasmussen (2010) outweighs the regress in technical efficiency resulting in a total factor productivity progress of 2.1 percent.

The effects of the inputs and outputs on the distance measure (D_o) are evaluated in the distance elasticities and are calculated at the sample mean values and presented in table 3. The distance elasticity of an input can be interpreted as the relative effect on the aggregate output given a relative increase in the particular input. Distance elasticities can also be interpreted as the relative importance of the variables, i.e. feed accounts for 47.7 percent of the inputs, whilst land accounts for 22.9 percent of the input. Increasing feed input by one percent leads to an increase in the aggregate output by 0.45 percent. The right-hand side of table 3 presents the number of observations, which violate the monotonicity condition. For the time variable, it is the number of observations with technological regress in the analysis.

The negative sum of the distance elasticities of the inputs indicates the elasticity of scale. The elasticity of scale at mean values is found to be 1.06, which indicates increasing returns to scale. While most smaller farms experience larger returns to scale, larger farms have, on average, approximately constant returns to scale. The returns to scale found in our analysis are considerably lower than those measured by Rasmussen (2010), who identified an elasticity of scale of, on average, 1.19 and declining over time. As our empirical results show that most farms operate under increasing returns to scale, increasing farm size with investments should generally increase a farm's productivity, even if the farm's efficiency remains unchanged. We do not consider this effect in our analysis of adjustment costs and investment utilisation, because we find it more reasonable to compare each farm with a (hypothetical) “best practice” farm of the farm's current size than to compare it with a farm of its size before the investment.

Table 2. Estimation results of model

Variable	Par.	Estimate	S.E.	*p*-value	Variable	Par.	Estimate	S.E.	*p*-value
Constant	α_0	-1.3565	0.4839	0.0051	$\ln(x_4)\ln(y_2/y_1)$	φ_4	-0.0259	0.0174	0.1361
$\ln(y_2/y_1)$	α_1	1.1517	0.1103	< 2.2e-16	$\ln(x_5)\ln(y_2/y_1)$	φ_5	-0.0416	0.0165	0.0118
$\ln(y_2/y_1)^2$	α_{11}	0.0171	0.0049	0.0000	$\ln(x_6)\ln(y_2/y_1)$	φ_6	0.0439	0.0179	0.0145
$\ln(x_1)$	β_1	-0.2405	0.1751	0.1695	$\ln(x_7)\ln(y_2/y_1)$	φ_7	0.0389	0.0202	0.0538
$\ln(x_2)$	β_2	0.0900	0.0881	0.3068	t	ω_0	0.2269	0.0229	< 2.2e-16
$\ln(x_3)$	β_3	-0.5438	0.1737	0.0017	t^2	ω_{00}	-0.0174	0.0008	< 2.2e-16
$\ln(x_4)$	β_4	-0.6517	0.2124	0.0022	$t\ln(y_2/y_1)$	ω_{01}	-0.0457	0.0023	< 2.2e-16
$\ln(x_5)$	β_5	0.1998	0.1111	0.0721	$t\ln(x_1)$	ω_1	-0.0184	0.0037	0.0000
$\ln(x_6)$	β_6	0.2670	0.1706	0.1175	$t\ln(x_2)$	ω_2	-0.0285	0.0019	< 2.2e-16
$\ln(x_7)$	β_7	-0.4173	0.1692	0.0137	$t\ln(x_3)$	ω_3	0.0247	0.0036	0.0000
$\ln(x_1)\ln(x_1)$	β_{11}	-0.0957	0.0365	0.0087	$t\ln(x_4)$	ω_4	0.0296	0.0043	0.0000
$\ln(x_1)\ln(x_2)$	β_{12}	-0.0960	0.0145	0.0000	$t\ln(x_5)$	ω_5	-0.0190	0.0034	0.0000
$\ln(x_1)\ln(x_3)$	β_{13}	0.1728	0.0261	0.0000	$t\ln(x_6)$	ω_6	-0.0045	0.0039	0.2495
$\ln(x_1)\ln(x_4)$	β_{14}	-0.1043	0.0308	0.0007	$t\ln(x_7)$	ω_7	0.0122	0.0046	0.0085
$\ln(x_1)\ln(x_5)$	β_{15}	-0.0061	0.0261	0.8163	Piglets, H_1	ρ_1	-0.0221	0.0052	0.0000
$\ln(x_1)\ln(x_6)$	β_{16}	0.1025	0.0295	0.0005	Slaughter, H_2	ρ_2	-0.2244	0.0076	< 2.2e-16
$\ln(x_1)\ln(x_7)$	β_{17}	0.0601	0.0327	0.0659	Soil, H_3	ρ_3	-0.0707	0.0045	< 2.2e-16
$\ln(x_2)\ln(x_2)$	β_{22}	0.0124	0.0084	0.1427	Inefficiency equation				
$\ln(x_2)\ln(x_3)$	β_{23}	0.0302	0.0139	0.0303	Age	δ_1	-1.9026	0.6372	0.0028
$\ln(x_2)\ln(x_4)$	β_{24}	0.0466	0.0164	0.0046	Age^2	δ_2	0.2084	0.0713	0.0035
$\ln(x_2)\ln(x_5)$	β_{25}	0.0198	0.0126	0.1160	Size	δ_3	-0.1038	0.0309	0.0008
$\ln(x_2)\ln(x_6)$	β_{26}	-0.0160	0.0142	0.2598	I_t^r	δ_4	-0.0045	0.0042	0.2838
$\ln(x_2)\ln(x_7)$	β_{27}	0.0202	0.0162	0.2117	I_{t-1}^r	δ_5	-0.0133	0.0154	0.3873
$\ln(x_3)\ln(x_3)$	β_{33}	-0.0834	0.0272	0.0022	I_{t-2}^r	δ_6	0.0873	0.0282	0.0020
$\ln(x_3)\ln(x_4)$	β_{34}	0.0062	0.0276	0.8221	I_{t-3}^r	δ_7	0.0973	0.0258	0.0002
$\ln(x_3)\ln(x_5)$	β_{35}	-0.0068	0.0261	0.7935	Age * I_t^r	δ_8	0.0029	0.0019	0.1299
$\ln(x_3)\ln(x_6)$	β_{36}	-0.0027	0.0268	0.9185	Age * I_{t-1}^r	δ_9	0.0066	0.0075	0.3807
$\ln(x_3)\ln(x_7)$	β_{37}	-0.0915	0.0302	0.0024	Age * I_{t-2}^r	δ_{10}	-0.0378	0.0133	0.0044
$\ln(x_4)\ln(x_4)$	β_{44}	-0.0377	0.0332	0.2562	Age * I_{t-3}^r	δ_{11}	-0.0450	0.0123	0.0003
$\ln(x_4)\ln(x_5)$	β_{45}	0.0642	0.0312	0.0394	Age^2 * I_t^r	δ_{12}	-0.0003	0.0002	0.1322
$\ln(x_4)\ln(x_6)$	β_{46}	-0.0216	0.0316	0.4936	Age^2 * I_{t-1}^r	δ_{13}	-0.0007	0.0009	0.4038
$\ln(x_4)\ln(x_7)$	β_{47}	0.0749	0.0365	0.0403	Age^2 * I_{t-2}^r	δ_{14}	0.0034	0.0014	0.0138
$\ln(x_5)\ln(x_5)$	β_{55}	-0.0374	0.0181	0.0393	Age^2 * I_{t-3}^r	δ_{15}	0.0046	0.0013	0.0005
$\ln(x_5)\ln(x_6)$	β_{56}	-0.0669	0.0255	0.0087	Size * I_t^r	δ_{16}	0.0000	0.0000	0.0024
$\ln(x_5)\ln(x_7)$	β_{57}	0.0357	0.0249	0.1519	Size * I_{t-1}^r	δ_{17}	0.0000	0.0000	0.1868
$\ln(x_6)\ln(x_6)$	β_{66}	-0.0368	0.0365	0.3136	Size * I_{t-2}^r	δ_{18}	0.0000	0.0000	0.7641
$\ln(x_6)\ln(x_7)$	β_{67}	0.0151	0.0324	0.6401	Size * I_{t-3}^r	δ_{19}	0.0000	0.0000	0.0896
$\ln(x_7)\ln(x_7)$	β_{77}	-0.1427	0.0466	0.0022	$Sigma^2$	σ^2	0.4815	0.1344	0.0003
$\ln(x_1)\ln(y_2/y_1)$	φ_1	-0.0536	0.0147	0.0003	Gamma	γ	0.9465	0.0151	0.0000
$\ln(x_2)\ln(y_2/y_1)$	φ_2	-0.0716	0.0091	0.0000					
$\ln(x_3)\ln(y_2/y_1)$	φ_3	0.0786	0.0150	0.0000					

Log likelihood value: 3,018

Table 3. Distance elasticities and monotonicity for inputs and outputs in the model

Variable	Mean of distance elasticities	Distance elasticities at mean values	Median of distance elasticities	No. and percentage of observations violating the monotonicity assumption
Crop output	0.369	0.369	0.372	16 (0.2%)
Animal output	0.631	0.631	0.628	0 (0.0%)
Feed input	-0.477	-0.476	-0.481	0 (0.0%)
Intermediate pig input	-0.033	-0.033	-0.013	4,126 (44.5%)
Intermediate crop input	-0.076	-0.076	-0.079	1,538 (16.6%)
Land	-0.229	-0.229	-0.232	65 (0.7%)
Labour	-0.069	-0.070	-0.062	296 (3.2%)
Capital	-0.115	-0.115	-0.116	66 (0.7%)
General costs	-0.065	-0.065	-0.064	600 (6.5%)
Time	0.038	0.038	0.040	*7,756 (83.6%)
Elasticity of scale	1.063			

* Number of observations with technological regress

The mean values of the marginal effects, the marginal effects at mean values, and the median marginal effect are presented in table 4 along with the mean values of the variables. The statistical significance of the effect of each z-variable is tested with a likelihood ratio test; the p-values of these tests are presented in column “P-value of LR test” of table 4.

Table 4. Marginal effects of explanatory variables on efficiency

Variable	mean of the variable	mean marginal effect	median marginal effect	marginal effect at mean values	P-value of LR test
Net investments (I_t^r)	0.0301	-0.01039	-0.00832	-0.00939	0.0000
Net investments (I_{t-1}^r)	0.0293	-0.00206	-0.00260	-0.00491	0.1872
Net investments (I_{t-2}^r)	0.0321	0.09183	0.07073	0.07535	0.0002
Net investments (I_{t-3}^r)	0.0372	0.07426	0.05991	0.07085	0.0020
Age	4.61	0.00222	-0.00014	0.00133	0.0000
Size	25.6	0.00073	0.00060	0.00051	0.0002

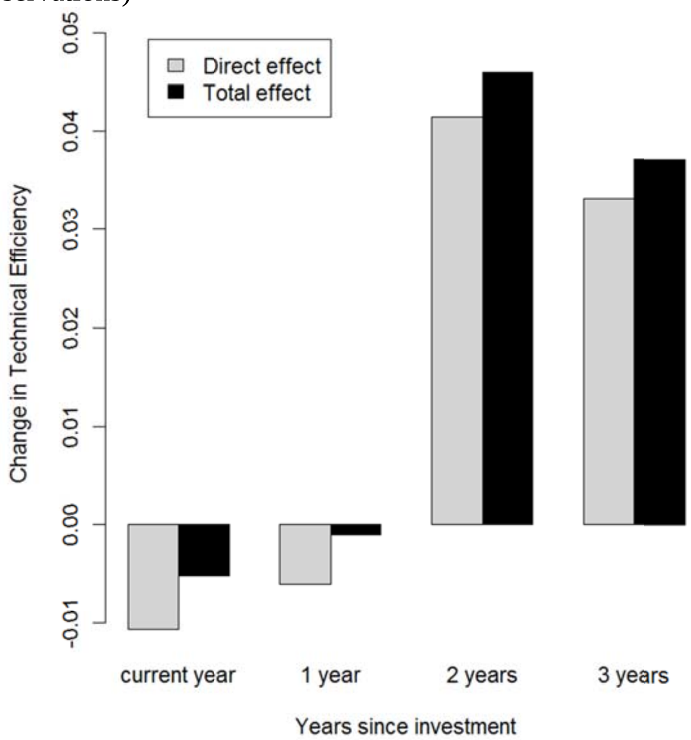
Note: in order to improve readability, the marginal effects of the investment variables (I_{t-k}^r) are multiplied by 1,000 so that the figures indicate the effect of investing €1,000,000.

The mean and the median effects of investments in the current year and the previous year, as well as these effects calculated for the average farm are all negative. These negative effects can be explained by adjustment costs in the year of the investment and in the subsequent year, which is consistent with most adjustment cost models in the literature (e.g. Abel & Eberly, 1994; Hüttel et al., 2010).

Figure 3 shows the direct effect (i.e. ignoring the indirect effect of investments via farm size) and the total effect of a €500,000 investment on the technical efficiency in the current year and in each of the three following years. As our estimation results confirm that efficiency increases with farm size and farm size increases with capital stock, the indirect effects of investments on efficiency via the size of the farm reduce the adjustment costs in the year of the investment and in the subsequent year and increase the positive effects in years two and three after the investment. While the negative effects in the year of the investment and in the subsequent year are rather small (0.5% and 0.1%, respectively), the positive effects two years and three years after the investment are rather large (4.6% and 3.7%, respectively).

Hence, our hypothesis 1 is supported as we find a negative relationship between the current and previous year's investments and efficiency. Hypothesis 2 is also supported as the investments made two to three years before positively affect farm efficiency.

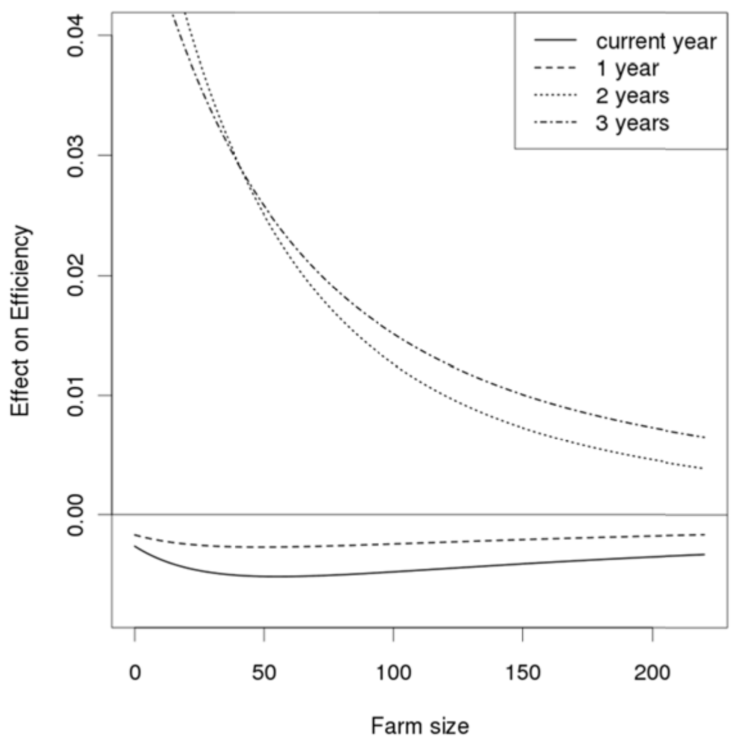
Figure 3. The direct and total effect of a €500.000 investment on farm efficiency (mean values over all observations)



A €500,000 investment is a relatively large sum for small farms and it is expected that it will have a larger impact on the small farms compared to the larger farms. The effect on efficiency of a €500,000 investment depending on farm size is presented in figure 4.

This figure shows that the adjustment costs (negative effects of current and previous year's investments) relative to the output are highest for farms with a size of around €50,000 Standard Gross Margin and that they decrease as the size of a farm increases, which is consistent with the theoretical model of, e.g. Abel and Eberly (1994). As expected, the relative gains from investing €500,000 are much larger for small farms than for large farms.

Figure 4. The effect on efficiency of an investment of €500,000 depending on farm size.



Technical efficiency also significantly (P<0.001) depends on the farmer's age. The relationship between the farmer's age and technical efficiency calculated at the mean values of all other variables is presented in figure 5. The most efficient farmers are aged 49, but the effect of age is not very large (less than 1%).

The farmer's age not only affects efficiency directly, but also the adjustment costs. This effect is highly statistically significant (P<0.001). Figure 6 shows the effect of investing €500,000 on efficiency depending on age and illustrates that the adjustment costs, due to investments in the current year and the previous year, are relatively unaffected by age. The positive effects two and three years after the investment are smallest for farmers under 38 years of age. Farmers who are in their fifties achieve the best investment utilisation, while young farmers only achieve a small efficiency gain two and three years after the investment. An interpretation is that younger farmers have prolonged adjustment costs which reduce or off-set the positive contribution of investment two and three years after the investment.

Figure 5. Effect of age on farm efficiency in the mean of size and investments

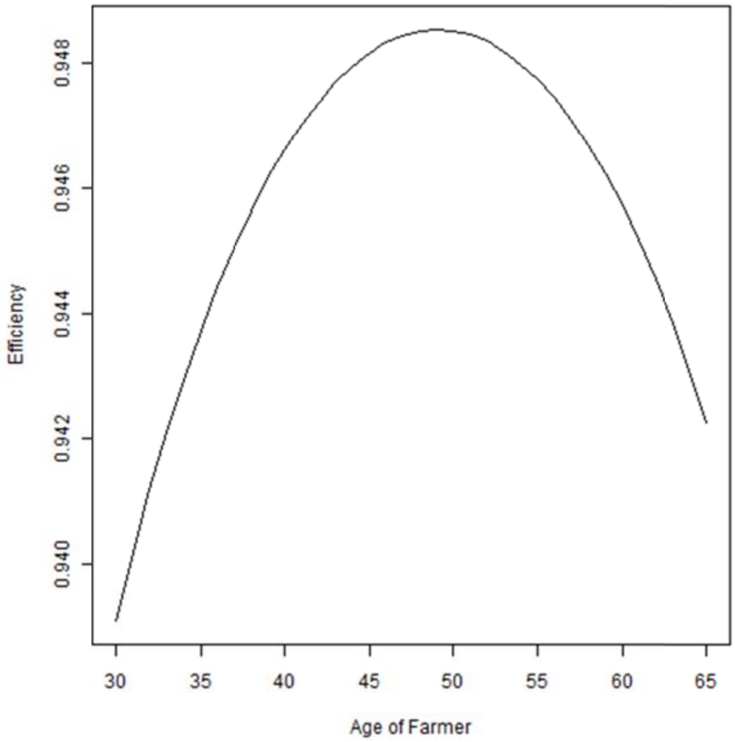
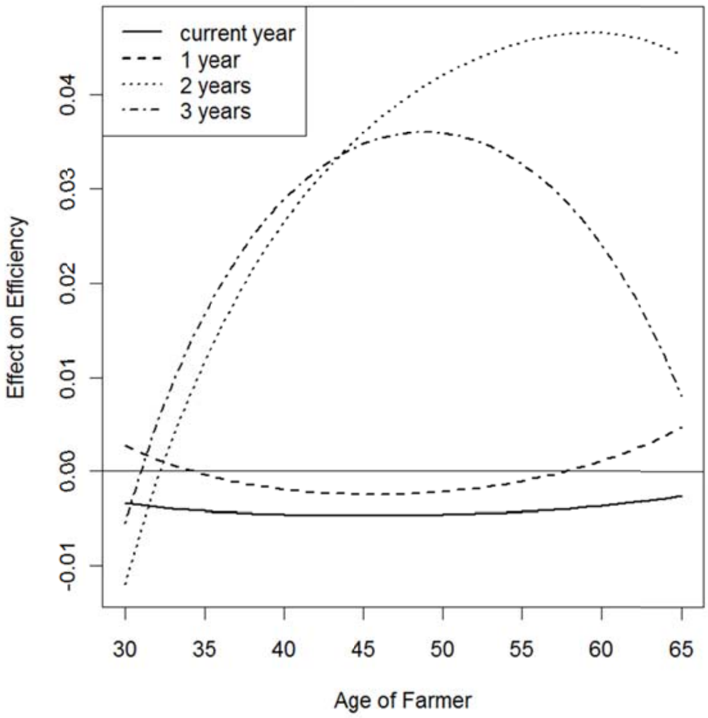


Figure 6. Marginal effect of investment and effect of age on efficiency



Hypothesis 3 is supported, as age has a significant effect on the investment utilisation. Furthermore, we confirm the proposed hypothesis that middle-aged farmers are the most efficient, as the optimal age of farmers investing is 49 years.

We calculate the marginal effects of investments on profit at the sample mean values using the formula derived in the previous section. The marginal effects of investments made in the current year and in the previous three years are -0.0059, -0.0018, 0.0378, and 0.0336, respectively. These results indicate that the adjustment costs are 0.6% of the investment volume in the current year and 0.2% of the investment volume in the following year. Hence, total adjustment costs are 0.8% of the investment volume. However, in the second and third year after the investment, additional profits of 3.8% and 3.4% of the investment volume, respectively, are realised. Based on a real interest rate of 5% per year, the net present value of these extra profits is about 5.6% of the investment volume in the year of the investment. The relative level of adjustment costs is about half of the magnitude found in Gardebroek and Oude Lansink (2004), who found that adjustment costs were 1.6 per cent of the total investments in buildings (not net investments).

6. Robustness check

Capital measurement is pivotal and we therefore analyse the implications of changes in the measurement to test whether the results are robust to changes in the measurement of capital. Several models with different measurements of capital were applied to test the robustness of the results from the SFA-model. One robustness check on capital variable is performed by estimating the depreciation as a constant proportion of the capital stock, 8 percent for buildings and 15 percent for machinery, instead of using the actual depreciation. This also has a small effect on the investments, as the new investments are defined as total investments minus reinvestments, which are defined as being equal to depreciation. The marginal effects of investments on efficiency in the current year and two years later are very similar to the results found in the original model (see table 5). However, the marginal effect on efficiency three years after the investment is somewhat larger (0.088 vs. 0.075) and the marginal effect on efficiency one year after the investment is even positive (0.013 vs. -0.002).

Another model, with capital measured as the start-of-the-year value instead of the end-of-the-year value, is also estimated as a robustness check, because it contributes to the estimation of the adjustment costs after investment. Start-of-the-year capital does not include any of the investments undertaken during the year. Capital consumption is a flow measure of capital which measures the consumed capital in the period. If considerable investments are made within an accounting year, the end of the year capital stock estimate is higher than the start-of-the-year value. The capital stock estimate is used to calculate the user-cost of capital, which is used as the measure of capital input in our models. The marginal effects based on this model are rather similar to the ones found in our original model and to the previous alternative model (see table 5). The similarity of these results indicates that the depreciation and the book values of newly acquired assets in the farm accounts are treated reasonably in our data set and that our findings are robust to alternative measurements of capital and depreciation.

A third model is estimated in order to further check the robustness of the results in the original model. In this model, the (lagged) investments in real estate are included. Hence, when the farmer buys the neighbouring farm, the model includes the investment in the buildings, machinery, and livestock. It is not evident that the investment in the neighbouring farm increases the technical efficiency of the expanded farm. When the goal of the acquisition is to utilise pig units and machinery, then an increase in efficiency can be expected. But, if the purpose of the acquisition is to own more land, the investments in farm buildings, which must be purchased together with the land, can decrease the technical efficiency of the expanded farm. The marginal effects on farm efficiency from this model are also presented in table 5. Fewer observations (9,046) are used to estimate the model, because an additional lag is needed in some years to separate land from buildings, pig units, and machinery in the accounts. On average, the investments in assets as parts of a whole farm are 21 percent of the total investments with considerable variation from farm to farm. The results show that the inclusion of buildings, machinery, and livestock investments from existing farms does not considerably affect the marginal effects of investments, except for the first year after the investment, when the marginal effect is positive. The effect in the third year after the investment is smaller according to this model.

The robustness check using three alternative models indicates that the results are robust to changes in the measurement of capital, deflation, and investments and that the compounded marginal effect of investments on farm efficiency is positive.

Table 5. Marginal effects for alternative models

	Mean of marginal effects on efficiency			
Variable	Original model	Estimated depreciation	Start of the year capital	Including other buildings
Net investments (I_t^r)	-0.01039	-0.00967	-0.00934	-0.01143
Net investments (I_{t-1}^r)	-0.00206	0.01321	-0.00225	0.00021
Net investments (I_{t-2}^r)	0.09183	0.09404	0.09150	0.11306
Net investments (I_{t-3}^r)	0.07426	0.08815	0.08142	0.02076
Age	0.00222	0.00236	0.00191	0.00174
Size	0.00073	0.00075	0.00084	0.00081

7. Conclusion

In this paper, we presented a theoretical model for adjustment costs and investment utilisations that illustrates their causes and types and shows in which phases of an investment they occur. Furthermore, we developed an empirical framework for analysing the size and timing of adjustments costs and investment utilisation. Special consideration was given to the measurement and deflation of capital and, therefore, new price indices for deflating the capital stock and depreciation in microeconomic data sets were proposed. This deflation method recognises the accounting principles when the price index is constructed.

We estimated an output distance function as an efficiency effect frontier (Battese & Coelli 1993, 1995), whereby we allowed the farm's technical efficiency to depend on lagged investments, farmer's age, and farm size, as well as interactions between these variables. Furthermore, we derived methods for calculating the marginal effects of these z-variables on technical efficiency and adjustment costs.

Investments in farm assets have a positive effect on the farm efficiency two and three years after the investment. The optimal age of farmers, in terms of investment, is when they are in their fifties, which implies that middle-aged farmers and larger farms are better at utilising their investments. Farmers aged 49 have *ceteris paribus* the highest technical efficiency.

The adjustment costs associated with investments reduce the farm's efficiency in the investment year. With an investment of €500,000, farm efficiency falls by one half percentage point. Investments made in the previous year have a small negative effect on efficiency measured for the mean sized and mean aged farmer. An investment of €500,000 made two and three years ago has a strong positive effect on efficiency of 4.6 and 3.7 percentage points, respectively.

The competitiveness of Danish pig producers on the international market is important for the Danish pig industry as the industry is highly export-oriented. The investment utilisation is an important factor for future competitiveness, as the capital invested in assets and technology codetermines the productivity of the farm together with the skills of the farmer.

Knowing the investment utilisation and the factors, which determine it, can help agricultural advisors obtain a high utilisation of investments on farms and help to maintain a competitive Danish agricultural sector. During the financial crisis, multiple manufacturing firms have outsourced their production to Asia or Eastern European countries to reduce wages and many blue collar workers have lost their jobs. The jobs lost are not expected to return, which is why it is important to maintain positions for blue collar workers in Denmark. There are many blue collar jobs in Danish agriculture as well as in the agribusiness industry.

Appendix

Derivation of the marginal effect of a z-variable on profit

We measure adjustment costs in terms of reduced output, whilst assuming radial changes of the output vector, i.e. $\mathbf{y}=(y_1, y_2) = \lambda \mathbf{y}^0 = (\lambda y_1^0, \lambda y_2^0)$, where y_1^0 and y_2^0 are the observed output quantities. Hence, we can calculate the marginal effect of a *z* variable by:

$$\frac{\partial \pi}{\partial z} = \left(\frac{\partial \pi}{\partial y_1} \frac{\partial y_1}{\partial \lambda} + \frac{\partial \pi}{\partial y_2} \frac{\partial y_2}{\partial \lambda} \right) \left(\frac{\partial \lambda}{\partial D} \right) \left(\frac{\partial D}{\partial TE} \right) \left(\frac{\partial TE}{\partial z} \right). \tag{31}$$

While we have derived the last term on the right-hand side ($\partial TE / \partial z$) in equation (22), we derive the other terms successively. For the sake of simplicity, we assume that the covariances between all stochastic terms are zero, so that we can take the expectations of these terms separately. As profit is:

$$\pi = p_1 \cdot y_1 + p_2 \cdot y_2 - \sum_{i=1}^{K} w_i \cdot x_i \tag{32}$$

and we assume that only output (y_1, y_2) is affected, while all input quantities $(x_1, \cdots, x_K)$ and all prices $(p_1, p_2, w_1, \cdots, w_K)$ remain unaffected, we get $\partial \pi / \partial y_1 = p_1$ and $\partial \pi / \partial y_2 = p_2$, i.e. the prices of the two outputs. From the definition of the radial changes above, we can see that $\partial y_1 / \partial \lambda = y_1^0$ and $\partial y_2 / \partial \lambda = y_2^0$. If we take equation (18) and replace the set of all possible output vectors $\boldsymbol{S}(\mathbf{x})$ by the observed input vector $\mathbf{y}^0$ and replace the actual input vector $\mathbf{y}$ by the radial multiplication of the observed input vector $\lambda \mathbf{y}^0$, we can see that the minimum of δ must be equal to λ. As the output distance D is equal to the minimum of δ and hence, equal to λ, we get $\partial \lambda / \partial D = 1$. Finally, we get $\partial D / \partial TE = 1$, because in the output distance function, the inefficiency term u is substituted by the negative logarithmised output distance $-\ln(D)$ and the relationship between technical efficiency TE and the inefficiency term u is $TE = e^{-u}$, so that $D = e^{-u} = TE$. Putting everything together, we get:

$$\frac{\partial \pi}{\partial z} = (p_1 y_1^0 + p_2 y_2^0) \left(\frac{\partial TE}{\partial z} \right) = R \left(\frac{\partial TE}{\partial z} \right), \tag{33}$$

where R is total revenue.

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