A COMPARISON OF EFFICIENCY AND PRODUCTIVITY GROWTH OF PIG FARMING IN THE NETHERLANDS AND DENMARK

Minor Thesis

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A comparison of efficiency and productivity growth of pig farming in the Netherlands and Denmark

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Preface

This minor thesis at Business Economics chair group is part of my MSc study Animal Sciences at Wageningen University. This thesis gives an overview of the efficiency and productivity performance of pig farmers in the Netherlands and Denmark.

Although my limited economic background, I never regret the choice for doing this assignment. I had to spend many hours watching the computer screen, searching for solutions to resolve error after error. It was a memorable moment, when finally the code was running as I intended and results came out. It has not been in vain, I really learned a lot by doing this thesis.

I would like to thank my supervisor, dr. Grigorios Emvalomatis, for his support and patience during this thesis process. He always helped me with explaining, sometimes two or more times, the tough theory behind this study. Without his help and suggestions, I probably would have been lost in literature.

Lotte Kroeze

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Abstract

This study aims to propose a data envelopment analysis (DEA) model to measure technical efficiency of pig farms in the Netherlands and its largest competitor, Denmark. The results based on sample data from 1995 to 2008 show an overall bias-corrected technical efficiency of 84.4% for the Netherlands, compared to a technical efficiency score of 82.5% for Denmark. Bootstrapped results of the Malmquist TFP index show that productivity growth rates are significantly ($\alpha = 0.05$) different for Dutch and Danish pig farmers. Technical change and efficiency change measurements for both countries resulted in statiscally verified productivity growth rates of 0.8% and 0.2% for the Netherlands and Denmark, respectively. The relatively small TFP growth in the fourteen-year time period can be explained by disease outbreaks and restrictive policy regulations resulting in limited production possibilities, driven by negative efficiency changes rather than technological improvements. Scale effects of less than one per cent mean that Dutch and Danish pig farms, on average, did not change their size relative to the optimal size.

Keywords: pig farming, efficiency, DEA, productivity growth, Malmquist TFP index

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1. Introduction

Historically, pig farming has been a cyclical production process. Pig production is one of the few agricultural sectors that are most exposed to the market and therefore pig farmers adapt their production in response to market changes (Hadley et al. 2013). Cost control and cost efficiency are important forces behind structural changes in pig production, for example rapidly changes towards increased production specialization and reduction of the number of pig farms, at the same time accompanied by increasing farm sizes.

Pig producers encounter increased pressure to become more efficient to simply remain in business (Tonsor and Featherstone 2009). Productivity changes influence competitiveness and therefore measuring and monitoring production efficiency and productivity of pig farming is important for enhancing profitability.

Various developments affect the international competitiveness of the Dutch pig farming sector. This study is done to gain insight in these economic developments due to new techniques over time and the effects on efficiency performance and productivity growth in pig production in the Netherlands, compared to Denmark.

1.1. The Dutch and Danish pig sectors

Pig production is a major agricultural branch in the Netherlands. Dutch pig farmers have to compete with other pig producing countries in the North-West of Europe, in particular with Denmark. The Netherlands and Denmark have comparable pig production systems. In the Netherlands, pork production accounts for 29% of total livestock production[1]. Data from FADN (the European Farm Accountancy Data Network) reveal that Denmark is the most specialized country in Europe in terms of pig production, with pork production accounting for 46% of the value of total Danish livestock production. According to Eurostat, in 2011 the Netherlands had an average pig population of 12.2 million live pigs and Denmark had an average pig population of 12.3 million live pigs (Eurostat 2012).

Although the Netherlands and Denmark export a large part of their pigs and pork production, the Dutch and Danish inhabitants are also large consumers of these products. In 2006, the Dutch pork consumption was 48.2% of the average total meat consumption of 85 kg per head. In Denmark, pork contributed for 48.7% of the average total meat consumption of 107 kg per head in 2006 (Eurostat 2012).

Pig production in the Netherlands and Denmark consists of three farm types: farrowing farms, fattening farms and ‘closed’ or integrated farms. The integrated farms have both breeding sows and fattening pigs. In both countries, most pig production systems are conventional, there are only a few organic farms (Boogaard et al. 2011). FADN distinguishes pigs based on live weight, regardless of age. Piglets are pigs of less than 20 kg live weight. Fattening pigs are piglets of 20 kg or more, excluding boars and cull sows. Breeding sows are sows of 50 kg or more. Other pigs are pigs of 20 kg or more, but which are not included in the other three categories (European Commission 2001; European Commission 2002).

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[1] Percentages are an own calculation based on the FADN database (2010).

In this study, pig production in the Netherlands and Denmark from 1995 to 2008 is analysed. During this period, different issues occurred that have influenced the pig sector. From February 1997 until March 1998, the Netherlands had to cope with an outbreak of the Classical Swine Fever (CSF). In this period, approximately 700.000 pigs in infected herds were culled, over 1 million pigs were slaughtered pre-emptively and over 7 million pigs were slaughtered for animal welfare reasons (Elbers et al. 1999). Although the CSF reached neighbouring countries as Belgium and Germany, no infection was detected in Denmark. In 2001, the Netherlands were again plagued with a disease outbreak, this time Foot and Mouth Disease (FMD). This outbreak started in February 2001 in Great Britain and was soon thereafter detected in the Netherlands. The disease outbreak officially ended in June 2001 (Bouma et al. 2003). Although no pig herd in the Netherlands was confirmed as infected, 118.000 pigs were culled pre-emptive (CBS 2001) and 104.272 pig herds were vaccinated (Bouma et al. 2003). Pigs are not preventive vaccinated against FMD for export reasons. Pig slaughterhouses in the Netherlands were closed for at least one week, slaughterhouses in affected areas were out of function for nine weeks (CBS 2001).

In the period 1995 to 2008 also policy makers influenced pig farming in both countries. Due to agricultural land-based manure production rights, there was large potential for pig farms with many hectares of arable land to increase their scale of production. To prevent an overproduction of manure, a restructuring law was introduced by the Dutch government in 1998. The manure production rights were replaced by so-called ‘varkensrechten’ or animal production rights which allowed farmers to a maximum number of animals. The aim of this legislation was to slightly reduce pig production in the Netherlands (Baltussen et al. 2010). In 1999, some other manure disposal agreements and regulations were entered, due to environmental policies. In Denmark, the Agriculture Act regulates ownership and use of agricultural land and the number of livestock allowed per amount of farm land. The Danish government also decided to introduce stricter rules regarding livestock density on farm land from 1998 onwards (Rasmussen 2010).

1.2. Problem statement

The Netherlands, Denmark and Germany form almost a single pig production area. The Netherlands and Denmark are competing for these export markets, by exporting the majority of their production of piglets and slaughtering pigs to Germany, as could be seen in Figure 1.1 and Figure 1.2 (Eurostat 2010). In these figures, the arrow width is proportional to the volume of the intra-EU foreign trade surplus, in tons of weight.

In Figures 1.1 and 1.2 is shown that the Netherlands produces and exports a combination of piglets for fattening and fattened pigs for slaughtering. Denmark is mainly exporting piglets for fattening. Denmark accounts for about 74% of EU exports of piglets. Germany is the main importer, with 77% of European imports of piglets (Eurostat 2010).

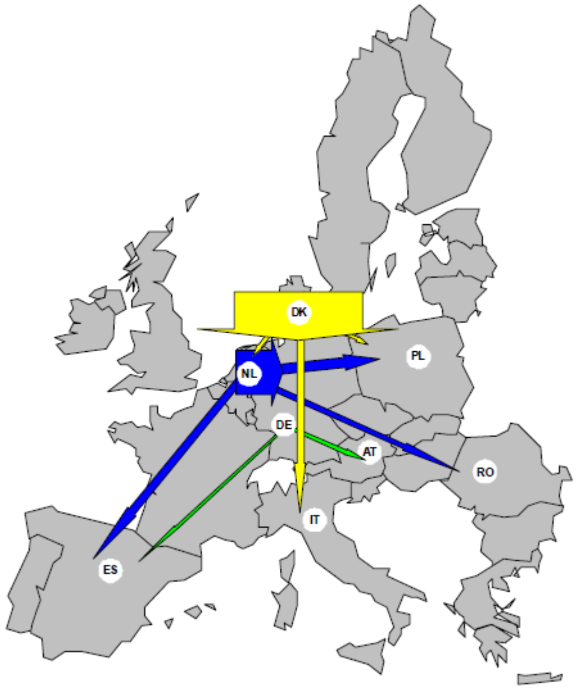

Figure 1.1. Net intra-EU exchanges of piglets for fattening in 2008 (Eurostat, 2010).

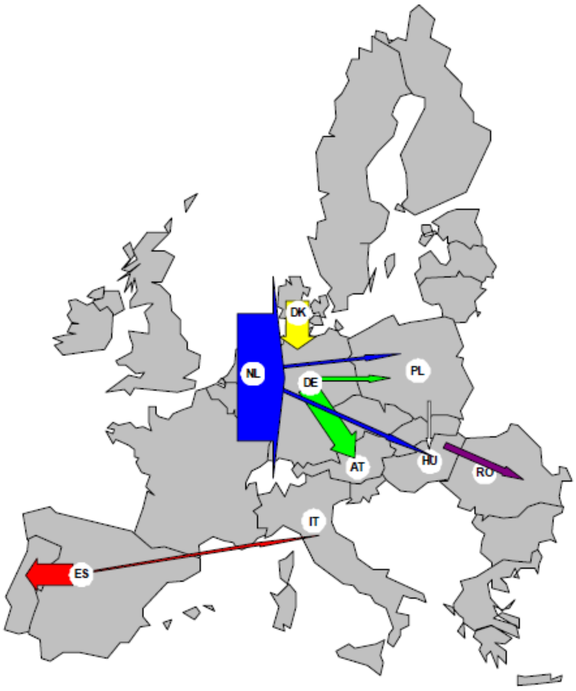

Figure 1.2. Net intra-EU exchanges of pigs for slaughtering in 2008 (Eurostat, 2010).

Denmark is the most important pig producer and exporter in Europe and the largest competitor for the Netherlands. If the lead of Danish pig production grows, this may have consequences for the export position of the Netherlands.

Monitoring efficiency and productivity performance in pig production could have beneficial effects for farmers or the pig farming sector as a whole. Efficiency has a direct impact on the production level and the production costs. The potential for cost reduction is equal to the difference between the observed technical efficiency score and the optimal technical efficiency level of 1 (Lansink and Reinhard 2004).

1.3. Research objective and research questions

The objective of this research is to determine if there are differences in technical efficiency and productivity between Dutch and Danish pig farms and how these differences develop over time. In order to achieve this objectives, the following research questions are formulated:

- What is the average technical efficiency of pig farms in the Netherlands and Denmark?
- What is the evolution of total factor productivity of pig farms over time in the Netherlands and Denmark?
- Are there statistically significant differences in TPF-growth rates between the two countries?

1.4. Research outline

Standard efficiency measurement is the determination of best production performance within a population of farms. Inefficient pig farms either use more inputs to produce a certain quantity of outputs than the best practicing farms, or an inefficient farm produces a smaller quantity of outputs from a given amount of input (Lansink and Reinhard 2004). Pig production efficiency depends on several variables as the feeding ratio and the insemination method, as well as piglet mortality and size class (Galanopoulos et al. 2006). The standard efficiency scores of pig farms in the Netherlands and Denmark are calculated by Data Envelopment Analysis (DEA).

Productivity can be used to compare performance of farms at a given point of time. Productivity change is the movement in productivity performance of farms over time (Coelli and Rao 2005). Total Factor Productivity (TFP) determines overall productivity and can be used to compare the relative productivity of farms in the Netherlands and Denmark, at one point in time. TFP-growth rates can be used to measure relative productivity in a certain production period, compared to productivity in the previous period (Coelli and Rao 2005). In this study, TFP is measured using the Malmquist index methods. Malmquist indices derived with the use of DEA have often been employed for investigating changes in productivity, either at a farm or sector level in agriculture. However, since DEA is deterministic and a frontier estimation is therefore likely to be sensitive to measurement errors (Sharma et al. 1997), DEA results will be bootstrapped to avoid statistical noise.

The thesis is organised as follows: chapter 2 contains a description of the data and an explanation of the TFP growth, DEA and bootstrapping calculations used in this research. Chapter 3 presents the results from DEA efficiency measurements and the Malmquist TFP index. The last chapter considers the discussion over the results and the conclusions of the study.

1.5. Empirical studies

Research on efficiency and productivity of pig production is, compared with other agricultural enterprises, limited and has focused on several different subjects. Besides that, different approaches are used to measure efficiency and productivity, which vary over time and between countries. Changes in agricultural efficiency and productivity over time can be attributed to a number of factors. Technical change is often mentioned as the most important factor, but also changes in production scale, changes in technical efficiency and changes in input and output composition can contribute (Rasmussen 2010).

One of the first efficiency studies on pig production is done by Sharma et al. in 1997. In 1998, Rowland et al. investigated efficiency in farrow-to-finish farms in the United States. According to their research, scale efficiency is positively related to revenues from pig production. Two variables, number of litters per farm per year and pounds of meat produced per litter per year, were found to have a positive and significant impact on technical efficiency (Rowland et al. 1998). Key and McBride (2003) also investigated productivity of pig production in the United States. They identified increased knowledge and information transfer as important reasons for increased productivity. Tonsor and Featherstone (2009) also inquired into production efficiency of specialized pig producers in the United States. Their research concluded that pig production changed drastically in recent years. Tonsor and Featherstone (2009) mentioned that understanding of differences in productivity across production specializations is necessary to understand the on-going transition to more specialized production and to anticipate the future of the pig production industry.

Furthermore, Tonsor and Featherstone (2009) found bootstrapped confidence intervals to prove significant differences in efficiency across different pig production specializations.

Oude Lansink and Reinhard (2004) investigated technical and environmental performance of Dutch pig fattening farms using DEA and found a high overall technical efficiency score for Dutch pig fattening farms. This study found that Dutch farmers that are engaged in other (non-pig) activities produced less efficient compared to specialized pig farmers. The presence of many pig farms engaged in similar activities had no effect, so external scale economies can be neglected. Moreover, they concluded that pig fattening farms in the Netherlands operate on a scale which is close to the optimal size, with scale efficiency of, on average, 98%. Oude Lansink and Reinhard (2004) also computed technical change as the change of the frontier due to addition of virtual farms to the dataset. This research demonstrated the usefulness of DEA in analysing future technology options of pig production.

Agricultural productivity growth in Denmark is measured by Rasmussen (2010). This study investigated TFP growth and individual TFP growth components for pig farming, dairy farming and crop farming and found that technical efficiency scores decreased with farmer age and farm size. Input scale efficiency of Danish pig farms increased significantly over the time period 1985 to 2006. Rasmussen (2010) suggests this gradually increase not only contributes to an absolute larger scale, but also towards a more efficient scale of production.

2. Materials and methods

2.1. Description of the data

Data on pig production farms are collected from FADN, the European Farm Accountancy Data Network. FADN, which started sampling in 1965, collects every year accountancy data from a sample of agricultural firms in the European Union. The FADN network does not contain data from all agricultural holdings, but includes only farms deemed to be commercial. Commercial farms are classified according to a minimum economic size, expressed in European Size Units (ESU). In the FADN data network, farms are distinguished based on three criteria: region, economic size and type of farming. FADN uses a rotating sampling scheme, in which farms remain in the panel for on average four to five years, to avoid selection bias (FADN 2010).

The dataset used for this study contains information from pig producers in the Netherlands and Denmark, with farm data from 1995 to 2008. The farms are selected based on revenues derived from pig production. Only farms with 75% or more of their revenues derived from pig production are kept in the dataset. Farms with extreme outliers in one or more years of observation are removed from the dataset. After selecting the data with these requirements, the dataset for the Netherlands includes 273 pig farms, with a total of 1568 observations. The dataset for Denmark contains 3588 observations, derived from 1064 pig farms.

Pig production features multiple outputs and multiple inputs. The variables used in the model are specified into two outputs and five inputs. FADN is used to construct the variables (see Appendix I). The two defined outputs are:

1. Revenues from pigs. This output value includes deflated revenues from production of piglets, fattening pigs and pork.
2. Other output, which means deflated sales of all other output produced on the farm. Other output is calculated as total output minus output from pig production.

Five input variables are specified: capital, labour, livestock, feed and materials. These five categories are described in the model as:

1. Capital includes all fixed inputs and contains machinery, agricultural land, permanent crops, land improvements and farm buildings. For each component an average and deflated value is calculated. The average value is calculated by summing up the beginning value and closing value of each observation and dividing it by two.
2. Labour contains paid and unpaid labour, which has contributed to the production of the farm during the accounting year. Labour is measured in Annual Working Units (AWU).
3. Livestock is measured as the deflated value of all livestock, so the average value of pigs and other animals present in the farm during the accounting year.
4. Feed consists of purchased feed, measured in terms of deflated values. Home-grown feed, which is produced on the farm, is not included, because this is included as a cost to other inputs.
5. Materials is a category of inputs, which contains: seeds and plants, fertilizers, crop protection, crop-specific costs, feed for other livestock, livestock-specific costs, energy and other direct inputs. The eight components are deflated separately, with different price indices.

All variables are valued in monetary terms, except labour. To measure efficiency and productivity of pig production over time independent of inflation, revenues and input costs are deflated. The input and output values are deflated using price indices obtained from Eurostat, specified for the Netherlands and Denmark (see Appendix II). The base year for deflation is 2000. The output variables are deflated after the equations were defined. The individual components of the input variables were deflated before the variables were constructed.

After constructing the variables, there were some observations with a negative value for other output. For the Netherlands, 32 observations with a negative other output were observed, that means 2.0% of all observations. For Denmark, seven observations had negative other output, which is only 0.2%. The observations with negative values for other output were excluded from the dataset. There were also observations with a positive value for other output close to zero, which means the pigs output is almost equal to the total output of the farm. This can also be problematic, because these farms are too specialized in pig production. DEA cannot easily deal with zero output, therefore farms with zero other output were also excluded from the dataset. Due to this restriction, again 38 observations (2.5%) were dropped out for the Netherlands. For Denmark only two observations (0.01%) were additionally removed. The final dataset used for the efficiency and productivity measurements contains 1498 observations for the Netherlands and 3579 observations for Denmark.

The average values and corresponding standard deviations of the constructed variables are calculated. The summary statistics of the constructed output variables and input variables appear in table 2.1 and 2.2 for the Netherlands and Denmark, respectively.

Table 2.1. Summary statistics for the Netherlands

		The Netherlands			
Variables		**Mean**	**SD**	**Min.**	**Max.**
Pigs	(€)	544900	435942	17440	2833000
Other Output	(€)	25270	42497	6	542800
Capital	(€)	859900	688067	14570	5071000
Labour	(AWU)	2.00	1.20	0.30	7.73
Livestock	(€)	235700	184438	12740	1240000
Feed	(€)	259100	201346	13630	1299000
Materials	(€)	99240	80333	7606	641900

Table 2.2. Summary Statistics for Denmark

		Denmark			
Variables		**Mean**	**SD**	**Min.**	**Max.**
Pigs	(€)	555700	421141	13790	3682000
Other Output	(€)	90830	77368	3	861000
Capital	(€)	1584000	1445655	704	13560000
Labour	(AWU)	2.97	1.96	0.33	17.00
Livestock	(€)	231300	179577	7631	1794000
Feed	(€)	243600	174485	12370	1814000
Materials	(€)	85890	63605	3510	554300

2.2. Total Factor Productivity growth

Farm productivity can be defined as the ratio of output that a farm produces to the inputs that are used. The Total Factor Productivity (TFP) is a variable which accounts for the effects in total output, involving all inputs, outputs and production factors (Coelli and Rao 2005). TFP determines productivity of farms at a given point of time. In contrast, TFP growth determines the rate of change and movement in productivity performance of a farm over time.

TFP growth can be measured by using Data Envelopment Analysis (DEA), because TFP growth is the product of individual effects as technical change, efficiency change and scale efficiency (Coelli and Rao 2005). These effects constitute independent factors of productivity change (Balk 2001). DEA is a linear programming approach to the estimation production frontiers and the calculation of efficiency methods. The methodology of DEA will be further explained in paragraph 2.3.

The Malmquist TFP index is used to determine TFP growth. The Malmquist Index is proposed by Malmquist (1953) and formalized by Caves, Christenen and Diewert in 1982. Succeeding these introducers, Färe et al. (1994) describes how the Malmquist TFP index can be expressed as the product of a technical efficiency change index and a technical change index.

The Malmquist TFP index is defined using distance functions. The index measures the TFP growth between two data points, by calculating the ratio of the distances of each data point (Coelli et al. 2005). Distance functions describe a multi-input, multi-output production technology.

The output distance function is defined on the output set P(x), where $P(x) = \{ q{:}x \text{ can produce } q \}$, as:

$$d_o(x,q) = \min \{\delta : (q/\delta) \in P(x)\} \quad (1)$$

where the output set P(x) represents the set of all output vectors q, which can be produced using the input vector x. The output set P(x) implies that it is not possible to produce unlimited levels of outputs, with a given set of inputs. The output distance function $d_o(x,q)$ can be directly estimated using DEA, because DEA can identify production frontiers and can compute a distance value δ. The distance function $d_o(x,q)$ will take a value less or equal to one, if the output vector q is an element of the production set P(x) (Coelli et al. 2005).

Because of the use of distance functions, Malmquist indexes do not require input or output prices and do not require the researcher to specify objectives such as cost minimization or profit maximization. An input distance function focuses on a maximal proportional contraction of the input vector, given an output vector. An output distance function considers a maximal proportional expansion, given an input vector. The input and output distance functions describe the same underlying technology (Coelli et al. 2005).

The Malmquist TFP index measures TFP growth between certain data points. The Malmquist TFP index measures the proportional change in outputs between the base period s and period t, this is illustrated in Figure 2.1.

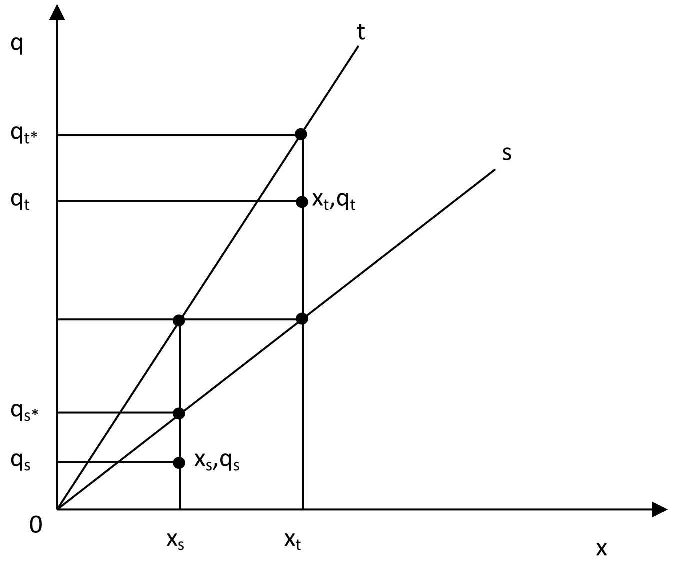

Figure 2.1 Malmquist TFP index

Figure 2.1 illustrates a single input - single output Malmquist index, where the farm produces output q_s and q_t in period *s* and period *t*, respectively. The curve *t* is the production frontier in period *t* and curve *s* is the production frontier in period *s*. In both periods, the farm is producing below the optimal production technology. In period *s*, the farm can increase productivity in time *s* depending on the distance towards point q_{s^*} on the production frontier *s*. In Figure 3.1 the farm can increase productivity in period *t* even more, depending on the distance towards point q_{t^*}. The increase in productivity between period *s* and period *t* is due to the effect of technical progress and changed technologies.

The output-oriented index for period *s* and period *t*, with d^c as the distance function under CRS and d^v as the distance function under VRS, is defined as:

$$m_o(q_s, x_s, q_t, x_t) = \left[\frac{d_o^{cs}(q_t, x_t)}{d_o^{cs}(q_s, x_s)} \times \frac{d_o^{ct}(q_t, x_t)}{d_o^{ct}(q_s, x_s)} \right]^{½} \qquad (2)$$

and a decomposition of this productivity index is:

$$m_o(q_s, x_s, q_t, x_t) = \frac{d_o^{ct}(q_t, x_t)}{d_o^{cs}(q_s, x_s)} \times \left[\frac{d_o^{cs}(q_t, x_t)}{d_o^{ct}(q_t, x_t)} \times \frac{d_o^{cs}(q_s, x_s)}{d_o^{ct}(q_s, x_s)} \right]^{½} \qquad (3)$$

where the first term $d_o^{cs}(q_t, x_t)$ represents the distance from the period *t* observation to the period *s* frontier. A value of m_o greater than one indicates a positive TFP growth from period *s* to period *t* and a value of m_o below one indicates a decline in TFP (Coelli and Rao 2005). The four distance measures *d* can be calculated by solving four linear programming models, by using DEA (Färe et al. 1994).

From the second equation (3), the technical change and efficiency change can be derived (Färe et al. 1994). The ratio outside the brackets is the change in relative efficiency between period *s* and *t*:

$$\frac{d_o^{ct}(q_t, x_t)}{d_o^{cs}(q_s, x_s)} \tag{4}$$

The efficiency change is the movement to the production frontier and is equivalent to the ratio of the technical efficiency in period *t* to the technical efficiency in period *s* (Coelli et al. 2005).

The geometric mean of the two ratios inside the brackets captures the shift in technology between period *s* and period *t*, so the technical change is defined as:

$$\left[\frac{d_o^{cs}(q_t, x_t)}{d_o^{ct}(q_t, x_t)} \times \frac{d_o^{cs}(q_s, x_s)}{d_o^{ct}(q_s, x_s)}\right]^{½} \tag{5}$$

The relative efficiency change can be divided into two components, the pure technical efficiency and scale efficiency change (Färe et al. 1994). The pure efficiency change is technical efficiency free from scale effects. Pure efficiency captures the ability of a farm to become more efficient in production, due to new technologies. Pure efficiency change is defined as:

$$\frac{d_o^{vt}(q_t, x_t)}{d_o^{vs}(q_s, x_s)} \tag{6}$$

Coelli et al. (2005) considered scale efficiency change as the effect of a farm being able to become more productive by adjusting its scale. The scale efficiency change is defined as:

$$\frac{d_o^{vt}(q_t, x_t) \,/\, d_o^{vt}(q_t, x_t)}{d_o^{vs}(q_s, x_s) \,/\, d_o^{vs}(q_s, x_s)} \tag{7}$$

Efficiency scores and productivity differences can be obtained by using distance calculations from the technical production frontier. The required distance functions for the Malmquist TFP index can be calculated using Data Envelopment Analysis (DEA) (Coelli et al. 2005).

2.3. Data Envelopment Analysis

DEA is used to construct a piece-wise linear production frontier over the data. Linear programming methods are used to construct this non-parametric frontier. The frontier is estimated from a set of *N* observed farms (Simar and Wilson 1998). Technical efficiency can be measured relative to the frontier, as the distance between the observed data point and the frontier (Coelli et al. 2005).

DEA can be either input-oriented or output-oriented. If the analysis is input-oriented, the DEA method defines the frontier by seeking the maximum possible proportional reduction in input usage, with fixed output levels. If the analysis is output-oriented, the DEA method seeks the maximum increase in output production, with fixed input levels (Coelli et al. 2005). In this study, DEA is output-oriented. The output orientation is selected, because in agriculture in general it seems to be more logical to produce with a fixed set of inputs and trying to reach the maximum attainable level of outputs, rather than the opposite. Beside fixed inputs as capital, also inputs as unpaid (family) labour can be assumed to be nearly fixed.

Given data for *N* farms in a particular time period, the linear programming model for an output-oriented DEA model can be defined as:

$$\begin{aligned} &\max_{\theta,\lambda} \quad \theta, \\ &st^{2} \quad -\theta q_i + Q\lambda \geq 0, \\ &\qquad x_i - X\lambda \geq 0, \\ &\qquad \lambda \geq 0, \end{aligned} \tag{8}$$

where θ is a scalar, λ is a *N*x1 vector of weights, q_i is a *M*x1 vector of output quantities for the *i*th farm, x_i is a *K*x1 vector of input quantities for the *i*th farm, Q is a *N*x*M* matrix of output quantities for all *N* farms and X is a *N*x*K* matrix of input quantities for all *N* farms. The scalar θ takes a value equal to one or greater than one, so θ – 1 is the proportional increase in outputs that could be achieved by the *i*th farm (Coelli et al. 2005).

The radial contraction of the input vector, x_i, produces a projected point (Xλ, Qλ) on the surface of this technology. The constraints in the equation ensure that this projected point lies within the feasible production set. The feasible set is the set of all input-output combinations that are feasible and therefore consists of all points along the production frontier (Coelli et al. 2005).

The two orientation methods provide the same technical efficiency scores under Constant Returns to Scale (CRS), but different scores under Variable Returns to Scale (VRS) (Coelli et al. 2005). Returns to scale properties are important for the calculation of TFP. In case of CRS output increases proportionally to increased input, while under VRS the increase in output is more or less proportional to the increase in input and the returns to scale can be increasing or decreasing.

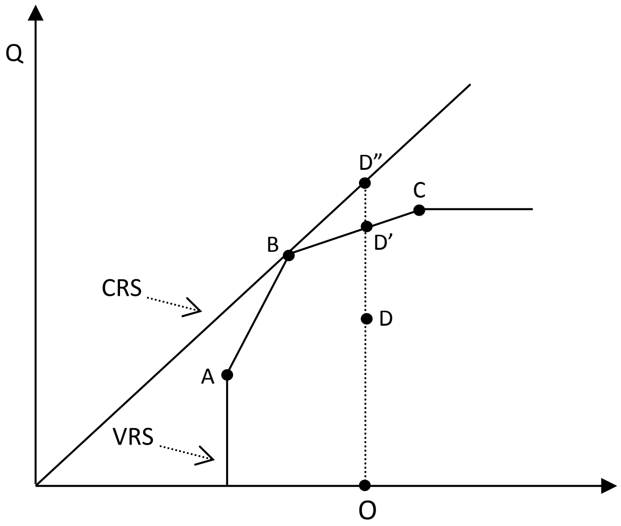

Figure 2.2. Output-oriented DEA

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[2] The notation “st” stands for “subject to” (Coelli et al. 2005).

The isoquant in Figure 2.2 is an illustration of an output-oriented DEA problem. In this one-input, one-output example, four farms are included. Farm A, B and C are efficient farms, because these farms define the frontier. Farm D is therefore mentioned as an inefficient farm. Farms B and C are peers for farm D. The peers define the relevant part of the frontier and the points where farm D could produce efficient, that is point D’ and D’’. The distances DD’ and DD’’ are the amounts by which all outputs could be proportionally increased without increasing inputs, depending on the technology used. In this DEA output example, farms A, B and C would have an efficiency score equal to one, these farms would also be their own peer (Coelli and Rao 2005).

Data can always be enveloped with a VRS model as well as a CRS model (Balk 2001). Figure 2.2 also shows that both technologies can be used for DEA measurements. For the calculation of technical efficiency and change in relative efficiency, CRS is satisfactory. CRS is applied when it is assumed that all farms operate at an optimal scale, but in practice, due to imperfect competition, restrictions and policy regulations this is not often the case. Therefore, in this study it is more reasonable to use VRS. The use of VRS enables technical efficiency calculations devoid of scale effects (Coelli et al. 2005).

The linear programming model for an output-oriented DEA-model provides information for the technical efficiency score (TE). In this case, it is assumed that the model contains two outputs, produced with identical input vectors. Under CRS, the technical inefficiency of point D is DD’’, while under VRS the technical inefficiency of point D is DD’. Technical inefficiency can be measured as:

$$TE_{crs} = OD / OD'' \tag{9}$$

$$TE_{vrs} = OD / OD' \tag{10}$$

Technical efficiency measured under CRS and technical efficiency measured under VRS is equal if farms operate at an optimal scale. If the underlying production technology is CRS, the farm is automatically scale efficient. If there is a difference between these two technical efficiency scores, D’ and D’’, for a particular farm, this is due to scale inefficiency (Coelli et al. 2005). Scale efficiency (SE) is defined as:

$$SE = TE_{crs} / TE_{vrs} = (OD / OD'') / (OD / OD') = OD'' / OD' \tag{11}$$

As a farm is usually unable to alter its scale of operation in the short run, one could view the TE_{vrs} score (equation 10) as a reflection of what can be achieved in the short run and the TE_{crs} score (equation 9) as the possibilities in the long run. Besides scale efficiency, another efficiency measure can be obtained by decomposing technical efficiency, namely pure technical efficiency (Coelli et al. 2005). All efficiency measurements are between zero and one, as a value of one means complete efficiency.

2.4. Bootstrapping

Data Envelopment Analysis (DEA) is suitable to calculate Malmquist productivity indices. The disadvantage of DEA is that estimate results may be affected by sampling variation, causing distances relative to the frontier to be underestimated. This underestimation or bias is due to the fact that DEA is referred as being deterministic, but efficiency is measured relative to an estimate of the true (but unobserved) production frontier. The issue of uncertainty due to sampling variation in DEA models is revealed by Simar and Wilson (1998), which resulted in the introduction of the bootstrapping method as a statistical interpretation also for the Malmquist TFP index.

Bootstrapping is a method which can deal with sampling variability of the finite DEA-dataset. Bootstrapping allows the construction of confidence intervals for DEA efficiency scores, by equalizing the empirical distribution (Balcombe et al. 2008). The key principle of bootstrapping is to provide an infinite simulation of the true sampling distribution, by repeating observations from an unknown population and using the obtained data sample as a basis. The simulation involves replicating the data-generating process, thereby creating a large number B of pseudo-estimates. By doing this data-generating process for period *s* and period *t*, the simulation is defined by:

$$S^* = \{x_{it}^*, y_{it}^*) \mid i = 1,\dots,N \; ; t,s\} \tag{12}$$

and applying the original estimators to these pseudo-samples, where each bootstrap replication measures the distance from an observation in the original sample *S* to the frontiers estimated for either period from the pseudo-data in sample *S**(Simar and Wilson 1999). The bootstrap method is based on the idea that if *S** is a reasonable estimator of *S*, the known bootstrap distribution will mimic the original unknown sampling distributions of the estimators of interest (Simar and Wilson 1998).

After computing the bootstrap values , the original estimators of the distance functions or Malmquist indices can be corrected for any finite-sample bias. The set of bootstrap Malmquist indices will be used as an alternative to statistical inference, based on parametric assumptions, to remove bias and calculate standard errors. Consider the set of bootstrap estimates for the Malmquist index for each farm $i = 1, \dots, N$ and bootstrap replication $b = 1, \dots, B$ as:

$$\{ \widehat{M}_i^* (t,s)\,(b) \}_{b=1}^{B} \} \tag{13}$$

The efficiency and technology change indices can be analysed similarly (Simar and Wilson 1999). The bootstrap bias estimate for the original estimator $\widehat{M}_i\,(t,s)$ is defined as:

$$\widehat{\text{bias}}_{\mathbf{B}}\,[\widehat{M}_i\,(t,s)] = B^{-1}\textstyle\sum_{b=1}^{B} \widehat{M}_i^*\,(t,s)\,(b) - \widehat{M}_i\,(t,s) \tag{14}$$

which is the empirical bootstrap analog of $E[\widehat{M}_i\,(t,s)] - M_i\,(t,s)$. Therefore, a bias-corrected estimate of $M_i\,(t,s)$ can be defined as:

$$\begin{aligned} \widehat{\widehat{M}}_i\,(t,s) &= \widehat{M}_i\,(t,s) - \widehat{\text{bias}}_{\mathbf{B}}\,[\widehat{M}_i\,(t,s)] \\ &= 2\,\widehat{M}_i\,(t,s) - B^{-1}\textstyle\sum_{b=1}^{B} \widehat{M}_i^*\,(t,s)\,(b) \end{aligned} \tag{15}$$

In the previous equation (15) $\widehat{\widehat{M}}_i\,(t,s)$ is bias-corrected, rather than an unbiased, estimator, since the equation includes only a first-order correction of the bias in $\widehat{M}_i\,(t,s)$ (Simar and Wilson 1999). This equation is used to calculate the bias-corrected estimates of the efficiency and productivity measures.

The confidence intervals were calculated to obtain an empirical approximation to the bootstrapped distribution. The confidence intervals were calculated on the bias-corrected estimator, by sorting the values ($\widehat{M}_i^*$ (t,s) (b) - $\widehat{M}_i$ (t,s)), $b = 1, \ldots, B$ by algebraic value and then subtracting (($\alpha/2$) x 100)-percent of the elements at either end of the array (Simar and Wilson 1999). In this case, for calculation of the 95% confidence intervals, $\alpha = 0.05$ is used.

In this study, maintaining the assumption of variable returns to scale, a set of 2000 bootstrap iterations were performed (Wilson 2010). The simulated data-generating process results in a distribution of efficiency and productivity measures that represents an estimate of the true distribution. By approximating the sampling variation of the estimated frontier, sensitivity of efficiency scores can be analysed (Simar and Wilson 1998). The bootstrapped results should provide a statistically substantiated conclusion of efficiency and productivity measurements of this research.

3. Results

In this chapter, the results obtained by using DEA and the Malmquist TFP index in combination with the bootstrap method are summarized. In the first section, the efficiency scores obtained with DEA are presented[3][4]. In the second section, the TFP growth rates and TFP growth components are presented. The results are obtained by comparing 1498 observations of the Netherlands to 3579 observations of Denmark, with samples from 1995 to 2008. The annual number of observations is shown in Table 3.1.

3.1. Data Envelopment Analysis

In this study, an output-oriented DEA method is used. Figures 3.1 and 3.2 show the distribution of the estimated non-bias corrected technical efficiency scores for 1995 to 2008 under variable returns to scale, respectively for the Netherlands and Denmark. The shape of Figure 3.1 suggests a higher variability of efficiency scores for the Netherlands. This result could be due to the smaller sample size or less homogeneity among pig farms in the Netherlands, compared to Denmark.

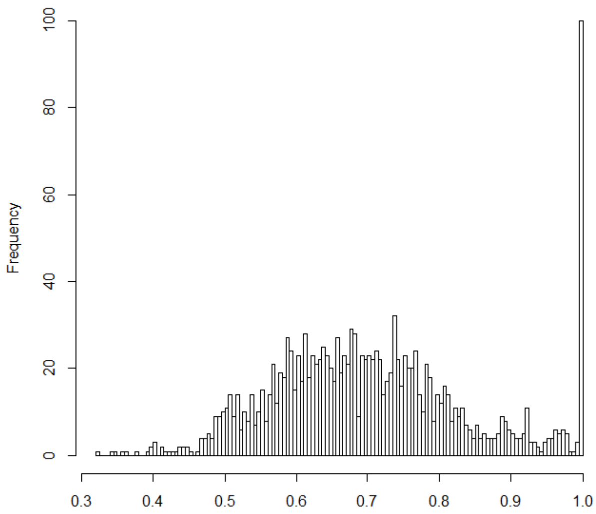

Figure 3.1. Technical efficiency for the Netherlands

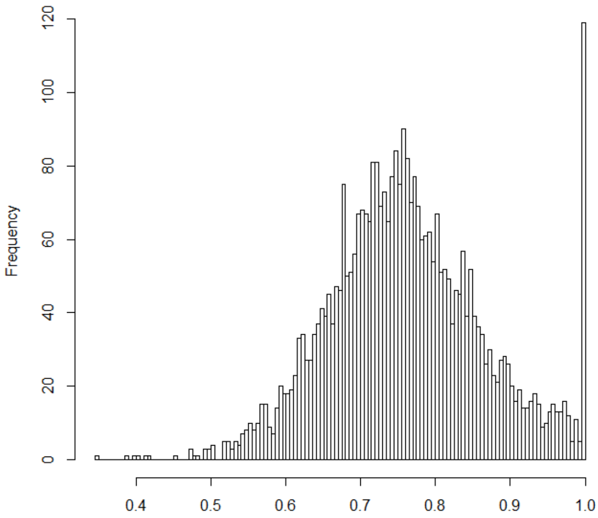

Figure 3.2. Technical efficiency for Denmark

Table 3.1 presents the estimated average values of the bias-corrected technical efficiency for both countries. The mean of technical efficiency for the Netherlands over the sample period is 0.8443, with a standard deviation of 0.0618. The overall mean for Denmark is 0.8246, with a standard deviation of 0.0267. Note that the overall mean implies that over the fourteen-year period of time, pig farms in the Netherlands and Denmark produced respectively 84.4% and 82.5% of the output that could potentially have been produced by using the given input quantities. These technical efficiency scores are lower than technical efficiency scores found in empirical studies. Lansink and Reinhard (2004) found that pig farms in the Netherlands were 90% technical efficient (Lansink and Reinhard 2004), compared to a technical efficiency score of 88% for Denmark (Rasmussen 2010).

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[3] Data of FADN was analysed with R, the software of the R-project is designed for statistical computing.

[4] The package 'FEAR is used for frontier efficiency analysis with R (Wilson 2010).

Table 3.1. Technical Efficiency for the Netherlands and Denmark, for 1995 to 2008

	Technical efficiency			Number of observations	
Years	**The Netherlands**	**Denmark**		**The Netherlands**	**Denmark**
1995	0.8853	0.8412		91	222
1996	0.8565	0.8575		111	284
1997	0.8555	0.8340		97	268
1998	0.7844	0.8140		86	178
1999	0.8971	0.8428		96	242
2000	0.9004	0.8570		99	297
2001	0.6608	0.8533		96	327
2002	0.7913	0.7985		105	294
2003	0.8786	0.8043		100	252
2004	0.8897	0.8181		127	324
2005	0.8617	0.8026		125	321
2006	0.8726	0.8104		124	256
2007	0.8421	0.8524		126	129
2008	0.8795	0.7642		115	185
Average	**0.8443**	**0.8246**	**Total**	**1498**	**3579**

In Table 3.1 is shown that the lowest technical efficiency scores for the Netherlands were observed in 1998 and 2001. This reduction in efficiency can be explained by the outbreak of animal diseases, the Classical Swine Fever (CSF) in 1997-1998 (Elbers et al. 1999) and Foot and Mouth Disease (FMD) in 2001 (Bouma et al. 2003). Both disease outbreaks did not occur in Denmark during that time. Although, Denmark could have encountered disadvantages of these outbreaks in the Netherlands, especially the CSF outbreak. The relatively low technical efficiency score for Denmark in 1998 could be explained by the occurrence of CSF in other European countries, because these disease outbreaks resulted in market restrictions and export bans for pork.

The policy regulations for agricultural production, introduced in 1998 for both the Netherlands and Denmark, could have influenced technical efficiency. However, Rasmussen (2010) mentioned that these regulations apparently did not significantly influence the adjustment of farm scale and level of production in Denmark (Rasmussen 2010).

Technical efficiency scores are relatively constant over time, despite the fact that most farms remain in the dataset for more than one year. The relatively constant values can be explained by the fact that new farms entering the sample must on average have an higher technical efficiency than farms remaining in the sample. However, FADN leaves farms up in the sample for a maximum period of five years.

3.2. Total Factor Productivity growth

This sections shows the bootstrapped results of Total Factor Productivity (TFP) growth. In Table 3.2 the Malmquist index numbers for each year are shown. These numbers and the corresponding confidence intervals are bias-corrected.

Figure 3.3 shows the cumulative TFP growth per year for Dutch and Danish farms. The base year is 1995, with a value of 1. In figure 3.3 can be observed that no measure of productivity growth is available for Denmark from 2006 to 2007. In 2006, FADN renewed the entire pig farming dataset for Denmark, therefore no productivity change between 2006 and 2007 could be measured.

For Malmquist index numbers and TFP growth components, geometric averages are used instead of arithmetic means. Because TFP growth values are not independent of each other, the average value of a certain time period is more accurate represented by the geometric mean. Besides that, the geometric mean is also more sensitive to extreme values.

Table 3.2. Malmquist index numbers

	The Netherlands			Denmark		
Years	**Malmquist**	**5%**	**95%**	**Malmquist**	**5%**	**95%**
1995-1996	1.0818	1.0746	1.0862	0.9718	0.9692	0.9753
1996-1997	0.9817	0.9768	0.9875	0.9726	0.9707	0.9784
1997-1998	0.8243	0.8109	0.8274	0.8904	0.8833	0.8949
1998-1999	1.1462	1.1397	1.1552	1.1874	1.1812	1.1917
1999-2000	1.1124	1.1093	1.1288	1.0113	1.0078	1.0120
2000-2001	0.9058	0.8833	0.9102	0.9385	0.9369	0.9421
2001-2002	1.0467	1.0431	1.0593	0.9185	0.9112	0.9197
2002-2003	1.0023	0.9953	1.0092	1.0741	1.0651	1.0749
2003-2004	1.1074	1.1026	1.1112	1.0296	1.0266	1.0356
2004-2005	0.9160	0.9094	0.9180	0.9847	0.9821	0.9878
2005-2006	0.9563	0.9539	0.9657	1.0139	1.0077	1.0149
2006-2007	0.9330	0.9249	0.9347	-	-	-
2007-2008	1.1589	1.1510	1.1608	1.0616	1.0620	1.0849
Average	**1.0082**			**1.0017**		

In Table 3.2 the results of the Malmquist index are presented. The average annual result for the Netherlands is an increase in productivity with 0.8%. The average annual result for Denmark is a productivity growth of 0.2%. The estimates of productivity growth are statistically significant at the $\alpha = 0.05$ level in all but one instance. Except for the period 1996-1997, there are no overlapping confidence intervals and therefore the differences in productivity growth between the Netherlands and Denmark in all other years are statistically proven.

No previous measurements of productivity growth for pig farming in the Netherlands are available. The study of Lansink and Reinhard calculated only a potential technological development of 4%, based on technical efficiencies and scale efficiencies (Lansink and Reinhard 2004). Rasmussen (2010) measured for Danish pig farms a productivity change of 2.1% over the period 1985-2006. Although pig farming had the lowest productivity growth of the investigated agricultural sectors, technological changes in pig farming increased significantly over this time period (Rasmussen 2010).

TFP growth development in the period 1995 to 2008 is shown in the graph of Figure 3.3. The blue line represents the productivity growth in the Netherlands and the red line the productivity growth in Denmark. The graph shows also that overall productivity growth is higher in the Netherlands. Although pig farms in the Netherlands experienced a deeper decline around 1998, their productivity growth in next years is larger. This pattern can be expected, because a deeper drop in productivity growth needs a relatively larger growth to reach the same productivity level again. The decline between 1997 and 1998 can be explained by the CSF outbreak (Elbers et al. 1999).

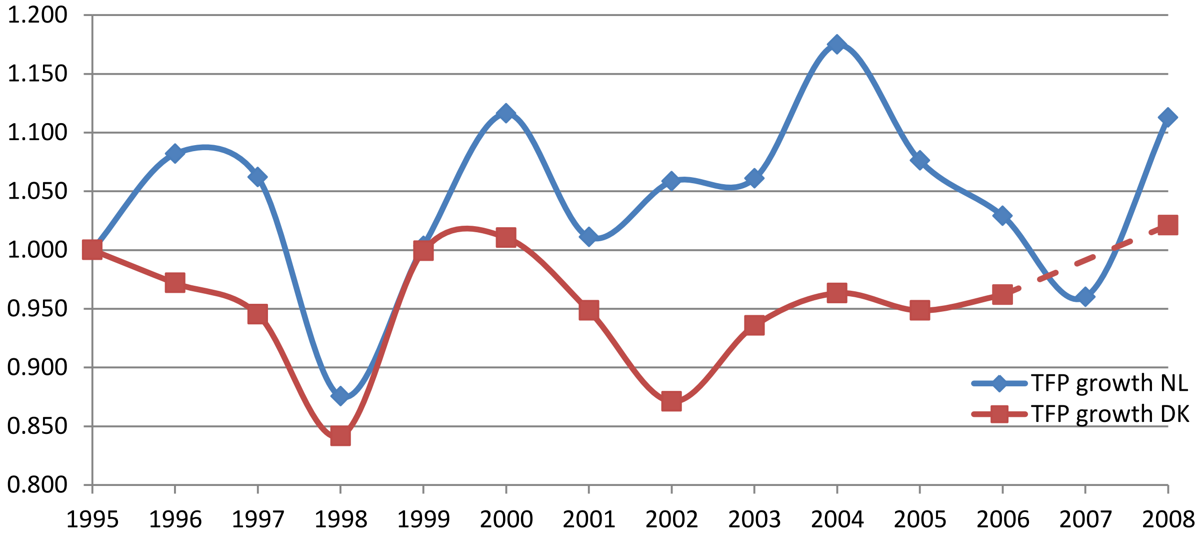

Figure 3.3. TFP growth for the Netherlands (NL) and Denmark (DK), for 1995 to 2008

3.2.1. TFP growth components

This paragraph describes the results found for the four TFP components. First technical change and efficiency change are treated. Moreover, efficiency change is further divided into pure efficiency change and scale efficiency change.

Table 3.3 describes the technical change for the Netherlands and Denmark, for 1995 to 2008. Technical change represents the shift in technology as the distance between the frontier in period *s* relative to frontier in period *t* (Balk 2001). In this study, a period between two frontiers covers one year. The distance between the measured frontier and the frontier of best practice farms is a indication of the potential for improving technical performance, due to technologies that are new from the perspective of the farmer (Lansink and Reinhard 2004).

The annual technical change is 1.7% for the Netherlands compared to 1.9% for Denmark. The higher technical change in Denmark implies that Danish farms were more able to achieve advantages from technical progress. With the exception of the year 1997-1998, all technical change measurements are significantly different between the Netherlands and Denmark.

Table 3.3. Technical change for the Netherlands and Denmark, for 1995 to 2008

	The Netherlands			**Denmark**		
Years	**Tech. change**	**5%**	**95%**	**Tech. change**	**5%**	**95%**
1995-1996	1.0912	1.0808	1.1304	0.9653	0.9446	0.9771
1996-1997	0.9842	0.9647	1.0170	1.0110	1.0035	1.0378
1997-1998	0.8949	0.8852	0.9508	0.8883	0.8734	0.9133
1998-1999	1.0508	0.9546	1.0410	1.1764	1.1427	1.1907
1999-2000	1.1086	1.0873	1.1360	1.0109	0.9883	1.0177
2000-2001	1.2490	1.3133	1.4369	0.9452	0.9322	0.9595
2001-2002	0.9435	0.8153	0.9426	0.9685	0.9675	0.9987
2002-2003	0.8913	0.8328	0.8961	1.0715	1.0380	1.0834
2003-2004	1.1090	1.0709	1.1167	1.0173	0.9893	1.0296
2004-2005	0.9183	0.9030	0.9403	1.0074	0.9945	1.0308
2005-2006	0.9450	0.9226	0.9622	1.0081	0.9823	1.0221
2006-2007	0.9750	0.9647	1.0076	-	-	-
2007-2008	1.1332	1.0888	1.1385	1.1937	1.2106	1.2830
Average	**1.0173**			**1.0186**		

Table 3.4 presents the efficiency change for both countries. The annual efficiency change is -0.89% for the Netherlands and -1.66% for Denmark. There are overlapping confidence intervals for six out of thirteen years, which means that no significant efficiency changes exist between the Netherlands and Denmark. Both countries show on average a decline in efficiency change, which implies that pig farms had difficulties with becoming more efficient in producing output without adjusting the inputs.

Table 3.4. Efficiency change for the Netherlands and Denmark, for 1995 to 2008

	The Netherlands			**Denmark**		
Years	**Eff. change**	**5%**	**95%**	**Eff. change**	**5%**	**95%**
1995-1996	0.9914	0.9498	0.9959	1.0067	0.9943	1.0257
1996-1997	0.9974	0.9606	1.0101	0.9620	0.9357	0.9673
1997-1998	0.9211	0.8468	0.9192	1.0024	0.9700	1.0150
1998-1999	1.0907	1.0967	1.1755	1.0093	0.9960	1.0326
1999-2000	1.0034	0.9833	1.0234	1.0003	0.9910	1.0181
2000-2001	0.7253	0.5795	0.6734	0.9929	0.9777	1.0037
2001-2002	1.1093	1.1081	1.2296	0.9484	0.9141	0.9441
2002-2003	1.1246	1.1171	1.1871	1.0024	0.9852	1.0250
2003-2004	0.9986	0.9886	1.0282	1.0120	0.9999	1.0355
2004-2005	0.9975	0.9690	1.0076	0.9774	0.9528	0.9861
2005-2006	1.0120	0.9965	1.0356	1.0058	0.9858	1.0259
2006-2007	0.9569	0.9187	0.9595	-	-	-
2007-2008	1.0227	1.0131	1.0548	0.8893	0.8268	0.8809
Average	**0.9911**			**0.9834**		

Remarkable are the results for the Netherlands for 2000 to 2001 for both technical change and efficiency change. From the price index for pig output in Appendix II (Eurostat 2012) can be read that in 2001 prices for pig production were low, as the price index needs to compensate for almost 20% depreciation compared to year 2000. In Denmark, the price index for 2001 had to compensate for only 7% depreciation. An explanation for the low pig revenues in 2001 is the FMD disease outbreak. Since prices went down a lot and were already upgraded by deflation, the financial compensation farmers received for culled or slaughtered animals can explain the extreme value for technical change in 2000-2001.

In Table 3.5, pure efficiency change is presented. Pure efficiency has on average changed with -0.55% in the Netherlands and -1.27% in Denmark from 1995 to 2008. If pure efficiency change is negative, farms were less efficient over time and experienced a loss in efficiency by adopting technologies.

Table 3.5. Pure efficiency change for the Netherlands and Denmark, for 1995 to 2008

	The Netherlands			**Denmark**		
Years	**Pure eff. change**	**5%**	**95%**	**Pure eff. change**	**5%**	**95%**
1995-1996	0.9791	0.9394	0.9773	0.9991	0.9827	1.0093
1996-1997	0.9990	0.9608	1.0017	0.9770	0.9541	0.9795
1997-1998	0.9527	0.8770	0.9352	0.9954	0.9637	0.9998
1998-1999	1.0767	1.0916	1.1484	0.9928	0.9738	1.0069
1999-2000	1.0002	0.9872	1.0110	1.0050	0.9993	1.0237
2000-2001	0.7718	0.6103	0.6979	0.9913	0.9733	0.9957
2001-2002	1.1193	1.1252	1.2140	0.9613	0.9276	0.9536
2002-2003	1.0735	1.0757	1.1211	1.0161	0.9986	1.0340
2003-2004	0.9998	0.9958	1.0261	1.0111	0.9968	1.0276
2004-2005	0.9870	0.9604	0.9896	0.9796	0.9562	0.9867
2005-2006	1.0112	0.9983	1.0300	1.0108	0.9911	1.0222
2006-2007	0.9744	0.9356	0.9695	-	-	-
2007-2008	1.0289	1.0215	1.0552	0.9130	0.8491	0.8976
Average	**0.9945**			**0.9873**		

Table 3.6 presents the scale efficiency change for both countries. The average annual numbers explain that Dutch and Danish farms operate on a scale that is respectively 0.35% and 0.39% less efficient than the technically optimal size. The average value both countries is close to one, which means that a large proportion of the farms in the sample were able to have an operational size which is most efficient in terms of minimizing average costs (Tonsor and Featherstone 2009).

However scale efficiency change is independent of technical change (Balk 2001), technologies are often in favour of larger farms. As farms can often not increase production capacities in the short run and time is needed to adjust their farm size to technologies, this can explain why not all farms were on average producing at an optimal scale.

Table 3.6. Scale efficiency change for the Netherlands and Denmark, for 1995 to 2008

	The Netherlands			**Denmark**		
Years	**Scale eff. change**	**5%**	**95%**	**Scale eff. change**	**5%**	**95%**
1995-1996	1.0126	0.9952	1.0219	1.0077	1.0028	1.0180
1996-1997	0.9985	0.9829	1.0118	0.9847	0.9721	0.9878
1997-1998	0.9668	0.9397	0.9860	1.0070	0.9953	1.0170
1998-1999	1.0131	0.9765	1.0274	1.0167	1.0109	1.0295
1999-2000	1.0032	0.9852	1.0128	0.9954	0.9849	0.9969
2000-2001	0.9397	0.9133	0.9611	1.0016	0.9981	1.0103
2001-2002	0.9911	0.9581	1.0141	0.9866	0.9770	0.9906
2002-2003	1.0475	1.0203	1.0617	0.9865	0.9772	0.9946
2003-2004	0.9987	0.9794	1.0064	1.0009	0.9927	1.0103
2004-2005	1.0106	0.9985	1.0218	0.9978	0.9871	1.0032
2005-2006	1.0007	0.9864	1.0088	0.9950	0.9854	1.0056
2006-2007	0.9820	0.9669	0.9939	-	-	-
2007-2008	0.9940	0.9785	1.0033	0.9740	0.9591	0.9844
Average	**0.9965**			**0.9961**		

4. Discussion and conclusion

In the first section, the research methods and results will be discussed. The second section of this chapter gives the conclusions of this research.

4.1. Discussion

The dataset used for this study contains observations of a fourteen-year time period. Although it is favourable to have a large dataset and the Malmquist indices make use of different production frontiers for different years, it can be difficult to make a correct comparison between both countries based on overall means over this time period.

The dataset used contains observations of several types of pig farms. The pig farms were deemed to be commercial, because they were selected based on revenues derived from pig production, but not distinguished by farm specialization. However the FADN-dataset does not distinguish different farms types, it would be possible to make a separation between farrowing, fattening and integrated farms. Different types of specialized farms have different production systems and produce different outputs, e.g. piglets and slaughtering pigs or meat, therefore efficiency and productivity performance results would be more useful if they were measured for different specializations. Farms that obtained a higher percentage of their farm revenues from specialized pig production were relatively more efficient (Rowland et al. 1998). Tonsor and Featherstone (2009) also measured efficiency and productivity for different farm types and mentioned that different results were seen if the production specializations were separated. In this study, differentiation of production specialization was not possible because of too small sample sizes. For bootstrap calculations, a sample size of at least thirty observations per year is needed, derived from farms that are in the sample in both years. The dataset of the Netherlands could not reach this amount of observations for all years and therefore no distinction could be made between farm specializations.

Performance of pig production is also depending on different production phases. Because the source of inefficiency differs, it can be more useful to examine efficiency for specific phases to see where farms need to improve most (Chen 2012). However, a one-stage DEA model as used in this study fails to identify the degree of inefficiency of performance in each phase. A multi-level or multi-activity analysis, like the DMNDEA used in the research of Chen (2012), can be used in future research compare different production activities and production phases of pig production in the Netherlands and Denmark.

Different restrictions as the animal production rights and environmental policies limit the farmer’s ability to adjust the farm size to an economically optimal scale. Production conditions and circumstances as disease outbreaks also affect production. Those restrictions are involved in defining of the feasible set. Production frontiers change because of restrictions and unusual influences. This could have been affected results in some years, especially the years with disease outbreaks.

The bootstrapping method of Simar and Wilson (1999) was used to present bias-corrected estimates of efficiency, TFP growth and its components. In this study, standard errors were not calculated. If only sampling variability has to be removed, standard errors could be calculated. Confidence intervals were used to correct bias. Some results of TFP growth components calculations, observed for years 2000-2001 of the Netherlands and 2007-2008 of Denmark, have means are not within the confidence interval of that specific year. No extreme outliers can be detected within the results of these years and these results are considered as reliable.

This study has shown that bootstrapped Malmquist TFP indices are useful to evaluate the productivity of pig producers. TFP growth rates can be used to predict the tendency in competitiveness of Dutch and Danish pig production for the following years. The results can be improved by additional research. For additional research, a larger dataset with pre-selected data of different pig production specialization types is preferred. It is also recommended to look for possibilities to distinguish production factors and multiple activities, which can be an important research area for further improvements of pig production.

4.2. Conclusion

Malmquist indices have been widely used in previous research to examine changes in productivity and efficiency. This study has also demonstrated its usefulness in investigating efficiency and productivity. By using Data Envelopment Analysis and the Malmquist TFP index, efficiency and productivity performance of Dutch and Danish pig farms were measured. The results were bias-corrected by doing bootstrapping. The research objective was to determine if there are significant differences in technical efficiency and productivity growth between pig farms in the Netherlands and Denmark and how these differences develop over time.

Although it would be preferred that the dataset contains more observations, in particular the sample for the Netherlands, reliable results are produced. Due to the fact that farms can be in the FADN panel for a maximum of five years, the data sample consists of representative farms. When interpreting the results, it should be kept in mind that changes include both within-farm changes and between-farm changes. The changes in efficiency and productivity therefore refer to the Dutch and Danish pig sector as a whole, instead of individual farms.

The statistically verified results obtained with DEA show that pig farms in the Netherlands have an overall technical efficiency score of 84.4%, compared to an efficiency score 82.5% for the Danish farms in the sample. That means that Dutch pig farms produced with lower costs per unit of production, as the difference between the observed technical efficiency score and 1 is the potential for cost reduction. Still, the amount of inputs could be reduced by 15.6% for the Netherlands if all farms could produce on the production frontier. Denmark could increase production with 17.5% if Danish farms could operate on the efficient frontier.

The second research question requires explanation of the evolution of total factor productivity growth of pig farms over time. The average annual TFP growth rate is significantly higher for the Netherlands, compared to Denmark, with growth rates of respectively 0.8% and 0.2%. By using DEA, the TFP growth rate is decomposed in four components: technical change, efficiency change, pure efficiency change and scale efficiency change. Comparing all TFP growth components, the largest significant difference between pig production in the Netherlands and Denmark is explained by the technical change component. Scale efficiency change shows the smallest difference between both countries. In the period 1995 to 2008, overall efficiency decreased in both countries. This inefficiency means that productivity increased insufficient to compensate investment costs. Even with new technologies, farms were not able to benefit from economies of scale in a way that makes optimal use of these technologies.

The relatively small TFP growth rate in the Netherlands and Denmark can be explained by the restrictive regulations and limited production possibilities, driven by negative efficiency changes rather than technological improvements. Technical efficiency and technical change only have a minor effect of productivity growth in both countries. The results suggests that events and restrictions that occurred during this fourteen-year period had an important impact on the average productivity growth rates. The maximum established production level and restrictions of capital and other resources limited pig farms to adjust farm size to economic and technological conditions. Therefore, promoting technology rather than increasing efficiency may be a more appropriate strategy for pig producers in the Netherlands and Denmark to remain their competitive position in the European export market.

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Appendix I: Data specification and variable construction

The output and input variables used for the analysis are constructed by using FADN. The codes that are used are described in the same way as in the official FADN documentary (Commission) 2002) (Commission) 2002). All variables, except labour, are measured in monetary values and deflated by price indices for 1995 to 2008, with base year 2000. The price indices are obtained from Eurostat (Appendix II).

Output variables

1. Pigs

The output variable 'pigs' contains the output from pigs, which includes piglets, fattening pigs and meat (pork). The variable is constructed as:

Net output = sales + farmhouse consumption – purchases + gross stock change (DR)
NO pigs = E56SA + E56FC – E56PU + D43DR + D44DR + D45DR + D46DR

2. Other Output

The variable 'other output' means all other outputs produced by pig farms and is constructed as:

Other output = total output – output from pigs = SE131 – NO pigs

Input variables

1. Capital

The capital variable includes all fixed inputs and is categorized in five components. For each component the current value is calculated, as the average of opening and closing valuations.

Machinery: (G101BV + G101CV)/2
Agricultural land: (G95BV + G95CV)/2
Permanent crops: (G96BV + G96CV)/2
Land improvements: (G97BV + G97CV)/2
Farm buildings: (G98BV + G98CV)/2

2. Labour

Labour is recorded as both paid and unpaid labour. Variable SE010 means total labour input, measured in Annual Working Units (AWU).

SE010 = unpaid labour input + paid labour input

3. Livestock

Livestock is described in table D. Pigs and all other farm animals are included in the livestock value calculation.

The average value of present livestock is measured as: (DTOTBV + DTOTCV)/2

4. Feed

The value of input variable 'feed' consists of purchased feed. Home-grown feed is not included.

SE320 = feed for pigs and poultry (total value)

5. Materials

The materials variable consists of the following components:

Seeds and plants: SE285
Fertilizers: SE295
Crop protection: SE300
Crop-specific costs: SE305
Feed for other livestock: SE310
Livestock-specific costs: SE330
Energy: SE345
Other direct inputs: SE356

The value of the input variable 'materials' is calculated as:

SE285 + SE295 + SE300 + SE305 + SE310 + SE330 + SE345 + SE356

Appendix II: Price Indices

Variables (Appendix I) which are measured in monetary values (all variables, except labour) are deflated by price indices. The price indices are obtained from Eurostat, except the price index for ‘Agricultural land’. The price index for ‘Agricultural land’ for year *x* (1995 to 2008) is calculated, with base year 2000 (price index = 1.00), by the following formula:

$$y = \frac{\text{value of land in year } x \text{ (€/ha)}}{\text{value of land in year 2000 (€/ha)}}$$

The values of land (€/ha) in the Netherlands and Denmark for 1995 to 2008 are obtained from Eurostat.

Table A.1. Price indices for output variables

	Pigs		Agricultural goods	
Years	The Netherlands	Denmark	The Netherlands	Denmark
1995	1.031	1.031	1.028	0.949
1996	1.139	1.201	1.068	0.978
1997	1.169	1.237	1.067	1.039
1998	0.814	0.796	0.938	0.986
1999	0.774	0.749	0.897	0.929
2000	1.000	1.000	1.000	1.000
2001	1.192	1.098	1.074	1.061
2002	0.936	0.906	0.969	1.037
2003	0.807	0.843	0.925	1.049
2004	0.906	0.973	0.949	0.996
2005	0.915	1.021	0.934	1.010
2006	0.968	1.080	0.988	1.124
2007	0.872	0.981	1.010	1.180
2008	0.973	1.145	1.136	1.162

Table A.2. Price indices for input variables

	Seeds and planting stock		Energy and lubricants		Fertilisers and soil improvements	
Years	The Netherlands	Denmark	The Netherlands	Denmark	The Netherlands	Denmark
1995	0.891	0.998	0.664	0.640	1.036	1.026
1996	1.022	1.024	0.721	0.713	1.074	1.103
1997	0.943	1.031	0.771	0.737	0.969	1.040
1998	0.899	1.034	0.762	0.709	0.929	1.009
1999	1.010	0.997	0.766	0.795	0.870	0.990
2000	1.000	1.000	1.000	1.000	1.000	1.000
2001	1.039	1.037	1.128	1.002	1.215	1.188
2002	1.077	1.079	1.098	1.003	1.146	1.092
2003	1.105	1.057	1.200	1.032	1.193	1.012
2004	1.053	1.095	1.167	1.115	1.217	1.178
2005	1.119	1.088	1.358	1.314	1.303	1.270
2006	1.111	1.072	1.630	1.430	1.409	1.252
2007	1.205	1.084	1.601	1.442	1.496	1.315
2008	1.246	1.248	1.720	1.723	2.459	2.232

	Plant protection products		Veterinary expenses		Compound feeding stuffs for pigs	
Years	**The Netherlands**	**Denmark**	**The Netherlands**	**Denmark**	**The Netherlands**	**Denmark**
1995	0.939	0.748	0.898	1.027	1.086	1.081
1996	0.963	0.805	0.961	0.980	1.098	1.137
1997	0.925	0.821	1.007	0.963	1.162	1.150
1998	0.957	0.821	0.987	0.912	1.106	1.054
1999	0.988	0.926	0.975	0.925	1.014	0.954
2000	1.000	1.000	1.000	1.000	1.000	1.000
2001	1.084	1.008	1.042	1.071	1.102	1.083
2002	1.102	0.995	1.076	1.094	1.124	1.078
2003	1.115	0.947	1.099	1.160	1.045	1.051
2004	1.146	1.008	1.112	1.227	1.046	1.110
2005	1.060	0.998	1.131	1.258	1.035	0.988
2006	1.105	0.881	1.144	1.244	1.014	1.032
2007	1.174	0.929	1.162	1.277	1.140	1.275
2008	1.213	1.104	1.191	1.297	1.574	1.532

	Other goods and services		Materials		Machinery and equipment	
Years	**The Netherlands**	**Denmark**	**The Netherlands**	**Denmark**	**The Netherlands**	**Denmark**
1995	0.877	0.954	0.889	0.935	0.901	0.926
1996	0.913	0.954	0.903	0.944	0.919	0.938
1997	0.947	0.995	0.925	0.961	0.934	0.956
1998	0.963	0.996	0.957	0.975	0.964	0.973
1999	0.973	0.998	0.978	0.986	0.979	0.985
2000	1.000	1.000	1.000	1.000	1.000	1.000
2001	1.031	1.037	1.023	1.018	1.024	1.021
2002	1.056	1.059	1.041	1.027	1.043	1.032
2003	1.060	1.084	1.056	1.046	1.059	1.052
2004	1.083	1.115	1.078	1.092	1.081	1.106
2005	1.115	1.138	1.121	1.136	1.127	1.151
2006	1.166	1.185	1.153	1.162	1.160	1.178
2007	1.226	1.255	1.174	1.192	1.182	1.210
2008	1.230	1.340	1.208	1.246	1.211	1.266

	Farm buildings		Agricultural land	
Years	**The Netherlands**	**Denmark**	**The Netherlands**	**Denmark**
1995	0.883	0.876	1.054	1.185
1996	0.903	0.900	1.038	1.170
1997	0.927	0.926	1.041	1.139
1998	0.947	0.954	1.020	1.086
1999	0.987	0.990	1.012	0.969
2000	1.000	1.000	1.000	1.000
2001	1.048	1.042	0.963	1.003
2002	1.086	1.067	0.948	0.956
2003	1.108	1.093	0.928	0.927
2004	1.129	1.115	0.888	0.886
2005	1.146	1.142	0.884	0.833
2006	1.176	1.195	0.863	0.806
2007	1.207	1.266	0.846	0.779
2008	1.257	1.304	0.828	0.769