Essays on pig production efficiency and farmers' financial decisions under uncertainty

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Abstract

Recent structural changes in agricultural production towards fewer, but larger, units pose challenges for farmers in decision making about practical production and about managerial practices to increase efficiency, which are vital for farm productivity and profitability. In studies using mathematical programming and econometric models, this thesis evaluated farm-specific characteristics related to the individual technical efficiency (TE) of each input and output factor and of managerial characteristics associated with persistent TE (PTE) and residual TE (RTE). Regarding farm-specific variables, the results indicated that advisory services, farm location and most housing practices were not significant for technical efficiency, with the exception of recent technology such as heated floors. Use of written instructions on feeding and in preventing infectious diseases was associated with higher technical efficiency. For the best results, decision makers should use separate approaches depending on pig production specialisation and the input or output efficiency requiring improvement. Regarding managerial practices, managerial experience, economy-driven goals and use of strategic management accounting practices were drivers of PTE. In contrast, conducting bookkeeping checks more frequently and focusing on meeting market demands in terms of quality were negatively associated with PTE. Joint time significance evaluation of lagged individual technical efficiency on variables of structural change in the regression model confirmed the long-term nature of investments in Swedish pig farming.

Under uncertainty, decisions made by farmers may be biased, producing suboptimal solutions. For example, illusion of control can give a sense of controlling power in situations where the outcome is determined by chance. Alternative ways to collate and analyse data are needed to evaluate behaviours under uncertainty. Presence of illusion of control in farmers' financial decisions was explored in a study with a framed economic experimental design, survey data and a psychological scale. The results did not indicate the presence of illusion of control in the sample of Swedish farmers studied. The outcome measures showed low levels of correlation, suggesting that different methods and measurement instruments are complements, rather than substitutes.

Findings provide information that could help farmers in their complex production and managerial decisions.

Keywords: behavioural finance, data envelopment analysis, framed field economic experiments, multidirectional efficiency analysis, risk and uncertainty, stochastic frontier, structural change, Swedish pig industry, technical efficiency,

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Dedication

To the memory of my beloved father *Jozef Labaj* and to my mum *Ľudmila Labajová.*

To my husband *Oscar* and children *Svetlana, Amelia* and *Henrik*.

Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Labajova, K., Hansson, H., Asmild, M., Göransson, L., Lagerkvist, C.J. & Neil, M. (2016). Multidirectional analysis of technical efficiency for pig production systems: The case of Sweden. *Livestock Science* 187, 168-180.

II Manevska-Tasevska, G., Hansson, H. & Labajova, K. (2017). Impact of management practices on persistent and residual technical efficiency – a study of Swedish pig farming. *Managerial and Decision Economics* 38, 890-905.

III Labajova, K., Hansson, H. & Lagerkvist, C.J. (2017). Effect of technical efficiency on structural changes in Swedish pig production. (manuscript)

IV Labajova, K., Lagerkvist, C.J. & Rommel, J. (2018). Exploring illusion of control in Swedish farmers' investment and financing decisions. (manuscript)

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Abbreviations

CRS	Constant returns to scale
DBC	Drake beliefs about chance
DEA	Data envelopment analysis
DF	Distance function
ESU	European Size Units
EU	European Union
F	Farrell
FADN	Farm Accounting Data Network
FES	Farm Economic Survey
GFP	Growing finishing production
IPP	Integrated pig production
MEA	Multidirectional efficiency analysis
OLS	Ordinary least squares
OTE	Overall technical efficiency
PI	Potential improvement
PP	Piglet production
PTE	Persistent technical efficiency
RTE	Residual technical efficiency
SEK	Swedish crowns
SUR	Seemingly-unrelated regression
TE	Technical efficiency
USD	US dollars
VRS	Variable returns to scale

1 Introduction

The field of economics deals with allocation of resources and market coordination, but also with human behaviour and decision making. It concerns rational allocation of scarce resources to obtain the optimal outcome, but also factors within sociology and psychology influencing decision making on resource allocation and business management (Thaler, 2015). Using the case of pig production in Sweden, this thesis examines these two sides of economics, *i.e*. rational processes involving optimal allocation of scarce resources and those relating to psychology and the behavioural sciences. Within this framing, the thesis explores two specific topics:

(i) Technical efficiency measures and structural changes in Swedish pig production (Papers I, II, III).

(ii) Farmers' financial decisions under uncertainty: Evaluation of the presence of illusion of control among Swedish pig farmers (Paper IV).

1.1 Importance of technical efficiency in relation to structural changes in pig production

Recent structural changes in agriculture have been associated with the emergence of larger, but fewer, farms. The pig industry in Sweden and in other European Union (EU) countries is no exception. The number of pig farms in Sweden decreased by 74% between the year 2000 and 2016, while farm size increased by 193% (Statistics Sweden, 2017). Similarly, pig farms in other EU[1] countries increased in size by 65% in the period 2005-2013, whereas the total number of production units decreased by 45% (Eurostat, 2017). Despite these

[1]The 28 European Union countries, not including Sweden and Croatia.

structural changes and re-organisations, pig production in Sweden is not reaching its potential and is characterised by low productivity and profitability (Swedish Board of Agriculture, 2014).

Technical efficiency is a factor that strongly influences productivity and is important for profitability, including that of pig farms. Differences in the technical efficiency of pig production in Sweden and other countries suggest that some pig producers use their resources better in the production process than others (Galanopoulos *et al*., 2006; Oude Lansink & Reinhard, 2004; Sharma *et al*., 1999; Heshmati *et al*., 1995). Based on this, it appears that adjustment to change can be challenging from a production perspective. Therefore identifying the qualitative aspects of production that affect technical efficiency could be vital for businesses to survive in tough competition by becoming more productive and more profitable. Areas of pig production related to general practices, housing systems, feeding regimes and health and cleaning practices have been identified as being of high importance in improving efficiency in the pig industry (Whittemore & Kyriazakis, 2008). However, aggregated measures of technical efficiency commonly used in previous research may not be able to identify all the aspects of production that relate to individual inputs and outputs. More detailed elaboration of technical efficiency measures on individual input and output level is therefore needed, to better assess farm-specific characteristics and their relationships to individual technical efficiency indices. Furthermore, division of pig production into piglet production, growing-finishing production and integrated production[2] is important, in order to distinguish between differences in technology and to capture unique relations of production factors to individual technical efficiency indices in each production type.

Moreover, structural change can have huge impacts on managerial capacity and the decision-making process when the size of the business increases. However, managerial practices may be overlooked when organisation and management are considered from an economic and more quantitative perspective (Rougoor *et al*., 1998). For a set of farms operating with similar production factors in terms of labour, capital and material inputs, the total performance and outcome can vary depending on differences in managerial practices of the individual farmer (Boehlje & Eidman, 1984). Previous studies have identified models that combine personal and cognitive aspects of managers, their managerial practices of planning, implementation and control and the technical and biological aspects of the production, and have linked these to the economic performance of the business or farm in general (Frese, 2009; Shane *et*

[2]According to the Swedish Board of Agriculture, weight of piglets is <20 kg and weight of growing-finishing pigs is ≥20 kg. Integrated production includes both piglet and growing-finishing pig production on the same farm.

al., 2003; Rougoor *et al*., 1998). However, more empirical research is needed on the relationship between managerial practices and efficiency in pig production. Such research should involve a wider range of managerial factors, in order to address the changes in the industry. In addition, the managerial practices employed by pig farmers are believed to be related to fixed technical efficiency, which does not vary over time, as opposed to time-varying technical efficiency, which changes over time due to random factors such as weather conditions and market policy changes (Kumbhakar *et al*., 2014). Using measures of overall technical efficiency, as is done in the existing literature, may not reveal all the relations between managerial practices and technical efficiency, as the effects of time-varying technical efficiency can diminish the influence of managerial variables. Hence it is important to distinguish between fixed and time-varying technical efficiency when evaluating associations between managerial practice factors and technical efficiency.

Furthermore, technical efficiency could have direct effects and could partly explain the ongoing structural change in the pig industry in Sweden. Assuming that only the most productive and profitable businesses can survive competition, productivity and its component technical efficiency could be important factors driving further structural change and farm growth (Diamond, 1997; Timmer, 1988; Johnston & Kilby, 1975; Johnston & Mellor, 1961; Schultz, 1953). The existing literature only provides qualitative descriptions of pig production and the effects of variables on structural change. Thus thorough quantitative evaluation of possible effects of technical efficiency on structural changes is needed, based on longer data sets, to capture the time dimension of technical efficiency and investments associated with structural changes in pig production in Sweden.

Identifying production factors and managerial practices of farmers that lead to higher technical efficiency and determining whether technical efficiency in itself affects the variable of structural change would provide important information for farmers, but also for policymakers and advisors in the pig industry. Individual farmers could adjust their production and managerial practices in order to take advantage of the ongoing structural changes and use their existing resources to the maximum. Advisors could use the findings to improve their advisory services and spread knowledge among farmers. From a policy perspective, such information is also relevant in formulating and evaluating new strategies for increasing profitability in pig production.

1.2 Decision making under uncertainty: Influence of illusion of control on financial decisions

Classical decision-making theory is based on perfect rationality, where the information is available and under perfect competition the optimal solution is always reached (Bloisi *et al*., 2003). However, this theory has been criticised for its lack of realistic assumptions and normative principles, since in times of uncertainty and imperfect competition, decision making is not easy and the solution might not be optimal or maximising (Simon, 1979). Several empirical studies have shown deviations from average behaviour predicted by the standard assumptions of rationality, which are known as bias (*e.g*. Camerer & Fehr, 2006).

One of the biases believed to influence financial decisions under uncertainty is illusion of control. Illusion of control belongs to the group of positive illusions and was described by Thompson (1999) as the tendency for people to overestimate their ability to control events, for instance to feel that they control outcomes over which they evidently have no influence. Illusion of control can increase the motivation and persistence of an individual, which can be advantageous in situations where control is possible (Bandura, 1989). However, if the individual confuses a chance situation with a skill situation, being influenced by illusion of control can have negative consequences (Fenton-O'Creevy *et al*., 2003; Gollwittzer & Kinney, 1989).

One of the professional groups that might be influenced by illusion of control is farmers. They are particularly prone to high risks and decisions under uncertainty due to the unique nature of seasonal production under natural and ambient conditions (Höllinger, 2003; Harwood *et al*., 1999). Farmers deal not only with business risks, but also financial risks associated with the need to finance business operations and maintain cash flow levels adequate to repay debts and meet other financial obligations (Hardaker *et al*., 2015; Drollette, 2009). However, previous research on illusion of control has usually studied this phenomenon in a gambling context, working with students or the general public. Thus little is known about illusion of control in business or financial situations and even less about how it affects particular working groups. The need to study farmers' behaviour from a policy perspective, due to their unique production conditions associated with great risks, is highlighted in recent literature (Colen *et al*., 2016; Viceisza, 2016). Moreover, farmers in Europe and Sweden in particular invest billions of Euro in their production every year (Eurostat, 2017). Knowing whether farmers as a group or as individuals are prone to illusion of control could raise awareness of possible erroneous decisions and overconfidence and, at the same time, prevent negative consequences of such decisions.

2 Literature review

2.1 Structural changes in agriculture

Factors behind structural changes in different industries are studied in the existing literature on macro level, describing the dynamics within the sectors of *e.g*. manufacturing, agriculture and services (Herrendorf *et al*., 2014; Barkley, 1995; North, 1994). Another approach is to analyse changes on micro level, as quantitative analysis of variables that affect structural changes within areas of the agricultural sector (Samson *et al*., 2016; Kirchweger & Kantelhardt, 2015; Zimmermann & Heckelei, 2012; Breustedt & Glauben, 2007; Weiss, 1999). Structural changes in pig production have been described on micro level only from a qualitative perspective (Geels, 2009; Honeyman, 1996; Boehlje, 1995; Fulton & Gillespie, 1995; Karantininis *et al*., 1995; Kliebenstein & Lawrence, 1995). Based on theoretical production literature about growth and productivity (O'Donnell, 2010; Ha *et al*., 2001) and studies that point to economies of scale, technological progress and productivity as having effects on growth, technical efficiency could be one of the variables that explains structural changes in pig production (Zimmermann & Heckelei, 2012; Geels, 2009; Breustedt & Glauben, 2007; Diamond, 1997; Timmer, 1988; Johnston & Mellor, 1961; Cochrane, 1958; Schultz, 1953). The variable structural change can be defined in different ways, but the most common according to Goddard *et al*. (1993) is to focus on the number and size of farms. Some studies express the size of farms by non-monetary measures, in livestock units for animal production or in agricultural area occupied for farms without animal husbandry (Kirchweger & Kantelhardt, 2015). Other studies express farm size in monetary economic values, such as European Size Units (ESU) (Zimmermann & Heckelei, 2012).

2.2 Technical efficiency and organisational management

An organisation by definition comprises a social group of people that is structured and managed to accomplish certain needs or goals (BusinessDictionary, 2018; McNamara, 2018; Bloisi *et al*., 2003). Even though goals differ between businesses, from a long-term perspective maximisation of economic goals such as profitability is vital for every business in order to be able to continue current production and expand or invest for the future (Ha *et al*., 2001). Profitability depends on productivity, which refers to the way in which existing resources are used to produce a certain amount of outputs. Productivity increases if the amount of outputs per unit inputs increases (Bloisi *et al*., 2003). Producers can influence productivity through increased efficiency of production (Coelli *et al*., 2005; Ha *et al*., 2001). It is essential for all business managers, including the managers of farms or agricultural businesses, to understand the processes that drive technical efficiency, in order to be more productive and profitable.

From the perspective of production economics, the production function represents the transformation of all inputs into outputs from the business, given a certain level of production technology (Coelli *et al*., 2005). Inputs and outputs of production can vary, but a basic sub-division into labour, raw materials and capital is commonly applied to the input side of the organisation (Bloisi *et al*., 2003). For agricultural operations, a further sub-division into variable inputs, such as feed, fertilisers and number of animals, and fixed inputs, such as land, is often appropriate. The outputs from farm operations can range from one to several main output groups in the form of physical units or services, depending on the type of production. Agricultural outputs can be referred to as the main outputs from production and any additional non-agricultural output generated can be referred to as 'other output'.

The production function represents the frontier of feasible production, *i.e.* the maximum obtainable output produced given certain levels of inputs and production technology (Kumbhakar *et al*., 2015). If for any reason the farm is not operating on its frontier, *i.e.* it produces less output than the maximum possible, this shortcoming may be due to inadequate technical efficiency of production. The efficiency measure depends on the given technology and, in multi-input/multi-output agricultural production, also on the combination of all inputs used and outputs produced. Analysis of technical efficiency by comparing production with similar technological processes may thus make it possible to identify farms that use the best mixture of inputs to produce the maximum output and thus produce on the frontier of production potential set relative to other production units. Similarly, such analysis makes it possible to identify inefficient farms that produce less output for a certain amount of inputs relative to the best firms in the industry.

2.3 Technical efficiency from an empirical perspective

Technical efficiency (TE) was first defined by Farrell (1957) as a simple measure that allowed use of multiple inputs. It has since been elaborated into parametric and non-parametric methods of estimation of production frontiers and measurement of technical efficiency coefficients (Coelli *et al*., 2005). From an empirical perspective, the literature on technical efficiency reveals differences in overall technical efficiency coefficients obtained by data envelopment analysis (DEA) or stochastic frontier methods for pig production in Sweden and other countries (Tonsor & Featherstone, 2009; Galanopoulos *et al*., 2006; Oude Lansink & Reinhard, 2004; Sharma *et al*., 1999; Rowland *et al*., 1998; Heshmati *et al*., 1995). Furthermore, some studies on the efficiency of pig production have expanded the analysis into two stages, where technical efficiency measures calculated in the first stage are related to 'farm-specific characteristics', socio-economic variables or managerial practices in the second stage in order to explain observed differences in technical efficiency (Gaspar *et al*., 2009; Tonsor & Featherstone, 2009; Galanopoulos *et al*., 2006; Oude Lansink & Reinhard, 2004; Sharma *et al*., 1999; Rowland *et al*., 1998; Heshmati *et al*., 1995).

Existing research within pig production practices or managerial practices relates the variables of interest to overall DEA or stochastic frontier technical efficiency. A slightly different approach to measuring technical efficiency indices is to use multidirectional efficiency analysis (MEA), which allows individual technical efficiency indices to be calculated for each input and output factor of production (Asmild *et al*., 2003; Bogetoft & Hougaard, 1999). The MEA approach has been applied mainly to non-agricultural production, for example in evaluation of the bank sector, transportation, healthcare, energy and environmental performance (Wang *et al*., 2015; Wang *et al*., 2013; Asmild & Matthews, 2012; Asmild & Pastor, 2010; Asmild *et al*., 2009; Holvad *et al*., 2004). It has been used in only a few cases to evaluate agricultural production, for example Danish, Malaysian and Swedish dairy production and Lithuanian family farms (Hansson *et al*., 2018; Binti *et al*., 2017; Asmild *et al*., 2015; Asmild *et al*., 2003). To the best of my knowledge, the MEA method has not been previously used to measure technical efficiency in pig production.

Technical efficiency coefficients can also be estimated by a modified stochastic frontier model that decomposes the error term into four parts (Kumbhakar *et al*., 2015). This multiple decomposition permits calculation of persistent and residual efficiency, while accounting for firm effects. Decomposition is important due to the fact that some variables, such as managerial practices, might be related to the part of technical efficiency that does not change over a short period of time. This type of technical efficiency (fixed technical efficiency) is captured as persistent efficiency, while factors that vary over time, such as weather conditions or farmer's experience, determine the residual efficiency (time-varying technical efficiency).

The methods for calculation of technical efficiency presented above employ a static approach. However, it is also possible to perform dynamic estimation of technical efficiency, in a process that takes into account inter-temporal relations in production decisions (Ang & Oude Lansink, 2018). A dynamic approach is relevant in industries with high capital investments associated with adjustment costs of quasi-fixed factors of production that cannot be changed quickly to optimal levels (Silva & Stefanou, 2007, 2003). This approach has been implemented in dynamic DEA analysis of food and glasshouse industries (Kapelko, 2015; Silva *et al*., 2015), parametric calculations of dynamic technical efficiency in the airline industry, evaluations of commercial banks and, in agriculture, assessment of dairy farms (Emvalomatis *et al*., 2011; Tsionas, 2006; Ahn & Sickles, 2000). Determination of technical efficiency by the MEA method has also been elaborated to account for dynamics in production decisions, *e.g*. in a study of European dairy manufacturing firms (Kapelko & Lansink, 2017).

Previous studies using technical efficiency analysis to compare pig production characteristics or managerial practices have generally used only a few production variables, such as insemination method, weaning age and own feed, farm characteristics such as region, size and hired labour, and some demographic characteristics of the farmer, such as age, sex, education and experience. Production variables such as housing construction, pen type, use of modern technology, feed type, feed composition and communication around feed practices and hygiene standards have been identified in many qualitative productivity studies as having an influence on pig production (Johansen, 2014; Göransson & Lindberg, 2011; Rydberg *et al*., 2011; Olsson *et al*., 2009; Whittemore & Kyriazakis, 2008; Galanopoulos *et al*., 2006; Tuyttens, 2005; Campos Labbé, 2003; Sauber *et al*., 1999; Mattsson, 1998; Olsson *et al*., 1996; Olsson *et al*., 1994; Wallgren *et al*., 1993; Maton & Daelemans, 1992). However, they have not necessarily been related to the technical efficiency of farms in these studies. Managerial variables that could be related to technical efficiency have also been identified in the literature, *e.g*. variables related to farmers' capacity, such as level of education, experience, participation in training activities for managers and self-evaluation of knowledge. Variables related to type of managerial practices used, such as strategy type, management accounting practices and deliberate strategy planning, have also been identified in the general managerial literature (Frese, 2009; Cadez & Guilding, 2008; Shane *et al*., 2003; Miles *et al*., 1978) or in specialist literature concerning managerial practices in agriculture (Gloy *et al*., 2016; Hansson, 2008; Galanopoulos *et al*., 2006; Rougoor *et al*., 1998).

2.4 Illusion of control

The opinions of different individuals about control over outcomes in different life situations have been discussed over nearly a century (Lefcourt, 1973; Kelley 1967; White, 1959; Heider, 1958; Adler, 1930). However, Langer (1975) was the first to present the term ‘illusion of control’ and to provide a definition. She defined it as “an expectancy of a personal success probability inappropriately higher than the objective probability would warrant” (Langer, 1975: 113). In a psychology perspective, illusion of control is regarded as cognitive bias that belongs to the group of positive illusions (Kahneman *et al*., 1982).

To date, illusion of control has mainly been studied by psychologists as a phenomenon occurring in gambling situations (Lopez-Gonzalez *et al*., 2018; Ejova *et al*., 2015; King *et al*., 2011; Ejova *et al*., 2010; Ginakis & Ohtsuka, 2005; Ohtsuka & Hyam, 2003; Langer & Roth, 1975). It has also been studied to some extent in financial or business settings (Meissner & Wulf, 2017; Fenton-O’Creevy *et al*., 2003; Simon *et al*., 2000; Kahai *et al*., 1998; Kottemann *et al*., 1994). Economic experiments, which differ from psychology experiments in the use of incentives, have also studied illusion of control related to financial or business decision making (Sloof & von Siemens, 2017; Charness & Gneezy, 2010; Fellner, 2009; Fast *et al*., 2008; Grou & Tabak, 2008). Recently, neuroscientists have studied illusion of control using functional magnetic resonance imaging (Lorenz *et al*., 2015). Researchers have also focused on the factors that mediate illusion of control, such as personal involvement, familiarity, experience or knowledge (Blanco & Matute, 2015; Matute & Blanco, 2014; Yarritu *et al*., 2014; Fellner, 2009; Thompson, 1999; Kahai *et al*., 1998). Previous research on illusion of control has mainly involved students or the general public, while only a few studies have been conducted on particular groups of professionals (Durand, 2003; Fenton-O’Creevy *et al.,* 2003). One study with a non-experimental design examined illusion of control among farmers in the USA, using past data in the analysis (Just & Roberts, 2004).

3 Approach taken and methods used in the thesis

In the work presented in this thesis, two-stage technical efficiency analysis (Coelli *et al*., 2005) was implemented to evaluate the correlations between technical efficiency measures of Swedish pig farms and practical production variables (Paper I) and managerial practices (Paper II). Similarly, two-stage technical efficiency analysis was used to evaluate the effect of technical efficiency on the variable structural change, expressed as percentage change in pig production unit size in the Swedish pig industry (Paper III). Finally, an economic experiment and a survey were performed to evaluate the presence of illusion of control in Swedish farmers' financial decision making under uncertainty.

3.1 Two-stage technical efficiency analysis

In two-stage technical efficiency analysis, technical efficiency scores are first obtained by parametric or non-parametric methods. These technical efficiency scores are then used in the second stage econometric or correlation analysis to evaluate the effect of explanatory variables on technical efficiency or to evaluate the effect of technical efficiency scores on the dependent variable of interest (Coelli *et al*., 2005).

In the first stage of the analysis in Paper I, individual technical efficiency indices were calculated using multidirectional efficiency analysis (MEA) for each input and output and overall technical efficiency indices were calculated by data envelopment analysis (DEA) for piglet, growing-finishing and integrated pig production in Sweden. In the second stage, Spearman correlations with variables within the categories general practices, housing systems, feeding practices and health and cleaning practices were evaluated using the technical efficiency indices obtained from the first stage.

In Paper II, the average persistent and residual technical efficiency indices were first calculated. Regression analysis was then used to evaluate the impact of managerial practices (in the form of variables describing who the manager is and what the manager does) on the persistent and residual technical efficiency indices.

In the first stage of the analysis in Paper III, individual MEA technical efficiency indices were calculated for each input and output and overall DEA technical efficiency indices were calculated for integrated pig production in Sweden. In the second stage, the effect of the lagged technical efficiency indices on the variable structural change was evaluated in regression and correlation analysis.

3.1.1 Technical efficiency analysis

When studying technical efficiency, a distinction can be made between an input and output perspective, as defined by Farrell (1957). Input efficiency focuses on the resources used in production, *i.e.* whether and by how much inputs can be proportionally reduced, given the amounts of outputs. Output efficiency focuses on the outputs of production and measures whether and by how much outputs can be proportionally increased given the amounts of inputs. Depending on the production technology, the frontier of maximum production possibilities can be obtained using the distance function (DF) method by identifying companies that operate at the most efficient level (Malmquist, 1953; Shephard, 1953). The distance function method uses minimal contraction of input vectors given the output vector for input-oriented technical efficiency analysis, and maximal expansion of the output vector given the input vectors for output-oriented technical efficiency analysis. Using the distance function method, it is also possible to identify businesses operating at a lower level of technical efficiency by comparing them to the businesses that operate at the production frontier (Coelli *et al*., 2005). Technical efficiency indices take a value between 0 and 1, where efficient firms producing on the production possibility frontier are given a value of 1 and less efficient firms have score less than 1 relative to the production possibility frontier. Several parametric and nonparametric methods for determining the production possibility frontier and for calculating technical efficiency indices are available. In Papers I and III of this thesis, the nonparametric DEA method (Coelli *et al*., 2005; Charnes *et al*., 1978) and the nonparametric MEA method (Asmild *et al*., 2003; Bogetoft & Hougaard, 1999) were used to calculate technical efficiency coefficients. In Paper II, the parametric model of Kumbhakar *et al*. (2014) for stochastic frontier analysis, which distinguishes between persistent and residual technical efficiency measures and firm heterogeneity, was also applied.

The DEA approach is a well-established nonparametric technique for measurement of overall input or output efficiency of production (Coelli *et al*., 2005; Charnes *et al*., 1978). It involves the use of linear programming methods to construct a non-parametric piece-wise surface (or frontier) over the data and efficiency measures are then calculated relative to this surface along a ray from the origin to the observed production point (Coelli *et al*., 2005). When a firm operates under variable returns to scale (VRS), a convexity constraint has to be implemented in the linear optimisation (Coelli *et al.*, 2005). By using a convex hull of intersecting planes, the data points are enveloped more tightly in VRS DEA analysis than in the constant returns to scale (CRS) model, which uses a conical hull to envelop the data. Furthermore, the efficiency scores calculated in VRS DEA are greater than, or equal to, those obtained using the CRS model (Coelli *et al.*, 2005). Using a similar approach as in identifying input-oriented DEA, the efficiency frontier for the output VRS operation can be obtained.

The nonparametric MEA method for calculating individual technical efficiency indices (Asmild *et al.*, 2003) provides detailed information about performance, since the vector of efficiencies is specified relative to a benchmark constructed from the improvement potential in each of the input and output factors. This analysis allows for reduction of some inputs and a simultaneous increase in some outputs. The results on technical efficiency indices are obtained in three steps (Asmild & Matthews, 2012). When using MEA analysis, step one is to perform separate linear programming calculations for each observation and for each input and output factor. Given a production with two inputs, X_1 and X_2, and fixed outputs, and where L represents the production possibility set and X_A and X_B are production plans (Figure 1), solutions from step one give an ideal reference point X_A^* and X_B^* that indicates the largest possible reduction in each input dimension separately (Asmild *et al.*, 2003). In step two, another linear programme is solved using the ideal reference point X_A^* and X_B^* calculated in step one. The results of the optimal value from step two determine benchmark selection $S_A^{PI}$and S_B^{PI} for production plans X_A and X_B and the vector of relative variable-specific MEA efficiencies.

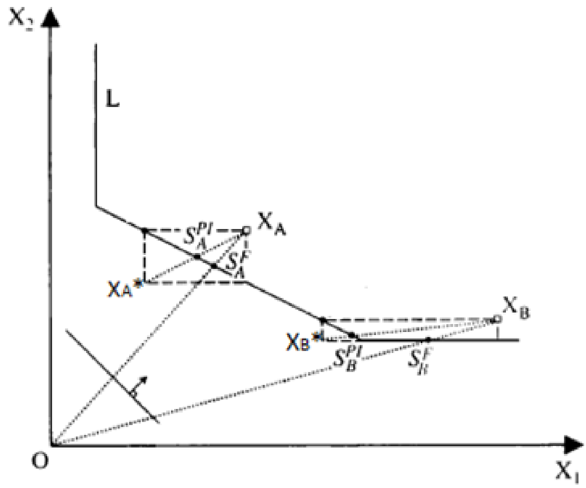

Figure 1. Comparison of data envelopment analysis (DEA) and multidirectional efficiency analysis (MEA) in calculating technical efficiency. X_1 and X_2 = inputs, L = production possibility set, X_A and X_B = production plans (with benchmarks $S_A^{PI}$and S_B^{PI} and S_A^F and S_B^F in the potential improvement (MEA) and Farrell (DEA) method, respectively). (Adapted from: Asmild *et al.*, 2003).

The differences between MEA and DEA calculations lie in the selection of the benchmarks. The DEA method selects a benchmark for improvements in proportion to past production and in the same linear programming calculation as technical efficiency scores are determined, whereas MEA separates the selection of benchmark from the calculation of technical efficiency scores and looks for improvements in proportion to the potential improvements (Bogetoft & Hougaard, 1999). Furthermore, DEA is based on radial contraction of all inputs or all outputs, while the advantage of MEA is in its individual determination of potential improvements relative to benchmarks for each input and output separately. The differences in selection of benchmarks between DEA and MEA are illustrated in Figure 1. Selection of the benchmark is represented by S_A^{PI} and S_B^{PI} when the potential improvement method of MEA is used and by S_A^F and S_B^F when the Farrell (1957) efficiency index of DEA is used. As can be seen in the diagram, the final selection of benchmarks is different. Hence the ranking of firms in terms of technical efficiency scores using MEA and DEA will differ accordingly. This difference is due to the fact that the DEA analysis does not take into consideration the dominant set of individual inputs or outputs, while the MEA analysis takes this set into consideration (Asmild *et al*., 2003).

The parametric method to calculate technical efficiency scores is a stochastic frontier approach where the frontier of production possibilities is represented by a production function best suited for the given production situation (Kumbhakar *et al*., 2015; Coelli et al., 2005). This model is called a stochastic frontier production function, because the output values are bounded from above by the stochastic (random) variable. The stochastic error can be positive or negative and the stochastic frontier outputs vary around the deterministic part of the model. In addition to the deterministic part and the random noise or error term, the model also accounts for an inefficiency term. The technical efficiency is then calculated as the output of the firm relative to the output that could be produced by a fully efficient firm using the same input vector. In order to calculate technical efficiency, the parameters of the stochastic production frontier model have to be estimated with an econometric approach. The basic model as described by Coelli *et al*. (2005) assumes that technical efficiency is nonvariant over time and does not take into account the heterogeneity of firms.

There are different modifications of the basic stochastic frontier model that account for firm heterogeneity, persistent efficiency or time-varying residual efficiency, but most of the variations are based on assumptions that are not fully satisfactory (Kumbhakar *et al*., 2015). When applied to panel data, the model by Kumbhakar *et al*. (2014) allows for more realistic decomposition of efficiency terms, while still accounting for firm heterogeneity and noise. This model splits the error term into four components: (i) the latent heterogeneity of firms; (ii) short-run (time-varying) residual inefficiency; (iii) persistent or time-invariant inefficiency; and (iv) random shocks. Estimation of this model comprises three steps. In step one, the standard random or fixed effect panel regression is used to estimate parameters and at the same time gives predicted values of time-invariant and time-variant components of the error term. In step two, the time-varying component from the first step is used to calculate time-varying residual technical inefficiency using the stochastic frontier technique (Jondrow *et al.*, 1982) and by taking the expected value of the negative residual inefficiency the residual technical efficiency (RTE) is estimated. In step three, the time-invariant error component term from step one is used in a stochastic frontier model to estimate the persistent technical inefficiency (PTE) component, using the Jondrow *et al.* (1982) procedure, and the persistent technical efficiency can be obtained by taking the expected value of the negative persistent technical inefficiency component. Overall technical efficiency (OTE) can be calculated from the product of persistent technical efficiency and residual technical efficiency (Kumbhakar *et al.*, 2015).

When choosing a method for calculation of technical efficiency, several aspects have to be considered. Nonparametric methods do not require assumptions about the functional form of the production function and distributional form for the inefficiency term, but they do not account for the noise in the calculations and are not suitable for drawing statistical inferences about the results. When the technical efficiency of individual input and output variables is of interest, individual MEA TE analysis is preferable to overall DEA TE analysis. If the production is believed to have persistent technical efficiency due to managerial factors, the applied stochastic frontier model elaborated by Kumbhakar *et al*. (2014) is appropriate to use, instead of basic stochastic frontier technical efficiency analysis or non-parametric analysis.

3.1.2 Second-stage analysis

The results from the first stage of analysis, where technical efficiency coefficients were calculated, were used in the second stage of the analysis in Papers I, II and III to further investigate the relationships between technical efficiency measures and other variables of interest.

In Paper I, overall DEA TE indices and individual MEA TE indices calculated in the first stage were used in Spearman non-parametric correlation analysis in the second stage. Three-year average DEA and MEA technical efficiency indices for individual farms were matched with corresponding individual production variables of the farms in four different areas: (i) general practices; (ii) housing systems; (iii) feeding practices; and (iv) health and cleaning practices. Correlations were performed separately for each of three production types, namely piglet production, farrow-to-finish production and integrated pig production. The relationships between efficiency variables can be also analysed by regression analysis (Tonsor & Featherstone, 2009; Galanopoulos *et al*., 2006; Oude Lansink & Reinhard, 2004; Rowland *et al*., 1998). Nonetheless, considering the small sample of data available in Paper I a decision was made to use correlation analysis, since that can be used for a small sample from a non-normally distributed dataset without assuming a linear relationship between variables. Moreover, the problem of omitted variable bias and of outlying observations is not relevant when correlation analysis is used.

In Paper II, the estimated average of persistent technical efficiency (PTE), residual technical efficiency (RTE) and overall technical efficiency (OTE) indices were used in the second stage of the analysis to match explanatory variables of managerial practices obtained from survey data. Seemingly unrelated regression BiTobit model analysis was performed to investigate the relationship between PTE and RTE in one model (Model 1) while in a second model (Model 2) the influence of management practices on PTE and OTE was investigated. Since the dependent variable of technical efficiency measures is censored from above, it cannot be higher than 1, so the Tobit model is suitable in this situation. Furthermore, seemingly unrelated regression analysis accounts for the possible interdependency between PTE and RTE calculated for the same production units and using the same set of explanatory variables, as was the case in Paper II.

In Paper III, a slightly different approach to two-stage analysis was employed, where overall DEA and individual MEA TE indices obtained from the first stage were used as explanatory variables in ordinary least squares (OLS) regressions in the second stage of the analysis. Six time-lagged dimensions (t-1 to t-6) of all technical efficiency indices in individual OLS regressions were used to evaluate the joint time effect of efficiencies by the Wald test of joint significance. The dependent variable was the variable structural change, expressed as percentage change in production unit size. Spearman non-parametric correlations were also performed, to evaluate the association of technical efficiency indices with the variable of structural change.

The two-stage approach has been criticised in the literature for producing biased results due to the exclusion of relevant variables that may influence firm efficiency from the model that estimates technical efficiency coefficients, by either parametric or nonparametric methods, and due to the fact that variables from the first stage may be correlated with the variables used in regression of the second stage (Simar & Wilson, 2007; Coelli *et al*., 2005; Battese & Coelli, 1995; Kumbhakar *et al*., 1991). However, using only one-stage analysis in Papers I-III would not have permitted use of the panel data on input and output variables for calculation of technical efficiency indices, due to the cross-sectional nature of explanatory variables from the survey. Furthermore, using just one year of panel data for input and output variables that match the survey data would have resulted in a smaller data sample, while adding a large amount of independent explanatory variables in calculation of technical efficiency indices, which would have biased the estimation of technical efficiency scores (Coelli *et al*., 2005), so that these appeared higher than in reality. If only a limited number of explanatory variables were used, such as age, farm size, farmer education and farmer experience, it would be plausible to use one-stage analysis with cross-sectional data.

3.2 Economic experimental approach to measure illusion of control

In Paper IV, an economics experiment approach was combined with a survey and application of a psychological scale to examine the research question: Are farmers affected by illusion of control in their financial decisions on loan repayment allocations? Between- and within-subject illusion of control was analysed in the experiment by comparison of results from treatment and baseline groups and applying a measure of illusion of control over random outcomes determined from the survey. Performance-based incentives and a written script were used for the experiment. Every participant received a show-up fee for a finished session.

To support behavioural economics with empirical evidence, researchers tend to conduct different types of economic experiments with real economic incentives and to study real people in controlled laboratory or field situations (Harrison & List, 2004). Illusion of control has been measured by both experimental and survey methods in previous studies. Measuring illusion of control using the experimental method requires an experiment set-up to be designed, mostly in a practical financial, business or gambling situation. The participants have to solve different tasks such as invest, bet or play a game, and the results in diverse forms are used as the basis for evaluation of illusion of control (Charness & Gneezy, 2010; Fellner, 2009; Grou & Tabak, 2008). The survey method for measuring illusion of control involves enquiring about perception of control over a random outcome in an approach which can range from a single direct question to an elaborate psychological scale (Moodie, 2008; Wood & Claphan, 2005; Ohtsuka & Hyam, 2003). The direct question or scale can stand on its own, or can be combined with a practical experiment investigating a follow-up question (Ejova *et al*., 2010; Kwak *et al.*, 2010; Biais *et al*., 2005; Fenton-O'Creevy *et al*., 2003; Simon *et al*., 2000).

In contrast to survey data collection, the laboratory setting permits direct control of some variables and the changes in the variable of interest can be isolated by designing two settings, a treatment group and a control group, which are identical in all but the treatment variable (Falk & Heckman, 2009). The variable of interest is that which evokes an illusion of control in the decision process. Langer (1975) suggests that confusion about skill in the chance situation elevates feelings of control of the result and thus creates illusion of control. In a skill situation, the result is partly due to abilities, knowledge, choice, familiarity, passive or active involvement and competition, whereas in a random situation the individual has no control over the outcome. Thompson (1999) also describes factors that influence illusion of control based on situation, such as personal involvement, familiarity, foreknowledge of the desired outcome and success at the task. Fenton-O'Creevy *et al*. (2003) claim that illusion of control is strengthened by stressful and competitive situations, including financial trading. Charness and Gneezy (2010), on the other hand, show that if participants are asked to pay for more believed control, the illusion of control disappears.

The work in this thesis follows the definition of Thompson (1999), who describes illusion of control as the tendency for people to overestimate their ability to control events. The illusion of control was tested in Paper IV as active involvement in the random outcome of a roll of a die and the possibility to pick the "winning" numbers. In random situations, outcome is given by an independent probability that cannot be changed. If the die shows six numbers, the probability of any one of the numbers turning up as a result of the throw is one in six, regardless of who rolls the die, how they throw it or where. If, for some reason, an individual believes that a certain number has a higher probability of turning up (*e.g.* two in six), that individual may be influenced by illusion of control. Such a situation may arise on including active involvement in the chance event, for example when the individual rolls the die instead of somebody else rolling it for them (Charness & Gneezy, 2010; Fellner, 2009).

Experiments can be given a contextualised (or framed) design, when the context of the situation is described and mimics the real situation, or a decontextualised design, when the experiment is presented in an abstract way (Harrison & List, 2004). When deciding on an experiment to measure illusion of control among Swedish pig farmers in Paper IV, the approach of Fellner (2009) was used, but modified to suit the financial and economic reality in the Swedish agricultural setting. Exploratory interviews were conducted with farmers in order to determine an appropriate design for the experiment and frame it in a way that resembled reality, but was also practical and understandable for the farmers (*cf.* Rommel *et al.*, 2017).

Certain rules apply when conducting economics experiments, as opposed to psychology experiments, that relate to the four features of experimentation: (i) script enactment; (ii) repeated trials; (iii) performance-based monetary payments; and (iv) proscription against deception (Hertwig & Ortmann, 2001). As regards (i) and (ii), economists usually give participants in a trial the full detailed script and the opportunity to repeat and learn how the experiment works (Fellner, 2009; Biais *et al.*, 2005). Psychologists usually do not provide any script and do not give participants any preparation or repeat trials (Langer & Roth, 1975). As regards (iii), economists generally provide financial incentives based on the performance of individuals in the given task, as well as a show-up fee (Holt & Laury, 2002; Binswanger, 1980). Psychologists usually give participants only a show-up fee, a nonmonetary remuneration that is not performance-based or no incentive at all (Lopes & Oden, 1999; Kahai *et al.*, 1998; Langer & Roth, 1975). Views about (iv) (deception) also differ greatly between psychology and economics studies. Deception is used in psychology experiments and is even accepted under the ethical principles of psychological societies (Fenton-O'Creevy *et al.*, 2003), whereas deception is not accepted in economics experiments. Since most of the experiments conducted on illusion of control have been carried out by psychologists and published in psychology journals, they do not follow the rules for experiments carried out by economists. The empirical findings of psychology studies have higher variability than those of economic studies and are usually not comparable (Hertwig & Ortmann, 2001).

4 Data collection

Three types of data sources (secondary, survey, experiment) were used for the empirical work presented in this thesis. Secondary data were used in Papers I, II and III. Primary data were obtained from survey questionnaires to support the analysis in Papers I, III and IV. An experimental design was used to collect primary data for Paper IV.

4.1 Choosing a data collection method

When choosing a data collection method, several aspects have to be taken into consideration. It is always more economical and less time-consuming to use secondary data that have been collected in the past. These data are most probably readily available and, after some preliminary examination or compilation, ready to use for the analysis. If the secondary data are based on actual behaviours in the past, such as purchases, investments and production economics data, the real situation is captured as it was in that particular moment in time. The disadvantage when using secondary data is that they have not been collected exactly for the purpose of the analysis, and might not always contain the information needed. Since there is no direct involvement in data collection, the source of data or the information provided, secondary data might be erroneous. For example, the exact situation and circumstances of the data collection are often not known and there may be a number of factors affecting behaviour that cannot be controlled for.

When the data required for an analysis are not available, it is necessary to obtain primary data, for example with the help of a questionnaire. The advantage of this method is that it can provide answers to questions tailored for the needs of the analysis. However, collection of data by questionnaire is more expensive and time-consuming than using secondary data. The preparation stage before actual collection of data is much longer and the distribution of questionnaires and collection of responses also takes more time. If respondents are rewarded for completed questionnaires, the costs are even higher. A disadvantage of mail questionnaires is that it is not possible to control for who is actually answering the questions. Conducting personal interviews would eliminate this problem, but the time requirement and costs would be much higher. Another disadvantage of survey data collection is that it is sometimes uncertain whether respondents would actually behave in the way they report if real economic incentives were involved based on the answers, or if some element of the influencing factors changed.

Another method for collecting primary data is in laboratory experiments. This method is preferable if a high degree of control over the data collected is necessary. Having participants come to a laboratory ensures that the subjects asked to answer are the actual respondents. The laboratory setting also permits control of some variables directly and changes in the variable of interest can be isolated (Falk & Heckman, 2009). This is not always possible in field or survey data collection. If economic incentives are used, it can be assumed that participants would be motivated to answer as they would in a real situation, where economic incentives are a high priority. One disadvantage of the laboratory experiment is in collecting data from a particular working group, rather than from student volunteers or the general public. Laboratory experiments are also more expensive, due to the need to provide a show-up fee and an incentivised payoff, and it takes a longer time to design the experiment and to collect data than for secondary data collection.

4.2 Secondary data

Secondary data were used to calculate technical efficiency indices in Papers I, II and III, as well as some explanatory variables for the second-stage analysis in Papers I and II. The dependent variable (structural change) in Paper III was also calculated from secondary data. These data were obtained from the Swedish Farm Economic Survey (FES), which is carried out by Statistics Sweden on behalf of the Swedish Board of Agriculture. The FES data are used as the Swedish input for the European Union Farm Accounting Data Network (FADN) but, unlike basic FADN data, the FES database contains more data, including physical units of inventory, labour and land in addition to monetary units. However, the FES does not cover all farms in Sweden. Instead, approximately 1000 farms report data on income statement, balance sheet and some background variables, and around 10% of the farms are replaced every year, forming an unbalanced panel. The FES data are stratified to ensure representation of all geographical locations, production types and herd sizes. Pig production farms represent approximately 12% of farms in the Swedish FES database.

In Paper I, FES data from 2009-2011 were used and farms that receive more than 50% of their income from pig production were included. This resulted in a total of 286 observations (where each farm could be represented more than once). The farms were categorised according to specialisation into: piglet production (124 observations for 54 farms), growing-finishing pig production (60 observations for 26 farms) and integrated pig production (102 observations for 43 farms). The MEA and DEA technical efficiency indices were calculated for each farm and for every year the farm was present in the database. The technical efficiency indices were calculated separately for the three production groups.

In Paper II, data from 2002-2012 following the FADN classification for pig production (two-thirds of income from pig production) were used. This resulted in a total of 1229 observations that represented 196 individual pig farms. Piglet production accounted for 47% of these 196 farms, growing-finishing production for 20% and integrated pig production represented 33%.

In Paper III, FES data on integrated pig production in Sweden for the period 2002-2011 were used. In order to capture the specialisation in integrated pig production, the sample was restricted to observations for which the value of income from pig production exceeded 50% of total income. This resulted in 356 observations for a total of 86 farms.

4.3 Primary data of collection - survey

Secondary data from the FES database were not sufficient for the analysis in Papers I and II. Therefore a mail survey was distributed to farmers who participated in the FES in 2010 and who reported some income from pig production. Before designing the questionnaire, face-to-face interviews were held with pig producers and an in-depth review of the literature was conducted. Commercial pig producers were consulted about the final version of the questionnaire. The Swedish Board of Agriculture helped distribute a total of 138 questionnaires by mail in 2012, followed by two reminders and, where, necessary by telephone calls. This yielded 87 responses (response rate 63%). Responding farmers were rewarded with a gift voucher worth SEK 300 (1 USD = 6.7 SEK; Oanda, 2015) for a local garden centre, as a token of appreciation for their time and effort. For Paper I, 71 usable responses were obtained, 31 representing piglet production, 16 growing-finishing production and 24 integrated pig production. The ‘farm-specific characteristics’ variables used in correlation analyses in Paper I were obtained from the responses. For Paper II, 75 usable responses were obtained, 35 representing piglet production, 18 growing-finishing production and 22 integrated pig production. The management practices variables used in Paper II, represented as a set of human capital factors and a set of strategic management characteristics, were obtained from the questionnaire responses.

A separate survey was conducted to collect socio-economic and farm-related variables for Paper IV. This survey was part of a larger collection of primary data that included experimental design and questions about perceived control over the outcome, as well as a psychological scale to measure illusion of control among farmers. In total, 41 completed questionnaires were collected, together with the results of experiments and the psychological scale.

4.4 Primary data - experimental study

In Paper IV, an experimental study was conducted to collect the data for the main variable of interest, measure of illusion of control. A multi-stage computer laboratory experiment was programmed and conducted with the experimental software z-Tree (Fischbacher, 2007). The experimental design followed the approach of Fellner (2009), modified to suit the financial and economic reality in the Swedish agricultural setting. Exploratory interviews were conducted with farmers before designing the experiment and validation experimental sessions were held to finalise the design.

The original plan for collection of data was to conduct laboratory sessions with several respondents (10-15 at a time). This initial plan proved to be difficult and different sources and locations across Sweden had to be combined to obtain 41 completed responses. Data were collected from 21 farmers on two different occasions during June and July 2012 at agricultural fairs in southern and eastern Sweden, using a mobile computer laboratory. An advertisement about the experiment was placed in the fair programme and invitations to participate in the study were sent to 300 farmers in the area of the fair. Data collection was complemented with personal visits to farmers in the Uppsala region, who completed the experiment on the computer on their farms. The farmers recruited were randomly assigned to one of the two groups (treatment group and control group) in the experiment. The experiment lasted from 30 to 45 minutes. There was no time limit, but at certain stages of the experiment a red banner on-screen prompted farmers to make a decision. As a show-up fee, respondents were rewarded with an SEK 300 gift voucher for a local garden centre. In addition, the gain from the incentivised stage of the experiment was paid as the exact sum, in the form of a gift voucher mailed to the participants by regular mail.

5 Summary of Papers I-IV

5.1 Paper I: Multidirectional analysis of technical efficiency for pig production systems: The case of Sweden

Despite structural changes in the pig industry in Sweden and in other European Union countries, whereby the number of farms is decreasing but the pig herd size is increasing, the pig industry is still facing challenges in the form of low production and profitability (Swedish Board of Agriculture, 2014). Technical efficiency, a factor that influences productivity, has been found to differ among pig producers in Sweden and in other countries. Several studies have also examined the influence of some farm-specific variables on aggregate technical efficiency indices (Tonsor & Featherstone, 2009; Galanopoulos *et al*., 2006; Oude Lansink & Reinhard, 2004; Sharma *et al*., 1999; Rowland *et al*., 1998; Heshmati *et al*., 1995). However, aggregate measures of technical efficiency may not show the real influence of some variables related to individual input and output measures of technical efficiency indices.

The aim of Paper I was to identify farm-specific characteristics associated with higher technical efficiency indices on disaggregated level, calculated by multidirectional efficiency analysis (MEA) (Asmild *et al*., 2003; Bogetoft & Hougaard, 1999) for piglet production, growing-finishing production and integrated pig production in Sweden. Four groups of farm-specific characteristics were identified, namely: (i) general practices; (ii) housing systems; (iii) feeding practices; and (iv) health and cleaning practices. For comparison, the aggregated technical efficiency indices were also calculated by data envelopment analysis (DEA) (Coelli *et al*., 2005; Charnes *et al*., 1978).

In the first stage of the analysis, the data were used to calculate the technical efficiency indices were Swedish Farm Economic Survey (FES) data for 2009-2011. Individual MEA TE indices were calculated for five inputs (feed, labour, variable inputs, fixed inputs and land) and two outputs (outcome from pigs and other outcome), in separate analyses for piglet production, growing-finishing production and integrated pig production. Overall input and output DEA TE indices were also calculated using these data. A separate survey of farms that participated in FES in 2010 was conducted in order to obtain data on farm-specific characteristics related to general practices, housing systems, feeding practices and health and cleaning practices. The three-year average results of individual MEA and overall DEA technical efficiency indices were used in non-parametric Spearman correlation in order to identify farm-specific characteristics that influence the technical efficiency indices for piglet production, growing-finishing production and integrated pig production.

The results showed that correlation of farm-specific characteristics with individual MEA TE indices revealed extra details. Some more farm-specific characteristics resulted in more statistically significant results or a higher level of significance compared with the correlation results obtained with overall input and output DEA TE indices.

In general, correlations for individual MEA TE indices with farm-specific characteristics in the 'general practices' and 'housing practices' categories were rarely or never statistically significant. Exceptions were that using cross-trough pens in growing-finishing production was highly correlated with the technical efficiency of feed, variable and fixed inputs and both output technical efficiency indices. Using cross-trough pens was also highly correlated with the technical efficiency indices for feed, labour inputs and output from pigs in integrated pig production. Use of a heated floor was positively correlated with labour technical efficiency indices in growing-finishing and in integrated pig production, but was not significantly correlated with any of the technical efficiency indices in piglet production. A longer time since the last renovation of pig houses negatively affected all technical efficiency indices in integrated pig production except for 'other production'.

Regarding effects of 'feeding practices' on individual MEA TE indices, the results indicated that restrictive feeding increased all technical efficiency indices in growing-finishing production except that for land, while having individual feeding increased the feed, variable and fixed input technical efficiency indices and both output technical efficiency indices for piglet production. Manual feeding in integrated pig production resulted in negative correlations for all technical efficiency indices except that for 'other production'. Using wet feed was positively correlated with labour and land input technical efficiency indices and the technical efficiency index for output from pig production in growing-finishing production, as well as with the labour technical efficiency index in integrated pig production. Producing all or part of the feed on-farm was positively correlated with almost all technical efficiency indices for piglet production except that for fixed inputs. In contrast, buying feed from others was positively correlated with labour technical efficiency in growing-finishing production. Being organised and having written instructions on feeding positively increased the technical efficiency of labour and land inputs and pig production output for growing-finishing production, as well as the feed, variable, fixed inputs and land technical efficiency indices, and both output technical efficiency indices, for integrated pig production.

The results also indicated that in the category ‘health and cleaning practices’, having written instructions on infection control in piglet production was positively correlated with feed, labour, fixed and land input technical efficiency indices and with the technical efficiency index for output from pig production. Taking action after a deviation from instructions for infection control and checking the feeding trough more times per day resulted in positive correlation of all technical efficiency indices in growing-finishing production. Adjusting levels of feed in piglet production was positively correlated with all technical efficiency indices for that specialisation.

Different types of policy-related conclusions can be drawn from the results in Paper I. For example, the data indicate that if the labour efficiency is to be increased, investments in new technology, *e.g.* wet feed equipment and heated floors, in growing-finishing and integrated pig production, use of cross-trough pens and elimination of manual feeding in integrated pig production, and production of feed on-farm in piglet production can be of interest. Use of written instructions on infection control in piglet production and on feeding practices in growing-finishing and integrated pig production can be recommended in order to increase the technical efficiency of income from pigs. Overall, the uniqueness of each pig production specialisation was also reflected in the results from Paper I. Thus the particular specialisation should be taken in consideration when making recommendations for improving the efficiency of pig production.

5.2 Paper II: Impact of management practices on persistent and residual technical efficiency – a study of Swedish pig farming

Managerial practices such as management control approaches that farmers implement on their farms and the human capital of farmers influence the technical efficiency of the farm (Manevska-Tasevska & Hansson, 2011; Hansson, 2008; Rougoor *et al*., 1998). More specifically, accumulated capacity in managerial practices is likely to affect the time-invariant persistent technical efficiency (PTE) as opposed to the residual technical efficiency (RTE), which can vary over time due to random effects (Kumbhakar *et al*., 2014; Kumbhakar & Heshmati, 1995). A number of previous studies have measured the effect of managerial practices on overall technical efficiency (OTE) (*e.g*. Hansson, 2008; Galanopoulos *et al*., 2006; Puig-Junoy & Argiles, 2004; Wilson *et al*., 2001; Willock *et al*., 1999), but the findings might be less precise than those obtained if a distinction between PTE and RTE had been made.

The aim of Paper II was to assess the effect of farmers’ management practices on PTE and RTE and to compare the results to the analyses when OTE was used. By evaluating how managerial factors affect the different technical efficiency indices, the objective was to determine the reasons for differences in farm efficiencies and thus to identify changes farmers could make in their long-term or short-term approaches in order to become more efficient.

The data used for calculating technical efficiency indices for pig farms in Sweden were obtained from the Swedish Economic Survey (FES) database 2002-2012 and the data on managerial practices and socio-economic characteristics were collected from a questionnaire mailed directly to the pig farmers that participated in FES in 2010. As recommended in the literature (Frese, 2009; Cadez & Guilding, 2008; Shane *et al*., 2003; Rougoor *et al*., 1998), variables were included to account for two groups of managerial practices, "who farmers are", and "what farmers do", as a set of human capital factors and a set of strategic management characteristics.

The analysis was performed with a multi-level approach, where the parametric stochastic frontier random effects panel model elaborated by Kumbhakar *et al*. (2015) was used in step one to estimate RTE, PTE and OTE. In step two, the two-equation seemingly-unrelated regression (SUR) BiTobit model (Huang, 1999) was used to evaluate the impact of management practices on technical efficiency. Since managerial practices are likely to affect long-term efficiency (PTE), two separate BiTobit SUR models were used, one in which PTE compared with RTE was used as the dependent variable and one in which PTE compared with OTE was used.

The results showed that growing-finishing production was the most efficient specialisation, with higher values of PTE, RTE and OTE than piglet or integrated pig production. The results from the simultaneous regression analysis of BiTobit models showed that, as expected, managerial practices influenced the long-lasting PTE and had almost no significant effect on RTE. In particular, managerial experience, economy-driven goals and use of strategic management accounting practices, including updated budgets and PigWin software, were drivers of persistent efficiency on the farms. In contrast, conducting bookkeeping checks more frequently had a negative effect on PTE. Farmers focusing on meeting market demands in terms of quality were also less efficient. Effects on OTE were similar to those on PTE, but the hidden effect of RTE on OTE was visible in managerial experience and frequent bookkeeping use, which were not significant for OTE but showed significant effects for PTE. From a policy perspective, the similar overall values of PTE and RTE obtained show the importance of including both when making decisions about improving efficiency in pig production. Policy measures supporting the analytical capacity of farmers in general and the managerial skills of young farmers in particular should be considered if long-term PTE is to be increased. For farmers orientated towards high quality of production, extra support in marketing, labelling or other market-related knowledge would be of benefit to boost their product value and eventually increase total output.

5.3 Paper III: Effect of technical efficiency on structural changes in Swedish pig production

The ongoing structural reorganisation in the agricultural sector, where fewer but larger farms are emerging, is most likely due to the need for increased profitability, which is attainable by economies of scale, technological advances and modernisation (Zimmermann & Heckelei, 2012; Geels, 2009; Breustedt & Glauben, 2007; Cochrane, 1958). The Swedish pig industry is no exception in this regard, as the number of farms decreased by 74%, but pig herd size increased by 193%, from 2000 to 2016 (Statistics Sweden, 2017). High productivity is a well-established precondition for growth and one of its components, technical efficiency, could thus be an important factor driving farm growth (Diamond, 1997; Timmer, 1988; Johnston & Kilby, 1975; Johnston & Mellor, 1961; Schultz, 1953). Aggregate measures of technical efficiency (Farrell, 1957) might not be sufficient in determining the impact that technical efficiency has on structural change, since it might be assumed that the individual input and output components of technical efficiency affect growth differently.

The aim of Paper III was to examine the extent to which technical efficiency determines the percentage change in growth of pig production operations in Sweden and, in particular, to compare the results of individual technical efficiency indices calculated by multidirectional efficiency analysis (MEA) (Bogetoft & Hougaard, 1999) with the overall aggregated measure of technical efficiency indices calculated by data envelopment analysis (DEA) (Coelli *et al.*, 2005; Charnes *et al.*, 1978). Since factors of growth in the pig industry are mainly described on qualitative level in the literature, the quantitative research presented in Paper III on the time dimension effect of lagged individual technical efficiency variables on size of production unit is a novel contribution in the area of structural change and growth of firms.

Data used in the analyses were obtained from the Swedish Farm Economic Survey (FES) for 2002-2011 for integrated pig production in Sweden. This type of production involves both piglet and finishing pig production. From the farm-level panel data, seven individual MEA TE indices were calculated, for feed, labour, variable, fixed and land inputs and output from pigs and other output, as well as two overall input and output DEA TE indices. Six time-lagged dimensions (t-1 to t-6) of the technical efficiency indices were used in ordinary least square (OLS) regressions separately for individual MEA TE indices and overall DEA TE indices, to evaluate the joint time effect of efficiencies on percentage change in production unit size in integrated pig production. Six models for each group of technical efficiency indices were created by simplification of the full model, where all time dimensions were included (t-1 to t-6) by taking away the latest time dimension at a time.

The results of Wald tests of joint significance suggested that a model in which three time lags of individual MEA TE indices were used was the best fit with the reality of long-term investments that structural change requires. Statistical significance of the results increased with the time lag increase in the model from t-1 up to t-3. When more than three time lags were added to the model, the significance of individual time lags was lost. Analysis performed with DEA TE indices did not confirm the long-term nature of investments. The individual effect of each technical efficiency index lagged to time t-3 was evaluated by the Wald test of joint significance in OLS regressions and by performing nonparametric Spearman correlations adjusted for the Bonferroni significance levels with the variable structural change, expressed as percentage change in production unit size. None of these resulted in significance and an individual effect was not confirmed for any of the technical efficiency indices. This result might be due to the fact that individual variables affect structural change in different ways for individual farms and the overall effect is not visible.

5.4 Paper IV: Exploring illusion of control in Swedish farmers' investment and financial decisions

Under certain conditions where a skill element is introduced in chance situations, the illusion of control, defined by Thompson (1999) as people's tendency to overestimate their ability to control events, can evoke beliefs of control over random outcomes. The illusion of control occurs mainly in decisions made under uncertainty and can be also present in financial and investment decisions (Thaler, 2012; De Bondt & Thaler, 1995). Illusion of control has mostly been studied previously with students or the general public in gambling settings (Stephens & Ohtsuka, 2014; King *et al*., 2011; Ejova *et al*., 2010; Ohtsuka and Hyam, 2003). Only a few existing studies about illusion of control have dealt with financial decisions under uncertainty (Meissner & Wulf, 2017; Fast *et al*., 2008; Biais *et al*., 2005; Simon *et al*., 2000) and even fewer with illusion of control in specific professional contexts (Durand, 2003; Fenton-O'Creevy *et al*., 2003). Farmers deal with substantial production risks due to weather conditions, but also financial risks when investing in new technology (Harwood *et al*., 1999). Previous experimental studies on farmers have focused on elicitation of risk and ambiguity attitudes (Bougherara *et al*., 2017; Bocquého *et al*., 2014), but to the best of my knowledge no previous study has examined the illusion of control in farmers' financial decisions under uncertainty.

The aim of Paper IV was to examine illusion of control among Swedish farmers related to farm investment and financial decision making under uncertainty. The illusion of control variable was measured in three dimensions. First, illusion of control was assessed in an experiment designed according to economic principles. Second, farmers were asked to express perceived control over random outcomes after each part of the experiment. Third, the Drake Beliefs about Chance inventory (DBC) was used to measure illusion of control. DBC is a psychological scale designed to measure overall illusion of control that was first elaborated by Wood and Clapham (2005), but in Paper IV some of the questions were modified to an agricultural setting.

The framed field computer experiment was programmed and conducted with z-Tree (Fischbacher, 2007), where farmers participated in two trials to measure illusion of control from experiment with monetary incentives. The experiment was inspired by Fellner (2009) and adjusted to suit the setting of financial and investment decisions by Swedish farmers. The main task of subjects in the experiment was to allocate loan repayments for the purchase of new tractor between safe (5 years) and riskier options (1 and 2 years) of binding periods, while minimising the cost of the loan and thus the cost of the investment. The uncertain future interest rate was determined by the random outcome of a throw of a 10-sided die according to the given probabilities. Farmers were assigned randomly to two groups that differed in the order of two experimental settings. In the base setting, the instructor rolled the die in order to determine the future interest rate and in the treatment setting farmers rolled the die themselves and could choose the numbers that represented different probabilities of the future outcome of interest rate. This setting involved the participants to some extent in the process of determination of the future interest rate, but there was no objective control, since the outcome of a roll of a die is a purely random event. The outcome of the experiment determined the payments that farmers received, in addition to the 300 SEK gift voucher for participation in the study.

The experiment had a within- and between-subject design and the illusion of control variable was calculated for both designs. The main outcome variable was loan allocation to the risky options, where farmers were considered to be acting under the illusion of control if they allocated larger loan amounts to the risky option when they were in charge of rolling the die (Fellner, 2009; Grou & Tabak, 2008). Furthermore, two survey measures of illusion of control were tested. First, participants were asked about their perceived control over the outcome of the interest rate on a nine-point scale (where one means no control and nine means total control). In principle, perceived control should be zero over purely random outcomes. Thus, any positive value would indicate illusion of control. Second, the Drake Beliefs about Chance (DBC) inventory scale, which consists of two measures (superstition and illusion of control) was implemented, but with some questions with a general gambling formulation modified to suit an agricultural setting.

Data were collected at different locations across Sweden. In total, 41 answers were obtained by recruitment of participants at agricultural fairs and in individual visits to farmers. In addition to the experiment and survey questions to assess illusion of control, some data on the demographic and socio-economic characteristics of farmers were also collected at the end of the study.

On evaluating the results of the experiments, no clear pattern of illusion of control emerged. Between-subject effects were tested with a non-parametric Mann-Whitney U test for both trials and within-subject effects with a Wilcoxon signed-rank test for both orders, but no significant results were obtained. The within-subject design revealed that 66% of farmers did not change their behaviour when in charge of rolling the die, 15% allocated a higher amount to the risky options and 20% decreased their allocation to the risky options.

Perceived control over the outcome of interest rate was evaluated from the survey question. The results showed that, on average, farmers responded with 5.2 on a nine-point scale when the instructor rolled the die, compared with 5.9 when they themselves rolled the die in the first trial. For a totally random outcome, there should be no difference. Testing for within and between effects again resulted in no significant results. The within-subject design made it possible to check the answers of individual farmers, which revealed that 29% had greater perceived control and 22% less perceived control between the two treatments and 49% did not change their ratings between the two trials. The results from the five-point psychological DBC inventory scale revealed a moderate average value of 1.8 for superstition in the sample, while the illusion of control scale and adapted questions to agricultural context approached the upper limit, with 2.68 and 3.25 respectively. This suggests presence of illusion of control in the sample.

Correlation analysis of the results was conducted for the different measures of illusion of control. For the DBC scale, all partial scores correlated strongly and positively, which suggests that all partial scales measured the same construct, including the questions with a modified agricultural framing. In contrast, there were no significant correlations between the experimental measure or perceived control measure and DBC scale measures of illusion of control, which would suggest that these scales measure something different.

To conclude, there was no indication of illusion of control in the experimental data or perceived measure of illusion of control in the survey data. However, the DBC psychological scale suggested the presence of illusion of control in the sample. The significant correlations obtained for the DBC scale results with questions modified to an agricultural setting indicate that, in future, researchers could rely on existing psychological scales, with slight modifications to the framing of the questions if necessary. Overall, the experiment, perceived control and psychological scales proved to be complements, rather than substitutes, as measures of illusion of control.

6 Contributions of the thesis

The contributions of this thesis are both empirical and methodological. In an empirical perspective, the work extended the literature on technical efficiency in pig production by calculating individual technical efficiency indices for pig production using a novel multidirectional efficiency analysis (MEA) approach. This allowed technical efficiency measures to be obtained for each input and each output of different specialisations in pig production. The method also allowed for a simultaneous decrease in some inputs and an increase in some outputs, which is not possible in overall input or output data envelopment analysis (DEA) or stochastic frontier analyses. Using Farm Economic Survey (FES) data, it was also possible to divide pig production into its main specialisations based on technology, namely piglet production, growing-finishing production and integrated pig production. This division has been used only rarely in the literature and mostly for the first stage in calculation of overall technical efficiency indices. Compared with existing studies in the literature on the practical production characteristics that influence the technical efficiency of pig production, a much wider range of variables was examined in this thesis. The variables were grouped into four areas: (i) general practices; (ii) housing systems; (iii) feeding practices; and (iv) health and cleaning practices. Analysis of data on this extensive list of explanatory variables and calculation of individual technical efficiency indices for each input and output for three pig production specialisations provided a detailed picture of the variables affecting individual technical efficiency indices for a particular production type.

This thesis distinguishes between persistent technical efficiency (PTE) and residual technical efficiency (RTE) of pig production, here for the example of Sweden, using the stochastic frontier model developed by Kumbhakar et al. (2015). To the best of my knowledge, this thesis is the first work to make such a distinction when calculating technical efficiency indices for pig farms. The separation of technical efficiency into persistent and residual efficiencies is important when analysing the influence of variables that do not change over time. In this thesis, this division also made it possible to identify some variables that affect persistent technical efficiency even when the effect on overall technical efficiency is not significant. The collection of primary data especially for the purpose of the studies in this thesis permitted evaluation of variables that have not been studied previously. Furthermore, it was possible to match the data from the survey about qualitative variables to the production and economic data for each farmer in FES dataset.

The approach used for explaining the structural change in pig production in Sweden with the explanatory variables of individual technical efficiency indices calculated by MEA is a unique empirical contribution to the literature. To the best of my knowledge, this thesis is also the first to explore how technical efficiency affects farm size on quantitative level over time. In previous studies, structural changes in pig production have been analysed only from a qualitative perspective.

The contribution of the work summarised above is particularly significant in view of the importance and relevance of the subject area. Structural change is a major trend not only in the Swedish pig industry, but also in pig production in other European Union countries. Information on the characteristics, production or managerial, that affect technical efficiency in new structural types of pig production and whether technical efficiency in itself affects structural change is vital for farmers and also for policymakers, in order to formulate new strategies for increasing profitability in pig production.

The novel experiment to study illusion of control presented in this thesis differs from other studies on illusion of control in that it frames the experiment to the financial decisions of farmers related to allocation of loan into different repayment periods. To date, illusion of control has mainly been studied in gambling situations or in a few investment-framed analyses, in studies using student volunteers or the general public as the research group. Farmers have not been analysed in previous studies about illusion of control. Moreover, unlike in the natural sciences, experiments are not widely used in social sciences, with the exception of psychology. However, the importance of behavioural studies and incentivised experiments is increasing and even demanded from a policy perspective. Until now, policy makers have based their decisions solely on conventional analytical methods.

In future work, some modifications could be introduced to make the analysis and final results even more valuable. For example, use of dynamic MEA analysis could be beneficial in describing the quasi-fixed inputs of investments in pig production, while use of a truncated model, as opposed to a BiTobit model, could be useful in the second stage of analysis comparing persistent and residual technical efficiency. Moreover, slight changes to the design of the experiment on illusion of control regarding differences between base and treatment groups would be helpful to fully evaluate the influence of the treatment variable on presence of illusion of control. For example, allowing farmers to pick numbers on 10-sided die that determined lower or stable interest rates and having farmers roll the die themselves to determine future interest rates could be separated into two different treatments.

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