Chapter 1

Factors of farm performance: an empirical analysis of structural and managerial characteristics

Steven Van Passel[†], **Ludwig Lauwers**[‡], **Guido Van Huylenbroeck**[§]

[†] *Policy Research Centre for Sustainable Agriculture, Belgium*

e-mail: Steven.VanPassel@Ugent.be

[‡] *Centre for Agricultural Economics, Belgium*

e-mail: Ludwig.Lauwers@ewbl.vlaanderen.be

[§] *University of Ghent, Belgium*

e-mail: Guido.VanHuylenbroeck@Ugent.be

Abstract

The agricultural sector faces a continuous process of structural change, which has important consequences for productivity and efficiency of farming. A consistent way of monitoring this process, and to support related policy making, is to analyse the performance of agricultural farms with productive efficiency techniques. In this chapter, the impact of managerial and structural characteristics on farm efficiency is analysed with a stochastic frontier model. First, an overview is given of similar studies looking to relations between structural characteristics, agent factors, and efficiency. Next, an empirical productive efficiency analysis is done on an unbalanced panel of 1018 Flemish farms over a 14-years period (1989-2002). The stochastic production frontier is estimated using the random-effects model with time-invariant efficiency, and with the translog as functional form. Finally, the stochastic production function is extended with extra regressors, to understand why farms differ in their relative efficiency. Empirical results show significant effects of education, the prospect of succession, farm size, type and location, age of farmers, solvency, and dependency on subsidies. Results are discussed in terms of capacities and incentives to perform better. Insight of the impact of these determinants helps to understand the driving factors of structural change and how policy may respond to it.

Keywords: farm performance, efficiency, structural determinants, managerial determinants

1.1 Introduction

Due to technological change and changing agricultural policies, in particular in industrial countries since the second half of the 20th century, the structure of the agricultural sector is rapidly changing. Labour leaves the sector, farm enterprizes increase in size and a growing share of agricultural production is produced by a relatively small number of highly specialised farm businesses (OECD 2002). The changing structure has important consequences for equity within agriculture, productivity and efficiency of farming, the demand for government services and infrastructures, and the well-being of local communities (Weiss 1999).

To monitor this process and to support policy making it is important to analyse the relationship with the performance of agricultural farms. A consistent and challenging way of doing this is to measure farm efficiency. Existing efficiency analysis techniques help to understand why farms differ in their relative efficiency. Differences in performance raise a lot of policy relevant questions (Poppe & van Meijl 2004): What are the determinants of these differences, can these differences be influenced by policy, to whom should support be targeted: frontrunners or laggards, and so on.

Such questions even become more important in the light of nowadays policy changes, e.g. the shift from the mere agricultural sector scope to the more integrated (rural, sustainability) approaches.

In this chapter, we focus on the impact of managerial and structural characteristics on farm performance. This research highlights the interplay between farm efficiency and farm characteristics. First, an overview of similar studies is given. Next, own empirical research is reported, based on the Farm Accountancy Data Network (FADN) from Flemish farms. This research uses stochastic frontier analysis for estimating the production frontier and for calculating firm-level technical efficiencies. In order to analyse the impact of firm-specific factors on efficiency, we enlarged the stochastic production frontier with extra regressors, indicating firm characteristics that are postulated to affect firm efficiency.

1.2 The impact of managerial and structural characteristics on performance

Several studies have attempted to understand variations in farm performance, in particular technical efficiency, by differences in e.g. size, organisational type and agent factors. Figure 1.1 shows a framework to classify the different characteristics in explaining efficiency. Both agent factors and structural factors have impact on farm efficiency. Agent factors are managerial characteristics of the farm such as the education level and age of the farm manager. Structural factors are classified in on-farm factors and off-farm factors. Examples of on-farm factors are the farm size, farm type, organizational type and the farm location. Up- and downstream relations and government interventions are examples of off-farm structural factors.

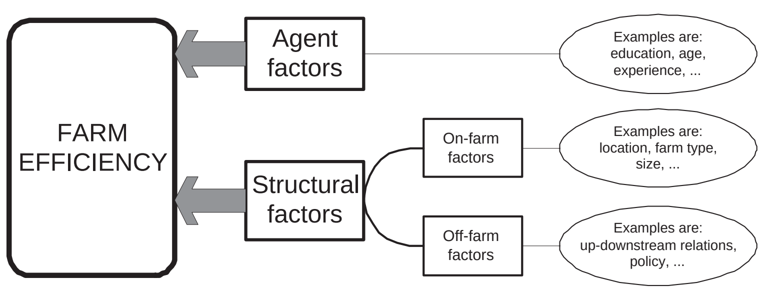

Figure 1.1: Factors affecting technical efficiency

1.2.1 Structural factors affecting efficiency

Farm size Debates concerning the *optimal farm structure* and *optimal farm size* have a long history in agricultural economics (Gorton & Davidova 2004). Hall & LeVeen (1978) explore the relationship between economic efficiency and farm size. They found for Californian farms that the long-run average cost curve is relatively flat after initially declining rapidly. Igliori (2005) found for farms in the Brazilian Amazon that the smaller farms are less efficient. Larger farms in the UK (Thirtle & Holding 2003), in the Greek agricultural sector (Rezitis, Tsiboukas & Tsoukalas 2002), in wheat farming in eastern England (Wilson, Hadley & Asby 2001), and in Portugese dairy farms (Hallam & Machado 1996) are operating more efficient than smaller farms. On the other hand, Polish farms greater than 15 ha have lower efficiency than smaller farms (Munroe 2001). Also for Irish farms (O'Neill, Leavy & Matthews 2001) and for Philippine rice farmers (Herdt & Mandac 1981), a negative relationship between farm size and efficiency are found. Hall & LeVeen (1978) and Seckler & Young (1978) state, however, that factors such as management, resource quality and the overall institutional structure are even more important than farm size. This may be the reason why the observed relationships between size and efficiency are not universal.

The empirical measures used to classify farm size can be criticized (Gorton & Davidova 2004). Common measures, such as land area, may be inappropriate for capturing differences in farming systems. European size unit measures, based on standard gross margins, have rarely been used as measure of farm size in efficiency studies (Gorton & Davidova 2004), but can be an acceptable solution (Lepoutre, Mathijs, Nevens, Van Passel & Van Huylenbroeck 2004).

Finally, it's important to notice that size is a relative concept so the search for a single *optimal size* is futile given the heterogeneity of farming systems and specialization of production factors (Verma & Bromley 1987).

Organizational type Rent, share, owner-operated, and other organizational forms are different types of agricultural forms (Roumasset 1995). A wide range of possibilities exists, going from a family farm to a large, factory-style corporation (Allen & Lueck 1998).

The impact of organizational type on efficiency is in particular an important issue in transitional economics. Mathijs & Swinnen (2001) found with data from former East Germany that partnerships emerging from the large-scale collective and state farms had a lower technical efficiency than family farms. Thiele & Brodersen (1999) found that the differences in ownership and production types are not important in explaining the inefficiencies of East German farms, but the differences in inefficiencies are rather the result of sub-optimal input allocations. Brada & King (1993) found similar results investigating state and private farms in Poland. They conclude that the internal organization of farm units does not explain differences in efficiency. On the other hand, agricultural policies and administrative distribution of inputs are at the origin of a sub-optimal allocation of resources in former Polish agriculture (Brada & King 1993). Using survey data on Bulgarian and Hungarian crop and dairy farms, Mathijs & Vranken (2001) found that family farms are performing better than corporate farms in the case of crop farms but not for dairy farms.

Farm type Although farms tend to evolve toward more product specialization, a lot of farms are still mixed. The fact that most farms are multi-product firms suggest, that the benefits of diversification are significant in agriculture. Economies of scope are one of these possible benefits, reflecting the reduced cost associated with producing multiple outputs and the risk-reducing effects of diversification (Chavas 2001). The efficiency in using resources can differ between farm types. Brümmer (2001) found for Slovenian private farms that the specialized cattle farms are less efficient than other farm types. Also, in the UK less specialized farms are found to be more efficient than other farms (Thirtle & Holding 2003). However, Hallam & Machado (1996) found for Portugese dairy farms that the efficiency is independent with the degree of specialization. Finally and contrarily, Santarossa (2003) found that specialized Scottish farms are more efficient.

Other structural factors Differences in efficiency can also be explained by environmental characteristics, such as soil quality, vegetation, altitude, climate, rivers, rain, temperature etc... Igliori (2005) found that the presence of forests and rivers are negatively and significantly correlated with efficiency for farms in the Brazilian Amazon. In the case of private farms in Slovenia, Brümmer (2001) showed that farms situated more than 600 meters above sea level are less efficient.

Location is a factor in explaining differences in efficiency, which links the farm location to environmental characteristics. O'Neill et al. (2001) found that farmers in the West of Ireland are less efficient than farmers in the east of Ireland. Scottish farmers in less favored areas are also less efficient. Also for Greek agricultural farms, location is found as an important determinant in explaining differences in efficiency (Rezitis et al. 2002).

Other factors, not always easy to differentiate from organisational factors, are ownership difference, financial factors and technology. For example farms can differ in the amount of owner-occupied land. Thirtle & Holding (2003) show for UK farming that farms with a higher proportion of owner occupied land are more efficient.

Also financial determinants can have an impact on efficiency. Chavas & Aliber (1993) found that medium and long-run debt financing has a positive effect on technical efficiency. O'Neill et al. (2001) and Thirtle & Holding (2003) found that the debt ratio to assets is positively related to efficiency.

Key technology variables can also have an impact on farm efficiency. On Australian dairy farms, one of the important determinants of differences in farm efficiency is the type of dairy shed used (Kompas & Che 2004).

Finally, also off-farm structural factors can influence firm efficiency (see figure 1.1). Contracting with upstream processors increases efficiency through facilitating the adoption of technology and access to credits. For Hungarian and Bulgarian farms Mathijs & Vranken (2001) found a strong positive effect of contracts with downstream processors on efficiency. Also support payments can influence efficiency. On Irish farms there is a negative relationship between dependency on direct payments and farm efficiency (O'Neill et al. 2001). Also on Hungarian farms inefficiencies are partly explained by subsidies, whereas Hungarian farms that had established export markets were more efficient (Piesse & Thirtle 2000).

1.2.2 Agent factors affecting efficiency

Age The age of the farm manager may be an indication for experience. Testing a model for technical inefficiency effects on paddy farmers from an Indian village, Battese & Coelli (1995) showed, however, that older farmers are more inefficient than the younger ones. Also, in the UK young farmers are working more efficient than older ones (Thirtle & Holding 2003). Other studies report similar results, indicating that older farmers are unwilling or unable to adopt technical innovations (Herdt & Mandac 1981, Parikh, Farman & Shah 1995). On the other hand wheat farmers in eastern England who have more years of managerial experience have higher levels of efficiency (Wilson et al. 2001). Wilson et al. (2001) argue that older farmers are more experienced and take profit of their knowledge to use inputs more efficiently.

In the UK, a positive relationship between age and efficiency was found up to the age of 49 years after which the relationship between age and efficiency became negative (O'Neill et al. 2001). In Chinese agriculture, farm efficiency increases with the age of the primary decision maker before he reaches the age of 40 and declines afterwards (Liu & Zhuang 2000). Farmers become more skillful as they grew older, but the learning-by-doing effect is attenuated as the farm managers reach the middle age (Liu & Zhuang 2000).

Education Investment in education can be seen as a strategy to improve agricultural productivity, principally through its complementarity with inputs as fertilizers, pesticides, irrigation, high-yielding variaties, and effective research and extension services (Lockheed, Jamison & Lau 1980). Farmers with more years of schooling tend to be less inefficient. In an application for Pennsylvania dairy farms Stefanou

& Saxena (1988) found that education and experience play an important role in the level of efficiency. The effect of schooling should be positive as better educated farmers are expected to have more skills to run their farm more efficiently (Parikh et al. 1995, Kalirajan 1990, O'Neill, Matthews & Leavy 1999, Battese & Coelli 1993, Battese & Coelli 1995, Mathijs & Vranken 2001, Liu & Zhuang 2000, Igliori 2005). The effects of education are much more likely to be positive in modern agricultural environments than in traditional ones, so the effectiveness of education is enhanced in a modernizing environment (Lockheed et al. 1980).

Management characteristics Including aspects of the decision-making process in explaining differences in efficiency is an important step (Rougoor, Trip, Huirne & Renkema 1998). Wilson et al. (2001) found that the objectives of maximizing profits and maintaining the environment are positively correlated with the technical efficiency of wheat farmers in eastern England. Trip, Thijssen, Renkma & Huirne (2002) found a statistically significant association between a high intensity of data recording and a high level of result evaluation and efficiency (Trip et al. 2002).

Other agency factors The level of education is only one indicator that determines the knowledge of the manager. Other indicators are for example following extra training, attending workshops and reading specialist publications. O'Neill et al. (1999) and O'Neill et al. (2001) measured the participation of Irish farmers to a training course and found significant positive impact on efficiency. Also farmers, who receive regular visits from advisory services, were working more efficiently (O'Neill et al. 1999, O'Neill et al. 2001). Those farmers who seek information are also associated with higher levels of technical efficiency (Wilson et al. 2001).

Having a successor for farming activities can also determine farm efficiency. Having a farm successor is significant in explaining the level of technical efficiency on Irish farms (O'Neill et al. 1999).

Human capital matters not only through age and education but also trough gender. Based on survey data on Bulgarian and Hungarian crop and dairy farms, Mathijs & Vranken (2001) found that farms with a higher proportion of woman are more efficient.

1.3 Empirical model: the stochastic frontier model

1.3.1 The basic firm efficiency model

The performance of an enterprize can be defined in different ways, for example ratio indicators, index numbers and relative efficiency scores. An important performance measure is efficiency. Farell (1957) defined efficiency as the success in producing as large as possible an output from a given set of inputs. This definition implies an efficient production function, or production frontier, to which the actual production is referred. Hence, the standard definition of a production frontier (or function) is that it gives the maximum possible output for a given set of inputs. The production function defines a boundary or frontier. Deviations of observed outputs from this frontier are in principle one-sided and can be taken to reflect inefficiency (Cornwell & Schmidt 1996).

To measure efficiency one has to known the form of the production function. Frontiers can be estimated with different methods. The two principal methods are data envelopment analysis (DEA) and stochastic frontiers (SFA) (Coelli, Rao & Battese 1998). DEA involves the use of linear programming methods to construct a non-parametric piece-wise frontier over the data ('an envelope'). Since DEA is non-parametric, it is robust to the kind of specification error that may arise in the choice of functional form of the production frontier. However DEA is non-statistical, so the determinants of its inefficiency estimates cannot be determined simultaneously. Furthermore, the DEA approach cannot disentangle inefficiency from random noise. This statistical noise is due to factors outside the control of firms such as weather. This means that any deviation from the frontier is regarded as inefficiency (Cornwell & Schmidt 1996).

In this chapter we will use stochastic frontier analysis (SFA) for estimating the production frontier. The main argument is that we want to analyse directly the determinants of the efficiency estimates.

Aigner, Lovell & Schmidt (1977) and Meeusen & Van den Broeck (1977) introduced the stochastic frontier production:

$$y_{it} = \alpha + f(x_{it}, \beta) + v_{it} - u_i \tag{1.1}$$

With v_i as a two sided i.d.d.(independent and identically distributed) error term and with u_i as a non-negative i.d.d. error term. Both v_i and u_i are assumed to be independent of the input variables x_{ik} and of each other.

The error term v_i accounts for measurement error and random errors such as weather, strikes and luck. The error term u_i measures the technical efficiency. One of the advantages of panel data is that firm-specific technical efficiencies can be estimated without assumptions about the distribution of the errors. Another advantage is the possibility to estimate the firm specific technical efficiencies consistently (Cornwell & Schmidt 1996).

The parameters of the stochastic frontier model can be estimated using the maximum -likelihood method. Our model will be estimated using unbalanced panel data. We tested different estimation techniques given the panel structure of the data. Instead of treating the u_i as fixed (fixed effects model) we assumed that the u_i are (Cornwell & Schmidt 1996): (i) independent and identically distributed (i.d.d.) from a one-sided distribution ($u_i > 0$) and (ii) uncorrelated with x_{it} and v_{it} for all t. The used model is called the random effects panel data formulation with time-invariant inefficiency. It's worth mentioning that the benefits of panel data come at the expense of another strong assumption that firm efficiency does not vary over time (Cornwell & Schmidt 1996).

The use of stochastic frontier analysis implies the choice of the functional form. The Cobb-Douglas functional form has been commonly used in the estimation of frontier models. The simplicity of this functional form is very attractive. The Cobb-Douglas production function has fixed input elasticities and returns to scale. A number of alternative functional forms have also been used in the frontier literature, e.g. the translog functional form (Christensen, Jorgenson & Lau 1973). An important advantage is that the translog form imposes no restrictions upon returns of scale or substitution possibilities (Coelli et al. 1998).

The basic specification for the model in equation 1.1 can be written as:

$$\begin{aligned} Ln(Yield_{it}) = \; & \alpha + \beta_1 ln(Lab_{it}) && + \beta_2 ln(Cap_{it}) && + \beta_3 ln(Area_{it}) \\ & + \beta_4 ln(Med_{it}) && + \beta_5 Time_{it} && + \tfrac{1}{2}\beta_6 [ln(Lab_{it})]^2 \\ & + \tfrac{1}{2}\beta_7 [ln(Cap_{it})]^2 && + \tfrac{1}{2}\beta_8 [ln(Area_{it})]^2 && + \tfrac{1}{2}\beta_9 [ln(Med_{it})]^2 \\ & + \tfrac{1}{2}\beta_{10} [Time_{it}]^2 && + \beta_{11} ln(Lab_{it}) * ln(Cap_{it}) && + \beta_{12} ln(Lab_{it}) * ln(Area_{it}) \\ & + \beta_{13} ln(Lab_{it}) * ln(Med_{it}) && + \beta_{14} ln(Lab_{it}) * Time_{it} && + \beta_{15} ln(Cap_{it}) * ln(Area_{it}) \\ & + \beta_{16} ln(Cap_{it}) * ln(Med_{it}) && + \beta_{17} ln(Cap_{it}) * Time_{it} && + \beta_{18} ln(Area_{it}) * ln(Med_{it}) \\ & + \beta_{19} ln(Area_{it}) * Time_{it} && + \beta_{20} ln(Med_{it}) * Time_{it} && + v_{it} - u_i \end{aligned} \quad (1.2)$$

The dependent variable $Yield_{it}$ is the deflated total yield (gross output) in Euros of the farm i in year t. The inputs used in the production proces are: (i) : the total amount of labour of the farm i in year t (Lab_{it}), (ii) the total amount of deflated farm capital of the farm i in year t (Cap_{it}), (iii) the total amount of utilized agricultural area of the farm i in year t ($Area_{it}$), (iv) the total amount of intermediate consumption of the farm i in year t (Med_{it}). $Time_{it}$ is a time trend and v_{it} and u_i are defined as above.

We have estimated both the Cobb-Douglas and the translog functional forms. Now we can test the null hypothesis that the Cobb-Douglas form is an adequate representation of the data, given the specifications of the translog model. This can be tested by using the generalized likelihood-ratio test (Coelli et al. 1998). The H_0 and H_1 are:

$H_0 : \beta_6 = \beta_7 = \beta_8 = \beta_9 = \beta_{10} = \beta_{11} = \beta_{12} = \beta_{13} = \beta_{14} = \beta_{15} = \beta_{16} = \beta_{17} = \beta_{18} = \beta_{19} = \beta_{20} = 0$
$H_1 :$ *at least one* β $(6 \rightarrow 20) \neq 0$

In our case, the translog functional form is preferred above the Cobb-Douglas functional form. The hypothesis that the coefficients of the second order term in equation 1.2 were 0, was rejected[1]. We can calculate predictions of firm-level technical efficiencies following Battese & Coelli (1988).

1.3.2 Characteristics affecting efficiency

Knowing the efficiency of farming is interesting, but understanding why farms differ in their relative efficiency can been seen as crucial (Gorton & Davidova 2004).

Determinants of technical inefficiencies among firms can be investigated by regressing the predicted inefficiency effects, obtained from an estimated stochastic frontier upon a vector of firm-specific factors such as firm size, age and education of the managers. This is called the second-stage analysis. But, there is a problem with this two-stage approach. In the first stage the inefficiency effects are assumed to be independently and identically distributed (i.d.d.) for predicting the values of the inefficiency effects (the approach of Jondrow, Lovell, Materov & Schmidt (1982)). However, in the second stage, the predicted inefficiency effects are assumed to be a function of firm-specific factors, which implies that they are not i.d.d. So this approach can lead to biased results. As a solution the parameters of the stochastic frontier and the inefficiency model should be estimated simultaneously (Reifschneider & Stevenson 1991, Battese & Coelli 1995).

In order to analyse the impact of firm-specific factors on efficiency, we extend the stochastic production function with extra regressors, indicating firm characteristics that are postulated to affect firm efficiency (Reifschneider & Stevenson 1991)[2]. The inefficiency term u_i is decomposed in several systematic influences related to specific firm variables (z_{it}) and one non-negative random error term w_i capturing the residual unexplained firm technical inefficiency:

$$u_i = g(z_{it}, \beta) + w_i \tag{1.3}$$

[1]The test statistic is calculated as (Coelli et al. 1998): $LR = -2[ln(L(H_0)) - ln(L(H_1))]$ where $L(H_0)$ and $L(H_1)$ are the values of the likelihood functions under the null and alternative hypotheses. If H_0 is true this test statistic is usually assumed to be asymptotically distributed as a χ^2 random variable with degrees of freedom equal to the number of restrictions involved (in this case 15). Reject H_0 in favor of H_1 if LR exceeds $\chi^2(\alpha)$. Thus the critical value for a test of size ($\alpha = 0,05$) is 25,00 (Neter, Kutner, Nachtsheim & Wasserman 1996). In this case the LR exceeds the critical value, so we have to reject H_0 and take the translog formulation as functional form.

[2]An other but similar approach is proposed by Battese & Coelli (1995)

Making the combination of the equations 1.1 and 1.3, we obtain the firm-specific efficiency model:

$$y_{it} = \alpha + f(x_{it}, \beta) + g(z_{it}, \beta) + v_{it} - w_i \tag{1.4}$$

Important to note on this approach is the fact that this analysis assumes unconditionality. For example take the size of a firm. We analyse the impact of the size on firm efficiency assuming that efficiency has no impact on size. An example of a conditional analysis between technical efficiency and farm size has been made by Alvarez & Arias (2004). They found that more efficient farmers increase the size of their operations. But on the other hand, Alvarez & Arias (2004) found the same positive relation between efficiency and size in the unconditional approach as in the conditional approach[3].

1.4 Empirical efficiency analysis of Flemish farms

1.4.1 Data

This study uses farm accountancy data from a group of 1018 Farms in Flanders, belonging to the Belgian Farm Accountancy Data Network (FADN). The Belgian FADN data are collected and managed by the Centre for Agricultural Economics (CAE). Data of 1018 farms for a period of 14 years (1989-2002) are available. The number of observations of each farm differs from 1 to 14 (unbalanced panel data). In total the sample contains 8926 observations of 1018 different farms. Table 1.1 shows some descriptive statistics of the variables.

The 8926 Flemish observations belong to six different farm types (FADN-typology): (i) specialist field crops (960 observations), (ii) specialist grazing livestock (3414 observations), (iii) specialist pigs (1493 observations), (iv) mixed cropping (164 observations), (v) mixed livestock (1565 observations) and (vi) mixed crops-livestock (1330 observations). Further, the five different Flemish provinces are used to group the observations according to location: (i) Antwerpen (2048 observations), (ii) Vlaams-Brabant (1624 observations), (iii) West-Vlaanderen (2066 observations), (iv) Oost-Vlaanderen (1865 observations) and (v) Limburg (1323 observations). Next, each farmer in our dataset is each year asked about his expectancy about his succession. There are three possibilities (successor1, successor2, successor3): (i) there is a successor (1146 observations), (ii) it's not clear yet if there is a successor (3815) and (iii) there is no successor (3965 observations). Finally, we can divide all 1018 Flemish farmers into five different levels of agricultural education (diploma1 till

[3]The relationship between size and efficiency was the same, but stronger in the unconditional than in the conditional approach

Table 1.1: Descriptive statistics of the data

Variable	mean	Std. Deviation	Minimum	Maximum
Grossoutput (Euro)	186910	141368	1420	1499698
Agriculturalarea (ha)	31	23	0	264
Labour (in full-time equivalent units)	1.55	0.49	0.11	6.35
Farm capital (Euro)	246667	159921	248	1188975
Intermediate consumption (Euro)	105451	87629	2335	853650
Age of farm manager	43	11	19	77
Solvency[1]	0.46	0.32	0	1
Size unit[2]	19	11	1	125
Share land in property[3]	0.27	0.26	0	1
Years accounting by CAE[4]	16 years	10 years	1 year	44 years
Subsidies interest[5] (Euro)	2420	2991	0	31920
Subsidies revenues[6] (Euro)	455	1412	0	41674
Subsidies costs[7] (Euro)	0.23	5.35	0	165
Subsidies income[8] (Euro)	4290	6408	0	136763

[1] measured as own capital divided by total capital
[2] based on the standard gross margin (FADN n.d.)
[3] the amount of land in property over the total amount of utilized farm land
[4] the total number of years that the Centre for Agricultural Economics (CAE) do/did the bookkeeping of the farm
[5] subsidies on investments (interest support)
[6] subsidies on animal products (subsidies on sale and purchase of animals are not included)
[7] subsidies on farm costs (subsidies on investments are not included)
[8] direct payments to producers: suckler cow premium, slaughter premium, set-aside premium, arable crops hectare aid,etc..

diploma5): (i) certificate of higher agricultural education (19 farmers), (ii) certificate of higher technical agricultural education (175 farmers), (iii) certificate of lower technical agricultural education (219 farmers), (iv) certificate of technical and vocational agricultural education (55 farmers) and (v) no certificate of agricultural education (550 farmers).

1.4.2 The basis model results

The results of the estimation of the translog stochastic production frontier defined in equation 1.2 are given in table 1.2.

The firm efficiency is directly estimated in equation 1.2 trough the firm specific variable u_i which measures the deviation of individual firms' output from the production frontier (Jondrow et al. 1982).

We can test whether there are no technical inefficiency effects in the model. Under

Table 1.2: Estimated coefficients of the translog stochastic production frontier

Variables	Coefficient	standard error	Variables	Coefficient	standard error
$Constant$	1,3208***	0,0841	$ln(Lab_{it}) * Time_{it}$	0,0047***	0,0017
$Ln(Lab_{it})$	0,4441***	0,0671	$ln(Lab_{it}) * ln(Cap_{it})$	0,0187	0,0168
$Ln(Cap_{it})$	0,3251***	0,0276	$ln(Lab_{it}) * ln(Area_{it})$	0,0016	0,0037
$Ln(Area_{it})$	0,0552***	0,0071	$ln(Lab_{it}) * ln(Med_{it})$	-0,1164***	0,0162
$Ln(Med_{it})$	0,3223***	0,0225	$ln(Cap_{it}) * ln(Area_{it})$	0,0084***	0,0015
$Time_{it}$	0,0358***	0,0034	$ln(Cap_{it}) * ln(Med_{it})$	-0,1172***	0,0046
$[ln(Lab_{it})]^2$	0,0579***	0,0121	$ln(Area_{it}) * ln(Med_{it})$	-0,0134***	0,001
$[ln(Cap_{it})]^2$	0,0219***	0,0033	$ln(Cap_{it}) * Time_{it}$	0,0049***	0,0009
$[ln(Area_{it})]^2$	0,0052***	0,0002	$ln(Area_{it}) * Time_{it}$	0,0012***	0,0002
$[ln(Med_{it})]^2$	0,1305***	0,003	$ln(Med_{it}) * Time_{it}$	-0,0076***	0,0008
$[Time_{it}]^2$	-0,0021***	0,0001			
Number of observations	8926		Variances: $\sigma^2(v)$	0,0227	
Iterations completed	31		Variances: $\sigma^2(u)$	0,0685	
Log likelihood function	3226,3		Variances: σ^2	0,0912	

* significant at 10%, **significant at 5%, ***significant at 1%

the null hypothesis, $H_0 = \gamma$[4], the model is equivalent to the traditional average response function, without the technical inefficiency effect u_t.

We test the following hypotheses:

$H_0 : \gamma = 0$ (*there is no inefficiency*)
$H_1 : \gamma \neq 0$ (*there is inefficiency*)

In this case the LR exceeds the critical value, thus we have to reject H_0 and hence the traditional response function is not an adequate representation of the data[5]. So *there is technical inefficiency.*

Knowing that there is technical inefficiency we can calculate predictions of firm-level technical efficiencies as in Battese & Coelli (1988). The mean efficiency of all 1018 firms equals 81,6%, we observe a minimum efficiency of 47% and a maximum efficiency of 100%. Figure 1.2 shows the histogram of all predictions of the 1018 firm-level technical efficiencies. These results show a wide range in the level of technical efficiencies across all farms.

[4] γ can be calculated as in (Battese & Corra 1977): $\gamma = \frac{\sigma^2(u)}{\sigma^2(u)+\sigma^2(v)} = \frac{\sigma^2(u)}{\sigma^2} = \frac{0,06848}{0,09116} = 0,75$. A value of γ of zero indicates that the deviations from the frontier are due entirely to noise, while a value of one would indicate that all deviations are due to technical inefficiency (Coelli et al. 1998).

[5] The one-side generalized likelihood-ratio test should be performed when ML estimation is involved because this test has the correct size (Coelli, 1995):$LR = -2[ln(L(H_0)) - ln(L(H_1))]$ where $L(H_0)$ and $L(H_1)$ are the values of the likelihood functions under the null and alternative hypotheses. H_0 is rejected in favor of H_1 when LR exceeds $\chi^2(\alpha)$.

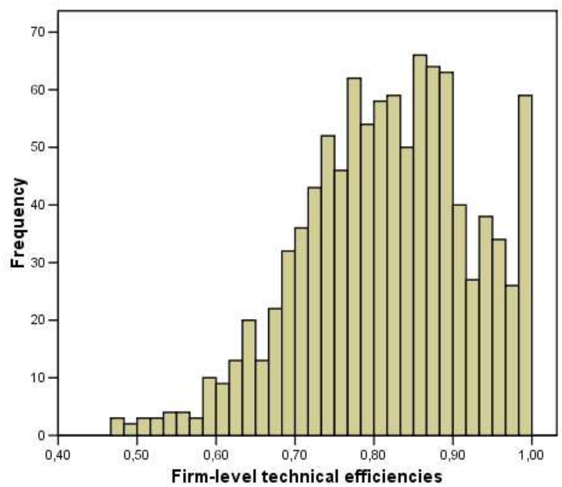

Figure 1.2: The frequency distribution of the predictions of firm-level technical efficiencies

1.4.3 Characteristics affecting efficiency: empirical results

The impact of structural and managerial firm characteristics on efficiency is analysed with the model mentioned in 1.3.2. The farm characteristics are assumed that they only affect the level of technical efficiency thereby systematically shifting the production frontier up- or downwards. Variables indicating structural aspects are: (i) location (*Antwerpen, Brabant, Oost-Vlaanderen, Limburg and West-Vlaanderen*), (ii) farm type (*specialist field crops, specialist grazing livestock, specialist pigs, mixed cropping, mixed livestock and mixed crops-livestock*), (iii) farm size (*size unit*), (iv) solvency, (v) relative amount of land in property (*share land*) and (vi) dependency on subsidies (*subsidiesinterest, subsidiesrevenues, subsidiescosts and subsidiesincome*). Variables indicating managerial aspects are: (i) age, (ii) education level (*diploma1 till diploma5*), (iii) number of years in accounting network (*yearsaccounting*) and (iv) succession (*successor1, successor2 and successor3*). The results are shown in table 1.3.

Impact of managerial characteristics Several farm aspects have a significant impact on efficiency (table 1.3). The level of education is divided in five groups (from diploma1 till diploma5). Diploma1 indicates that the manager has a very

Table 1.3: Estimated coefficients of the enlarged stochastic production frontier

Variables	Coefficient	standard error	Variables	Coefficient	standard error
$Constant$	1,1861 ***	0,0920			
$Ln(Lab_{it})$	0,3953 ***	0,0615	$Oost-Vlaanderen$	0,0285 ***	0,0101
$Ln(Cap_{it})$	0,2887 ***	0,0321	$Limburg$	0,0134	0,0117
$Ln(Area_{it})$	0,0587 ***	0,0082	$Specialist\ field\ crops$	-0,0324 **	0,0135
$Ln(Med_{it})$	0,5459 ***	0,0278	$Specialist\ grazing\ livestock$	-0,0449 ***	0,0110
$Time_{it}$	0,0506 ***	0,0034	$Mixed\ cropping$	-0,0792 ***	0,0205
$[ln(Lab_{it})]^2$	0,0405 ***	0,0108	$Mixed\ livestock$	-0,0368 ***	0,0109
$[ln(Cap_{it})]^2$	0,0165 ***	0,0041	$Mixed\ cropslivestock$	-0,0473 ***	0,0127
$[ln(Area_{it})]^2$	0,0049 ***	0,0004	$Years\ accounting$	0,0013 ***	0,0003
$[ln(Med_{it})]^2$	0,0837 ***	0,0036	$Share$	0,0690 ***	0,0117
$[Time_{it}]^2$	-0,0018 ***	0,0001	$Diploma2$	-0,0485 ***	0,0148
$ln(Lab_{it}) * Time_{it}$	0,0044 ***	0,0015	$Diploma3$	-0,0423 ***	0,0144
$ln(Lab_{it}) * ln(Cap_{it})$	0,0135	0,0160	$Diploma4$	-0,0694 ***	0,0159
$ln(Lab_{it}) * ln(Area_{it})$	-0,0010	0,0035	$Diploma5$	-0,0536 ***	0,0138
$ln(Lab_{it}) * ln(Med_{it})$	-0,1017 ***	0,0146	$Successor1$	0,0349 ***	0,0073
$ln(Cap_{it}) * ln(Area_{it})$	0,0075 ***	0,0018	$Successor2$	0,0126 **	0,0055
$ln(Cap_{it}) * ln(Med_{it})$	-0,0964 ***	0,0060	Age	-0,0025 ***	0,0003
$ln(Area_{it}) * ln(Med_{it})$	-0,0141 ***	0,0010	$Solvency$	-0,0789 ***	0,0092
$ln(Cap_{it}) * Time_{it}$	0,0019 **	0,0009	$Sizeunit$	0,0079 ***	0,0003
$ln(Area_{it}) * Time_{it}$	0,0013 ***	0,0002	$Subsidies\ interest^1$	-0,0210 ***	0,0007
$ln(Med_{it}) * Time_{it}$	-0,0085 ***	0,0008	$Subsidies\ revenues^1$	-0,0229 ***	0,0012
$Antwerpen$	0,0633 ***	0,0093	$Subsidies\ costs^1$	0,1008	0,6130
$Brabant$	-0,0184 *	0,0113	$Subsidies\ income^1$	-0,0029 ***	0,0005
Number of observations	8926				
Iterations completed	55				

* significant at 10%, ** significant at 5%, *** significant at 1%

[1] the subsidies are calculated as a percentage of total revenues, indicating the dependency on payments

the omitted variable for location is *West-Vlaanderen*, for education *diploma1*, for succession *successor3* and for farm type *specialist pigs*

high level of eduction, diploma5 indicates a very low level of education. The mean firm efficiencies are shown in table 1.4. Table 1.3 and 1.4 show that managers with the highest level of eduction are more efficient than managers with lower education.

Table 1.4: Mean firm efficiency of different education levels

Education level	mean efficiency	Number of observations	Std. Deviation
Diploma1	0,8455	19	0,0931
Diploma2	0,8367	175	0,0937
Diploma3	0,8336	219	0,0981
Diploma4	0,8052	55	0,0899
Diploma5	0,8016	550	0,1141

The impact of age of the agricultural manager on efficiency is negative, indicating that older managers are less efficient. So age has an invers impact on efficiency in this sample. Does this mean that experience has no impact on farm performance? Older farmers should take profit of their experience to use inputs more efficiently. The problem is that other variables intervene. Further exploration of the data reveals that there is a positive link between age and solvency: in general older farmers have less debts than the younger ones. Also the outcome of the education variable is linked to age: in our data base, in 2002, the average age of the highest educated farmers was about 41 years, while the average age of the lowest educated farmers was 48 years. Further research is needed to unravel these interactions. The coefficient of the variable *yearsaccounting* is significant and positive, meaning that farmers who do the bookkeeping for many years in the accounting system are operating more efficient. All farmers in our data sample do the bookkeeping in the FADN accounting system but the number of years is different. A possible explanation of the positive effect is the fact that farmers get feedback and in this way can improve their efficiency.

In the sample three succession indicators are defined. The first indicates that the prospect of a successor for the present manager is almost certain (*successor1*), the second means that it is not yet clear whether or not there will be a successor (*successor2*), the third indicator indicates that there is no successor available (the omitted variable). Observing the results of the inefficiency model in table 1.3, we find that agricultural firms with successor are more efficient than farms without a successor. Also farms with uncertainty about succession have a significant higher efficiency.

Impact of structural characteristics With respect to the farm type, the results of the firm-specific inefficiency model in table 1.3 show that the estimated coefficients are significant. In the model, the omitted sector is the specialist pigs sector. These results show that all agricultural sectors have a significant lower efficiency then the specialist pigs sector.

The Flemish firms are all situated in one of the five Flemish provinces. The five provinces are Antwerpen, Vlaams-Brabant, Limburg, Oost-Vlaanderen and West-Vlaanderen (= the omitted province in table 1.3). The results show that the efficiency in the province Antwerp and Oost-Vlaanderen are significant higher and the efficiency in Brabant is significant lower than in West-Vlaanderen.

The effect of farm location on efficiency is significant, but certainly not easy to explain. Differences in soil-type, landscape, erosion, easiness of cultivation are possible explanations but all this characteristics are linked and the reality is too complex to give a clear explanation of the significant different effect on efficiency of those Flemish regions.

Also financial determinants have an impact on efficiency. In our model we incorporate the financial parameter solvency. If solvency equals 1, all capital is financed with farmers money (net worth) and if solvency equals 0, all capital is financed with debts. Table 1.3 shows that solvency has a negative impact on efficiency. This means that farmers with low solvency rates are more efficient than farmers with higher solvency rates. A possible explanation is that farmers with a low solvency have repayment obligations. In this way those farmers are stimulated (forced) to work more efficiently. But also other aspects (e.g. policy measures) could explain this result. Note that our analysis is unconditional, it's also possible that efficient farms have higher investment rates and thus lower solvency rates (if their using more loan capital to pay the investments).

To analyse the impact of size on efficiency, we also added a size unit in the inefficiency model. Table 1.3 shows that size has a significant positive impact on efficiency. So bigger farms are working more efficient than smaller ones.

Also, the share of land in own property has a significant impact on efficiency. Farms with a higher share of owned land are more efficient. A possible explanation is that farmers will do a better job in working on the land that they own.

Finally, the impact of the dependency on support payments is found to be significant. The more a farm depends on support payments, the lower its efficiency in using its resources. In our case, we distinguish four types of support payments, and as illustrated in the data section, the two most important are interest subsidies and income subsidies. The latter group consists of many different income grants, e.g. arable area payments, slaughter premiums and suckler cow premiums. The other two, but minor, are subsidies on the revenues of animal products and subsidies on farm costs. The latter is not substantial, and has no impact on efficiency. The other types have a significant negative impact on efficiency.

1.4.4 An overview of the impacts on efficiency

The parameter estimates for the inefficiency model, presented in table 1.3, and summarized in table 1.5, only indicate the direction of the effects of these variables upon inefficiency (Wilson et al. 2001). Through differentiating each of the explanatory variables in the inefficiency model with respect to each of the inefficiency effects variables (evaluated at their mean values), we can calculate the quasi-elasticities for each firm variable (z) as: $\varepsilon_z = \frac{du}{dz}\frac{\tilde{z}}{\tilde{u}}$. $\tilde{u}$ stands for the estimated mean efficiency of our sample, $\tilde{z}$ is the mean value of the firm variable in question. The quasi-elasticities are shown in table 1.5. The impact of size on efficiency has the highest elasticity. A 10% increase in size will result in a 1.8% increase in efficiency. Observing the different subsidies categories, we see that especially the dependency on interest subsidies will lower the firm efficiency. The impact of the other subsidies is much lower.

Table 1.5: An overview of some determinants of efficiency

Firm characteristic	Significant impact on efficiency (yes or no)	Direction of impact positive(+) or negative (-)	quasi-elasticity
Firm size	yes	+	0.1843
Firm solvency	yes	-	-0.0445
Firm accounting	yes	+	0.0254
Dependency on interest subsidies	yes	-	-0.0362
Dependency on revenue subsidies	yes	-	-0.0067
Dependency on costs subsidies	no		
Dependency on direct income support	yes	-	-0.0080
Age of firm manager	yes	-	-0.1337
Share own land	yes	+	0.0228
Education of firm manager	yes		
Succession of firm manager	yes		
Number of years since take over	no		
Firm location	yes		
Firm sector	yes		

Notice that the size of the effects, measured by the quasi-elasticities, is only valid for small changes.

1.5 Conclusion and Discussion

In this chapter, the continuous structural change in agriculture has been used as point of departure and motivation to measure farm efficiency. Efficiency is defined here in the sense Farell (1957) introduced it: the relative position of the actual production with respect to the efficient, frontier production function. Measuring farm efficiency is thus seen as a consistent way of monitoring farm performance in a changing environment. Not only the performance measurement itself, but also the understanding why farms differ in their relative efficiency can bring new insight in the process of structural change and feedback to the concerned policies and government interventions.

Many managerial and structural characteristics are linked to farm performance. Stochastic frontier analysis of a representative Flemish farm data panel revealed that farm size, farm accounting and having a high share of own land have a positive effect on efficiency. On the other hand farm solvency, farmer's age and dependency on support payments are found to be negatively related to farm efficiency.

The link between managerial and structural characteristics and efficiency can be discussed in terms of capacities and incentives. Intrinsic capacities are e.g. education, size, age, the presence of a successor on the farm. The effect of schooling is clear, and empirically confirmed by the SFA on the Flemish farms. As also learning-by-doing enhances experiences, and thus capacities to use inputs better, the effect of age should be efficiency increasing. On the other hand, age of the farmer, who is not only manager, but also, and mostly, the main provider of labour, can become negatively related to efficiency when negative effects outweigh the positive. The empirical analysis showed an overall negative relationship, but non-linear relationship would perhaps better differentiate between the predominantly positive and negative phase.

Succession has a positive impact on efficiency. In many cases, the successor works together with his parents on the farm, and the combination of young labour forces, familiarity with new technologies and learning-by-doing experiences may increase capacities, but also provide extra incentives to perform better. The prospect that the farm business will continue incite to adopt new technologies, renewed investments, or simply to get the best from the ongoing practices. The negative link between solvency and efficiency has probably also to be interpreted in this way. Low solvency can mean lot of new investments, and thus increase the capacities linked to the use of new technologies, but also it can mean an extra whip for getting better results that allow for repaying the debts. Age, combined with the prospect of succession, may also reflect the existences of incentives. Becoming older in agriculture may mean becoming satisfied with the earned income and rather wanting to slow down activities. Having a successor, however, provides new incentives to keep the farm highly performing.

What does this means for structural change? Specialized pig farms are found to be the most efficient farm type. This is not surprising, given the scarcity of space in Flanders. High productivity per unit of space becomes, however, also the main threat. High productivity also means a high level of by-products. Internalization of environmental effects means extra inputs that are needed for the same outputs. Size of the farm is another positive factor of efficiency. Here, the problem of conditionality, however, arises. A bigger size guarantees more efficiency, but on the other hand farm growth may be facilitated when the farm performs better. Structural change in agriculture highly depends on the farm life cycle. The fact that a non negligible part of the farms have an older farmer without successor slow down the efficiency improvement of the sector.

Finally, what may be the role of the authorities? Policies to improve taking-over of non efficient farms by efficient farms will improve the performance of the overall agricultural sector. Based on the results of our study, it may be crucial that farms without successor stay not too long in business, before their production factors can be taken over by other, more efficient farmers. However, other outcomes of the study suggest a negative correlation of efficiency with subsidies on investments (in which first instalment is comprised). The more a farm depends on support payments, the lower its efficiency in using its resources. The reason for this unexpected result is not clear. Very plausible would be that they give wrong incentives, e.g. for doing sub-optimal investments, or getting stuck in business that is not profitable anymore. The results may suggest that agricultural policy is encouraging a less competitive agricultural sector by providing grants. On the other hand, there could be environmental and social benefits (e.g. survival) arising from those policy measures. Also the problem of conditionality can arise. It is also possible that farmers with a low efficiency level receive more support payments which can be the objective of the policy makers.

Finally, the methodology employed in this research to estimate and calculate efficiency and productivity take not into account the environmental costs associated with the use of agricultural inputs or the environmental benefits associated with the production of agricultural goods. Integrating the environmental considerations into the calculation of agricultural performance will be a major research challenge in the near future. Furthermore, this chapter showed that age, solvency and subsidies are slow-down factors of efficiency. This is appropriate as a first indicator, but in order to unravel the mechanisms through which efficiency and structural change can be steered, this is not sufficient. To study the interaction of age, education and solvency and their impact on farm performance in more detail is also an interesting and challenging topic for the future.

Bibliography

Aigner, D., Lovell, C. & Schmidt, P. (1977), 'Formulation and estimation of stochastic frontier production function models', *Journal of Econometrics* **6**(1), 21–37.

Allen, D. W. & Lueck, D. (1998), 'The nature of the farm', *Journal of Law and Economics* **41**(1998), 343–386.

Alvarez, A. & Arias, C. (2004), 'Technical efficiency and farm size: a conditional analysis', *Agricultural Economics* **30**(2004), 241–250.

Battese, G. & Coelli, T. (1988), 'Prediction of firm-level technical efficiencies with a generalized frontier production function and panel data', *Journal of Econometrics* **38**(3), 387–399.

Battese, G. & Coelli, T. (1993), 'A stochastic frontier production function incorporating a model for technical ineffciency effects', *working papers in econometrics and applied statistics, University of New England* .

Battese, G. & Coelli, T. (1995), 'A model for technical inefficiency effects in a stochastic frontier production function for panel data', *Empirical Economics* **20**, 325–332.

Battese, G. & Corra, G. (1977), 'Estimation of a production frontier model: With application to the pastoral zone of Eastern Australia', *Australian Journal of Agricultural Economics* **21**(3), 169–179.

Brada, J. C. & King, A. E. (1993), 'Is private farming more efficient than socialized agriculture?', *Economica* **60**(237), 41–56.

Brümmer, B. (2001), 'Estimating confidence intervals for technical efficiency: the case of private farms in Slovenia', *Eruopean Review of Agricultural Economics* **28**(3), 285–306.

Chavas, J.-P. (2001), *Handbook of Agricultural Economics*, Vol. 1, Elsevier Science, chapter Structural change in agricultural production: economics, technology and policy, pp. 263–285.

Chavas, J.-P. & Aliber, M. (1993), 'An analysis of economic efficiency in agriculture: a nonparametric approach', *Journal of Agricultural and Resource Economics* **18**(1), 1–16.

Christensen, L., Jorgenson, D. & Lau, L. (1973), 'Transcendental logarithmic production frontiers', *Review of Economics and Statistics* **55**(1), 28–45.

Coelli, T., Rao, D. P. & Battese, G. (1998), *An introduction to efficiency and productivity analysis*, Kluwer Academic Publishers.

Cornwell, C. & Schmidt, P. (1996), 'Production frontiers and efficiency measurement', *In: Matyas, L., Sevestre,P., The Econometrics of Panel Data* .

FADN (n.d.), Farm accounting data network: An a to z methodology, Technical report, FADN, website.

Farell, M. (1957), 'The measurement of productive efficiency', *Journal of the Royal Statistical Society, Series A (general)* **120**(3), 253–290.

Gorton, M. & Davidova, M. (2004), 'Farm productivity and efficiency in the CEE applicant countries: a synthesis of results', *Agricultural Economics* **30**, 1–16.

Hall, B. F. & LeVeen, E. P. (1978), 'Farm size and economic efficiency: the case of California', *American Journal of Agricultural Economics* **60**(4), 589–600.

Hallam, D. & Machado, F. (1996), 'Efficiency analysis with panel data: a study of portuguese dairy farms', *European Review of Agricultural Economics* **23**(1), 79–93.

Herdt, R. & Mandac, A. (1981), 'Modern technology and economic efficiency of Philippine rice farmers', *Economic Development and Cultural Change* **29**, 375–399.

Igliori, D. C. (2005), 'Determinants of technical efficiency in agriculture and cattle ranching: A spatial analysis for the Brazalian amazon', *Environmental Economy and Policy Researc, discussion paper series* .

Jondrow, J., Lovell, C., Materov, I. & Schmidt, P. (1982), 'On the estimation of technical inefficiency in the stochastic frontier production funtion model', *Journal of Econometrics* **19**(2–3), 233–238.

Kalirajan, K. (1990), 'On measuring economic efficiency', *Journal of Applied Econometrics* **5**(1), 75–85.

Kompas, T. & Che, T. N. (2004), 'Production and technical efficiency on Australian dairy farms', *International and Development Economics Working Paper, Asia Pacific school of economics and Governement* **04-1**.

Lepoutre, J., Mathijs, E., Nevens, F., Van Passel, S. & Van Huylenbroeck, G. (2004), Indelingen van Vlaamse land- en tuinbouwbedrijven: een analyse en beleidsaanbevelingen., Stedula publicatie 11, Steunpunt Duurzame Landbouw.

Liu, Z. & Zhuang, J. (2000), 'Determinants of technical efficiency in post-collective Chinese agriculture: Evidence from farm-level data', *Journal of Comparative Economics* **28**, 545–564.

Lockheed, M. E., Jamison, D. T. & Lau, L. J. (1980), 'Farmer education and farm efficiency: A survey', *Economic Development and Cultural Change* **29**(1), 37–61.

Mathijs, E. & Swinnen, J. J. (2001), 'Production organization and efficiency during transition: an empirical analysis of East German agriculture', *The Review of Economics and Statistics* **83**(1), 100–107.

Mathijs, E. & Vranken, L. (2001), 'Human capital, gender and organisation in transition agriculture: measuring and explaining the technical efficiency of Bulgarian and Hungarian farms', *Post-Communist Economics* **13**(2), 171–187.

Meeusen, W. & Van den Broeck, W. (1977), 'Efficiency estimation from cobb-douglas production functions with composed error', *International Economic Review* **18**(2), 435–444.

Munroe, D. (2001), 'Economic efficiency in Polish peasant farming: an international perspective', *Regional Series* **35**(4), 461–471.

Neter, J., Kutner, M., Nachtsheim, C. & Wasserman, W. (1996), *Applied Linear Statistical Models*, WCB/McGraw-Hill.

OECD (2002), *Agricultural policies in OECD countries: Monitoring and evaluation*, Organisation for economic co-operation and development.

O'Neill, S., Leavy, A. & Matthews, A. (2001), Measuring productivity change and efficiency on Irish farms, Technical report, Teagasc Rural Economy Centre.

O'Neill, S., Matthews, A. & Leavy, A. (1999), 'Farm techical efficiency and extension', *conference paper presented at the Irish Economics Association Conference in April 1999* .

Parikh, A., Farman, A. & Shah, M. K. (1995), 'Measurement of economic efficieny in Pakistani agriculture', *American Journal of Agricultural Economics* **77**, 675–685.

Piesse, J. & Thirtle, C. (2000), 'A stochastic frontier approach to firm level efficiency, technological change, and productivity during the early transition in Hungary', *Journal of Comparative Economics* **28**, 473–501.

Poppe, K. J. & van Meijl, H. (2004), Adjustment and differences in farm performance: A farm management perspective from the Netherlands, Technical Report 2.04.09, The Agricultural Economics Research Institute (LEI).

Reifschneider, D. & Stevenson, R. (1991), 'Systematic departures from the frontier: A framework for the analysis of firm inefficiency', *International Economic Review* **32**, 715–723.

Rezitis, A. N., Tsiboukas, K. & Tsoukalas, S. (2002), 'Measuring technical efficiency in the Greek agricultural sector', *Applied Economics* **34**, 1345–1357.

Rougoor, C. W., Trip, G., Huirne, R. B. & Renkema, J. A. (1998), 'How to define and study farmers' management capacity: theory and use in agriculture economics', *Agricultural Economics* **18**(3), 261–272.

Roumasset, J. (1995), 'The nature of the agricultural firm', *Journal of Economic Behavior and Organisation* **26**, 161–177.

Santarossa, J. M. (2003), 'Technical and financial sustainability in Scottish agriculture', *Scottish Agricultural College working paper* .

Seckler, D. & Young, R. A. (1978), 'Economic and policy implications of the 160-acre limitation in federal reclamation law', *American Journal of Agricultural Economics* **60**(4), 575–588.

Stefanou, S. & Saxena, S. (1988), 'Education, experience, and allocatieve efficiency: A dual approach', *American Journal of Agricultural Economics* **70**(2), 338–345.

Thiele, H. & Brodersen, C. M. (1999), 'Difference in farm efficiency in market and transition economies: empirical evidence from West and East Germany', *European Review of Agricultural Economics* **26**(3), 331–347.

Thirtle, C. & Holding, J. (2003), Productivity of UK agriculture: causes and constraints, Technical report, Department for Environment, Food and Rural Affairs.

Trip, G., Thijssen, G., Renkma, J. & Huirne, R. (2002), 'Measuring managerial efficiency: the case of commercial greenhouse growers', *Agricultural Economics* **27**, 175–181.

Verma, B. & Bromley, D. (1987), 'The political economy of farm size in India: the elusive quest', *Economic Development and Cultural Change* pp. 791–808.

Weiss, C. R. (1999), 'Farm growth and survival: Econometric evidence for individual farms in upper Austria', *American Journal of Agricultural Economics* **81**, 103–116.

Wilson, P., Hadley, D. & Asby, C. (2001), 'The influence of management characteristics on the technical efficiency of wheat farmers in eastern England', *Agricultural Economics* **24**, 329–338.