Abandonment of milk production under uncertainty and inefficiency: The case of West German farms

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Abstract

This paper examines the impact of technical efficiency on the optimal exit timing of farms in a stochastic dynamic framework. Starting from a standard real options approach, we incorporate technical efficiency via a production function and derive an optimal price trigger at which farms irreversibly exit production. Assuming separability of efficiency on the primal technology, we show that higher efficiency and higher returns to scale make the farm more reluctant to irreversibly exit production. We extend this model to a non-separable case, test it with West German farm-level data (2000 to 2008), and find evidence that efficiency is non–separable. We find that higher volatility of milk prices and higher efficiency delay farms' exit from the market. Volatility, however, interacts with time-varying efficiency: the propensity of inefficient farms to exit the milk market attenuates under more volatile market conditions.

Keywords: Efficiency, exit, real options, dairy.

JEL codes: D20, D21

1 Introduction

Decisions to suspend production or exit a market are among the most impactful decisions a manager can make. Firms' exit decisions are dynamic by nature, must be made in an uncertain economic environment, and it is costly to reverse them. In view of this irreversibility, firms consider exit decisions carefully and usually do not re-enter the market once production has been suspended. Given the importance of exit decisions, it is not surprising that many attempts have been made to explain why and when firms quit, the economic factors that may influence the decision, as well as their timing (e.g., Musshoff et al. 2012 and the literature cited therein). We focus our attention on the interaction of individual decision making and efficiency under uncertainty. Two strands of literature are particularly interesting for understanding firms' exit decisions. The first strand encompasses the real options approach, which provides a convenient framework for analyzing firms' decisions under uncertainty and irreversibility (Dixit and Pindyck 1994). By exploiting the analogy between financial options and (dis)investments, real options theory asserts that deferring an exit decision may increase a firm's profit even if the expected present value of cash flows falls below its liquidation value. This finding has been used to rationalize sluggish disinvestment and exit behavior. For example, O'Brien and Folta (2009) consider the impact of uncertainty and sunk costs on exit behavior, and confirm that uncertainty dissuades firms from exiting only when sunk costs are large. Further, Tauer (2009) studies the exit and entry decision of New York dairy farmers by estimating the entry and exit trigger prices for different types of farm cost structures, but without considering the efficiency of the farmer. Lastly, Luong and Tauer (2006) examine entry and exit decisions of Vietnamese coffee growers with various degrees of cost efficiency using real options theory.

The second relevant strand of literature emphasizes the impact of efficiency on firm exit. For example, Goddard et al. (1993) argue that more efficient firms show superior performance and are more viable in a competitive environment since they earn higher profits and increase their market shares at the expense of less efficient firms, thereby increasing industry concentration. This view is often labeled as the efficient structure hypothesis and can be traced back to Demsetz (1973). An implication of this hypothesis is that efficient and inefficient firms cannot coexist in the long run. The hypothesis that technical inefficiency increases the probability of firm exit has been empirically tested; Among others, Tsionas and Papadogonas (2006), Kumbhakar, Tsionas, and Sipiläinen (2009), and Wheelock and Wilson (2000) find a positive correlation between inefficiency and exit. At the same time, one can observe that inefficient firms persist in the market, at least in the short run (Emvalomatis, Stefanou, and Lansink 2011).

These two fields have received extensive attention, albeit separately; the purpose of this paper is to bridge the two aforementioned strands of literature. In particular, exit under output price uncertainty is considered while allowing for technical inefficiency. We begin from a standard real options model and use a generic production function with an efficiency term. We then derive the properties inherited from the original production function to the instantaneous profit function by using a dual Legendre transformation. Depending on how efficiency is assumed to interact with the technology in either a separable or non-separable manner, uncertainty impacts firms' reluctance to exit the market differently. In the separable case, efficiency increases the reluctance to exit the market, while in the non-separable case, the efficiency parameter interacts directly with the returns to scale parameter, thus resulting in a non-monotonic impact on the optimal exit trigger prices. Very inefficient firms that have lower returns to scale are found to be more reluctant to exit the market than more efficient firms. The paper closest to ours is Lambarraa, Stefanou, and Gil (2009), which studies the inefficiency of Spanish olive farmers in a real options approach. These authors consider the effect of inefficiency with a Cobb-Douglas technology and its persistence on investment decisions. Nonetheless, the impact of inefficiency on farmers' exit decisions under uncertainty is not directly shown. In contrast, our model allows us to rationalize the co-existence of firms of varying degrees of efficiency in the market by interacting uncertain output price and real options effects.

Germany is one of the largest dairy producers in the European Union (EU), and we apply our model to West German dairy farms. Three main factors introduced by the 2003 Common Agricultural Policy (CAP) reform and the 2008 health check induced volatility increases in milk and other commodity prices in Germany: the decoupling of direct payments from production levels, the progressive reduction of intervention prices, and the stepwise increases of milk quotas. As a result, the German dairy sector has been subject to dynamic adjustment processes such as specialization, farm growth, and shrinkage and closure, albeit with strong regional differences.

It is widely acknowledged that the efficiency and productivity of milk production constitute important drivers of the adjustment process in the dairy sector. The literature about economic efficiency analysis relating the efficiency and structural characteristics of dairy farms such as size, specialization, organization or financial structure is large (e.g., Curtiss 2002; Mosheim and Lovell 2009; Lambert and Bayda 2005). However, the direct relation of efficiency as a driver for adjustment decisions is rarely analyzed. As an exception, Zimmermann and Heckelei (2011) claim that higher milk prices may slow down structural change by releasing financial pressure on inefficient dairy farms, but they do not provide an efficiency analysis.

The role of milk quotas during the German dairy sector adjustment process, is still unclear and ambiguously discussed in the relevant literature. Production limitations introduced additional costs of adjustment for the quasi-fixed capital stock of growing farms. At the same time, the selling of production quotas serves as an exit premium for those farms that abandon milk production (cf. Hüttel and Jongeneel, 2011). Thus, the devaluation of the milk quotas introduced by the 2003 CAP reform through the stepwise increase in quantities will likely reduce investment costs. Together with the increase in milk price volatility, this can be judged as a fundamental change of the production environment. Our empirical analysis contributes to understanding the relationship between efficiency, milk price uncertainty, and farm-level decisions of ceasing milk production.

In the following section, we first present the general model without making functional assumptions about the way inputs combine to produce output. Homogeneity of the production technology helps to exemplify the intuition of our theory. We then consider a Cobb-Douglas production function and derive explicit exit conditions for a separable and non-separable efficiency. The third section presents the data and the empirical strategy.We measure time-varying efficiency via a directional output distance function. We include these efficiency scores in an exit equation where we study the effect of efficiency and volatility of output price on farm exit decisions. The fourth section introduces our results, and the last section concludes.

2 A model of farm exit under uncertainty and inefficiency

Our model departs from the standard real options approach suggested by Dixit (1989).[1] In contrast to Dixit, we do not consider entry and exit decisions simultaneously, and instead focus on the optimal timing of the exit decision. We assume the existence of an active farm—with potentially infinite life—which transforms a vector of inputs $\boldsymbol{x}$ into a scalar output y through production function $f: y = f(\boldsymbol{x})$, where $f: \mathbb{R}_+^P \rightarrow \mathbb{R}_+$.[2] The farm buys inputs $\boldsymbol{x} \in \mathbb{R}_+^P$ at non-stochastic price$\boldsymbol{w} \in \mathbb{R}_{++}^P$ to produce an output $y \in \mathbb{R}_+$ that can be sold at stochastic price $p \in \mathbb{R}_{++}$.

We are interested in a critical threshold for the stochastic price $p \in \mathbb{R}_{++}$ of the univariate output that triggers the farm's market exit. Stochastic output price is assumed to follow a Geometric Brownian motion:

$$(1) \qquad \frac{dp}{p} = \alpha dt + \sigma dz$$

where α is the drift rate of the stochastic process, σ is its volatility, and dz is the increment of a Wiener process. At each instant, the farm faces the choice of whether to continue production or to leave the market. In the case of continuing, the farm earns a profit flow $\pi(p, \boldsymbol{w})$ where $\pi: \mathbb{R}_+^{1+P} \rightarrow \mathbb{R}_+$. Exit is irreversible and farms have a positive liquidation value L upon exit. The decision problem of the farm constitutes an optimal stopping problem that can be solved by stochatic dynamic programming techniques.

The value of the farm at a certain time period t is equal to the sum of the operating profit over a short interval time $(t, t + dt)$ and the continuation value after time $t + dt$:

$$(2) \qquad V(p) = \pi(p, \boldsymbol{w})dt + E(V(p + dp)e^{-\rho dt})$$

---

[1] Here we refer to farms, but the model is also applicable to generic firms.

[2] In particular, f has the same properties as specified by Lau (1978): it is a finite, non-negative, real-valued, continuous, smooth, twice-continuously differentiable, monotonic, concave, and bounded function; a null output level with positive input (inaction) is possible.

where ρ is an exogenously specified discount rate.Applying Ito's lemma yields the following second-order differential equation:

$$(3)\qquad V'(p)\alpha p + \frac{1}{2}V''(p)\sigma^2 p^2 - \rho V(p) + \pi(p, \boldsymbol{w}) = 0.$$

To link efficiency and exit decision making, we model the production technology by deriving a general form of the stochastic profit flow. Except for simple functional forms of the production function, an explicit solution for the profit function is difficult to attain. We thus use the dual Legendre transformation to derive the structural properties of the profit function implicitly (cf. Lau 1978, Jorgenson and Lau 1974).

Efficiency is introduced in the primal production function through a separable short-term production efficiency parameter$a \in (0,1]$. The profit function resulting from the Legendre transform is then:

$$(4)\qquad \pi_a(p, \boldsymbol{w}, a) = sup_x\{paf(\boldsymbol{x}) - (\boldsymbol{w}'\boldsymbol{x}) | \boldsymbol{x} \in \mathbb{R}_+^P\}.$$

Assuming that f is a homogeneous production function of degree $k < 1$, we can express the profit function in multiplicatively separable terms as:

$$(5)\qquad \pi_a(p, \boldsymbol{w}, a) = g^*(\boldsymbol{w})h(a)h_1(p),$$

where g^* is a homogeneous function of degree $-k/(1-k)$, and is defined as $g^*: \mathbb{R}_+^P \to \mathbb{R}_+$. Moreover, h is a non-decreasing function of efficiency, defined as $h: \mathbb{R}_+ \to \mathbb{R}_+$. Finally, $h_1(p)$ is a homogeneous function of degree $1/(1-k)$ defined as $h_1: \mathbb{R}_+ \to \mathbb{R}_+$.[3]

We incorporate the profit function (5) that accounts for a separable efficiency term into the second-order differential equation (3). The value of an *active* farm in terms of the enhanced profit function must satisfy

$$(6)\qquad V'(p)\alpha p + \frac{1}{2}V''(p)\sigma^2 p^2 - \rho V(p) + \pi_a(h_1(p), \boldsymbol{w}, a) = 0.$$

Following Dixit (1989), the solution of the non-homogeneous second-order differential equation (6), after ruling out bubble solutions and imposing value matching and smooth pasting conditions, yields an implicit definition for the output price p_* that triggers an irreversible exit from the market:

$$(7)\qquad g^*(\boldsymbol{w})h(a)h_1(p_*) = \delta' L\left(\frac{\beta_2}{\beta_2 - \frac{1}{1-k}}\right),$$

where $\delta' = \rho - \frac{\alpha}{(1-k)} - \frac{k\sigma^2}{2(1-k)^2}$ is a risk-adjusted discount rate, and where the negative root of the second-order differential equation $\beta_2$is

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[3] The proof is similar to the one in Lau (1978) and Kumbhakar (2001).

$$(8)\qquad \beta_2 = \frac{1}{2} - \frac{\alpha}{\sigma^2} - \left\{\left[\frac{\alpha}{\sigma^2} - \frac{1}{2}\right]^2 + 2\frac{\rho}{\sigma^2}\right\}^{1/2}.$$

The optimality condition (7) states that the instantaneous profit on the left-hand side must equal the appropriately discounted liquidation value ($\delta' L$), times a multiple $\left(\frac{\beta_2}{\beta_2 - \frac{1}{1-k}}\right)$, which is lower than unity. Equation (7) shows that the exit trigger price decreases in efficiency a. That is, more efficient farms have a comparatively lower exit trigger compared to less efficient farms. Thus, a reluctance to irreversibly leave the market increases for more efficient farms.

The degree of homogeneity of the production function (k) has an impact on the level of exit trigger prices $h_1(p_*)$. In particular, an increase in k in (7) decreases both the multiplier of liquidation value L and δ', implying a higher reluctance of farms that have a higher degree of homogeneity in inputs. However, the effect of k on the level of exit trigger prices can differ depending on the properties of the production function considered.

Volatility decreases exit trigger prices. The impact of volatility on exit trigger prices depends on the level of efficiency. The lower the efficiency, the higher is the marginal effect of volatility on the exit trigger prices. The exit trigger prices decrease when drift rate α increases.

To illustrate this general framework and to attain a closed form for the optimal trigger price, we introduce a Cobb-Douglas production function with one input (x):

$$(9)\qquad f^{CD}(x) = x^{\theta}$$

where $f^{CD}\colon \mathbb{R}_+ \to \mathbb{R}_+$. Observed output ($y$) is less than or equal to the maximal producible output:

$$(10)\qquad y = x^{\theta} e^{-\phi}$$

where $\phi \in [0, \infty)$ is an inefficiency parameter, so that $a = e^{-\phi}$ can be considered an efficiency term that is separable from input x and output y.[4] The Cobb-Douglas technology results in a separable profit function:

$$(11)\qquad \pi_{\phi}(p, w, \phi) = e^{-\frac{\phi}{1-\theta}}(1-\theta)\left(\frac{\theta}{w}\right)^{\frac{\theta}{1-\theta}} p^{\frac{1}{1-\theta}}.$$

Under profit maximization, second-order conditions impose that $\theta < 1$, implying decreasing returns to scale on the production function.Considering that for the Cobb-Douglas case, k =θ, $\gamma = \frac{1}{1-\theta}$, $h_1(p) = p^{\gamma}$, and

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[4] In this context, an extension to multiple inputs is possible under the assumption that the efficiency parameter enters as a shifter of the whole production function, equally contracting efficient output across inputs.

$$(12)\quad g^{*}(w)h(e^{-\phi}) = e^{-\frac{\phi}{1-\theta}}(1-\theta)\left(\frac{\theta}{w}\right)^{\frac{\theta}{1-\theta}},$$

we obtain the following equation for the trigger price as a special case of (7):

$$(13)\quad e^{-\frac{\phi}{1-\theta}}(1-\theta)\left(\frac{\theta}{w}\right)^{\frac{\theta}{1-\theta}} p_{*}^{\frac{1}{1-\theta}} = \delta' L\left(\frac{\beta_2}{\beta_2-\frac{1}{1-\theta}}\right).$$

Because the efficiency term affects net worth only, it shifts exit trigger prices down as in (7), for the general homogeneous case.The derivative of the trigger price with respect to inefficiency is positive. More inefficient firms are less reluctant to exit the market. This finding is in line with the efficient structure hypothesis. For $\phi = 0$, equation (13) reduces to the standard real options exit trigger price with variable output (Dixit and Pindyck 1994). Moreover, as in the general case, the derivative of the trigger price with respect to volatility is negative, and the negative marginal effect of volatility is also decreasing with increasing efficiency as in (7). Finally, the exit trigger price decreases when the drift rate increases, as in the general homogeneous case.

A single multiplicative efficiency term restricts efficiency to act only as a shifter with respect to all production factors (Orea and Álvarez 2006). This term also implies a unitary elasticity of output with respect to the efficiency term. A natural extension of the separable efficiency case is to include a non-multiplicative efficiency term. Non-multiplicative efficiency implies that efficiency cannot be separated from the inputs and output in determining the level of trigger prices. Starting from the same production function (9), we assume that the production function is directly transformed by efficiency. We rely on a Box-Cox transformation (Box and Cox 1964), but other transformations would also be possible. The observed output obtained by our efficiency transformation is:

$$(14)\quad y = \frac{(f^{CD}(x))^{\xi}-1}{\xi} = \frac{(x^{\theta})^{\xi}-1}{\xi}$$

where $\xi \in (0,1)$ is considered as an efficiency parameter. For this specification the profit function takes the form:

$$(15)\quad \pi_{\xi}(p,w,\xi) = p^{-\frac{1}{\xi\theta-1}} w^{\frac{\xi\theta}{\xi\theta-1}}\left(\left(\frac{1}{\xi}\right)\left(\frac{1}{\theta}\right)^{\frac{\xi\theta}{\xi\theta-1}} - \left(\frac{1}{\theta}\right)^{\frac{1}{\xi\theta-1}}\right) - \frac{p}{\xi}.$$

Carrying out the same steps as for the separable case, we attain the following expression for the optimal exit trigger price p_{*}:

$$(16)\quad \frac{1}{\eta'}\left(\frac{p_{*}^{\eta} w^{1-\eta}\theta^{\eta}}{\eta-1}\right) - \frac{p_{*}\eta\theta}{(\rho-\alpha)(\eta-1)}\frac{\beta_2-1}{\beta_2-\eta} - L\frac{\beta_2}{\beta_2-\eta} = 0,$$

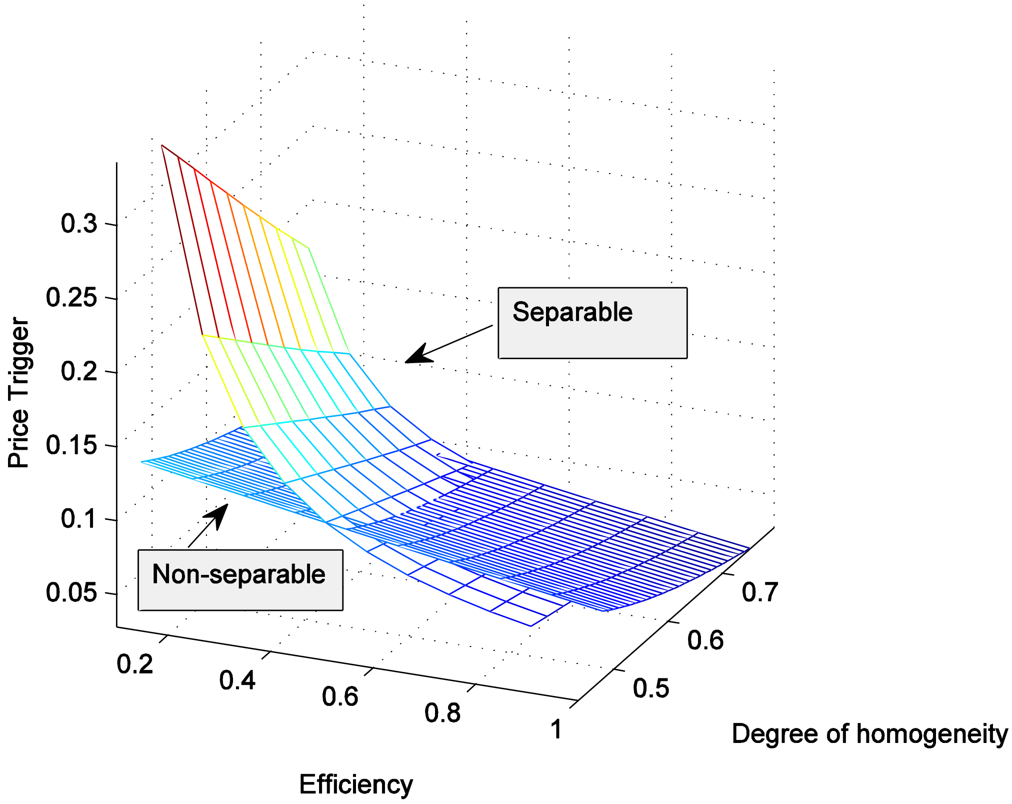
where $\eta = -\frac{1}{\theta\xi-1}$, and $\eta' = \rho - \alpha\eta - 1/2\sigma^{2}\eta(\eta-1)$ is a risk-adjusted discount rate.

To see how efficiency affects (16) we note that the derivative of η with respect to ξ is positive. Since $\eta > 1$, the sign of the derivative of equation (16) with respect to ξ will be the same as the sign of the derivative of (16) with respect to η. The latter, however, can be negative, in particular for low values of the returns to scale parameter θ. On the other hand, for higher values of θ, reluctance increases with efficiency. This not necessarily monotonic relationship between efficiency and exit trigger price contrasts the results under separable efficiency.

The derivative of (16) with respect to volatility (inequivocably positive) confirms an increasing reluctance to exit the market for increasing volatility, as in the separable case. Differently from the separable case, the negative marginal effect of volatility on exit trigger prices can increase with increasing efficiency. This is a direct consequence of the non-monotonic effect of efficiency on exit trigger prices. For low levels of the drift rate the negative marginal effect of volatility is instead decreasing for increasing efficiency. The impact of an increase in the drift rate is inequivocable if the drift rate is negative (as in the separable case). A less negative drift rate decreases the exit trigger prices.

The results implied by (13) and (16) are depicted in figure 1, where the behavior of the exit trigger prices under different separability assumptions is shown. We plot the exit trigger prices under both assumptions at a low volatility level. The impact of efficiency on the trigger prices is different depending on the assumptions. Especially for lower levels of efficiency, trigger prices appear more responsive to efficiency under a separable than under a non-separable efficiency. Under non-separable efficiency, the impact of efficiency on exit trigger prices is less incisive. This means that under non-separable efficiency, we can expect a lower discriminatory power of efficiency when determining the exiting firms. The graph also shows that firms with different efficiency levels may exhibit the same exit trigger price, provided they have different degrees of homogeneity.

Figure 1: Comparison of exit trigger prices for separable and non-separable efficiency in a Cobb-Douglas production function



Note: *Parameters are defined as follows:* $L = 1$, $w = 0.01$, $\sigma = 0.02$, *$\alpha=0$, $\rho=0.06$, $\theta=\{0.48,...,0.75\}$.*

3 Data and empirical strategy

In our empirical study we use an unbalanced panel data set for West German dairy farms from the Farm Accountancy Data Network (FADN) from 2000 and 2008. Dairy farms are defined as milk-producing farms irrespective of their degree of specialization. We consider only farms with a minimum of 4 years of milk production in the observed sample. We exclude as outliers farms below the 1% quantile and above the 99% quantile of the distributions of volatility and drift rate of milk returns. The resulting sample consists of 2,403 milk-producing farms with an average operating time of 7.5 years.

By their nature FADN data do not allow one to disentangle whether a farm gave up production or has been excluded from the sample but continues to exist. To overcome this flaw we confine our analysis to the abandonment of milk production rather than analyzing farm exits. Abandonment of milk production is identified as a situation where milk output and milk revenues are zero, while the farm continues to appear in the sample for at least one further year. According to this definition, 93 exits occur in the observation period of 2000–2008, which corresponds to an exit rate of 3.87%.[5]

We capture the effect of efficiency on the decision to exit dairy production by using a two-stage procedure: in the first stage, we measure efficiency via a directional output distance function. In the second stage we model the exit decision using a binary choice model where efficiency scores are included as explanatory variables.[6] In what follows we describe the two stages in detail, starting with the assumptions about the characterization of the production process.

Production technology

We characterize the production technology with three outputs and four inputs. The outputs are milk (in tons), number of sold dairy cows, and a residual category (other output), where we include an aggregated implicit quantity index. We use two quasi-fixed, and two variable inputs. The quasi-fixed inputs are land and capital; land includes arable land and grassland excluding woodland, other areas, and fallow land. Capital is defined as the sum of the total capital assets' opening values deflated with a weighted average price index, obtained by aggregating at the national level corresponding price indexes from EUROSTAT, with input value shares. The variable inputs are labor and intermediate inputs. Labor input is the amount of family and paid labor measured in working units. An implicit quantity index for intermediate inputs is obtained by aggregating feed, crop inputs, energy, and other inputs. Crop inputs are a similar aggregate implicit quantity index composed of seed inputs, fertilizers, and chemicals. Table 1 portrays descriptive statistics of the variables characterizing the production technology.

Table 1: Summary statistics of inputs and outputs

Variable	Mean	Std. Dev.	Min.	Max.
Milk output (tons)	280	226	0.200	2,840
Labor (AWU)	1.725	0.679	0.500	13
Land (in UAA)	59	38	6	632
Capital (IQ)	285	175	16	1,807
Intermediate Inputs (IQ)	62	45	3.180	647
Sold cows (number)	11	9	0	165
Other output (IQ)	0.320	5.129	0	654
N=17,973 (minimum presence is 4 years, maximum 9 years)				

Data Source: EU-FADN–DG AGRI 2000-2008. IQ indicates implicit quantity indexes in thousands.

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[5] Apparently, our sample is a subset of the number of farms that actually quit dairy production. According to the data of the agricultural census, the number of farms with dairy cows in Germany declined from 146,000 to 97,000 from 1999 to 2007, i.e., by 33.7%. Herein, the share of exiting farms with less than 10 cows makes up 68.5%, and with more than 99 cows make up a share of 9.7% from 1999 to 2007, including both total exit or simply abandonment of dairying.

[6] As an alternative, Tsionas and Papadogonas (2006) use a one-step procedure to jointly estimate efficiency scores and exit probabilities.

Efficiency measurement

Based on our theoretical consideration as presented in section 2, we presume that production efficiency in the dairy branch is a main determinant for the decision of ceasing milk production. We measure the level of efficiency in the direction of milk output using a directional output distance function (cf. Färe, Grosskopf, Noh, and Weber, 2005).

The estimation methodology, which exploits homogeneity properties of the directional output distance function, may cause a simultaneity bias (regarding radial distance, see Grosskopf, Hayes, Taylor, and Weber, 1997) via the presence of the regress and also among regressors on the right hand side. To eliminate this endogeneity problem we adapt the method by Guarda, Rouabah, and Vardanyan (2013), and consider as expansion direction only the milk output (in this case the regressand).We parameterize the directional output distance function with a second-order flexible quadratic functional form. The empirical model estimated is given by:

$$
\begin{aligned}
y_{1it} = a_0 + \sum_{p=1}^{P} a_p x_{pit} + \sum_{q=2}^{Q} b_q y_{qit} + \frac{1}{2}\sum_{p=1}^{P}\sum_{p'=1}^{P} a_{pp'} x_{pit} x_{p'it} \\
+ \frac{1}{2}\sum_{q=2}^{Q}\sum_{q'=2}^{Q} a_{qq'} y_{qit} y_{q'it} + \sum_{p=1}^{P}\sum_{q=2}^{Q} c_{pq} x_{pit} y_{qit} + \varepsilon_{it} - v_i
\end{aligned}
\tag{17}
$$

$$i = 1, \dots, N;\;\; t = 2000, \dots, 2008;\; q = 1, \dots, Q;\; p = 1, \dots, P$$

where y_{1it} is the level of milk output produced by farm i at time t, (a, b, c) are parameters to be estimated, x_{pit} is the level of input p used, y_{qit} is the level of output q produced, ε_{it} is a double-sided random error term, and v_i is a one-sided time-invariant term accounting for inefficiency.

To determine the appropriate estimation procedure we test whether the inefficiency terms, $v_{i,}$ are correlated with the regressors in (17) or not. Note that this refers to the distinction between separable and non-separable efficiency, as discussed in our theoretical model (section 2).While separability implies that efficiency effects are uncorrelated with the regressors and with the error term, non-separability allows efficiency effects to be correlated with the regressors. Accordingly, testing for separability is comparable to conducting a Hausman test in the panel data approach to test for a random versus a fixed effects model; however, since the data set is rather small and the coefficient range is comparably large, the rank of the difference variance matrix is not full. Consequently, we cannot trust the estimated Hausman test and thus, we refer to an alternative testing procedure by Arellano (1993), which treats the additional orthogonality assumption of the uncorrelated panel heterogeneity effect (random effect) with the regressors ($E[v_i x_{it}] = 0$) as an over-identifying restriction.[7] The

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[7] Here we refer to the STATA command “xtoverid” by Schaffer and Stillman (2010).

reported $\chi^2(35)$ test statistic (501.613) strongly rejects the randomness of the efficiency effects (p-value<0.001). Consequently, we estimate a correlated (fixed) effects model, which favors non-separable efficiency.

The time-invariant inefficiency term (v_i) in (17) is, however, a rather restrictive assumption since the German dairy sector underwent a pervasive process of structural change in the last two decades, driven by technological changes and by changes in the common agricultural policy of the EU. It is likely that farms reacted individually to these changes in the economic environment, which in turn leads to different levels of efficiencies over time (e.g. Cuesta 2000). Consequently, we propose to estimate (17) with a fixed-effects model and obtain a time-varying inefficiency term as proposed by Lee and Schmidt (1993): $v_{it} = \theta_t v_i$. In particular, $\theta_t$are unspecified time parameters relative to each period t to be estimated.[8]

While this model allows us to estimate a flexible time path of inefficiency, v_{it}, it does restrict the temporal pattern of all productive units to be the same. Finally, considering the nature of our estimated inefficiency measure, we rescale the inefficiency ($\hat{v}_{it}$) to be an efficiency measure (with efficient producers at 1) such that $\hat{u}_{it} = 1 - [\hat{v}_{it}/\max(y_{it})]$. Here, max (y_{it}) denotes the maximal quantity of milk produced by the most efficient farmer, who also produces the highest amount over the study period. We further include annual time dummy variables to capture how milk output increases compared to the reference year, in this case the year 2000. Differences in these dummies can be interpreted as technical change between years (cf. Cuesta 2000).

Given this approach and since we include specialized as well as non–specialized milk-producing farms in the estimation, but measure efficiency only in the direction of milk output, it is expected that specialized dairy farmers would have a higher efficiency when producing only milk compared to the efficiency measure for the whole sample.

Exit

In the second stage, the decision to exit from milk production is estimated by using a binary choice model. We opt for a logit model[9], where we include the estimated efficiency scores as explanatory variables, together with other relevant variables that determine the abandonment decision as suggested by the real options model in (16). The empirical counterpart is given by

$$\text{(18)} \qquad \Pr(e_{it} = 1 | Z_{it}, \boldsymbol{\zeta}) = \frac{1}{1 + e^{-Z_{it}\zeta}}$$

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[8] Here we refer to the STATA command “sfpanel” by Belotti et al. (2013). As in Lee and Schmidt (1993), $\theta_{2000}$is normalized to be 1.

[9] Alternatively, we estimated a probit model; however, normality of the error terms was rejected at any common significance level.

where exit is represented by a dummy variable e_{it}. This dummy variable is equal to 1 if a farm has zero milk output and revenue in the following period.$\boldsymbol{\zeta}$ is a vector of parameters to be estimated and Z_{it} is a matrix of explanatory variables. Apart from efficiency scores, Z_{it} contains an index of input cost that approximates the unitary input cost (w_{it}) and is supposed to increase the exit probability. The drift rate (α_i) is measured by the farm average of logarithmic milk returns among consecutive years of presence in the sample. This variable is expected to be inversely related to the probability of exiting. The same is true for the output price volatility (σ_i); it is derived from the standard deviation of logarithmic milk returns at the farm level. Milk quota prices at the NUTS 2 regional (r) level are used as a proxy for the liquidation value (L_{rt}). According to the theoretical model, the liquidation value is hypothesized to be an incentive to cease milk production. The proxy quota price, however, may have two effects. High quota prices provide an incentive for less-profitable farms to give up milk production and thus increase the probability of quitting production. However, a high milk quota price may also signal a high degree of competition among regional dairy farmers and may thus reflect high expected revenues from dairying. Accordingly, high quota prices may also reduce the probability of abandoning milk production (Peerlings and Ooms, 2008). Given our data, however, it is only possible to identify the dominating effect of the quota prices—as proxy for the liquidation value—on the probability to exit.

Additionally, we include a variable that accounts for the financial structure of the farm. In previous studies on disinvestments in agriculture, the financial structure of the farm turned out to be important (e.g., Hüttel et al. 2010; Hinrichs et al. 2008). Here we use the cash flow-to-asset ratio to capture the self-financing capability of the farm. Expansion or rationalization investments are more difficult to finance if farms have limited internal financing capability. As a result, terminating milk production may turn out to be the only feasible alternative. Thus, we hypothesize a higher probability of exiting for farms with lower cash flow-to-asset ratios.

Finally, we control for farm size through the use of economic size units (ESU), which are based on farm standard gross margin. Including a size variable allows us to test whether small farms are actually more prone to cease milk production, which is suggested by the observed characteristics of exiting farms (cf. table 2). On average, farms abandoning milk production are typically smaller than continuing farms, both in terms of gross margin—71 ESU and 74 ESU, respectively—and average herd size—19 cows versus 42 cows, respectively. Not surprisingly, exiting farmers produce, on average, less milk than continuing farms—122 tons and 284 tons, respectively. Additionally, average milk yield is lower among exiting farms than in continuing farms—5.9 tons per cow against 6.4 tons per cow. We further include regional dummy variables to control for unobserved regional-specific effects at the NUTS 2 level (federal states), as well as time dummy variables for each year to capture time trend effects not being captured by the variables. The summary statistics of the explanatory variables of all our observed farms are presented in table 2a.

Table 2a: Summary statistics of explanatory variables Z_{it}

Variable	Mean	Std. Dev.	Min.	Max.
All observations				
Variable input cost index	1.982	2.173	1	26
Drift Rate of milk returns	-0.008	0.020	-0.071	0.074
Regional milk quota price	0.536	0.178	0.258	0.908
Milk returns volatility	0.142	0.046	0.027	0.321
Cash flow to asset ratio	0.059	0.093	-0.940	4.723
Economic size units (ESU)	73	45	16	510
N=17,973 (2,403 farms)				

Data source: EU-FADN–DG AGRI 2000-2008. Data on regional milk quota prices are taken from the official auctions in Germany published by the farmers' association (DeutscherBauernverband).

The summary statistics of the explanatory variables for continuing and exiting farms are presented in table 2b.

Table 2b: Summary statistics of explanatory variables Z_{it} by exit-status

	Persisting farms (2,310 farms)				Exiting farms (93 farms)			
Variable	Mean	Std.Dev.	Min.	Max.	Mean	Std.Dev.	Min.	Max.
Variable input cost index	1.991	1.639	1.030	19.187	1.835	1.870	1.033	14.125
Drift Rate of milk returns	-0.009	0.021	-0.071	0.074	-0.015	0.028	-0.064	0.062
Regional milk quota price	0.538	0.083	0.327	0.764	0.577	0.093	0.413	0.764
Milk returns volatility	0.142	0.051	0.027	0.321	0.095	0.056	0.027	0.320
Cash flow to asset ratio	0.059	0.052	-0.125	0.460	0.067	0.114	-0.051	0.918
Economic size (ESU)	74	45	16	375	71	30	21	159

Data source: EU-FADN–DG AGRI 2000-2008. Data on regional milk quota prices are taken from the official auctions in Germany published by the farmers' association (DeutscherBauernverband).

4 Empirical Results

We use a panel data iterated least squares estimator to obtain empirical estimates of the technology parameters in the distance function (17), augmented by the time-varying inefficiency parameters following Lee and Schmidt (1993). Table 3 depicts the parameter estimates.

Table 3: Directional output distance function, time-varying inefficiency

Dependent variable: Milk output (tons)	Estimates	Standard errors
Labor (AWU)	10.653	0.030***
Land (ha)	0.851	0.000***
Capital(IQ)	0.275	0.000***
Intermediate Inputs(IQ)	1.532	0.000***
Sold cows (#)	0.733	0.000***
Other output(IQ)	-52.956	0.020***
Labor*Land	0.017	0.000***
Labor*Capital	0.039	0.000***
Labor*Int.Inputs	0.047	0.000***
Land*Capital	-0.001	0.000***
Land*Int.Inputs	0.018	0.000***
Capital*Int.Inputs	0.001	0.000***
Labor*Sold cows	0.364	0.000***
Labor*Other output	1.945	0.000***
Land*Sold cows	-0.014	0.000***
Land*Other output	-0.541	0.000***
Capital*Sold cows	0.001	0.000***
Capital*Other output	0.019	0.000***
Int.Inputs*Sold cows	0.032	0.000***
Int.Inputs*Other output	0.252	0.000***
Labor*Labor	-6.635	0.010***
Land*Land	-0.011	0.000***
Capital*Capital	0.000	0.000***
Int.Inputs*Int.Inputs	-0.020	0.000***
Sold cows squared	-0.058	0.000***
Other output squared	0.037	0.000***
Sold cows*Other output	-0.812	0.000***
Dummy year 2001	-0.672	0.020***
Dummy year 2002	3.472	0.020***
Dummy year 2003	-0.735	0.020***
Dummy year 2004	14.738	0.020***
Dummy year 2005	8.992	0.020***
Dummy year 2006	10.921	0.030***
Dummy year 2007	9.212	0.030***
Dummy year 2008	9.421	0.030***
θ_{2001}	1.106	0.000***
θ_{2002}	1.334	0.010***
θ_{2003}	1.447	0.010***
θ_{2004}	1.491	0.010***
θ_{2005}	1.573	0.010***
θ_{2006}	1.667	0.010***
θ_{2007}	1.654	0.010***
θ_{2008}	1.545	0.010***

*Note: *** shows p-value<0.01, ** shows p-value<0.05, and * shows p-value<0.1.*

Ideally, the estimated directional output distance function should be concave in the outputs. This is true for the number of sold cows, but not for the variable “other output” (the coefficients of the squared terms are -0.058 and 0.037, respectively). In first-order terms, inputs are, as expected, positively correlated to milk output production, while increasing “other output” decreases milk output.

The yearly dummy variables capture the development of milk output, and the estimates show a decrease in 2001 and 2003, followed by a steep increase in 2004. In the years after 2004 there is a significantly higher milk output level than in 2000, which reflects the total milk quota quantity increase introduced by the 2003 CAP reform.

The resulting efficiency estimates are summarized in table 4. The efficiency scores range from 0.575 to 1, with an average of 0.807. Even though the range between minimum and maximum efficiency is large, the standard deviation is rather small, i.e. efficiency scores are concentrated. The average technical efficiency is similar to other contributions: Emvalomatis, Stefanou, and Lansink (2011), for example, report an average efficiency of about 0.78. Furthermore, if we separate the specialized dairy farmers from the non-specialized dairy farmers, we obtain different efficiency distributions: efficiency estimates have a higher average among specialized dairy farmers than among non-specialized dairy farmers (0.818 compared to 0.785)[10].

From the estimated time parameters (θ_t) in table 3 we can see that the inefficiency is higher in later years, especially 2006. Indeed, as can be seen in table 4, average efficiency decreased from 2000 to 2006 and rose again in 2007 and 2008. At the same time the standard deviation decreased until 2007. This suggests that efficiency is, on average, lower and more diverse among farmers in later years than in earlier years in our sample.

Table 4: Summary statistics of estimated time-varying efficiency scores $\hat{u}_{it}$

Efficiency	N	Mean	Std. Dev.	Min.	Max.
2000	1,817	0.873	0.023	0.758	1
2001	2,022	0.859	0.026	0.732	1
2002	2,156	0.830	0.031	0.677	1
2003	2,224	0.816	0.034	0.650	1
2004	2,146	0.790	0.036	0.620	1
2005	2,116	0.779	0.038	0.599	1
2006	1,962	0.766	0.042	0.575	1
2007	1,840	0.768	0.042	0.578	1
2008	1,690	0.783	0.040	0.606	1
Total	17,973	0.807	0.051	0.575	1

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[10] Other transformations from inefficiency to efficiency scores, which are more common in the literature but less suitable for our case, might yield numerically different results.

We estimate the logit model by maximum likelihood. The results are reported in table 5.

Table 5: Results of second-stage exit, logit

Dependent variable: Exit probability	Coefficient	Robust SE
Variable input cost index	-0.066	0.070
Cash flow to asset ratio	-1.572	1.110
Economic size units (ESU)	-0.011	0.000***
Drift Rate of milk returns	-13.813	7.800*
Milk price volatility	-28.196	3.840***
Regional milk quota price	-0.352	2.780
Dummy Lower Saxony	0.517	0.480
Dummy Northrhine-Westphalia	0.370	0.540
Dummy Hessia	-0.227	0.670
Dummy Rhineland-Palatinate	-0.508	0.690
Dummy Baden-Wuerttemberg	-0.296	0.780
Dummy Bavaria	-1.569	0.590***
Dummy Saarland	-0.621	1.130
Dummy year: 2004	0.087	0.500
Dummy year: 2005	-0.197	0.530
Dummy year: 2006	0.861	0.490*
Dummy year: 2007	1.288	0.540**
Efficiency score	-29.370	3.030***
Constant term	21.870	3.210***
McFadden Pseudo R^2	0.284	
Number of farms	2,403	
Number of observations	10,288	

*Note: Asterisks ***, ** and * denote a p-value of <0.01, <0.05, and <0.1, respectively. Standard errors are clustered at the farm level. The reference period for the time dummy variables is 2003, with the reference region for the regional dummy variables being Schleswig-Holstein.*

Considering the unbalanced panel nature of our data, the overall fit (Pseudo R^2=0.284) of the model appears satisfactory. With regard to the explanatory variables we find that the variable input cost index has no significant effect on the probability of quitting milk production. This might be due to the fact that the cost index is constructed based on national price indices from external data sources. As hypothesized, the estimated coefficient of the cash flow to asset ratio has a negative sign. However, the impact of this variable is not significant. This insignificance may reflect the poor ability of this variable to capture financial stress, which is the underlying cause of market exits. We further find a negative coefficient of the economic size variable, that is, small farms are more prone to exit the market. Thus, our data confirm the observed process of structural change in the dairy sector in Germany, which has been characterized by a concentration of production capacity in larger farming units, while smaller farms have given up production.

The drift rate of milk prices has a significantly inverse effect on the probability of exit. That is, a higher trend in milk revenues reduces the probability of abandoning milk production. This finding is plausible since a higher drift indicates a higher expected profitability of milk production. Likewise, volatility of milk prices has a significantly negative effect on the probability of abandoning milk production, which is in line with our real options model. That is, a higher volatility of output prices increases the value of waiting and creates a larger range of inaction in terms of milk prices being trigger values.

With regard to the time dummies, we find a significantly higher probability of abandonment in the years 2006 and 2007. While farms in 2004 and 2005 are not significantly more or less likely to exit milk production compared to 2003, in both 2006 (p-value=0.078) and 2007 (p-value=0.017) farms show a significantly higher probability of exit compared to 2003. This can be explained by changes in the CAP. In particular, 2005 was the first year of implementing the 2003 CAP reform, i.e., the decoupling of direct payments and the deregulation of the milk market. At that time, dairy farmers might have expected falling milk prices in the nearer future, together with a devaluation of the milk quotas, as well as increases in milk price volatility.[11] Hence, farmers contemplating abandoning production might have taken the opportunity to sell their quotas at the still-high rates.

Contrary to theoretical considerations we find a negative coefficient of the regional milk quota price on exit probability, though it was insignificant (p-value=0.899). This result can be traced back to reasons that are rooted in our data. First, milk quota prices are located at the regional level and are thus only an imperfect proxy for individual liquidation values. Second, the impact of regional milk quota prices may also be diluted by including regional and time dummy variables. With regard to the farm location we find no significant difference in the probability of ceasing milk production compared to the reference region of Schleswig-Holstein in the North of Germany, with the exception of a significantly lower probability in Bavaria.

Finally, the empirical results confirm our hypothesis on the impact of technical efficiency on farm exits: the coefficient is negative and highly significant, i.e. efficient farms are more reluctant to exit milk production than inefficient ones. To obtain more detailed information on the magnitude of the impact of efficiency, we calculated its marginal effects. Figure 2 depicts the marginal effect of efficiency on the probability of exit for two different volatility regimes. Actually, this figure is the empirical counterpart of the non-separable case depicted in figure 1. Two findings are noteworthy: first, a change of efficiency has a different impact on the exit probability depending on the efficiency level. An increase in efficiency of an inefficient farm lowers exit probability, while this effect is not pronounced if the farm already produces at a high efficiency level. Second, increasing price volatility leads to a downward shift of the marginal effect of efficiency on exit probability. This downward shift is more distinct at low efficiency levels.

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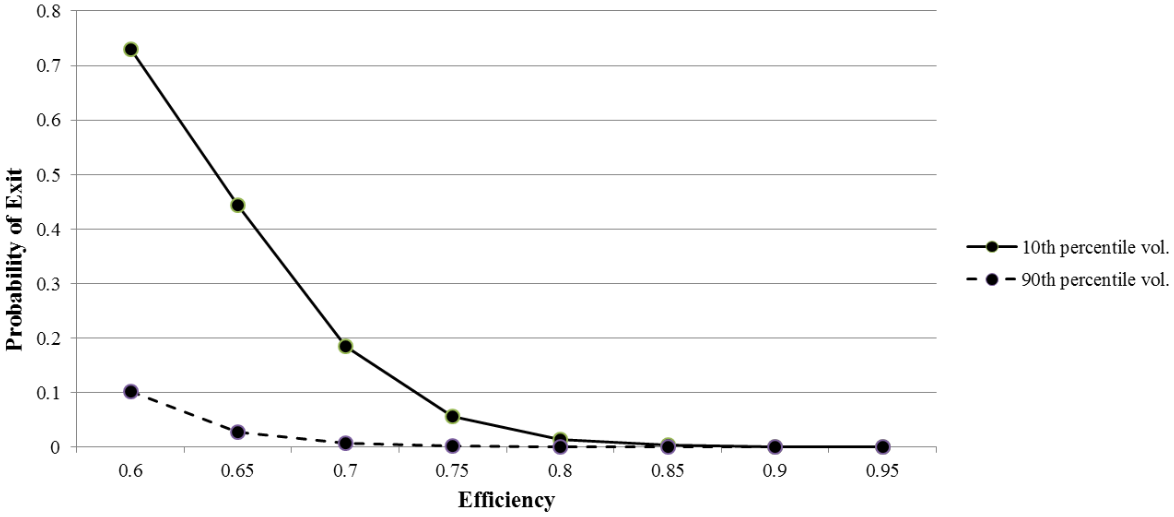
[11] See Business and Investment Barometer of Agriculture, provided by the farmers' union in Germany, published in March/April 09 (http://www.bauernverband.de/?redid=301312).

Figure 2: Marginal effects of technical efficiency on exit probability for different volatility levels



Note: The 10th percentile volatility level is 0.065, and the 90th percentile volatility level is 0.196.

5 Conclusions

In this paper, we develop a model to include production efficiency in the evaluation of the exit behavior of farms when subject to a stochastic output price that follows a Geometric Brownian motion. We accomplish this by directly modeling the technological structure of a farm, and by implicitly deriving a dual profit function through a Legendre transformation without assuming a specific functional form.

We derive a general class of results for homogeneous production functions, and more specifically for a Cobb-Douglas technology, with an efficiency term separable from the rest of the production factors. Efficient farms are more reluctant to exit the market; they believe in their potential to be profitable again if prices increase. If we include a non-separable efficiency term in a Cobb-Douglas technology, higher efficiency does not necessarily increase reluctance to exit. In both cases, volatility decreases exit trigger prices, thereby increasing reluctance to exit the market.

It is important to stress that our framework proposes a general methodology. Derived results on the dual homogeneous profit functions are just an example of a range of possible assumptions on the primal technology. Nonetheless, our example is general enough to show how efficiency can be included in a structural manner into the technology to derive farm exit behavior without assuming functional forms.

We test the theoretical model with a sample of milk-producing farms in West Germany. The data support the assumption of efficiency’s non-separability. Further, the empirical analysis confirms most hypotheses derived from the real options model. In particular, we find that the higher volatility of milk price decreases the probability of exit. Most important for our research question is that higher efficiency turns out to delay exit from the market. In other words, we find empirical support for the efficient structure hypothesis. However, farm-specific price volatility interacts with time-varying efficiency.

Since price volatility in the EU milk market increased due to the 2003 CAP reform implemented in 2005, this finding has an important implication for understanding structural change: the propensity of inefficient farms to exit the milk market attenuates under more volatile market conditions. This implies that heterogeneity of farms with respect to their efficiency will increase as a result of market liberalization. This conclusion, however, relies on the equivalence of time-varying volatility under varying market conditions and farm-specific risk that we capture in our empirical model.

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References

Arellano, M. (1993). On the testing of correlated effects with panel data, *J. Econom.*, 59 (1–2), 87-97.

Belotti, F., S. Daidone, G. Ilardi, and V. Atella, (2013). "Stochastic frontier analysis using Stata," Stata Journal, StataCorp LP, vol. 13(4), 718-758.

Box, G. E. P. and D. R. Cox (1964). An analysis of transformations. *J. Roy. Stat. Soc.-B 26* (2), 211–252.

Cuesta, R. A. (2000). A Production Model with Firm-Specific Temporal Variation in Technical Inefficiency: With Application to Spanish Dairy Farms. *J. Prod. Anal. 13* (2),139–158.

Curtiss, J. (2002): Efficiency and structural changes in transiton : a stochastic frontier analysis of Czech crop production. Aachen : Shaker, 2002.

Demsetz, H. (1973). Industry structure, market rivalry, and public policy. *J. Law Econ. 16* (1), 1–9.

Dixit, A. K. (1989). Entry and exit decisions under uncertainty. *J. Polit. Econ. 97* (3), 620–638.

Dixit, A. K. and R. S. Pindyck (1994). Investment under uncertainty. Princeton University Press.

Emvalomatis, G., S. E. Stefanou, and A. O. Lansink (2011). A reduced-form model for dynamic efficiency measurement: Application to dairy farms in Germany and the Netherlands. *Am. J. Ag. Econ. 93* (1), 161–174.

Färe, R., S. Grosskopf, D.-W. Noh, and W. Weber (2005). Characteristics of a polluting technology: theory and practice, *J. Econom.*, 126 (2), 469-492.

Goddard, E., A. Weersink, K. Chen, and C. G. Turvey (1993). Economics of structural change in agriculture. *Can. J. Ag. Econ., 41* (4), 475–489.

Grosskopf S, Hayes K.J., Taylor L.L., and W.L. Weber (1997). Budget constrained frontier measures of fiscal equality and efficiency in schooling. *Rev. Econ. Stat., 79* (1), 116–124

Guarda, P., Rouabah, A., and M. Vardanyan (2013). Identifying bank outputs and inputs with a directional technology distance function. *J Prod. Anal., 40* (2), 185-195

Hinrichs, J., Mußhoff, O., and M. Odening (2008). Economic Hysteresis in Hog Production. *App. Econ.,* 40 (3): 333-340.

Hüttel, S., and R. Jongeneel (2011). How has the EU milk quota affected patterns of herd-size change? *Eur. Rev. Agr. Econ. 38*(4): 497-527.

Hüttel, S., Mußhoff, O., and M. Odening (2010). Investment Reluctance: Irreversibility or Imperfect Capital Markets? *Eur. Rev. Agr. Econ. 37*(1): 51–76.

Jorgenson, D. W. and L. J. Lau (1974). Duality and differentiability in production. *J. Econ. Theory 9* (1), 23–42.

Kumbhakar, S. C. (2001). Estimation of profit functions when profit is not maximum. *Am. J. Ag. Econ. 83* (1), 1-19.

Kumbhakar, S. C. , E. Tsionas, and T. Sipiläinen (2009). Joint estimation of technology choice and technical efficiency: an application to organic and conventional dairy farming. *J. Prod. Anal. 31* (3), 151–161.

Lambarraa, F., S. E. Stefanou, and J. M. Gil (2009). The analysis of irreversibility, uncertainty and dynamic technical inefficiency on the investment decision in Spanish olive sector. 2009 Conference, August 16-22, 2009, Beijing, China 51397, International Association of Agricultural Economists, http://purl.umn.edu/51397. Accessed on 26th of July 2013.

Lambert, D.K. and V.V. Bayda (2005). “The Impacts of Farm Financial Structure on Production Efficiency.” *J. Ag. App. Econ.,* 37(1):277-289.

Lau, L. J. (1978). Applications of profit functions. Chapter 3 in Fuss, M. and D. McFadden (1978). Production Economics: a dual approach to theory and applications. Volume I: The theory of production. Eds. Amsterdam: North-Holland.

Lee, Y. H., and P. Schmidt (1993). ‘A Production Frontier Model with Flexible Temporal Variation in Technical Inefficiency.’ In The Measurement of Productive Efficiency: Techniques and Applications, edited by H. Fried, C. A. K. Lovell, and S. Schmidt, Oxford University Press.

Luong, Q. V. and L. W. Tauer (2006). A real options analysis of coffee planting in Vietnam. *Agric. Econ., 35*: 49–57.

Mosheim, R., and C.A. Knox Lovell (2009). “Scale Economies and Inefficiency of U.S. Dairy Farms.” *Am. J. Ag. Econ., 91*:777–794.

Musshoff, O., M. Odening, C. Schade, S. C. Maart-Noelck, and S. Sandri (2012). Inertia in disinvestment decisions: experimental evidence. *Eur. Rev.Agric. Econ., 40* (3), 463-485.

O’Brien, J. and T. Folta (2009). Sunk costs, uncertainty and market exit: A real options perspective. *Ind. Corp. Change, 18* (5), 807–833.

Orea, L. and A. Álvarez (2006). The role of inefficiency in regional productivity growth. Oviedo: Department of Economics, University of Oviedo, 1–21.

Peerlings, J. H. M. and Ooms, D. L. (2008). Farm growth and exit: consequences of EUdairy policy reform for Dutch dairy farming. Paper presented at the 12th EAAECongress, Gent (Belgium), 26 –29 August 2008.

Schaffer, M.E., and S. Stillman (2010). xtoverid: Stata module to calculate tests of overidentifying restrictions after xtreg, xtivreg, xtivreg2 and xthtaylor http://ideas.repec.org/c/boc/bocode/s456779.html.

Tsionas, E. and T. Papadogonas (2006). Firm exit and technical inefficiency. *Empir. Econ., 31* (2), 535–548.

Tauer, Loren W., (2006)."When to Get In and Out of Dairy Farming: A Real Option Analysis," Agricultural and Resource Economics Review, Northeastern Agricultural and Resource Economics Association, vol. 35(2), October.

Wheelock, D. C. and P. W. Wilson (2000). Why do banks disappear? the determinants of U.S. bank failures and acquisitions. *Rev. Econ. Stat., 82* (1), 127–138.

Zimmermann, A. and T. Heckelei (2012). Structural Change of European Dairy Farms – A Cross-Regional Analysis. Journal of Agricultural Economics, 63: 576–603.