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The Impact of Agri-Environmental Policies and Production Intensification on the Environmental Performance of Dutch Dairy Farms

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This study examines the impact of policies and intensification on the environmental performance of Dutch dairy farms in the period 2001–2010 using a hyperbolic distance function. The results indicate that the change from the Mineral Accounting System to the combination of the Application Standards Policy with decoupled payments has not significantly changed farms' hyperbolic efficiency. Farms receiving agri-environmental and animal welfare payments are less hyperbolically efficient than those that do not, highlighting greater decreases in desirable outputs than decreases in undesirable outputs. Finally, intensification increases hyperbolic efficiency, suggesting that intensive practices may increase production without harming the environment.

Key words: hyperbolic efficiency, policy evaluation, subsidies

Introduction

A long-lasting trend that characterizes dairy farming in Europe is the adoption of increasingly intensive agricultural practices. This intensification of the production process is manifested in observable data in two major ways (Caviglia-Harris, 2005): growing numbers of dairy cows per unit of land and increasing quantities of variable inputs, particularly feed concentrates, per animal. If the decision to adopt such production techniques is based on purely economic criteria, then it is expected that intensive production techniques could result in lower average costs. On the other hand, intensification has been associated with negative impacts on the environment. Specifically, the amounts of nutrients, such as phosphorus (P) and particularly nitrogen (N), imported into the production system in the form of dairy feed and fertilizers are typically greater than those exported in the form of milk products and those absorbed by crops that leave the farm, with the difference between the two leaching to the environment.

To abate the negative impact of intensive agricultural practices on the environment, policy makers in most European countries have implemented policies specifically aimed at reducing the amount of nutrient leaching. These policies usually set incentives that either partially internalize the negative externalities of nutrient leaching or provide rewards for reduced leaching and the application of environmentally friendly production techniques. Since changes in policies and intensification impact the production of both desirable outputs (i.e., cows' milk) and undesirable outputs (i.e., nitrogen surplus), evaluating the relationship between policy and farms' ability to

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The data used in the present work stems from the Dutch FADN system as collected by the Dutch Agricultural Economics Research Institute (LEI). The Centre of Economic Information (CEI) has provided access to these data. Results shown are and remain entirely the responsibility of the authors; neither they represent LEI / CEI views nor constitute official statistics.

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maximize desirable outputs and minimize undesirable outputs is important for future policy design. Therefore, there is a need to use integral measures, which account for both the aforementioned production aspects, in policy evaluations.

The Dutch dairy sector is characterized as an intensive farming sector, which has experienced various agri-environmental policies in recent years. This paper illustrates how Dutch dairy farms' performance, in terms of their ability to maximize desirable and minimize undesirable outputs, can be empirically computed using an integral measure. We aim to provide some insights into how those agri-environmental policies influence their performance. Given that the policies ruling EU farms are targeted toward reducing the production of undesirable outputs, the purpose of this study is to compute an integral measure that evaluates not only the success of these policies in minimizing undesirable outputs but also the way in which the production of desirable outputs is affected, because minimizing undesirable outputs may come at a cost of reducing desirable outputs.

Reviewing the recent methodological literature on efficiency measurement, we select a suitable methodology for an integral efficiency measurement. The measure considers farms' ability to maximize desirable outputs and minimize undesirable outputs, allowing us to account for a complex decision-making environment. Following Cuesta, Lovell, and Zofío (2009), who first used this measure in a parametric setting, we evaluate the impact of intensification and agri-environmental policies on the efficiency of Dutch dairy farms using the hyperbolic efficiency measure. One component considers maximizing desirable outputs, while the other component involves minimizing total nutrient surplus, providing a more general approach compared to the materials balance approach used by Coelli, Lauwers, and Van Huylenbroeck (2007) and Murty, Russell, and Levkoff (2012) in the sense that nutrients in outputs are not considered to be fixed.

We apply this well-established methodology to the case of Dutch dairy farms. The joint efficiency measure we use is more flexible than that used by Reinhard, Lovell, and Thijssen (1999) and Reinhard, Lovell, and Thijssen (2002), who measured either only farms' ability to minimize nutrient surplus (given desirable output) or only their ability to maximize their desirable outputs (given nutrient surplus). However, considering a joint measure can provide further information on potential (simultaneous) changes in the production of undesirable and desirable outputs. Furthermore, we use a more recent dataset that covers two important policy changes: i) the transition period from the Mineral Accounting System (MINAS) to the Application Standards Policy (ASP) and ii) the introduction of the optional agri-environmental and animal welfare payments. The former is considered to be one of the main reshaping features of the Common Agricultural Policy (CAP), while previous research on the latter has merely addressed the issue of the determinants of participation in such agri-environmental schemes without examining their impact on efficiency. Using a parametric specification allows us to identify the drivers of hyperbolic inefficiency in a one-step procedure. Given that the policies that have influenced the Dutch dairy sector not only reduced nitrogen surpluses but may also have affected the production of desirable outputs, the joint efficiency measure enables us to identify the effect of the policies on both production aspects.

The empirical findings confirm that policy-induced decreases in nitrogen surpluses are accompanied by simultaneous losses in the production of desirable outputs. This is because the effect of policies on the joint efficiency measure used is not positive. Such a finding highlights the advantage of using a joint efficiency measure when examining the relationship between policies and efficiency, as previous studies that examined the impact of policies on a single efficiency measure did not reveal changes in all production aspects.

Background and Related Work

In the Netherlands, the issue of nutrient leaching is of high importance due to the large share of dairy farming in total agricultural production and the special topology of the country (Oenema et al., 2011). The Netherlands was among the first EU member states to regulate nutrient leaching. In 1998, MINAS came into force in the Netherlands, aiming to achieve stabilization of manure production by

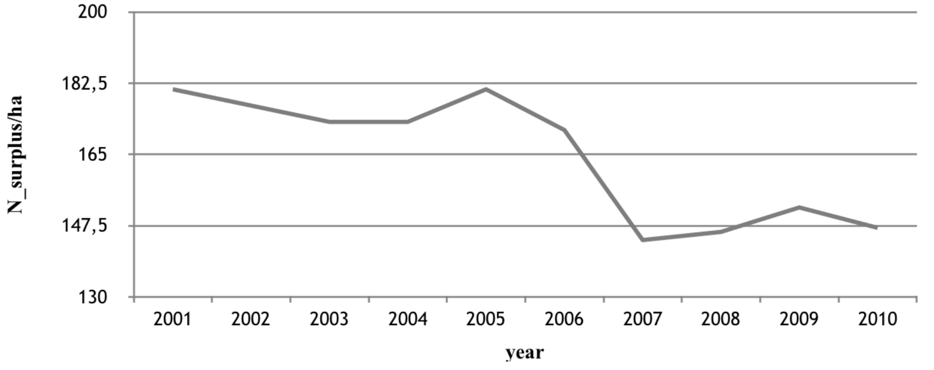

Figure 1. Nitrogen Surplus per Hectare for Dutch Dairy Farms, 2001–2010

reducing mineral surpluses. MINAS used a farm-gate-balance approach, measuring the N and P that entered and left the farm. Nutrient surplus was determined as the difference between the nutrients found in the inputs and in the outputs of the production process. This way of measuring nutrient leaching is known as the materials balance principle. Maximum permissible levels of surpluses were set and exceeding these levels resulted in payments of levies: 2.3 euro/kg for N and 9 euro/kg for P (Neeteson, 2000). However, the EU Court of Justice ruled that MINAS did not comply with the EU Nitrates Directive as it did not include application standards for nutrients.[1] Hence, the ASP came into force in 2006, setting application standards for N and P.[2] In contrast to MINAS, sanctions resulting from exceeding these standards took the form of fines and criminal justice (Berentsen, 2005).

The Dutch dairy sector was also influenced by several EU agri-environmental policies, such as agri-environmental and animal welfare payments and decoupled payments. Agri-environmental and animal welfare payments constitute an optional measure for farmers that encourage them to protect and enhance the environment on their farmland. Farmers who receive such payments are required to carry out agri-environmental commitments that involve more than the adoption of typical good farming practices. More specifically, farmers commit to adopting environmentally friendly farming techniques for at least 5 years and, in return, receive payments that provide compensation for applying these techniques. Examples of such techniques are reductions in fertilizers, pesticides, and stock density; appropriate soil management; and use of buffer strips. (Gailhard and Bojnec, 2015). Decoupled payments, introduced in 2006, oblige farmers to maintain their land in good agricultural and environmental condition and respect application standards for nutrients in order to receive their payments (Ciaian, Kancs, and Swinnen, 2014).

The above-mentioned policy instruments are expected to reduce the production of dairy farms' undesirable outputs by introducing incentives for responsible environmental practices. Indeed, based on the dataset used in the application that follows, Dutch dairy farms' nitrogen surpluses have sharply decreased since 2006, coincident with the period after ASP and decoupled payments were introduced. This is evident from Figure 1. However, farms may have achieved this decrease in nitrogen surpluses by diverting resources away from producing desirable outputs.

Several studies have examined the impact of these policies on farms' ability to maximize desirable outputs. Zhu and Oude Lansink (2010) and Zhu, Demeter, and Oude Lansink (2012) concluded that decoupled payments are negatively related to farms' ability to maximize desirable outputs, attributing this effect to a possible reduction in farmers' motivation. However, when it

[1] The EU Nitrates Directive was introduced in 1991 and forced EU member states to lower the nitrate load from agriculture to groundwater and surface waters. From 2002 onward, member states were also obliged to guarantee that applications of N from animal manure did not exceed 170 kg/ha per year.

[2] ASP set a standard for the application of N from animal manure of 170 kg/ha, as required by the EU Nitrates Directive, and a standard depending on soil type and crop for the application of mineral N and P from fertilizer and manure.

comes to the optional agri-environmental measures, empirical applications have merely focused on examining farmers' willingness to adapt to such measures and the determinants of their participation (Vanslembrouck, van Huylenbroeck, and Verbeke, 2002; Hynes and Garvey, 2009; Ma et al., 2012). Farmers who adopt intensive agricultural practices are less willing to participate in these agri-environmental measures, while less productive farms tend to report higher participation (Zimmermann and Britz, 2016).

Some studies have attempted to shed light on the impact of intensification on farms' ability to minimize nutrient surplus. Reinhard, Lovell, and Thijssen (1999) defined intensification as the ratio of milk production per hectare of land and found intensive farms to be more efficient in minimizing their nutrient surplus compared to extensive farms. According to Reinhard, Lovell, and Thijssen (1999), intensive Dutch dairy farms typically buy feed instead of producing it. Hence, the total nutrient surplus of farms that purchase feed is lower compared to those that produce it, since producing roughage on the farm requires applying fertilizers and manure and more nutrients are therefore imported into the system. Reinhard, Lovell, and Thijssen (2002) captured intensification as feed intake per cow, which they found to be negatively related to efficiency.

When it comes to agri-environmental policy evaluation, earlier empirical studies have focused on examining either farms' ability to maximize desirable outputs or to minimize undesirable outputs separately. Measuring the former by taking an output-expanding approach is straightforward. Measuring the latter has undergone several developments, with the most recent making explicit use of the materials balance condition. Based on the definition of the materials balance condition, Coelli, Lauwers, and Van Huylenbroeck (2007) and Murty, Russell, and Levkoff (2012) define efficiency as the ratio of minimum nutrients in inputs to observed nutrients in inputs, given the nutrients found in outputs, and measure efficiency in a nonparametric framework using data envelopment analysis (DEA). Hoang and Nguyen (2013) and Guesmi and Serra (2015) use the same approach to measure efficiency in a DEA framework and use a second-stage Tobit model to explain variation in farm efficiency. Nevertheless, it is apparent that national and EU policies may impact both farms' ability to maximize desirable outputs and minimize undesirable outputs. To assess the integral impact of such policies, it is necessary to measure a farm's ability to efficiently produce desirable outputs, given the inputs used with the minimal detrimental effect on the environment.

Integral measures of efficiency have been predominantly proposed in nonparametric settings using DEA (Färe et al., 1989; Färe, Grosskopf, and Zaim, 2002). Nevertheless, identifying the determinants of inefficiency can be computationally demanding when nonparametric techniques are considered. Bootstrap techniques and second-stage models are required to correct for serial correlation of the nonparametric efficiency estimates and identify the impact of environmental variables on inefficiency (Simar and Wilson, 2007).

In a parametric framework, Cuesta and Zofío (2005) and Cuesta, Lovell, and Zofío (2009) implemented the parametric counterpart of the hyperbolic efficiency measure introduced by Färe et al. (1989). Furthermore, Glass et al. (2014) incorporated inefficiency determinants to explain variability in hyperbolic efficiency scores, while Mamardashvili, Emvalomatis, and Jan (2016) used the hyperbolic efficiency measure to derive shadow prices for undesirable outputs.[3] This measure considers the possibility of both the expansion of desirable outputs and the contraction of undesirable outputs simultaneously, holding inputs fixed. Hyperbolic efficiency can, therefore, serve to measure farms' joint performance. Moreover, using a parametric setting facilitates examining inefficiency determinants, including polices.

[3] Shadow prices for nitrogen surplus were also derived in a recent study by Malikov, Bokusheva, and Kumbhakar (2018), who used a hedonic output-based index approach.

Modeling Approach

Theoretical Background

Efficiency measurement has been the subject of several studies. Stochastic frontier analysis (SFA), introduced by Aigner, Lovel, and Schmidt (1977) and Meeusen and van den Broeck (1977), constitutes the most popular parametric technique for measuring efficiency. Depending on the orientation toward which efficiency is measured, the farm-specific efficiency score reflects the ability of the farm to minimize input use when producing a given output vector or to maximize output production given the inputs used (Kumbhakar and Lovell, 2003). These SFA models assume a composed error structure in which the first error component captures purely statistical noise and the second nonnegative error component captures inefficiency.

Färe, Grosskopf, and Lovell (1985) modified the efficiency measure to allow for equiproportionate contraction of the input vector and expansion of the output vector simultaneously, introducing the notion of hyperbolic efficiency. The need to distinguish between desirable and undesirable outputs when evaluating producers' performance led Färe et al. (1989) to account for the contraction of undesirable outputs instead of inputs.[4] In the latter case, hyperbolic efficiency, enhanced for the production of undesirable outputs, reflects the farm's ability to expand desirable outputs and contract undesirable outputs, in equal proportions, without altering the quantity of inputs (Färe et al., 1989). In a parametric setting, two alternative approaches have been proposed in the literature that account for equiproportionate expansion of desirable outputs and contraction of undesirable outputs.

One alternative approach is the directional distance function, which gives inefficient farms a preassigned direction to reach the production frontier through a straight line.[5] Equiproportionality is achieved by choosing the direction that is proportional to the observed desirable and undesirable outputs (Färe et al., 2005). However, a weakness of the directional distance function is that the efficiency measure does not satisfy the very crucial property of commensurability (Peyrache and Coelli, 2009).[6]

The second alternative, the hyperbolic distance function, accounts for equiproportionate expansion of desirable outputs and contraction of undesirable outputs, where inefficient farms move along a hyperbolic path to reach the production frontier. Figure 2 illustrates such a hyperbolic path toward the frontier in the case of a single desirable output (y) and a single undesirable output (b). Consider a farm that is currently operating at point A. If the farm seeks to expand only y while keeping b fixed, it will move to point C. However, if the farm aims to contract b while keeping y fixed, it will move to point B. Finally, in the case of hyperbolic efficiency, the farm seeks to equiproportionately expand y and contract b, moving hyperbolically toward point D.

Now suppose that a new policy requires the farm operating at point A to reduce undesirable outputs from b' to b''. Adjusting the production of undesirable outputs in the short run may force the farm to move to point E. At this point, the farm will be more efficient in producing undesirable outputs, less efficient in producing desirable outputs, but more hyperbolically efficient since it will move to a point that is closer to the frontier. This hypothetical example suggests that movements of a farm responding to policy changes are unlikely to occur in a straight horizontal or vertical direction; efficiency changes are therefore better captured by a joint measure.

A hyperbolic distance function can be used to measure farms' hyperbolic efficiency in the case where input vectors, $\boldsymbol{x} \in R_+^Q$, can produce desirable output vectors, $\boldsymbol{y} \in R_+^K$, and undesirable output vectors, $\boldsymbol{b} \in R_+^M$. Following Cuesta, Lovell, and Zofío (2009), the hyperbolic distance

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[4] Ball et al. (2004) followed this procedure and used water contamination as an indicator of undesirable outputs.

[5] O'Donnell (2010) and subsequent work by Tozer and Villano (2013) relaxed the assumption of a preassigned direction toward the frontier.

[6] Commensurability refers to the scale invariance property. If this property is not satisfied, the efficiency measure depends on the units of measurement of the variables that enter the model.

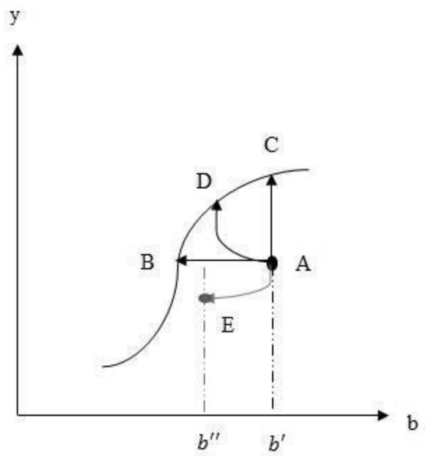

Figure 2. Hyperbolic Path of an Inefficient Farm toward the Frontier

function represents the maximum expansion of the desirable output vector and the equiproportionate contraction of the undesirable output vector so that producers reach the boundary of the production possibilities set, T, given the amount of inputs used:

$$(1) \qquad D_H(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{b}) = \min\left\{\theta > 0 \,:\, \left(\boldsymbol{x}, \frac{\boldsymbol{y}}{\theta}, \boldsymbol{b}\,\theta\right) \in T\right\},$$

where θ is a scalar. The hyperbolic distance function has a value range between 0 and 1 and can be used directly as a measure of efficiency: When $\theta = 1$, then the combination $(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{b})$ is on the boundary of the production possibilities set and, thus, represents a hyperbolically efficiency point. When $\theta < 1$, the point $(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{b})$ is in the interior of the production possibilities set and is associated with hyperbolic efficiency equal to θ. Using the almost homogeneity condition[7] and choosing the Kth desirable outputs for normalization purposes we have

$$(2) \qquad D_H\left(\boldsymbol{x}, \frac{\boldsymbol{y}}{y_K}, \boldsymbol{b}\, y_K\right) = \frac{D_H(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{b})}{y_K}.$$

Technically, the hyperbolic distance function is almost homogeneous of degrees 0, 1, -1, 1, nondecreasing in desirable outputs and nonincreasing in undesirable outputs and inputs. Unlike the directional distance function, Cuesta, Lovell, and Zofío's (2009) hyperbolic distance function satisfies the property of commensurability. In this study, we rely on the hyperbolic distance function to derive an efficiency measure that does not depend on the units of measurement of inputs and outputs, thus strengthening the reliability of efficiency score estimates.

Empirical Model

An estimable form of the distance function is obtained from equation (2) by replacing $D_H(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{b})$ with HE (i.e., hyperbolic efficiency), taking logs on both sides, rearranging, and appending an error term, v, that captures statistical noise to the righthand side of the equation:

$$(3) \qquad -\log y_K = \log D_H\left(\boldsymbol{x}, \frac{\boldsymbol{y}}{y_K}, \boldsymbol{b}\, y_K\right) + v - \log HE$$

[7] A function $f(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{b})$ is almost homogeneous of degrees λ_1, λ_2, λ_3, and λ_4 if $f\left(\mu^{\lambda_1}\boldsymbol{x}, \mu^{\lambda_2}\boldsymbol{y}, \mu^{\lambda_3}\boldsymbol{b}\right) = \mu^{\lambda_4} f(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{b})\ \forall\ \mu > 0$.

Parametrically, the hyperbolic distance function is specified as translog in inputs, desirable and undesirable outputs, and time, leading to

$$
\begin{aligned}
-\log y_{it}^{K} \quad = \quad & \alpha_0 + \sum_{q=1}^{Q} \alpha_q \log x_{it}^{q} + \frac{1}{2}\sum_{q=1}^{Q}\sum_{r=1}^{Q} \alpha_{qr} \log x_{it}^{q} \log x_{it}^{r} \\
& + \sum_{k=1}^{K-1} \beta_k \log \left[y_{it}^{k}\right]^{*} + \frac{1}{2}\sum_{k=1}^{K-1}\sum_{l=1}^{K-1} \beta_{kl} \log \left[y_{it}^{k}\right]^{*} \log \left[y_{it}^{l}\right]^{*} \\
& + \sum_{m=1}^{M} \delta_m \log \left[b_{it}^{m}\right]^{*} + \frac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{M} \delta_{mn} \log \left[b_{it}^{m}\right]^{*} \log \left[b_{it}^{n}\right]^{*} \\
& + \sum_{q=1}^{Q}\sum_{m=1}^{M} \pi_{qm} \log x_{it}^{q} \log \left[b_{it}^{m}\right]^{*} + \sum_{q=1}^{Q}\sum_{k=1}^{K-1} \rho_{qk} \log x_{it}^{q} \log \left[y_{it}^{k}\right]^{*} \\
& + \sum_{m=1}^{M}\sum_{k=1}^{K-1} \tau_{mk} \log \left[b_{it}^{m}\right]^{*} \log \left[y_{it}^{k}\right]^{*} + \zeta_t t + \zeta_{tt} t^2 + \sum_{q=1}^{Q} \phi_q t \log x_{it}^{q} \\
& + \sum_{m=1}^{M} \psi_m t \log \left[b_{it}^{m}\right]^{*} + \sum_{k=1}^{K-1} \omega_k t \log \left[y_{it}^{k}\right]^{*} + v_{it} + u_{it},
\end{aligned} \tag{4}
$$

where $u_{it} \equiv -\log HE_{it}$; $\left[y_{it}^{k}\right]^{*} = \frac{y_{it}^{k}}{y_{it}^{K}}$; $[b_{it}^{m}]^{*} = b_{it}^{m} \cdot y_{it}^{K}$; $q = 1, \ldots, Q$ indexes inputs; $k = 1, \ldots, K$ indexes desirable outputs; $m = 1, \ldots, M$ indexes undesirable outputs, subscript i represents individuals, and t is a time trend that increases by 1 between successive years (i.e., from 0 in 2001 up to 9 in 2010).

The composite error term, $v_{it} + u_{it}$, has a positive skewness. This is because the dependent variable has a negative sign. The two error components are assumed to follow the following distributions: $v_{it} \sim \mathcal{N}(0, \sigma_v^2)$ and u_{it} follows a normal distribution truncated from below at 0, $u_{it} \sim \mathcal{N}^{+}(\boldsymbol{z}_{it}'\boldsymbol{\xi}, \sigma_u^2)$. Hence, following the Battese and Coelli (1995) approach of inefficiency determinants, the location parameter of the inefficiency component, u_{it}, is specified as a function of explanatory variables, including farm-specific characteristics and policy variables $\boldsymbol{z}_{it}'$ and associated parameters $\boldsymbol{\xi}$.[8] We estimate the model in equation (4) using maximum-likelihood techniques, which allow us to obtain the conditional distribution of the inefficiency component, $E[u_{it}|\varepsilon_{it}]$, where $\varepsilon_{it} = v_{it} + u_{it}$. The hyperbolic efficiency of farm i in year t is calculated as

$$
HE_{it} \quad = \quad \exp\left[\log D_H(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{b})\right] \quad = \quad \exp(-u_{it}). \tag{5}
$$

Data

The data used for this application were provided by the Agricultural Economics Research Institute of the Netherlands (LEI). LEI, along with the Centre for Economic Information of the Netherlands (CEI), carry out the task of bookkeeping data for Dutch farms in order to comply with the requirements of the EU Farm Accountancy Data Network (FADN). The accounting data that FADN provides are collected regionally using a common questionnaire across all member states. The dataset contains farm-level economic and financial data (revenues from outputs, expenses on inputs, subsidies, etc.) required by FADN; for national policy purposes, data on nutrient surpluses are also

[8] We also consider a model in which the variables in $\boldsymbol{z}$ affect the variance of the inefficiency component and a model in which the $\boldsymbol{z}$ variables affect both the variance of inefficiency and the variance of the two-sided error term, v_{it}, as in Kumbhakar and Lovell (2003). However, in the application that follows, the results are qualitatively the same, while the employed model is favored by the data when compared to these two alternative models, based on the Bayesian Information Criterion (BIC).

available. FADN uses stratified random sampling, in which farms remain in the panel for 4–5 years on average, although there are cases where farms remain for more than 10 years. The dataset used here contains information on conventional Dutch dairy farms from 2001 to 2010. This study focuses on farms engaged primarily in dairy production. We therefore selected farms for which revenues from sales of cow's milk, beef, and veal account for at least 80% of their total revenues for every year in which they are observed. Our final dataset is an unbalanced panel with 2,105 observations.

Two desirable outputs are used in the translog specification of the hyperbolic distance function: deflated revenues from sales of cow's milk and milk-related products (milk), and deflated revenues and change in value of beef and veal, plus deflated revenues from sales of arable products, plants, flowers, vegetables, and horticultural products (other output). Five inputs are used in the translog specification: deflated value of capital, including buildings and machinery (K); labor, consisting of hired and family labor (L); land after aggregation of the owned and rented land (A); deflated value of variable inputs, consisting of expenditures on fertilizers, pesticides, purchased feed and energy (I); and livestock units (S). Finally, N surplus, calculated as the difference between the nitrogen contained in the inputs and the nitrogen contained in the outputs, is specified as an undesirable output. Figure 1 in Reinhard, Lovell, and Thijssen (1999) illustrates how nitrogen in inputs and outputs is calculated for Dutch dairy farms. The above-mentioned revenues and values are deflated using price indices obtained from EUROSTAT, using 2005 as the base year.

While the model can in principle cope with multiple undesirable outputs, the empirical analysis focuses on one undesirable output, N surplus. P surplus has been dropped from the model because 13.53% of observations had negative P surpluses. According to Keyzer (2010), P, in contrast to N, accumulates in the soil, whereas N can be evaporated and washed out by water. This fact provides a potential explanation for observing so many negative values for P surpluses. Following the same reasoning, since N can be easily washed out from the system, farmers apply N intensively on purpose in order to maintain desirable N levels on their farms; N surplus can therefore be a more important factor in explaining efficiency than P surplus.[9] Prior to estimation, the data for outputs and inputs are normalized by their geometric means, which enables us to interpret the model's parameter estimates associated with the first-order terms as distance function elasticities, evaluated at the mean of the data. We also transformed the time trend variable prior to estimation in deviations from its mean, in order to enable us to interpret the coefficient associated with this variable as minus the rate of productivity growth due to technical progress, evaluated at the mean of the data.[10]

The explanatory variables, z_{it}, affecting the inefficiency term, u_{it}, in equation (4) include two policy variables, an intensification indicator, a farm-specific control factor, and a time trend. First, since the main policy change in the period 2001–2010 consisted of the switch from MINAS to the combination of ASP with decoupled payments in 2006, we include a dummy variable (ASP-decoupled), which takes a value of 0 for the period 2001–2005 and 1 afterward. This dummy variable aims to capture differences in the hyperbolic efficiency scores before and after the introduction of ASP and decoupled payments. Additionally, a second dummy variable (payments) is specified to account for potential differences in the hyperbolic efficiency of farms that receive agri-environmental and animal welfare payments and those that do not.[11] The "payments" dummy takes a value of 1 for all t if farmers received agri-environmental and animal welfare payments in any year t and 0 otherwise. Both policies (ASP-decoupled payments and agri-environmental and animal welfare payments) introduce incentives to farms to reduce their nutrient surpluses, which is evident from Figure 1. Hence, one would expect that after 2006 (the time period that ASP with decoupled

[9] Reinhard, Lovell, and Thijssen (2000) also disregarded P surplus from their analysis as the monotonicity assumption for P surplus was violated for more than half of their observations.

[10] For instance, the derivative of the hyperbolic distance function with respect to an input q at the geometric mean of the data is $\frac{\partial \log D_H}{\partial x^q} = \alpha_q + 2\alpha_{qq}(\overline{\log x^q}) + \sum_{r=1}^{Q} \alpha_{qr}(\overline{\log x^r}) + \sum_{m=1}^{M} \pi_{qm}(\overline{\log b^m}) + \sum_{k=1}^{K} \rho_{qk}(\overline{\log y^k}) + \phi_q \bar{t} = \alpha_q$ because (due to the mean normalization) evaluation of the derivative at the mean of the data implies that $\overline{\log x_q}$, $\overline{\log x_r}$, $\overline{\log b_m}$, $\overline{\log y_k}$, and $\bar{t} = 0$.

[11] In the dataset, 34.8% of farms received agri-environmental and animal welfare payments.

Table 1. Summary Statistics of the Model's Variables

Variable	Mean	Std. Dev.
Milk (1,000€)	208.59	139.35
Other (1,000€)	24.69	22.14
Capital (1,000€)	161.88	110.99
Labor (1,000 man-hours)	3.10	1.35
Land (hectares)	56.04	34.35
Variable inputs (1,000€)	51.60	35.16
Livestock (livestock units)	153.57	93.98
Nitrogen surplus (1,000kg)	9.11	6.74
ASP-decoupled (dummy)	0.52	0.50
Payments (dummy)	0.35	0.48
Intensity (feed/livestock)/1000	0.30	0.10
Milk share (milk revenues/total revenues, %)	89.89	5.14
Trend (0–9)	4.67	2.89

Notes: Prior to estimation, all inputs and outputs are normalized by their geometric mean and the trend variable by its arithmetic mean.

payments came into force) farms would succeed in reducing their undesirable outputs compared to the period before, while farms receiving agri-environmental and animal welfare payments would be also doing better in terms of minimizing their undesirable outputs. However, reducing nutrient surpluses may affect the production of desirable outputs. Hence, our study evaluates the net effect of these policies on the joint efficiency measure. Finally, note that we allow the aforementioned payments to affect efficiency only and not output through the distance function. While a few studies in the literature, including Zhengfei and Oude Lansink (2006) and McCloud and Kumbhakar (2008), have allowed subsidies to directly affect output, we follow the typical approach of allowing subsidies to impact farms' efficiency levels because a technical relationship between output and subsidies does not exist. Since subsidies can relax farms' liquidity constraints and, therefore, their input use, controlling for input use is adequate to describe the relationship between outputs and inputs.

Purchased feed per livestock units (intensity) is used as an indicator of intensification, since, as mentioned in the introduction, dairy sector intensification is characterized by the increasing use of feed concentrates per animal. The share of revenues from milk production in total revenues (milk share) is included to capture the effect of specialization in milk production on hyperbolic efficiency. Finally, the time trend aims to capture changes in farms' hyperbolic inefficiency over time and takes values from 0 (for 2001) to 9 (for 2010). Table 1 presents summary statistics for the variables included in the analysis.

Results

Appendix Table A1 presents the complete set of estimation results for equations (4) and (5). Table 2 reports the parameter estimates of the first-order terms of the hyperbolic distance function. The left-side variable $\log y_{it}^{K}$ in equation (4) is negative. Therefore, and by visualizing Figure 2, the signs of the distance elasticities should have the following properties: i) for a given input vector $\boldsymbol{x}$ and undesirable output vector $\boldsymbol{b}$, an increase in outputs will bring the observation closer to the frontier. This means that the minimum possible contraction (θ) of the new output vector in equation (1) is larger. Therefore, the distance elasticity with respect to other output is expected to be positive. ii) For a given output vector $\boldsymbol{y}$ and input vector $\boldsymbol{x}$, an increase in undesirable outputs will move the observation to the right, and therefore further away from the frontier. This implies that the minimum possible contraction (θ) of the new output vector in equation (1) is smaller. Hence, the distance elasticity with respect to undesirable outputs is expected to be negative. Finally, iii) when an input increases *ceteris paribus*, the boundary of the production possibilities set moves upward. Therefore,

Table 2. Parameter Estimates of the First-Order Terms of the Hyperbolic Distance Function

Variable	Coeff.	Std. Err.	*p*-Value
log_other	0.027***	0.009	0.004
log_K	−0.023***	0.008	0.002
log_L	−0.023**	0.011	0.032
log_A	−0.078***	0.013	0.000
log_I	−0.379***	0.018	0.000
log_S	−0.385***	0.021	0.000
log_N	−0.069***	0.007	0.000
Trend	−0.019***	0.002	0.000

Notes: other refers to other outputs, K to capital, L to labor, A to land, I to variable inputs, S to livestock units, and N to nitrogen surplus. Double and triple asterisks (**, ***) indicate that the coefficient is significantly different from 0 at the 5% and 1% significance level, respectively.

Table 3. Parameter Estimates of Determinants of Hyperbolic Inefficiency

Variable	Coeff.	Std. Err.	*p*-Value
ASP-decoupled	−0.011	0.039	0.779
Payments	0.055**	0.024	0.020
Intensity	−0.875***	0.234	0.000
Milk share	−0.031***	0.004	0.000
Trend	0.010	0.010	0.308
Constant	2.864***	0.354	0.000

Notes: Double and triple asterisks (**, ***) indicate that the coefficient is significantly different from 0 at the 5% and 1% significance level, respectively.

the observation is found to be further away from the frontier, the minimum possible contraction (θ) of the new output vector in equation (1) is smaller, and the derivative of the distance function with respect to inputs is expected to be negative.

The results presented in Table 2 are in accordance to our prior expectations pointed above. The distance elasticity with respect to other output (log_other) is positive and reflects the share of other output (meat and crops) in the farms' total output composition. The low elasticity suggests that the share of other output on production is rather low. The elasticities of the distance function with respect to inputs have the expected negative signs and are statistically significant at the 5% significance level. The high distance elasticities for variable inputs and livestock units in absolute terms reflect the high cost share of these variables during the study period. The elasticity with respect to N surplus is negative and statistically significant, which is in accordance with our prior expectations: With reference to Figure 2, an increase in N surplus implies that the farm will become less efficient as the observation moves to the right and thus further away from the frontier. Finally, there is evidence that Dutch dairy farms experience technological progress since the production frontier moves upward with time.

Turning to the efficiency estimates, the average hyperbolic efficiency is 0.908,[12] ranging from a minimum of 0.374 to a maximum of 0.983. This result implies that farms can, on average, increase their desirable output production by 10% $(1/0.908 = 1.10)$ and, at the same time, reduce their undesirable output production by 9.2% $(1 - 0.908 = 0.092)$. Figure 3 presents a histogram of the hyperbolic efficiency estimates. The histogram of the hyperbolic efficiency estimates exhibits the typical left-skewed pattern. Most of the farms are highly efficient, while very few of them are less than 60% efficient. Finally, Table 3 presents the parameter estimates of the determinants of hyperbolic inefficiency.

[12] Robustness checks with respect to the distribution imposed on the inefficiency component reveal that the average of the efficiency estimates is not sensitive to different distributional assumptions.

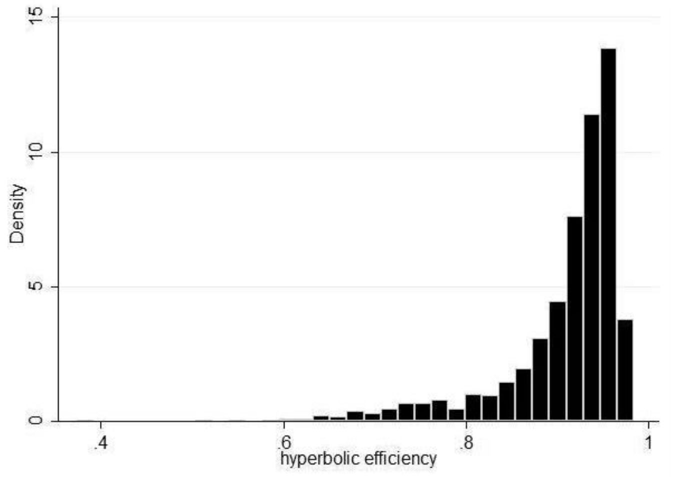

Figure 3. Histogram of Hyperbolic Efficiency Estimates

Table 4. Marginal Effects of the z Variables on Hyperbolic Efficiency

Variable	Mean	Std. Dev.	Min	Max
ASP-decoupled	0.001	0.001	0.000	0.002
Payments	−0.006	0.003	−0.011	−0.001
Intensity	0.093	0.049	0.009	0.181
Milk share	0.003	0.002	0.000	0.006
Trend	−0.001	0.001	−0.002	0.000

Except for the dummy variable used to capture the effect of the introduction of ASP and decoupled payments and the trend variable, all estimates are statistically significant at the 5% significance level. The parameter estimates presented in Table 3 show the effect of the variables in z on $E(u_{it})$. To derive meaningful results with respect to the effect of the variables in z on farms' hyperbolic efficiency, we derive their marginal effects by calculating the derivative of $E\left(e^{-u_{it}}|\varepsilon_{it}\right)$ with respect to each variable in z (for details on the calculation of marginal effects in stochastic frontier models, see Wang, 2002). The marginal effects were calculated at the specific values of the variables for each observation. Table 4 presents summary statistics of these marginal effects.

The coefficient of the dummy variable that controls for the introduction of ASP and decoupled payments (ASP-decoupled) is statistically insignificant, as mentioned before. This may occur because this policy, while reducing farms' nitrogen surplus, also reduces their desirable output production. Hence, we do not find differences in farms' hyperbolic efficiency between the transition period of MINAS and the combination of ASP and decoupled payments. As mentioned in the introduction, ASP and decoupled payments lowered farms' nitrogen surplus (evident in Figure 1) by setting application standards for nutrients from fertilizers and manure. Meanwhile, such measures lower the production of desirable output by restricting farms' technology. Therefore, the overall effect is insignificant.

The dummy variable capturing potential differences in hyperbolic efficiency between farms that receive agri-environmental and animal welfare payments (payments) and those that do not has a negative marginal effect on hyperbolic efficiency. Hence, these payments reduce the production of desirable output more than they decrease nitrogen surplus. Agri-environmental and animal welfare payments require farmers to adopt techniques that go beyond the usual good farming practices, imposing several constraints on the production technology. As previous research has indicated (e.g., Zimmermann and Britz (2016)), farms that receive such payments tend to be less productive. This implies that such farms operate in an area where their desirable output is low, although still close to the frontier (average efficiency is 91%). Hence, these farms operate in a region where the curve that describes the relationship between desirable and undesirable output is rather steep, meaning that a slight decrease in undesirable output is accompanied by a considerable reduction in desirable output, resulting in a negative overall effect on the hyperbolic efficiency.

The aforementioned causal interpretation of the effect of agri-environmental and animal welfare payments on hyperbolic efficiency may be counteracted by endogeneity/self-selection arguments, which maintain that farmers with low efficiency levels decide to receive these payments because this is the optimal strategy for them. However, these arguments may not be as strong as they appear, because this study combines productive and environmental efficiency. In this context, a farm may be highly inefficient in the hyperbolic measure, even if it is quite efficient when considering only desirable outputs. It would not make sense for the operator of such a farm to sign up for the payments, because this would entail a large reduction in desirable outputs in order to conform to the standards. Conversely, the operator of a farm that is very close to the frontier due to producing relatively few desirable outputs, but also polluting less, would obviously have an incentive to sign up for the payments, as these would come at minimal, if any, cost. Therefore, the effect of hyperbolic efficiency on the probability of receiving payments may be small. In contrast, receiving the payments is accompanied by production restrictions, which can only shrink the feasible set. Since the efficiency of farms that receive the payments is measured against a frontier defined by all farms (including those not subject to restrictions), the efficiency of farms that receive payments will be smaller. Therefore, the causal effect of payments on hyperbolic efficiency has a theoretical justification and is expected to be much stronger than the effect that self-selection could have.[13]

Production intensity positively affects hyperbolic efficiency. As already mentioned, intensification is characterized by an increasing use of inputs, particularly feed concentrates in the dairy diet, which results in higher animal productivity and higher desirable output production at the farm level. However, the intensive character of dairy farms can be detrimental to the environment because increased feeding results in more nutrients imported into the system (Reinhard, Lovell, and Thijssen, 2002). However, according to Reinhard, Lovell, and Thijssen (1999), intensive Dutch dairy farms tend to use less land and buy more feed to increase the productivity of their cows. Farms buying more feed instead of producing it on the farm tend to import fewer nutrients into the system than they potentially would have if they had produced the feed on the farm, since roughage production on the farm requires additional fertilizer use for grassland and, therefore, more nutrients. Hence, the increase in desirable output production is higher than the increase in nitrogen surplus.

Finally, milk share has a positive effect on hyperbolic efficiency, lending support to a rather intuitive interpretation. Specialized farms produce more desirable outputs due to their engagement in a single production activity and the associated advanced technology. In addition, lower fertilizer use due to less crop production results in lower undesirable outputs, which in turn implies better joint performance.

Concluding Remarks

Using a hyperbolic distance function and the Battese and Coelli (1995) approach of inefficiency determinants, we investigated the effects of agri-environmental policies and intensification on the hyperbolic efficiency of Dutch dairy farms between 2001 and 2010. Our dataset covers a period of two important policy interventions: the replacement of the Mineral Accounting System (MINAS) with the combination of the Application Standards Policy (ASP) and decoupled payments, and the introduction of optional agri-environmental and animal welfare payments. Farms' hyperbolic efficiency turns out to be relatively high (91%), indicating that farms do rather well in terms of their joint performance. Additionally, since some of the policies included in the analysis may not

[13] The editor suggested a way to distinguish between the two possible explanations (causality vs. selection), but our data do not allow us to implement his suggested approach.

only decrease undesirable outputs but also decrease or increase desirable output production, we were able to identify whether any of these effects were higher than the other in the case of a joint efficiency measure.

We find no significant changes in farms' hyperbolic efficiency during the transition period from MINAS to the combination of ASP and decoupled payments. The insignificant relationship may arise because policies intended to reduce farms' undesirable output production also reduce their desirable output production. By setting application standards for nutrients, ASP and decoupled payments reduced surpluses because farmers had an obligation to release fewer nutrients into the environment; by constraining farms' technology, their ability to produce desirable outputs (i.e., milk, meat) was also reduced. This result manifests the value of the employed model as opposed to models that consider a single efficiency measure. For instance, if one computed a single environmental efficiency measure (such as that of Reinhard, Lovell, and Thijssen, 1999, 2002), and given the decrease in nitrogen surplus, which is evident from Figure 1, a researcher would conclude that environmental efficiency increased after the introduction of ASP in combination with decoupled payments. Despite this result being true, standing on its own would hide important information concerning the simultaneous changes in the desirable outputs revealed by the current study.

We find that the agri-environmental and animal welfare payments had significant effects on hyperbolic efficiency. Farms receiving these payments are less hyperbolically efficient than those which do not, suggesting that the reduction in desirable output production is higher than the reduction in undesirable production. As mentioned in the introduction, farmers who receive these payments are required to adopt stricter environmentally friendly practices than the ones that ASP involves. However, such practices turn out to decrease farms' overall efficiency by imposing significant constraints on farms' technology. This result has useful policy implications. If reduction in undesirable outputs becomes more important, policies that aim to decrease it need to be designed such that the potential loss of desirable outputs is compensated. When a society has many policy measures, it is important to understand that different policies may offset each others' objectives. For future policy design, it is crucial to assess the overall effects of the different but related policies.

Intensification of feed per cow improves farms' joint performance. This result reveals that the increase in farms' desirable outputs as a result of employing intensive production techniques is greater than the increase in undesirable outputs attributed to the lower nutrient content of the purchased feed compared to on-farm roughage production. The finding of a positive effect of intensification of the use of feed per cow on the joint performance of dairy farms highlights that knowledge of the nutrient concentration of feedstuffs and nutrient requirements of the animals can provide the basis for more efficient feeding methods in order to prevent excretion of nutrients to manure. Thus, the development of programs focused on education of producers concerning dairy nutrition through farm visits, seminars, and newsletters can ensure that increased production can be achieved with minimal detrimental effects on the environment.

Finally, specialization in milk production increases farms' joint performance because specialized farmers not only produce higher levels of desirable outputs because they are more experienced in a single production activity but also produce fewer undesirable outputs because they use smaller amounts of inputs with high nutrient-leaching potential for crop cultivation purposes. Even though diversification of production is typically risk-reducing, this result suggests that any policy encouraging specialization in a single production activity should contribute to the sustainability of the production process.

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Appendix

Table A1. Estimates of the Model's Parameters

Variable	Coeff.	Std. Err.	*p*-Value
log_other	0.027	0.009	0.004
log_K	−0.023	0.008	0.002
log_L	−0.023	0.011	0.032
log_A	−0.078	0.013	0.000
log_I	−0.379	0.018	0.000
log_S	−0.385	0.021	0.000
log_N	−0.069	0.007	0.000
trend	−0.019	0.002	0.000
log_KK	−0.003	0.006	0.546
log_KL	0.028	0.019	0.140
log_KA	0.055	0.022	0.011
log_KI	−0.004	0.021	0.852
log_KS	−0.140	0.027	0.000
log_LL	0.079	0.022	0.000
log_LA	−0.086	0.044	0.047
log_LI	0.128	0.042	0.003
log_LS	−0.247	0.059	0.000
log_AA	0.084	0.027	0.002
log_AI	−0.004	0.049	0.940
log_AS	−0.035	0.069	0.610
log_II	−0.001	0.031	0.987
log_IS	−0.059	0.076	0.444
log_SS	0.196	0.065	0.002
log_NN	−0.008	0.001	0.000
log_other2	0.010	0.002	0.000
log_KN	0.015	0.006	0.008
log_LN	0.052	0.012	0.000
log_AN	−0.028	0.013	0.036
log_IN	−0.019	0.010	0.050
log_SN	0.031	0.019	0.102
log_K_other	−0.007	0.008	0.399
log_L_other	0.014	0.017	0.403
log_A_other	−0.011	0.017	0.545
log_I_other	0.132	0.018	0.000
log_S_other	−0.120	0.022	0.000
log_N_other	−0.011	0.005	0.024
trend2	0.002	0.000	0.000
trend_log_K	0.002	0.002	0.151
trend_log_L	−0.016	0.004	0.000
trend_log_A	0.002	0.004	0.591
trend_log_I	0.017	0.004	0.000
trend_log_S	−0.019	0.006	0.001
trend_log_N	0.001	0.001	0.410
trend_log_other	−0.001	0.002	0.727
Constant	−0.132	0.009	0.000

Continued on next page...

Table A1. – continued from previous page

mu	Coeff.	Std. Err.	p-Value
ASP-decoupled	−0.011	0.039	0.779
Payments	0.055	0.024	0.020
Intensity	−0.875	0.234	0.000
Milk share	−0.031	0.004	0.000
Trend	0.010	0.010	0.308
Constant	2.864	0.354	0.000
σ^2	0.035	0.006	
γ	0.733	0.054	
σ_u^2	0.026	0.006	
σ_v^2	0.009	0.001	

Notes: mu denotes the specification of the location parameter of the inefficiency term, u_{it}, σ^2 the variance of the composite error term, γ the ratio of the variance of the inefficiency component to the variance of the composite error term ($\frac{\sigma_u^2}{\sigma^2}$), σ_u^2 the variance of the inefficiency component, and σ_v^2 the variance of the error term that captures statistical noise.