Weather conditions and the impact of CAP subsidies on the technical efficiency of French dairy farms

Nabam Missamou [1] *, K Hervé Dakpo [1], Laure Latruffe [2]

[1] Paris-Saclay University, INRAE, AgroParisTech, PSAE, Palaiseau, France

[2] INRAE, Bordeaux School of Economics, University of Bordeaux, Pessac, France

* Author of correspondence: nabam.missamou@inrae.fr

Abstract

Several studies have concluded that CAP subsidies have a negative impact on the technical efficiency of farms. However, in the context of climate change, none of these studies took into account weather variations. The aim of our work is therefore to study the effect of these subsidies on French dairy farms' technical efficiency between 2002 and 2017, when weather conditions are taken into account. To do this, we used different models of stochastic frontier analysis in which the weather conditions are modelled differently. Our results show that, as in the literature, CAP subsidies have a negative impact on our sample farms, but that this effect is greatly reduced when weather conditions are taken into account.

Keywords: Dairy farms, technical efficiency, Common Agricultural Policy, Weather conditions, Subsidies, Stochastic frontier

JEL Codes: C46, D24, Q10

1. Introduction

The 2003 reform of the Common Agricultural Policy (CAP) marked a significant shift away from historically established coupled payments, as highlighted by Morhain (2015). This reform introduced decoupled payments based on the utilized agricultural area (UAA) rather than farmers' production levels. Decoupled subsidies are intended to divorce support from direct production incentives while bolstering farmers' incomes. Notably, the CAP constitutes a substantial portion of French farmers' income, averaging 84% (Kirsch et al., 2017), underscoring its vital role in the agricultural sector. However, debates persist regarding the efficacy and fairness of decoupled payments within this policy framework. Numerous studies have shown that decoupled payments impact production decisions (Bonfiglio et al., 2020; Katranidis & Kotakou, 2012; Martinez Cillero et al., 2021; Weber & Key, 2012). According to Hennessy (1998), decoupled payments can generate wealth and insurance effects[1], which in return will indirectly impact farmer's production decisions. Through these effects, decoupled payments can incentivize farmers to produce more (Hennessy, 1998). Even if decoupled subsidies' impacts are less important than coupled payments it doesn't solve the international concurrence problem (Swinbank & Tranter, 2005).

By affecting production decisions, decoupled payments have an impact on farm level technical efficiency[2]. In their meta-analysis, Minviel & Latruffe (2017) found that subsidies generally negatively affect farm's technical efficiency. However, in this meta-analysis a few studies found a positive impact of subsidies on technical efficiency. These opposite results can be explained by differences in how subsidies are integrated into the modeling of production, the specificities of the sample, and the sector studied (Li et al., 2022). Moreover, Serra et al. (2008), evaluating the effect of decoupled payment on technical efficiency, explain that the impact depends on the producer's risk aversion and input's effect on output variability. Lastly, the literature on the firm Martin & Page (1983) shows that management effort will lessen with a more sure revenue, growing inefficiencies simultaneously.

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[1] Respectively, higher and more stable revenue due to any subsidies will change production decisions even if these subsidies are not related to the level of production.

[2] Technical efficiency is the capacity of a producer to use the current technology in the best way possible. In other words, produce a maximum amount of output using a certain of inputs.

But in studies on technical efficiency, meteorological variation are taken into account. Indeed, the GIEC (2022) showed that there is currently a rise in average temperatures at the earth's surface and more frequent and more intense meteorological events. This Climate change is a very important topic in agriculture because it is the human activity the most dependent on climate (Oram, 1985). Among the numerous risks the agricultural sector faces, climate change is by far the most important (Nelson et al., 2014). Loss of yield will be more frequent, prices more fickle, and so there will be more food crises (D'Agostino & Schlenker, 2016). Even though most studies focus on crop production, breeding is also negatively impacted by meteorological change at least by forage production (Perez-Mendez et al., 2019). Direct and indirect effects of meteorological conditions on agricultural production are important in the estimation of technical efficiencies, because the capacity to produce under those conditions depends on management capacity of each farmer (Quiédeville et al., 2022).

Our objective in this paper is thus to re-assess the impact of decoupled payments when these meteorological considerations are taken into account in the model. We aim to answer whether the negative impact of agricultural subsidies on technical efficiency, widely revealed in the literature, is verified when weather variations are taken into account. We make the conceptual hypothesis that the guaranteed income provided by subsidies can have a consequence not only on farmers' efforts (Martin & Page, 1983) or their use of more or less risky production factors (Serra et al., 2008), but also on their use of production factors adapted to weather variations. In other words, agricultural subsidies would act as weather insurance. In this case, we expect an over estimation of technical efficiency when meteorological conditions are not taken into account in the analysis. This is done by incorporating information on weather conditions into the production function, under the assumption that weather conditions are variables that modify the shape of the production function (Perez-Mendez et al., 2019). The originality of our work also consists in estimating the effect of subsidies on technical efficiency with the SFA method. Our case study is dairy cattle farms in France and decoupled CAP subsidies over the period from 2002 to 2017. The choice of dairy production specialization is guided by the possibility of measuring the effects of climate on both animal and crop (forage) production. In addition, French dairy production represents a significant proportion of the national economy and is one of the largest in Europe (Sénat, 2023). We consider only decoupled subsidies because, from a conceptual point of view, these are subsidies that can be likened to a certain income with no direct effect on farmers' behavior (unlike coupled aid, which encourages farmers to produce certain crops).

The next section (second section) will be an overview of the literature on effect of meteorological conditions on agricultural production. The third section will describe the data used and the construction of the weather risk indicators that we integrate into the production technology modelling. In the third section we present the modelling of production frontiers using econometric methods of stochastic production frontier analysis (SFA). The fourth section presents the results and the sixth section concludes.

2. Literature review

There is a rich literature on the effect of meteorological condition on dairy farms. High temperatures and humidity have negative impact on dairy cow’s metabolism (Bohmanova et al., 2007; Kadzere et al., 2002; Pegorer et al., 2007; St-Pierre et al., 2003). When the outside temperature rises above a certain threshold, the cow tends to reduce her feed intake, which reduces its metabolic activity and therefore its internal heat, but also its dairy production. Relative humidity that is too high exacerbates the situation by reducing the effect of sweating, the cows' main means of thermoregulation. This problem could be all the more significant for France as dairy cows genetically selected for production often have a high feed intake index, which enables them to metabolize more milk but at the same time increases their heat production. These cows are therefore all the more sensitive to heat stress (West, 2003). Berman (2005) found that a temperature between -5°C and 24°C was optimal for milk production. The internal temperature of cows is therefore directly correlated with their milk production. Ingraham et al. (1976) have come up with an estimator that summarizes the effects of weather conditions on the internal temperature of cows. This is the Temperature Humidity Index (THI). This indicator predicts the cow's rectal temperature, with relative humidity and temperature as explanatory variables. The authors found a reduction of 0.32 liters of milk per unit of THI above the heat stress threshold of 70. Numerous studies found a negative effect of heat and water stress on milk production (Bucheli et al., 2022). This reduction in productivity translates into economic losses. For example, St-Pierre et al. (2003) proved that heat stress is responsible for an annual loss of between $897 Million and $1.5 Billion for the US dairy industry. Other studies, such as that by Bucheli et al. (2022) do not suggest that heat stress has any effect on milk income. In their study, Perez-Mendez et al. (2019) consider the indirect effects of the weather on milk production. They take into account the effects of THI on cows and the effects of temperature, humidity, sunshine, wind and rain on crops. The authors found no significant effect of THI on milk production, and concluded that weather variations have an indirect impact mainly on milk production by influencing forage production. In the case of mixed farming, temperature has a strong impact on the quality and quantity of fodder produced (Bloor et al., 2010; Gourdji et al., 2013). Schlenker et al. (2006) and Schlenker & Roberts (2009) explain that forage yields increase up to 29°C. Maximum and minimum daily temperatures can therefore be very good indicators of yields, particularly at different stages of plant development (Wilczek et al., 2010). Rainfall (Passioura, 1994), and sunshine (Crutzen & Ramanathan, 2004) are also determinants of yield in crop production. Moreover, plants are much more dependent on seasonal cycles than animals. At each stage of its development, the plant needs very specific weather conditions to maximize its yield components (Paulsen, 1994). This can be explained by the fact that heat increases the plants' demand for water to maintain photosynthesis, but reduces the availability of this water in the soil (Gourdji et al., 2013). Degree days (DD) are a very good synthetic climate yield indicator for crops (Snyder, 1985). This indicator, developed by Cross & Zuber (1972), report the exposure of plants to temperatures useful for their development, that is to say the sum of all degrees between vegetation zero and a maximal temperature.

3. Data

For this study we used the Farm Accountancy Data Network (FADN) which contain information about characteristics and accountancy of a representative panel of commercial exploitations[3] between 2002 and 2017. These accountancy data give farm level details of structuration, operation, communal location, and subsidies touched by farms. We focus on French dairy cattle and so we observe 3197 exploitations on this period. Give that the aim of this article is to integrated meteorological conditions, we also used daily data on rainfall, sunshine, temperature and relative humidity provided by *Météo France*. Data is given at the *Système d'Analyse fournissant des renseignements Atmosphériques à la Neige de Météo-France* (*SAFRAN*) grid level that is to say 8 km on 8 km grid.

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[3] Farms with a potential production by hectare (ha) above 25 000 €

We aggregated these meteorological data at the 96 Metropolitan France department level. In that respect all exploitations from a same department have the same meteorological conditions. To do this aggregation between SAFRAN and French administrative grid used the R package meteoRIT (Desjeux, 2021). This package allowed us to do this aggregation by a surface ponderation between the two grids and give to each department its mean climate conditions. We also divided the year in a hot period (spring and summer) and a cold period (autumn and winter).

From these two databases, we constructed variables necessary to our models. For outputs we have dairy (y_1) in thousands of liters, and other productions (y_2) in thousands of €. For inputs we have the Utilized Agricultural Area (UAA) (x_1) in ha, labor (x_2) in full-time equivalents (FTE), livestock (x_3) in livestock units (LU)[4], intermediate consumption (x_4) in thousands of 2015 deflated euros, and capital (fixed assets) (x_5) in thousands of 2015 deflated euros. For the meteorological data, we choose rainfall (z_1, z_2 depending on the cold or hot period) in mm and we use the average temperature in Celsius degrees (C°) and relative humidity in percentage to construct two new meteorologic indicators. To ensure that these indicators are as accurate as possible, we start by estimating hourly temperatures. Implementing data at the hourly level in the models increases the robustness and performance of the model (Tack et al., 2015). According to Snyder (1985), we can write :

$$\mathrm{T_h} = \frac{\mathrm{T_{max}} + \mathrm{T_{min}}}{2} + \frac{\mathrm{T_{max}} - \mathrm{T_{min}}}{2} \sin\left(\pi \frac{\mathrm{h} - 6}{12}\right) \tag{1}$$

with T the temperature, h time varying between 0 and 24 hours.

These new data can be used to construct degree days (DD) (z_3, z_4 depending on whether the period is cold or hot). In the case of permanent grassland, all temperatures between 0°C (vegetation zero) and 30°C are considered to be favorable to development (Monteiro et al., 2020; Moot et al., 2000). The second indicator we constructed is the THI (z5, z6 depending on whether the period is cold or hot). As presented previously, this is a good indicator of heat stress for cows (Dikmen & Hansen, 2009).

It is calculated using the following formula (NRC, 1971).

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[4] The Livestock Unit (LU) is used to estimate the size of a herd, using the feed of an adult cow as a reference. A 2-year-old heifer, for example, counts as 0.8 LU.

$$\mathrm{THI} = (1{,}8\mathrm{T} + 32) - [(0{,}55 - 0{,}0055\mathrm{RH}) * (1{,}8\mathrm{T} - 26.8)] \qquad (2)$$

with T the average temperature and RH the average relative humidity.

Finally, we selected a set of variables that are potential determinants of technical inefficiency. These are operating subsidies received (mainly decoupled subsidies) (s_1) in € (2015) per ha of UAA, the share of salaried labor in total labor (s_2), the proportion of rented UAA (s_3) and a dummy variable characterizing the level of education (or rather the low level of education) which is worth 1 if the farm manager has not completed secondary education (s4) and 0 if he has.

Table 1: Descriptives statistics of dairy farms between 2002 and 2017

	1st Quartile	**3th Quartile**	**Median**	**Moyenne**	**Standard-error**
Inputs/Outputs					
UAA (hectares) x_1	55,2	114,8	78,2	91,7	53,0
Labor (FTE) x_2	1,0	2,2	2,0	1,9	1,0
LU	60,1	127,9	88,4	101,9	58,8
Intermediate consumptions (thousands € 2015) x_4	53,9	127,9	83,9	100,5	67,8
Capital (thousands € 2015) x_5	76,6	262,2	150,2	193,5	170,6
Milk (thousands de liters) y_1	196,7	445,7	298,8	351,5	220,6
Other products (thousands € 2015) y_2	28,0	88,0	50,3	66,8	57,7
Inefficacy determinants					
decoupled subsidies /ha (€ 2015) s_1	301,2	442,3	366,1	381,1	136,9
% of salaried s_2	0,0	0,0	0,0	0,1	0,1
% de of rented UAA s_3	0,7	1,0	1,0	0,8	0,3
low level of education s_4	0,0	0,0	0,0	0,2	0,4
Meteorological variables					
Rainfall in cold period (mm) z_1	386,6	544,4	459,2	477,0	127,1
Rainfall in hot period (mm) z_2	331,1	510,4	410,4	430,7	131,2
DD in cold period z_3	1232,3	1691,9	1463,3	1455,4	291,6
DD in hot period z_4	2443,7	2731,6	2562,2	2579,9	257,3
THI in cold period z_5	44,0	49,0	46,6	46,4	3,1
THI in hot period z_6	55,7	58,0	56,7	56,7	2,1

Table 1 shows the descriptive statistics for our sample. The average UAA of our sample is comparable to the average UAA of French dairy farms (105 ha in 2020) (Agreste, 2020). In addition, the coefficient of variation for this variable is high (57%), reflecting considerable heterogeneity in farm size. As the interquartile coefficient is also high (76%), we can deduce that this dispersion is not due to isolated extreme values. In terms of livestock size, the average was 101.9 LU, which in relation to UAA equates to a stocking rate of around 1.11 LU/hectare. Regarding the labor, there were on average two full-time workers per farm. Generally speaking, the farms studied seem to make little use of salaried labor. In fact, salaried labor accounts for around 10% of total labor. Intermediate consumption includes expenditure on fertilizers, pesticides, seeds, concentrates, veterinary products and services. Capital is measured by the value of equipment, buildings and land improvements. It should be noted that a significant proportion (20%) of farm managers have no secondary education qualifications. Levels of decoupled farm subsidies per hectare amount to around €381 per hectare. As might be expected, the warm period shows much higher DDs on average than the cold period. However, if we compare the coefficients of variation, we can see that the cold period shows more variability in DD and THI (20% and 9% respectively) than the warm period (9% and 3% respectively).

4. Method

We use the SFA[5] method developed simultaneously by Aigner et al. (1977) and Meeusen & van Den Broeck (1977), which estimates technical efficiency using a two-term error function:

$$\mathrm{y} = \mathrm{f}(\mathbf{x}; \boldsymbol{\beta}) + \mathrm{v} - \mathrm{u} \tag{3}$$

where y is the observed output; $f\ (\cdot)$ is the function that represents the farm's production frontier; $\mathbf{x} \in \mathbb{R}^K$ is the vector of production factors; the $\boldsymbol{\beta}$ represent the set of parameters to be estimated from the production function; ν is an error term that represents the set of stochastic shocks not controlled by the producer (ex. environmental shocks, market shocks, political shocks, etc.), which is independent for each firm and follows a normal distribution $N(0, {\sigma_v}^2)$; u is a random term representing technical inefficiency, which is always positive or null, independent from ν and follows a semi-normal distribution $N^+(0, {\sigma_u}^2)$.

The SFA method, unlike non-parametric methods, separates production hazards and measurement errors from technical inefficiency (Zhu & Oude Lansink, 2010). The production function in equation (3) represents all the physical, chemical, biological and technical processes that enable production. It is therefore the theoretical maximum that a farm can produce with production factors $\boldsymbol{x}$. The SFA method makes it possible to evaluate and explain the gap between

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[5] Most of the estimates were made using the R package 'sfaR' (Dakpo et al., 2023).

this frontier and observed production y. This gap is represented by the two error terms v and u. In a perfect model, the u term reflects the management errors committed by the producer and thus his inefficiency. The SFA approach allows this technical inefficiency to be explained by exogenous factors, such as subsidies. To avoid the biases induced by a two-stage regression, the determinants of inefficiency are estimated simultaneously with the production frontier (Battese & Coelli, 1995). We then have:

$$\sigma^2_{\mathrm{u,i}} = \exp\left(\theta_0 + \sum_{m}^{M} \theta_{\mathrm{m}} s_{\mathrm{m}}\right) \tag{4}$$

where $\sigma^2_{\mathrm{u,i}}$ represents the variance of u; the θ are the parameters to be estimated; and the s variables are the determinants.

As explained above, our modelling takes weather conditions into account, and the production technology is thus defined as follows:

$$\Psi = \{(\mathbf{x}, \mathbf{y}, \mathbf{z}) \in \mathbb{R}^{\mathrm{K+Q+P}} \mid \mathbf{x} \text{ peut produire } \mathbf{y} \text{ sachant la météo } \mathbf{z}\} \tag{5}$$

To describe this production technology, we have chosen an output distance function $D_O(\mathbf{x}, \mathbf{y}, \mathbf{z})$, as it allows several outputs to be taken into account simultaneously. The output distance function provides a measure of the radial technical efficiency associated with the outputs. In other words, the output distance function determines the minimum value by which all outputs should be divided to arrive at the production frontier. It is therefore a value between 0 and 1. In the data we are using, the inputs (factors of production) available to us are not specific to milk production, but correspond to the farm's total agricultural activity. Thus, if we do not include all the outputs, we could wrongly consider a farm as inefficient if part of its inputs is not dedicated to milk production. If, for example, we consider two farms of the same size and one of them uses more fertilizer and buys more concentrates than the other without producing more milk, we would conclude that it is less efficient, even though it may have a cereal production activity. We cannot then compare the inefficiency of these two farms without taking into account production other than milk, which we call y_2. Given that the farms have inefficiency in the production of y_2 and that we also want to measure this inefficiency, we therefore include y_2 in the production technology.

For the output distance function, we assume a Translog-type functional form, which is more flexible than the Cobb Douglas form. In the absence of weather variables, the distance output function can be represented by :

$$\ln D_O(\mathbf{x},\mathbf{y}) = a_0 + \sum_{q=1}^{Q} \alpha_q \ln y_q + \sum_{k=1}^{K} \beta_k \ln x_k + \frac{1}{2}\sum_{q=1}^{Q}\sum_{r=1}^{Q} \alpha_{qr} \ln y_q \ln y_r + \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K} \beta_{kl} \ln x_k \ln x_l + \sum_{q=1}^{Q}\sum_{k=1}^{K} \delta_{qk} \ln y_q \ln x_k \tag{6}$$

A fundamental property of output distance functions is their homogeneity of degree 1 in the outputs. This property implies that for a positive real number κ we have :

$$D_O(\mathbf{x}, \kappa\, \mathbf{y}) = \kappa D_O(\mathbf{x},\mathbf{y}) \tag{7}$$

If $\kappa = \frac{1}{y_1}$, we have

$$\ln y_1 = -D_O\left(\mathbf{x}, \frac{\mathbf{y}}{\mathbf{y_1}}\right) + \ln D_O(\mathbf{x},\mathbf{y}) \tag{8}$$

Without loss of generality, $\ln D_O(\mathbf{x},\mathbf{y})$ represents the technical inefficiency $-u$ as in equation (3). Equation (8) becomes stochastic when the random term v is added:

$$\ln y_1 = -D_O\left(\mathbf{x}, \frac{\mathbf{y}}{\mathbf{y_1}}\right) + v - u \tag{9}$$

In our empirical application to the data described above, we estimate five models. In the first model (Model 1) we estimate the classical stochastic production frontier, i.e. without taking into account weather data or the determinants of technical inefficiency :

$$\ln y_1 = a_0 + \sum_{q=2}^{Q} \alpha_q \ln \frac{y_q}{y_1} + \sum_{k=1}^{K} \beta_k \ln x_k + \frac{1}{2}\sum_{q=2}^{Q}\sum_{r=2}^{Q} \alpha_{qr} \ln \frac{y_q}{y_1} \ln \frac{y_r}{y_1} + \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K} \beta_{kl} \ln x_k \ln x_l + \sum_{q=2}^{Q}\sum_{k=1}^{K} \delta_{qk} \ln \frac{y_q}{y_1} \ln x_k + v - u \tag{10}$$

In the second model (Model 2), we add the estimation of the determinants of inefficiency. Note that the econometric estimation will therefore make it possible to obtain the parameters of the effect of the determinants on technical inefficiency (and thus an inverse effect on technical efficiency).

$$\ln y_1 = a_0 + \sum_{q=2}^{Q} \alpha_q \ln \frac{y_q}{y_1} + \sum_{k=1}^{K} \beta_k \ln x_k + \frac{1}{2}\sum_{q=2}^{Q}\sum_{r=2}^{Q} \alpha_{qr} \ln \frac{y_q}{y_1} \ln \frac{y_r}{y_1} + \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K} \beta_{kl} \ln x_k \ln x_l + \sum_{q=2}^{Q}\sum_{k=1}^{K} \delta_{qk} \ln \frac{y_q}{y_1} \ln x_k + v - u(\mathbf{s}) \tag{11}$$

The following models take into account both the weather data and the determinants of inefficiency. Because of the presence of weather variables, we make several assumptions about the specification of these variables. In the third model (Model 3), weather variables z affect potential output by modifying the intercept a_0.

$$\ln y_1 = a_0 + \sum_{q=2}^{Q} \alpha_q \ln \frac{y_q}{y_1} + \sum_{k=1}^{K} \beta_k \ln x_k + \frac{1}{2}\sum_{q=2}^{Q}\sum_{r=2}^{Q} \alpha_{qr} \ln \frac{y_q}{y_1} \ln \frac{y_r}{y_1} + \frac{1}{2}\sum_{k=1}^{K}\sum_{l=1}^{K} \beta_{kl} \ln x_k \ln x_l + \sum_{q=2}^{Q}\sum_{k=1}^{K} \delta_{qk} \ln \frac{y_q}{y_1} \ln x_k + \sum_{p=1}^{P} \delta_p z_p + v - u(\mathbf{s}) \tag{12}$$

The fourth model (Model 4) considers the specific interactions between meteorological variables and inputs. For example, the variable THI modifies cow productivity, and in our model it therefore modifies the marginal productivity of the herd; the variables DD and rainfall affect the marginal productivity of the UAA. We therefore have :

$$\ln y_1 = a_0 + \sum_{q=2}^{Q} \alpha_q \ln \frac{y_q}{y_1} + \sum_{k=1}^{K} \beta_k \ln x_k + \frac{1}{2} \sum_{q=2}^{Q} \sum_{r=2}^{Q} \alpha_{qr} \ln \frac{y_q}{y_1} \ln \frac{y_r}{y_1}$$

$$+ \frac{1}{2} \sum_{k=1}^{K} \sum_{l=1}^{K} \beta_{kl} \ln x_k \ln x_l + \sum_{q=2}^{Q} \sum_{k=1}^{K} \delta_{qk} \ln \frac{y_q}{y_1} \ln x_k + \sum_{p=1}^{P} \delta_p z_p \tag{13}$$

$$+ \sum_{p=1}^{4} \varphi_{1p} z_p \ln x_1 + \sum_{p=5}^{P} \varphi_{3p} z_p \ \ln x_3 + v - u(\mathbf{s})$$

Finally, our fifth and last model (Model 5) is an adaptation of the one suggested by Perez-Mendez et al., (2019). In this model, the "effective" level of certain inputs is a function of their absolute levels and the meteorological variables. Livestock and UAA are the two inputs concerned here. These two factors are not affected in the same way by weather conditions, and we therefore have specific indicators for each. THI is used for livestock production, while DD and rainfall are used for crop production. This modelling also reflects the fact that the weather only has an indirect impact on milk production via the animals and the production of fodder or cereals.

Based on the first exploration of the data, we take into account two periods for the climatic indicators, the cold period (winter, autumn) and the hot period (spring, summer). A new function is then estimated, similar to equation (11) with the difference that the variables x_1 and x_3 are replaced respectively by x_1^* and x_3^* defined as follows :

$$\begin{aligned} \ln x_1^* &= \ln x_1 + \sum_{p}^{P} \gamma_p z_p \\ \ln x_3^* &= \ln x_3 + \sum_{p=5}^{P} \gamma_p z_p \end{aligned} \tag{14}$$

5. Results

Before estimation, the input and output variables are normalized by their geometric mean, which allows the first-order coefficients to be interpreted as mean-point elasticities.

Table 2 presents part of the results, they are the first-order coefficients for the input/output elasticities of the estimated parameters of the five models discussed in the previous section. In Model 1, the first observation is that the signs of the coefficients for the second output and the factors of production are consistent. The level of milk production increases with all the production factors at the average point, except for UAA, whose coefficient is not significant in Models 1 and 2. Increasing other production on the farm reduces milk production.

Tableau 2: Estimation results of the five SFA models

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Inputs/Outputs					
Other productions/Lait : $\ln\frac{y_2}{y_1}$	-0,23***	-0,23***	-0,235***	-0,24***	-0,196***
UAA $\ln x_1$ [$\ln x_1^*$]	0,01	0,004	0,064***	0,1*	[0,022***]
Labor $\ln x_2$	0,17***	0,17***	0,164***	0,17***	0,132***
Livestock $\ln x_3$ [$\ln x_3^*$]	0,21***	0,22***	0,191***	-0,77***	[0,326***]
Intermediate consumptions $\ln x_4$	0,55***	0,56***	0,511***	0,51***	0,469***
Capital $\ln x_5$	0,04***	0,04***	0,054***	0,05***	0,029**
Inefficiency determinants					
Subsidies/ha s_1		0,0012***	0,0004***	0,0004***	0,0005***
% of salaried s_2		0,07	-0,055	-0,05	0,018
% of rented UAA s_3		-0,14*	-0,119*	-0,11*	-0,164**
low level of education s_4		0,38***	0,319***	0,33***	0,294***
Meteorological variables					
Rainfall in cold period (mm) z_1			0,00002	0,00003**	0.001*
Rainfall in hot period (mm) z_2			-0,00008***	-0,0001***	0.003***
DD in cold period z_3			0,00005	0,00002	-0.006***
DD in hot period z_4			-0,0005***	-0,0005***	0.001*
THI in cold period z_5			0,004*	0,01**	-0.034***
THI in hot period z_6			0,028***	0,03***	0.025***
Interactions					
UAA / Rainfall in cold period $\ln x_1 \times z_1$				0,00003	
UAA / Rainfall in hot period $\ln x_1 \times z_2$				0,00009***	
UAA / DD in cold period $\ln x_1 \times z_3$				-0,00004*	
UAA / DD in hot period $\ln x_1 \times z_4$				-0,00002	
Livestock / THI in cold period $\ln x_3 \times z_5$				0,001	
Livestock / THI in hot period $\ln x_3 \times z_6$				0,01***	
Comparisons					
Mean efficacies	0,852	0,854	0,855	0,855	0,856
AIC	-9803	-9996	-11099	-11216	-11068

Note : *** = p-Value <0.001 ; ** = p-Value <0.01 ; * = p-Value <0.05

Model 2 provides a first confirmation of the results previously stated for Model 1 regarding input coefficients. As for the determinants of inefficiency, there is a significantly negative (positive) effect of subsidies on technical efficiency (inefficiency), as in most of the literature. The proportion of land rented has a positive impact on the technical efficiency of the farm. This could be explained by the fact that, if a farmer decides to rent land, it is because he knows that the latter will make him more efficient by his location or by the quality of his soil. In addition, it is possible that the fact that the farmer pays rent for some land encourages him to seek efficiency to maximize his profit and make this situation profitable. On the other hand, there is no significant effect of the proportion of employees in the holding on technical efficiency. Finally, as expected, the low level of education (i.e. lack of secondary education) has a negative effect on technical effectiveness.

Model 3 also confirms the previous results concerning input coefficients except that the UAA has a significantly positive impact on milk production in Model 3 while it has no significant impact in Models 1 and 2. The effects of the low level of education, the rent share and the wage share remain unchanged compared to Model 2. The negative effect of subsidies per hectare also remains significant but the level is reduced in this model which takes into account the weather data compared to Model 2. As for weather conditions themselves, they have a significant impact on production mainly in hot periods. At this time, DD and rainfall have a slightly negative effect on production, unlike THI which has a positive effect. It is understandable that in hot periods high DD can be synonymous with heat stress or even drought for plants. THI, on the other hand, captures both temperature and relative humidity, which could explain this positive effect. Moreover, it is the surplus in THI that causes a drop in production, yet we do not measure the effect of a surplus here. On the other hand, the negative sign of the rain coefficient is counter-intuitive, even if its value is extremely low.

In Model 4, we obtain an aberrant result according to which the size of the herd significantly decreases milk production when the climate variables (THI hot and cold periods) are zero, with an elasticity of -0.77. The elasticity of the livestock variable goes back to -0.16 at the average THI but remains negative. We hypothesize that this observed effect may be due to a poor specification of this model. As for the determinants of technical inefficiency, we find the same results as in the other models. Regarding climate data, there is an overall positive effect of THI on milk production and a positive effect of rain during cold periods. The interaction effects between meteorological variables and livestock or UAA, proposed by this model, are significant only in warm periods. In interaction with UAA, rainfall has a small but positive effect on production. Similarly, in interaction with livestock, THI has a positive effect on production in hot periods. However, since THI is an indicator of heat stress in cows, a negative effect could be expected in hot weather.

Finally, for Model 5, which is an adaptation of the model developed by (Perez-Mendez et al., 2019) by adding the determinants of inefficiency, we find as in the classic model of (Perez-Mendez et al., 2019) a predominant effect of livestock size combined with THI (x_1^*) and intermediate consumption on milk production. As regards meteorological variables, rainfall generally has a positive effect on the UAA input. As for the variables DD and THI, we observe rather counter-intuitive effects. For these two variables, there is a negative effect in cold periods and a positive effect in warm periods. It should be noted, however, that the weather variables used in this work measure the weather conditions of the year, not the weather shocks. As regards the determinants of inefficiency, this model still confirms the negative effect of subsidies per hectare and the low level of studies on technical efficiency, as well as the positive effect of the proportion of rent on this efficiency.

As shown in Table 2, the average inefficiency scores obtained in each model are similar, about 86%. This figure means that on average, producers can increase their total output by about 16% (1/0.86) while maintaining the same level of inputs. Model 4 has the lowest Akaike Information Criterion (AIC), which should make it the most relevant model, yet it has inconsistent results. Models 3 and 5 that have similar AIC seem more relevant.

6. Conclusion

The aim of this work was to analyze the effects of decoupled subsidies from the CAP on the technical performance of French dairy farms. The literature on the subject generally finds a negative effect of subsidies on the technical efficiency of farms. But at a time when the climate issue is becoming increasingly important in research, to our best knowledge, none of these studies take into account meteorological variables in their modelling. However the literature that studies the effects of weather on dairy production is rich. So we tried to make the link between these two literatures. The results of our estimates confirm with consistency the negative effects of the subsidies decoupled from the CAP received per hectare of UAA, on the technical efficiency of French dairy farms between 2002 and 2017.

This work represents a first step in understanding the role played by climate in the link between subsidies and technical efficiency. We propose here future avenues of research to improve the methodology we used. First, some limitations regarding weather data could be lifted. For example, another THI construct could be used to model thermal risk to cows. Indeed, we used its gross value in our estimates and we did not make a comparison with a situation where the temperature would be separated from the relative humidity, while these two parameters can have a significant effect on forage production (Perez-Mendez et al., 2019). In a future research, we could try to construct it in the same way as DD by taking into account only the values above the heat stress threshold for the cow. From the previously calculated hourly temperatures, the time spent by cows above the stress threshold could be determined, which would better reflect the severity of this stress (St-Pierre et al., 2003). In addition, due to limited computing capabilities, we were forced to aggregate all our weather data at the departmental level while they were available at the municipal level. Then, we built very synthetic economic indicators which allowed us to make quick estimates. Avoiding zero values while allowing a better understanding of the major trends in production mechanisms, but losing precision. In concrete terms, all our estimates confirm the strong impact of intermediate consumption on milk production, but it is impossible to know to what extent this impact is related to the use of concentrates, fertilizers, pesticides or antibiotics. However, these inputs are important adjustment variables in the face of weather variations for farmers (Bareille & Chakir, 2023). In addition, the reallocation of inputs in response to a subsidy is different depending on whether the input increases the risk of production (such as fertilizers) or decreases it (such as phytosanitary products) (Serra, 2006).

Another limitation is that the SFA model we use has been criticized by Battese et al. (1997). According to these authors, conventional production boundary models do not allow for precise consideration of production risk. Indeed, the assumptions of the classic SFA falsely impose a positive marginal risk for inputs. As a result, the risk effects of producing inputs such as antifreeze and phytosanitary products are poorly captured by the model. This classical SFA model could therefore be refined to evaluate public policies that affect production risk by modifying input allocations using more flexible models on the consideration of production risk, like Battese et al. (1997). Regarding the preference for risk, Kumbhakar (2002) develops a model to take it into account. Indeed, according to the literature, the negative effects of subsidies on technical efficiency could be explained by the change in the producer's attitude to risk.

In addition, it may be interesting to consider soil quality variables to obtain a more accurate estimate of the production boundary. With FADN data, it would also be possible to better break down intermediate consumption. Models could also be developed to estimate the effect of CAP subsidies and the role of weather on technical and environmental efficiency.

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