

How does eliminating the use of pesticides affect technical efficiency in Italian farms?

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Abstract

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Through specific legislation such as Regulation no. 2078/92 and policies like Agenda 2000, the European Union has directed financial support towards farms that are adapting their production processes to use less fertilisers and pesticides and which, consequently, have a lower impact on the environment. In this vein, European farmers are being incentivised to follow organic farming methods and participate in other agri-environmental policies aimed at reducing the use of chemicals in agriculture. In the literature, this concern with the use of pesticides is reflected by several studies that have used a quantitative approach to investigate the environmental effects of chemical inputs and the impact of agri-environmental subsidies on technical efficiency in farms. Nevertheless, there is a gap in knowledge in assessing the effect on technical efficiency in farms of completely eliminating the use of chemical products. The purpose of this research, then, was to analyse the effect on technical efficiency of a radical reduction in the use of pesticides in Italian farms, using sample data from the Farm Accountancy Data Network (FADN) for the period 2004 to 2019, investigated in function of the different specialisation and economic size of the farms included in the data set. The level of technical efficiency in the farms included in the sample has been assessed through a non-parametric approach, using Data Envelopment Analysis in two stages, both with and then without the use of pesticides. The research findings have shown that a radical reduction in pesticides in Italian farms has had a direct impact on farms, reducing their level of technical efficiency. In particular, the results show that farms of a small economic size have suffered the greatest drop in technical efficiency. Meanwhile, the specialisation of the farm production has differently influenced the effect of a reduction in the use of chemical pesticides and fertilisers.

Keywords: DEA; two-stage DEA; type of farming; separability; agri-environmental policy

Introduction

Since the early 1990s, the Common Agricultural Policy (CAP) has undergone some radical changes following the reforms instituted by Ray MacSharry in his time as European Union Commissioner, the focus on rural development that emerged from the Cork Conference in 1996, and the measures of renovation and innovation of the European countryside introduced through Agenda 2000. In this framework, a primary focus of the European Union in recent years has been to engineer a significant reduction in the use of chemi-

cals and pesticides in agriculture. Through specific legislation like Regulations 2078/1992, the European Union has targeted financial support at new typologies of agriculture that have a lower environmental impact such as organic farming and farms that adhere to the new agri-environmental policies by using low levels of pesticides and fertilisers in their productions.

The process by which the use of pesticides and fertilisers in farming has been reduced has been investigated in different countries of the European Union, and the findings have endorsed and given effectiveness to many measures

of the CAP implemented through the Rural Development Programme (Zimmermann & Britz, 2016; Mennig & Sauer, 2020; Mikus et al., 2021; Onâte et al., 2000; Bertoni & Olper, 2012). In the Italian literature, an incomplete diffusion of studies emerges aimed at estimating the effects of pesticide use in farming that has been able to influence both the chemical industry as well as agriculture policy (Donati et al., 1993).

In order to both reduce the use of chemical products such as fertilisers and pesticides in farming and to address the issue of pollution during the next seven-year period of the CAP for 2021-2027, the European Union has introduced a number of different measures and strategies through the New Green Deal, such as the Biodiversity Strategy 2030, the 'Farm to Fork' strategy, and the European Climate Law, all of which are aimed at protecting the soil and the environment (Montanarella & Panagos, 2021). The main consequence of these new strategies and policies has been the implementation of a radical change in the direction of agricultural techniques, which are now no longer addressed to a rise in yields through the indiscriminate use of chemical inputs but are, instead, focused on drastically reducing the environmental footprint of the primary sector and the emission of greenhouses gases in an effort to mitigate the effects of climate change (Vanloqueren & Baret, 2009).

The impact of the principles of the Green Deal strategy in the CAP is, however, economically and ecological demanding for farmers. As such, an integrated approach is necessary in the planning of EU agricultural policy that considers aspects of farm management alongside adequate environmental protection in order to guarantee acceptable socio-economic effects for farmers (Wrzaszcz & Prandecki, 2020).

Literature Review

Some agronomic actions included within the new agri-environmental policies intended to encourage the adoption of less intensive practices such as crop rotation and natural pest management techniques have implied significant increases in costs for farmers as well as reductions in production yield (Gren, 1994). In contrast, the indiscriminate use of pesticides in farming over many years has proved to be extremely damaging, both to the environment and to farms themselves. In fact, through a non-parametric quantitative approach using Data Envelopment Analysis (DEA), Skevas et al. (2014) assessed the role of undesirable inputs such as pesticides as environmental spill over that is able to reduce both the technical efficiency of land capital and also farming output (Skevas & Lansink, 2014; Skevas et al., 2012).

Some studies recently carried out in China have argued

that the driver for farmers to use fertilisers and pesticides is a cognitive perception of farmland cleanliness hence, if the farmland is considered clean, farmers use a lower quantity of chemical inputs (Zheng et al., 2020). Other recent research conducted in Romania has highlighted that the two main variables influencing the choice of farmers there to use pesticides are the individual farmer's skill and knowledge set and their perception of the risks of pesticide use (Petrescu-Mag et al., 2019). From their investigations, these authors have found that the decision process is driven by a greater-or-less awareness that the use of chemical pesticides can be replaced with agri-environmental measures such as bio inputs.

In all European countries, the main goal of policy makers and farmers is to improve productivity through reducing the level of technical inefficiency and obtaining better environmental performances (Lankoski & Thiem, 2020). These authors have investigated the role that support made available by agricultural policies can have on sustainable productivity hence, increasing the level of sustainability and environmental protection through a reduction of inputs. In this framework of environmental protection, the role of financial support disbursed to farmers is fundamental. From a literature review, it emerges that the objective of reducing the use of pesticides in agriculture has been emphasised over the next seven-year period of the CAP for 2021-2027 through the European Green Deal's two main strategies of "farm to fork" and Biodiversity. According to these strategies, it is essential to stimulate a transition to a greener production with a neutral or positive environmental impact, reducing the use of chemical inputs in agriculture, both to protect the landscape and to increase the biodiversity in the environmental as well.

The effectiveness of public and private policy in achieving a reduction in pesticide use in Europe reveals a multidisciplinary approach involving many different socio-economic and environmental aspects (Lee et al., 2019). In fact, these authors have argued the need for an integrated collaboration between farmers and public authorities that takes due consideration of various intrinsic features of the farm such as its economic size, geographical location, and productive specialisation, which are all important variables able to influence the decision to reduce pesticide use.

In the literature, several studies have addressed the significant concerns regarding the use of pesticides, investigating their environmental effects using a quantitative approach (Bakker et al., 2021). These authors have identified various social-psychological aspects driving the choice of farmers to reduce pesticide use in farms, underlining that the choice is influenced both by the decision of other farmers (sociological variables) and by the availability of alternative techniques of pest control (agronomic variable). Because a reduction in

the use of pesticides implies a perception of the risk of a loss in production by farmers, agri-environmental policy must be addressed to helping farmers develop a more complete knowledge of alternative crop protection techniques from the perspective of an integrated pest management (Damalas, 2021). A direct link exists between the productive specialisation of farms and the use of pesticides, since an intense use of these chemical inputs can represent the farmer's aversion to the risk of reducing their yield, even if an overuse of pesticides represents an economic loss for the farmer and is therefore actually technically inefficient (Singbo et al., 2015). Moreover, not all the measures of agri-environmental policy financed by the CAP seem to have an adequate appeal in significantly reducing the overuse of pesticides in the primary sector (Chèze & Martinet, 2020). These two authors studied the willingness of farmers to reduce pesticide use through a discrete choice experiment approach, finding that the farmer's perception of the risk of lower yields is the variable representing the main constraint in their choice to reduce the use of chemicals, while the input of financial support from outside the farm provides a good incentive to reduce pesticide use.

The reduction in the use of pesticides has the result of reducing the produced output, and thus generally leads to an increase in the use of other inputs such as machinery and labour in order to compensate the loss and obtain an adequate level of production (Manevska-Tasevska et al., 2021; Hansson et al., 2019). In many cases, however, the choice to reduce the use of a specific input is correlated to a clear decision by the farmer that is not focused on increasing productivity, but is instead aimed at pursuing other aims that may even be inefficient, such as supporting environmental protection. This latter aspect can be defined as a rational inefficiency, which explains that some choices can be technically inefficient but are able to satisfy other specific targets pursued by the farmer (Asmild et al., 2003; Bogetoft & Hougaard, 2003).

A quantitative approach to assess the impact of pesticides on farm management has been carried out by the analysis of technical efficiency estimated using a non-parametric approach such as the Data Envelopment Analysis or DEA (De Koeijer et al., 2002; Skevas et al., 2012, 2014; Skevas & Lansink, 2014). According to these authors, through DEA it is possible to assess by how much it is possible to reduce pesticide use without generating any loss in output. Indeed, using this approach, Singbo et al. in 2015 have argued that vegetable farmers have been less efficient in their use of pesticides than other farmers due to an overuse of these chemical products. A previous study using a dynamic DEA approach carried out in Dutch farms by Skevas and Lansing

in 2014 found that intrinsic features of the farm and other environmental aspects represented the main influence on the use of pesticides in farms and the choice of farmers to reduce or completely eliminate pesticides from their production process.

Barzman and Dachbrodt-Saaydeh argued in 2011 that a sharing and diffusion of knowledge and experience is an important starting point for reducing the use of pesticides in the primary sector hence, the introduction of new environmentally-friendly technologies has some impact on other farms in generating competition in their management choices (Cowan & Gunby, 1996). Möhring et al. (2020) identified that implementing pest management is crucially reliant on the farmers' need for information for their evaluation of costs and profit maximisation. As such, the policy decisions for a correct use of pesticides should give appropriate attention to the heterogeneous behaviour and rational decision making of farmers in order to shed light on the role that the financial support allocated through agri-ecological strategies implemented by the Common Agricultural Policy has on technical efficiency.

The main purpose of this research was to analyse the effect of a radical reduction in the use of pesticides in Italian farms in terms of technical efficiency in function of the farm's specific attributes, expressed both in terms of the type of farming specialisation and also its economic size. The research question was: are Italian farms more technically efficient when they completely eliminate the use of pesticides in farms? Furthermore, is there a difference in removing pesticides between type of farming and economic size? Consequently, it has been possible to assess whether pesticides represent a significant input in terms of costs in farming. In the current literature, there are no existing studies regarding the impact that pesticides have on technical efficiency, or on the effect that reducing or completely eliminating their use has on Italian farms. This research, therefore, has filled the gap in understanding the effect of a radical drop in the use of pesticides on the technical efficiency in farms, assessing which types of farming are more or less sensitive to changes in the farm management. The policy implications are twofold. It is possible both to investigate the impact that pesticides have on the management of farms, and also to evaluate if there is a need to implement new strategies of agri-environmental policy within the scope of the Common Agricultural Policy in order to compensate farmers for a reduction in technical efficiency.

Methodology

In literature, the assessment of technical efficiency has been investigated using two main different approaches: a parametric approach, namely Stochastic Frontier Analysis

(SFA) as proposed by Farrell (1957), and a non-parametric approach, namely Data Envelopment Analysis (DEA), as proposed by Charnes et al. (1978), Banker et al. (1984), Coelli et al. (2005), Battese & Coelli (1992), Kumbhakar et al. (2015), Charnes et al. (1978), Banker et al. (1984), Bravo-Ureta & Pinheiro (1993), Battese (1992) and Coelli (1996), Aigner et al. (1977). If the SFA is aimed at estimating a specific function of production such as Cobb-Douglas, a logarithmic function, or the translog function, the DEA, as a non-parametric approach, does not need *a priori* assumptions in the model nor a well-defined function of production (Coelli et al., 2005; Battese & Coelli, 1995; Aigner et al., 1977).

The estimation of the production function in the DEA is made using a linear programming approach that is, however, not able to assess some random noise in the estimation of the function of production. The technical efficiency score of each farm unit is then simply the distance from the estimated function of production of the combination of different inputs and the output (Aigner et al., 1977; Coelli et al., 2005; Battese & Coelli, 1992; Kumbhakar et al., 2015; Charnes et al., 1978; Banker et al., 1984).

In order to assess the function of production in the sample of Italian farms and the impact that the use of pesticides has on the productive process, the study has used a non-parametric approach, namely Data Envelopment Analysis. This is because in this field of study there is not a well-defined function of production that has been previously proposed in the literature aimed at estimating the impact of the environmental variable, in this case the reduction of pesticides in the productive process, on the function of production and on the technical efficiency of the farms included in the sample of study. Furthermore, a literature review has revealed a wide diffusion of studies and research of technical efficiency assessed through a parametric approach conducted in various European countries (Minviel & Latruffe, 2016; Galluzzo, 2020; Latruffe & Desjeux, 2016; Nowak et al., 2015; Nowak & Kubik, 2019; Balezentis, 2014).

The analysis has used firstly the DEA input oriented model in order to estimate the technical efficiency in all Italian farms included in the Farm Accountancy Data Network (FADN) dataset from 2004 to 2019 without considering the use of pesticides. The following phase of investigation has used a two-stage DEA input-oriented model with the purpose of estimating the impact of pesticides as an environmental variable in the sample of Italian farms. The study made use of R software, specifically the Benchmarking, rDEA and deaR packages, following Seifert and Otto's proposal (Bogetoft & Otto, 2010). The two-stage DEA is fundamental to estimate the impact of the use of pesticides, estimated as a proxy variable of the cost of pesticides. The inputs con-

sidered in the model were: labour, expressed as total hours of work in a farm over the year; land capital endowment, measured in hectares of usable agricultural area (UAA); specific costs linked to the production such as seed, fertiliser, and other items excluding pesticides; total farming overhead costs, namely supply costs linked to production activity but not attributable to specific lines of production; and assets, including agrarian capital, fixed assets, and investments. On the other side, the total output produced in farms represents the entire production of the farm. All input and output variables expressed in Euros have been deflated using the price index for the year 2015 published by Eurostat. The environmental variable (Z) is made up by the amount of pesticide used, expressed as the cost of pesticide deflated using the Eurostat price index for the year 2015.

According to the methodological assumptions proposed in literature by different authors such as Charnes et al. (1978), the technical efficiency of each farm can be estimated by solving a linear programming problem aimed at minimising the level of inputs used in the production process in the dual forms (Charnes et al., 1978; Banker et al., 1984; Coelli et al., 2005; Bravo-Ureta & Pinheiro, 1993; Battese & Coelli, 1992; Galluzzo, 2020; 2019; 2013) that is expressed in formulae as:

$$\min \theta_k^c - \varepsilon (\sum_{i=1}^s S_i^- + \sum_{r=1}^m S_r^+) \quad (1)$$

$$s.t. \sum_{j=1}^n \lambda_j x_i + S_i^- = \theta_0 x_{ik}, \quad i = 1, 2, \dots, m,$$

$$\sum_{j=1}^n \lambda_j x_i + S_i^- = \theta_0 x_{ik}, \quad i = 1, 2, \dots, m, \quad (2)$$

$$\sum_{j=1}^n \lambda_j y_{ij} - S_r^+ = y_{rk}, \quad r = 1, 2, \dots, s, \quad (3)$$

$$\theta_k^c, \lambda_j, S_i^-, S_r^+ \geq 0,$$

where λ is a semi-positive vector in R^k . The value of technical efficiency should be between 0 and 1, which is the frontier of optimal technical combinations of input-output due to a well-defined and usable technology for all farms in the FADN Italian sample.

In order to estimate the impact of the selected environmental variable, the research has used the separability condition proposed by Simar and Wilson in 2007 (Simar & Wilson, 2011; 2015; Daraio et al., 2018; Daraio & Simar, 2005; Kourtesi et al., 2012; Wang & Schmidt, 2002). The separability test is fundamental for assessing if there is a change in technical efficiency due to the environmental variable. This has been estimated using the test of separability proposed by

Simar & Wilson (2007) and by Daraio & Simar (2005). The assumption of separability is that the environmental variable (Z), in our case the cost of pesticides, is a vector able to act on the input and output variables and on the function of production, changing its shape with the consequence that the distribution of inefficiency is not dependent on the environmental variable (Bädin et al., 2012; Kourtesi et al., 2012; Wang & Schmidt, 2002). If the assumption of separability is true, the environmental variable does not have any effect on the technical efficiency and the function of production (Simar & Wilson, 2011). In contrast, if the assumption of separability is rejected, the environmental variable does influence the level of efficiency (Simar & Wilson, 2011; Kourtesi et al., 2012; Daraio et al., 2018). The null hypothesis of separability is that the two boundaries with and without the environmental variable are the same in the case of separability (Kourtesi et al., 2012; Wang & Schmidt, 2002; Bädin et al., 2012; Simar & Wilson, 2007; 2011; 2015; Daraio et al., 2018; Daraio & Simar, 2005):

$$\hat{\tau}_n = [\sum_{i=1}^n (\hat{D}'_{FDH,i,n}) (\hat{D}_{FDH,i,n})] / n \geq 0 \quad (4)$$

where n is the sample size

$$\hat{D}_{FDH,i,n} = Y_i (\hat{\lambda}_{FDH,i,n}(X_i, Y_i) - \hat{\lambda}_{FDH,i,n}(X_i, Y_i | Z_i)) \quad (5)$$

$\hat{\lambda}_{FDH}$ is the assessment of the technical efficiency using the full frontier of the function of production (Kourtesi et al., 2012). A large value of τ rejects the null hypothesis of separability, meaning that the selected environmental variable does have an effect (Kourtesi et al., 2012; Wang & Schmidt, 2002; Bädin et al., 2012; Simar & Wilson, 2007; 2011; 2015; Daraio et al., 2018; Daraio & Simar, 2005). The separabil-

ity test has an important role in determining whether the selected environmental variable, namely the use of pesticides has a discernible impact on the technical efficiency of Italian farms.

Results and Discussion

The research considers a sample of 3576 farms of different type located across all 20 Italian regions over the period 2004 to 2019. The greater part of the farms in the sample are constituted by fieldcrops (1169) and other permanent crops (695). In contrast, the least represented types of farming in the sample are made up by mixed farms and granivores, with 97 and 121 farms, respectively. In terms of economic size, less than 4% of the total Italian sample has been classified as belonging in the cluster of farms between 2000 - 8000 Euros, while only 4.7% of the Italian farms included in the FADN dataset have been classified as belonging in the cluster above 500 000 Euros.

Table 1 reveals that the average land capital is close to 32.54 ha, which is above the national average of 8.4 ha estimated in the last Agricultural Census carried out by the Italian Institute of Statistics (Istat). The use of labour varies considerably, ranging from a low of 600 to 54 422 hours per year in function of the type of farming undertaking, even if a significant share of the labour is provided by the family of the farmer. The average output in constant value is close to 122 760 Euros, with the lowest recorded value of 3953 Euros per year and a maximum value of around 4.2 million Euros in highly specialised farms. Specific costs of seeds, fertiliser, and other items linked to production excluding fertiliser averaged some 38 828 Euros, with a total farming overhead cost close to 8200 Euros. Focusing attention on individual costs correlated to the productions, an average of 4280 Euros

Table 1. Main descriptive statistics in input and output used in the assessment of technical efficiency in Italian farms

	Output	Labour	Land Capital	Specific Costs	Farming Overhead Cost	Assets
Mean	122 759.58	4247.45	32.54	38 828.26	16 706.01	526 604.24
Std. Deviation	220 164.29	3295.03	42.71	90 953.16	29 075.72	797 965.75
Count	3576.00	3576.00	3576.00	3576.00	3576.00	3576.00

Source: author's own elaboration on data available at <https://agradata.ec.europa.eu/extensions/FADNPublicDatabase/FADNPublicDatabase.html>

Table 2. Descriptive statistics in some costs of crops and in the allocation of financial subsidies disbursed through the CAP

	Fertilisers Cost	Pesticides Cost	CAP Subsidies	Environmental Subsidies	Second Pillar Cap Subsidies
Mean	4280.54	3556.04	14 216.34	1421.96	2399.68
Std. Deviation	7418.77	7429.05	31 832.87	2854.96	4557.50
Count	3576.00	3576.00	3576.00	3576.00	3576.00

Source: author's own elaboration on data available at <https://agradata.ec.europa.eu/extensions/FADNPublicDatabase/FADNPublicDatabase.html>

was spent for fertiliser, while 3556 Euros was spent for pesticides (Table 2). Average financial subsidies allocated through the Common Agricultural Policy were just over 14 000 Euros, one tenth of which amount represented subsidies allocated through the CAP to environmental support; in contrast, financial payments allocated through the Rural Development Programme averaged around 2400 Euros per farm during the period under investigation.

The research findings regarding the significant cost of using pesticides in farms have corroborated the findings of other authors that farmers have an aversion to the risk of not using pesticides that pushes them to use these chemical products (Bakker et al., 2021). This creates significant difficulties for Italian farmers to implement aspects of agri-environmental policy aimed at reducing the use of chemicals in their farms, as Damalas found in 2021. It is also important to underline the effect of the measures financed through the Common Agricultural Policy, as well as the level of farmer's knowledge of alternative measures in changing the patterns of use, or overuse, of chemical inputs in Italian farms, as investigations in other European countries has previously shown (Möhring et al., 2020; Barzman & Dachbrodt-Saaydeh, 2011).

Over the period of investigation, the average value of technical efficiency in all Italian farms included in the data sample without the use of pesticides was 0.57 which implies an excess of inputs of 43%. Differently stated, Italian farms used a greater quantity of input in order to produce the same level of output during the period of study. Regarding the impact of the environmental variable, namely the use of pesticides, the comparison between DEA and two stages DEA shows a clear difference in the average values, corroborating that the null hypothesis of separability can be rejected. This being the case, it can be affirmed that the use of pesticides does have an important effect on the technical efficiency of farms in the sample. Drawing some conclusions, the findings confirm that a reduction in the use of pesticides in farms does have an impact on the technical efficiency. The technical efficiency estimated using the two stages DEA approach, which was 0.51, was lower than the value of 0.57 estimated using the DEA. This means that a complete reduction of pesticides can increase the technical efficiency of Italian farms.

Comparing the density function, it emerges that the technical efficiency estimated by the 2 stages DEA is higher in farms that have completely reduced their use of pesticides (Figure 1). A reduction in the use of pesticides has a direct impact in Italian farms, leading to a drop in their efficiency. The findings in this research have shown that a reduction or a less intense use of pesticides in Italian farms has been able

to impact the technical and economic performances in farms, as Skevas et al. previously proposed in 2014, leading to an increased productivity of land capital due to a less severe exploitation of this input. A reduction of pesticide use has increased the technical efficiency without resulting in a loss in output, thus corroborating the findings of other studies (De Koeijer et al., 2002; Skevas et al., 2012; 2014).

Comparing the 8 main different types of farming prac-

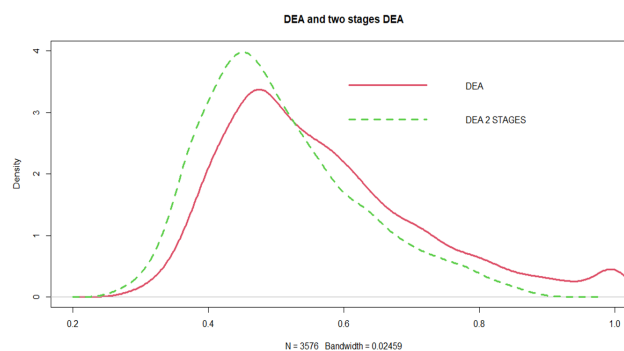


Fig. 1. Density function of technical efficiency estimated through DEA and two-stage DEA in all Italian farms

Source: author's own elaboration on data available at <https://agri-data.ec.europa.eu/extensions/FADNPublicDatabase/FADNPublic-Database.html>

ticed in all the Italian farms included in the FADN sample, the findings have underlined that a complete reduction of pesticides has had a significant effect in technical efficiency (Table 3). Considering all types of farming, in fact, it emerges that a use of pesticides has implied an enormous drop of technical efficiency in horticulture and granivores; in contrast, the lowest decreases in technical efficiency were found in Italian farms specialised in mixed production and other grazing livestock.

The Italian farms included in the data sample have been clustered in function of their economic size in order to assess whether their dimension influenced their sensitivity to the reduction of pesticides use. In fact, Table 4 reveals that the introduction of pesticides in farms was able to reduce the level of technical efficiency, which on average dropped from 0.56 to 0.50 hence, a direct consequence of the use of pesticides is to reduce the efficiency in farms. Focusing on all economic size clusters, the findings have shown that the greatest change in technical efficiency as a result of the reduction of pesticides was seen in farms that were part of the clusters 8000-25 000 Euros and 2000-8000 Euros. This implies that smaller farms are, on the whole, much more sensitive to the use of pesticides in farming.

Table 3. Technical efficiency change in all typologies of farming estimated through DEA and two-stage DEA

Type of farming	DEA	Two-stage DEA	t-test
Fieldcrops	0.506	0.467	9.023***
Horticulture	0.763	0.627	9.516***
Wine	0.640	0.561	9.629***
Other permanent crops	0.632	0.547	12.052***
Milk	0.522	0.476	5.598***
Other grazing livestock	0.492	0.455	6.025***
Granivores	0.717	0.618	5.738***
Mixed	0.459	0.424	3.025***
Mean	0.57	0.51	19.080***

*** p-value < 0.01

Source: author's own elaboration on data available at <https://agridata.ec.europa.eu/extensions/FADNPublicDatabase/FADNPublicDatabase.html>

Table 4. Technical efficiency change in all Italian farms clustered in their economic size estimated by DEA and two-stage DEA

Economic size (€)	DEA	Two-stage DEA	t-test
2000-8000	0.683	0.586	6.31***
8000-25 000	0.752	0.499	10.22***
25 000-50 000	0.523	0.469	8.67***
50 000-100 000	0.525	0.477	8.47***
100 000-500 000	0.588	0.532	9.93***
> 500 000	0.766	0.668	7.30***
Mean	0.567	0.507	19.08***

*** p-value < 0.01

Source: author's own elaboration on data available at <https://agridata.ec.europa.eu/extensions/FADNPublicDatabase/FADNPublicDatabase.html>

Farming specialisation and economic size can therefore be seen to be the two fundamental variables that had the greatest impact on the use of pesticides and influenced the technical efficiency, as argued respectively by Skevas & Lansing (2014) and by Möhring et al. (2020).

Conclusions

In the agenda of the Common Agricultural Policy for the next 7-year period, there are many agri-environmental measures focussed on reducing the use of chemical inputs in agriculture and protecting the environment. Indeed, the 'farm to fork' and biodiversity strategies have the target of significantly reducing the use of pesticides and fertilisers in agriculture, generating a new governance in the primary sector and in the protection of the environment by encouraging the diffusion of organic farming techniques.

This study has been able to explain that it is possible to reduce the levels of pesticides used in Italian farms without negatively impacting the level of technical efficiency. This radical decision has some consequences for farmers in function of the specialisation and the dimension of their farms. In fact, the complete elimination of pesticide use

in small farms with an economic size between 8000-25 000 Euros significantly increases the technical efficiency, and this has some far reaching political and economic implications, both for farmers and also for a new strategic political approach in the primary sector addressed to environmental protection. The research has revealed that a reduction in the use of pesticides increases the level of technical efficiency in farms, while a differentiated use of pesticides must be compensated adequately by specific financial support whose aim is to compensate the change in productivity in terms of lower output as well as a different allocation of inputs and investment put into action by farmers in fixed capital, costs of crops, and a different use of labour and machinery. In fact, a radical change in the management of farms brought about by a reduction in chemical inputs implies an increase in the use of other inputs such as machinery and labour necessary to obtain an adequate level of production, as investigations in other fields of agricultural economics suggest (Manevska-Tasevska et al., 2021; Hansson et al., 2019).

One of the most important weaknesses of this analysis is that while it may identify whether changes in the use of pesticides have influenced the level of technical

efficiency, this method is not adequate to define which single input and output have been involved in the pattern of inefficiency. This approach of estimating technical efficiency by DEA and two-stages DEA has not identified which input has been inefficient due to an excess of input or output used in the productive process. In this case further analysis should be addressed to investigating both the pattern of technical inefficiency and also identifying the reasons that push farmers to be rationally inefficient by reducing their use of pesticides (Asmild et al., 2003; Bogetoft & Hougaard, 2003) following a productive decision to reduce their use of chemicals in favour of environmental protection, even where such a decision sacrifices the higher levels of production that could be achieved by a greater use of chemical inputs. In general, it can be seen that farms specialised in vegetable production have been much more sensitive to the impact on technical efficiency brought about by changes in their use of pesticides than farms specialised in milk or other animal productions. This finding is in line with another study carried out by Singbo et al. (2015) according to which farms specialised in vegetable production were found to have been far less efficient in their use of pesticides. In this light, it is also important to underline how mixed farms, characterised by having the lowest level of technical efficiency, have suffered less in the case of a complete reduction of pesticides. This has corroborated how a diversification in farms on one side is able to reduce the technical efficiency on the other, making them less inefficient in the case of the reduction of the use of pesticides.

Drawing some policy conclusions, it is important when devising the measures of agri-environmental policy to be implemented by the Common Agricultural Policy to also consider the economic size of farms as a variable able to act on the technical efficiency. Small farms, which represent the vast majority of enterprises in the Italian primary sector, have shown themselves to be more sensitive to a reduction in the use of pesticides. This has some serious implications in that a worsening in the economic performances of small farms could stimulate an exodus from the Italian countryside and consequentially lead to an increase in socio-economic marginalisation in rural zones. This is particularly true in mountainous areas where the greatest concentration of small farms is found. The agri-environmental policies aimed at reducing pesticide use and bringing about a different allocation of inputs in agriculture must therefore take into consideration the economic size variable, and ensure the financial support made available to small farms is at an adequate and sustainable level.

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