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Productivity and environmental costs from intensification of farming. A panel data analysis across EU regions

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Abstract

This paper addresses the need of finding new ways of measuring environmental and economic performance of farming. The aim of this study is to inquire on the impacts that excessive intensification has on productivity and environmental costs in the long term and, additionally to explore empirically the trend of these two indicators over time. The contribution of this study is twofold: (a) to engage in the discussion that although intensification can boost yields and lower costs in the short-term, it might lead in the opposite direction in the long-term due to environmental and economic issues and (b) to explore current trends of productivity and environmental costs of farming. To this end, this paper performs a panel data analysis of productivity and environmental costs on a farm accounting database across European regions over the 1989-2009 period. The methodology uses output as an indicator of productivity and expenditures on energy, pesticides and fertilisers as proxy indicators of environmental costs. Results provide empirical evidence that regions under study have a negative trend of productivity and a positive trend of environmental costs in the years under study. These results correlate negatively with both, economic and environmental sustainability of farms. Arguably, this is aggravated in the latter due to hidden environmental costs valued at zero in traditional accounting.

Keywords: energy; European agriculture; fertilisers; pesticides; productivity; sustainability accounting.

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1. Introduction

Agriculture is facing, at least, a twofold increasing global pressure. On the one hand, an economic pressure due to an increasing population with a growing food demand and, on the other hand, an environmental pressure of bringing economic performance into line with environmental issues (WHO, 2005). In other words, agricultural sustainability revolves around many interconnected topics including but not limited to food security, food quality, environmental concerns and socio-economic issues. Over recent decades, intensive practices (e.g. economies of scale, use of genetically modified seeds, and reliance on external inputs, irrigation and the substitution of land) brought about significant changes in agricultural production. Intensive practices resulted in higher yields in the past (de Ponti et al., 2012), however they also resulted in undesirable misuse of common resources (Stern, 2006). Research is still inconclusive whether sustainable or alternative agricultural systems, which tend to have a positive or lesser impact of the environment (Pretty and Bharucha, 2014) are able to substitute prevailing intensive practices at a large scale. The main concern is related with food security given that comparisons among systems proved higher yields in intensive farms (Cisilino and Madau, 2007; Lansink et al., 2002).

Traditional defenders of intensive practices claim (i) increasing average yields (FAO, 2008) which hypothetically lead to (ii) increasing economic growth (de Wit, 1992) as its main advantages over alternative agricultural systems. Nevertheless the reliability of these claims is arguable on both environmental and economic levels.

On the environmental side, there is plenty of scientific evidence that natural resources essential to sustain agriculture are finite (Rockström, 2009). It is impossible to achieve infinite growth counting with finite resources (Schumacher, 1973). Therefore, an impressive growth of yields is doomed in the long run if it is based on a rapid depletion of resources. In this vein, the undeniable improved efficiency and increased average yields due to intensification in the past (de Ponti et al., 2012), might not be possible to continue in the future due to resource and environmental constrains caused by its very practices (Ruttan, 2002; Tilman et al., 2001). Among the most representative and environmentally harmful practices are the excessive reliance on costly technology, the heavy dependence on non renewable resources (Batie and Taylor, 1989), the misuse of direct energy inputs mainly in the form of fuels and oils and of indirect energy inputs mainly in the form of pesticides and fertilizers (Tabatabaeefar et al., 2009). More in detail, only the misuse of energy, pesticides and fertilisers is proved to cause degradation of soil (OECD, 2001), water pollutant runoff and leaching (OECD, 2012), negative effects on human health (Pimentel and Burgess, 2012; Wilson and Tisdell, 2001); loss of biodiversity (Mondelaers et al., 2009) and even a destructive interference with the nitrogen cycle at a global scale (Gruber and Galloway, 2008).

On the economic side, intensive high-yielding agriculture is associated with the law of diminishing marginal returns which claims that the relationship between the amount of an external input and the yield levels off requiring ever increasing external inputs (de Wit, 1992). Furthermore, diminishing marginal returns implies increasing marginal costs and rising average costs. It is important to highlight that increasing costs might endanger the potential of agricultural productivity, which is intrinsically linked to the capability of farmers to pay for required inputs to achieve it (Cerutti et al., 2013). Furthermore, there is evidence that this financial pressure lead to increasing debt per farm (Anielski et al., 2001).

It is generally accepted that a way of improving environmental and economic performance is to start with its accurate measurement (Ajani et al., 2013). The use of indicators has proved useful when there is no direct measurement available (Gaudino et al., 2014). Several complex methodologies encompassing multiple indicators have been designed and applied to farming, including but not limited to Life cycle Assessment (ISO, 2006), Ecological Footprint (Rees, 2000), DIALECT (Solagro, 2000), and FarmSmart (Tzilivakis and Lewis, 2004). Additionally, several researchers have actively designed frameworks to identify and value the environmental impacts of agriculture in monetary terms (Pretty et al., 2005, 2000; Tegtmeier and Duffy, 2004). However, no measuring system is globally or even nationally accepted and used in a systematic manner. One specific topic that has not received the attention it deserves is the impact that intensive agriculture has on environmental costs and productivity in the long term measured directly on monetary terms. This is particularly important if we consider that monetary values hide impacts valued at zero in traditional accounting. Hence, additional research is needed to enlighten this issue. Therefore, the aim of this study is twofold: (a) to inquire on possible impact of intensification on productivity and environmental costs in the long term and, (b) to explore empirically the trend of these two indicators over time. This paper contributes to the literature performing an empirical study of the trends of productivity and environmental costs of farming in the long-term. It performs a panel data analysis of productivity and environmental costs on a farm accounting database across European regions over the 1989-2009 period. The model proposed takes (i) farm output per hectare as indicator of productivity, and (ii) expenditures on energy, pesticides and fertilisers per hectare as proxy indicators of environmental costs.

The remainder of this article is organised as follows. Section 2 discusses the arguments that support our hypotheses of decreasing productivity and increasing environmental costs of intensification of farming in the long-term. Section 3 explains the methodology adopted in this paper to measure the behaviour of environmental costs and productivity over the period 1989-2009. Section 4 presents the results and a discussion of these findings and, finally, section 5 offers some concluding remarks, while identifying some of the limitations of the study and avenues for further research.

2. Hypotheses development

The notions of increasing productivity and decreasing costs lie at the core of discussions about intensification of farming. It is often understood that the increasing use of external inputs (e.g. energy, pesticides, fertiliser) boost yields and lower costs. Although this is possible in the short-term, nevertheless, in the long-term, an excessive intensification might lead exactly in the opposite direction. Systems that allow a turn in a more sustainable direction may be considered suboptimal in the short run, but nonetheless wiser in the long-term (Dietz et al., 2003).

One of the purposes of increasing intensification of farming is, arguably to increase yields; nevertheless a misuse of resources might lead to a decreasing productivity over time. This is due to the fact that farm productivity does not only depend on the amount of external inputs applied but also on the availability of environmental and economic resources.

On the one hand, it was already stated that "growth has no set limits in terms of population or resource use beyond which lies ecological disaster. Different limits hold for the use of energy, materials, water, and land" (UNWCED, 1987 p. 42). There is evidence that over time the excess of intensification impacts negatively on the scarcity of natural resources. An unbalanced application of fertilisers degrades the soil over time exploiting the pools of organic nitrogen in the soil (Robertson and Vitousek, 2009). Moreover, the degradation of soil fertility is expected to worsen in coming years due to climate change (Colonna et al., 2010). Similarly, water availability is also decreasing due to increasing water demand to ensure food security (Rockström, 2009). Although irrigated lands allowed a substantial increase in yields during the green revolution, however, water is becoming scarce and is not possible to keep increasing irrigated areas (Postel et al., 1996). On the other hand, over time if one productive resource remains fixed, or even worse becomes scarcer, productivity might be negatively impacted by the economic law of diminishing marginal returns. This microeconomic law holds that an additional unit of input (e.g. fertiliser) keeping constant the other input (e.g. land) will increase marginal product initially but will decrease and even cause negative marginal product in the long term. At this point adding additional units of the variable factor decreases the output instead of increasing it (Krugman and Wells, 2009 p. 307). This law is particularly important in agriculture where productive land is, without considering soil degradation, constant.

Based on the above discussion our first hypothesis is:

Hypothesis 1: *Output of farming decreases over time.*

Another purpose of increasing intensification of farming is, arguably, to lower costs of production, nevertheless, an excessive intensification might lead to an undesirable increase of costs in the long term. This is due to the fact, that being intimately related with productivity, costs also depend on environmental and economic factors.

On the environmental side, the fact that natural resources are becoming scarcer also affects the amounts of inputs required to achieve yields. It is proved that intensive farming requires increasing volumes of direct energy mainly for land preparation, irrigation, harvest, post-harvest processing, transportation and increasing volumes of indirect energy mainly in the form of pesticides and fertilisers (Margaris et al., 1996). For example, increasing pesticides doses will boost yields and lower costs in the short-term. However, in the long term it is demonstrated that the volume and number of pesticides required increase due to herbicide-resistant weeds (Heap, 2014).

On the economic side, “productivism” is defined as “a commitment to an intensive, industrially driven and expansionist agriculture with state support based primarily on output and increased productivity.” (Lowe et al., 1993 p.221). Accordingly, farmers will increase the use of external inputs in order to increase yields despite its environmental impacts. There is evidence of increasing costs of energy-based agro-chemicals such as pesticides and fertilisers (Edwards, 1989). Similarly, the vast world energy consumption of farming, calculated in a recent study at an annual 11 exajoules, is forecasted to rise due to increasing mechanisation of farming (Stavi and Lal, 2013). Furthermore, the growing demand for food will force to convert approximately 10^9 hectares of natural ecosystems into agricultural land by 2050, accompanied by comparable increases in fertilisers and pesticide use (Tilman et al., 2001).

The law of diminishing marginal product is also relevant in the analysis of environmental costs in the long term. The relationship between returns and costs of production is inverse. According to this law, decreasing returns imply increasing marginal costs and rising average costs in the long term. More precisely, it claims that the relationship between yields and the amount of an external input levels off requiring ever increasing external inputs (de Wit, 1992). As a consequence, we might already be at the point where adding additional energy, pesticides and fertiliser might decrease marginal product instead of increasing it. Therefore, the assumption that expenditures related with environmental damage would increase over time is therefore a priori not unreasonable. Therefore, based on the above discussion our second hypothesis is:

Hypothesis 2: *Environmental costs of farming increase over time.*

3. Methodology and sample description

3. 1 Empirical model

This study analyses the behaviour over time of (i) productivity of farming and (ii) environmental costs of farming using two different equations.

Equation (1) explains the behaviour of productivity of farming over time. A productivity function typically relates output to required production factors or inputs (Coelli et al., 1998). We test our first hypothesis formulating a model where output (*OUTPHA*) depends on time (*TIME)*, the inputs of environmental costs (*ENVCHA*), labour (ln*AWU*) and capital endowments (*MACHINERY*) which are two classical inputs in production functions (OECD, 2015; Ruttan, 2002), and additional control variables of economic size unit (ln*ESU*), subsidies (*SUBSIDIES*) and type of farming (*TYPEFARM*).

$$OUTPHA_{it} = \alpha_0 + \alpha_1 TIME_{it} + \alpha_2 ENVCHA_{it} + \alpha_3 lnAWU_{it} + \alpha_4 MACHINERY_{it} + \alpha_5 lnESU_{it} + \sum \alpha_s SUBSIDIES_{sit} + \sum \alpha_f TYPEFARM_{fit} + \varepsilon_{it} \quad (1)$$

Equation (2) explains the behaviour of environmental costs of farming over time. Environmental costs depend also on time, output, capital, size, subsidies and types of farming.

$$ENVCHA_{it} = \beta_0 + \beta_1 TIME_{it} + \beta_2 OUTPHA_{it} + \beta_3 MACHINERY_{it} + \beta_4 lnESU_{it} + \sum \alpha_s SUBSIDIES_{sit} + \sum \alpha_f TYPEFARM_{fit} + \omega_{it} \quad (2)$$

where all variables refer to a a type de farming and European region *i*, and year *t,* α and β are the parameters to be estimated, and *s* and *f* are the subscripts for subsidies and types of farming respectively.
Similarly to previous research (Coelli et al., 1998; Ruttan, 2002), this paper considers output per hectare as a reliable indicator of productivity performance in agriculture, thus being *OUTPHA* the dependent variable in equation (1).
Our dependent variable in equation (2), *ENVCHA* is the total amount spent on energy, pesticides and fertiliser per hectares. Previous research on environmental management accounting identifies annual expenditure on direct energy (consumed in the form of fuels and oils) as an environmental cost (United Nations, 2001; Jasch, 2003). Nevertheless, agriculture consumes energy also indirectly through the use of pesticides, fertilisers, animal feed and agricultural machinery among others (Eurostat, 2012). We select and include the expenditures on energy, pesticides and fertilisers on the basis of, at least, three reasons. First, these three inputs are considered the main forms of energy consumption of agricultural holdings (Tabatabaeefar et al., 2009). Second, the monetary measurement of its annual expenditure is available from traditional accounting. Third, there is a vast amount of research specifically on the environmental impact of energy, pesticides and fertilizers consumption (Gruber and Galloway, 2008; Pimentel and Burgess, 2012; Wilson and Tisdell, 2001). Overall, we consider that the sum of expenditures on energy, pesticides and fertilizers is a plausible indicator of environmental costs.

Our variable of interest in both equations is *TIME*. This study aims to test the behaviour of productivity and expenditures over time (see sample sub-section). To this end, we use different alternatives measures for *TIME*. In the first place, *TIME1* represents the continuous value for each calendar year. Secondly, *TIME3* represents a continuous variable on a three years basis. Therefore, *TIME3* takes values 1 to 7 for the periods 1989-1991 to 2007-2009 respectively. *TIME3* was added to reduce the high variability of farming due to unpredictable and arbitrary market and climate conditions (Pretty et al., 2010), which can significantly be reduced in a three year period (Cordts et al., 1984). Afterwards, we include dummy variables of *TIME3* indicating with value 1 that an observation belongs to a given period and 0 otherwise. We label these variables *TIME8991, TIME9294*, *TIME9597, TIME9800*, *TIME0103, TIME0406* and *TIME0709* respectively. The default variable is the first three years period: 1989-1981. According to our hypotheses H1 and H2 we hypothesize a negative sign for *TIME* in equation (1), thus indicating that productivity per hectares have decreased along the years under analysis. On the contrary, we hypothesize a positive sign for *TIME* in equation (2), thus indicating that expenditures per hectare have increased over the analysed period.
As it is usually assumed in production functions, we expect a positive sign for *ENVCHA*, *lnAWU* and *MACHINERY.* Annual work unit (AWU) approaches labour endowment and it is defined as the

total number of full time workers, including family work. Given the non normal distribution for this variable we use the natural logarithm, l*nAWU*. *MACHINERY* approaches capital endowment through the ratio of machinery to total assets. In equation (2) we also expect a positive sign.

We use European Size Units (ESU) as a variable of size control. Given the non-normal distribution for this variable we transform ESU in its natural logarithm, *lnESU*. This measure is commonly used by researchers and institutions in the European Union (EU) as a homogeneous measure of size for comparing heterogeneous types of farming (European Commission, 2013; Reidsma et al., 2010). It is traditionally claimed that economies of scale might decrease unit variable costs when volume increases (Balakrishnan and Labro, 2014). Larger farms are expected to have lower costs per units of production than smaller farms (Valero and Aldanondo-Ochoa, 2014). Herein, farms with larger size arguably benefit from economies of scale with respect to production and external input costs. On the contrary, smaller farms benefit from a different array of advantages such as flexibility (You, 1995); quicker response to changes (Knight and Cavusgil, 2004) and a higher tendency to try out creative solutions using and/or reusing constrained resources (Baker and Nelson, 2005). As a consequence, we do not expect any particular sign for size.

Given the importance of subsidies for farmers in Europe (Olper et al., 2014) we use different measures for subsidies. *INVESUBS*, *PRODSUBS* and *ENVISUBS* are the ratios of subsidies on investment, total subsidies for production (excluding environmental payments) and environmental payments to output respectively.

INVESUBS and *PRODSUBS* are not directly linked with environmental concerns, however both influence agricultural activities and outcomes. Therefore, we do not expect a particular sign for these two variables in equation (1) and (2).

In contrast, *ENVISUBS* is linked to specific agricultural outputs which are able to generate positive environmental impact or mitigate negative ones. These subsidies are designed to compensate farmers for any loss associated with practices aiming to benefit the environment (Kleijn and Sutherland, 2003). Thus, saving expenditures on harmful environmental inputs. Accordingly, for this variable, we do not expect any particular sign in equation (1) and a negative sign is expected in equation (2).

TYPEFARM controls for technical characteristics of types of farming included in our sample. We include dummy variables indicating, with value 1 and 0 otherwise, that an observation belongs to a given type of farming. The sample used in this study uses the official EU classification (Reg. 85/377/EEC), thus we consider: field-crops *(FIELDCRO)*; wine *(WINE)* and other permanent crops *(OPERCROP)*. The default variable is horticulture, which tends to be particularly intensive in the use of external inputs and more productive in comparison with other crops. Therefore it requires more inputs per hectare. As a consequence, we expect a negative sign for these variables in both equations (1) and (2).

We use *OUTPHA* in equation (2) as a control variable for productivity. From a productivism perspective, most of farmers will try to maximise productivity through the increasing use of inputs despite its environmental impacts. Therefore, we expect larger amounts of production to require ever increasing environmental costs per unit. Therefore, positive sign is expected for *OUTPHA* coefficient in equation (2).

3.2 Sample

Research data is obtained from the European farm accountancy data network (FADN), an annual survey launched in 1965 by the European Commission to collect accountancy data from a sample of farms in the EU. The content and format of FADN reports are essentially similar to standard financial statements. We analyse the 1989–2009 period, which is the longest publicly available database fulfilling our criteria (type of farming-region-year). These 21 years of homogeneous information provide the most suitable data series for our purpose. Due to the change in the methodology (FADN, 2014) there is a break in the time series after 2009[1]. As a consequence, data afterwards are not comparable with the data series used in this study.

Given the panel data structure of the sample we adjust *OUTPHA* and *ENVCHA* used as dependent and independent variables in equation (1) and (2). Herein, these variables are expressed in constant values of 2009.

We start from an initial database of 138 regions from countries member of the EU. In order to get more reliable results, we select only those countries that are present across the 21 years under study. Additionally, given that hectares is used as the measure of standardization, we select only those observations oriented to crop production. Thus, ensuring comparability.

Herein, the final sample for the empirical analysis uses a type of farming-region-year data covering 96 regions of 12 European countries. Table 1 shows the detail of regions per each country included in the sample. Although all countries are present in the 21 years, nevertheless neither all the regions practice all types of farming, or are all the regions present over the whole period under study. The countries most represented are Italy with 1,697 observations, France with 1,477, and Spain with 1,061. These three countries account for almost 70% of all observations. The remaining countries have less than 1,000 observations each.

(ADD TABLE 1 ABOUT HERE)

Table 2 offers the details on the number of observations across the years and type of farming included in our sample. Data tracks farms over 21 years adding up 6,282 observations. Given the sample selection procedure applied, the type of farming-region-year sample is homogeneous and not biased across the whole period.

(ADD TABLE 2 ABOUT HERE)

4. Results and Discussion

4.1 Descriptive statistics and univariate analysis

There is a steady increasing size in terms of ESU and AWU. There is also a predominant increasing trend in environmental costs. More specifically, there is an increase in 4 periods in comparison with its precedent (1992-1994, 1995-1997, 1998-2000 and 2004-2006*)*. The overall increasing productivity across time shows important fluctuations. This suggests a likely loss of productivity due to saturation and a lack of achievement of economies of scale.

(ADD TABLE 3 ABOUT HERE**)**

The subsequent multivariate analysis allows a deeper analysis on these issues controlling for the different factors influencing productivity and environmental costs throughout the period. Table 4 displays Pearson correlation coefficients between independent variables in equation (1) and (2).

1

FADN database available at <http://ec.europa.eu/agriculture/ricaprod/database/database_en.cfm> contains two datasets. The first one, based on the methodology used until 2009, labelled as SGM (from standard gross margin) provides information from 1989-2009. The second one, with the new methodology applied from 2010 is labelled as SO (from standard output) provides at the moment of writing this research information from 2004 to 2012.

(ADD TABLE 4 ABOUT HERE)

Although the high correlation coefficient between *lnESU* and *lnAWU* (0.7254), however, the highest variance inflation factor 2.79 for variable *lnESU* is clearly under the common rule of thumb 4 proposed (e.g. Allison, 1999), which indicates that collinearity is unlikely to affect estimations.

4.2 Multivariate analysis

Given that the panel data structure of our sample presents the typical autocorrelation pattern, we perform panel data estimations. The commonly used Hausman test rejects the null hypothesis of no correlation between individual effects and explanatory variables. The random effects estimator is inconsistent, while the fixed effects estimator is consistent, efficient and preferred to random effects in both equations (1) and (2). However, fixed effects estimation omits variables that remain unchanged across all periods considered (e.g. *TYPEFARM).* We believe that technological and specific characteristics of type of farming are important factors influencing our dependent variable, and thus we additionally perform random effects estimations.

The Breusch-Pagan Lagrange multiplier test for random effects confirms that panel data estimators are more appropriate than common OLS estimators for both models. The Breusch-Pagan/Cook-Weisberg test for heteroscedasticity significant with $p<0.01$ in all estimations reveals the existence of heteroscedasticity, we herein perform panel data estimations with standard errors adjusted for heteroscedasticity using the Huber–White robust variance estimator (White, 1980).

Table 5 displays results of panel data estimations for equation (1), for *TIME1*, *TIME3* and dummy variables of *TIME3* respectively. All R-squares are around 0.8 and significant with $p<0.01$. With the exception of subsidies on investment and production all control variables are significant with $p<0.05$ and present the expected sign. According to our results, increasing amounts of labour and machinery endowments, as well as of environmental inputs, influence higher productivity. The significant negative signs for size (with $p<0.01$ in all estimations) reveal that the advantages of small size prevail over economies of scale. Results are essentially the same with random effects estimations (see columns B, and D), where all types of farming displayed in the table influence lower productivity than horticulture, as expected.

(ADD TABLE 5 ABOUT HERE)

With respect to our variables of interest, the signs for time calendar (*TIME1*) and for the three-years variable (*TIME3*) are negative and significant with $p<0.1$ with the preferred fixed effects estimations, also similar to random effects estimations, and persistently providing support for our hypothesis H1. Column E displays results including dummy variables identifying three years periods. All coefficients are negative, and dummies for years 2004-2006 and 2007-2009 significant with $p<0.1$, thus indicating decreasing productivity with respect to the beginning period in our sample. Results of this last estimation with random effects, not displayed in table 5 for simplicity, are very similar. Additionally, we use Wald tests of simple and composite linear hypotheses to test that the coefficients of dummy variables of *TIME3* decrease significantly period after period. These tests provide significant differences in all the combinations of periods *TIME0406* and *TIME0709* with all previous periods. This reinforces the idea that there is a decreasing productivity with its minimum values in the last two periods under study. Overall, these results provide reinforced support for our hypothesis H1.

We rerun fixed effects estimations (not disclosed) for variables included in column C adding squared terms for variables *TIME3* and *ENVCHA*. The non significant coefficients for these squared variables reject curvilinear relationships with the dependent variable. Therefore, according to our results, despite the extant increasing input expenditure there is a sustained productivity loss of 117.51 and 320.19 € (in constant values of 2009) per hectare every year and three years respectively (see columns A and C). Similarly, measured in constant values of 2009, the attainment of 5.66 and 5.65 € per hectare requires a sustained additional expenditure of 1 € of energy, pesticides and fertilizers per hectare (see columns A and C).

Table 6 displays results for equation (2), for different specifications of our variable of interest and panel data estimations.
All R-squares are between 0.79 and 0.83, significant in all cases with $p<0.01$. With the exception of *MACHINERY* all variables present the expected sign. Surprisingly, *MACHINERY* significantly influence lower environmental costs.
This could be caused by the fact that farms with higher levels of investment in machinery, endow with more efficient and environmental friendly equipment (e.g. buying energy saving equipment; see also United Nations, 2003). However, the nature of the study does not allow inferring the reason of this negative influence. *lnESU*, *INVESUBS*, *PRODSUBS* do not result significant in any estimation. The coefficients of environmental subsidies are negative and significant (with $p<0.01$ and $p<0.05$). Thus, suggesting that environmental subsidies are achieving more sustainable practices and helping farmers to save environmental costs. Similarly, dummy variables for time of farming have the expected negative sign and are significant with $p < 0.01$ in all estimations. This reveals that all analysed type of farming have lower environmental costs than horticulture, as expected.

(ADD TABLE 6 ABOUT HERE)

With respect to our variables of interest, the signs for time calendar (*TIME1*) and for the three-years variable (*TIME3*) are positive and significant with $p<0.05$ both with the preferred fixed effects estimations and with random effects estimations. Herein, persistently providing support for our hypothesis H2. Column E displays results including dummy variables identifying three years periods. All coefficients are positive, and dummies for periods starting on 1998 and afterwards are significant. More in detail, the periods 1998-2000 and 2001-2003 are significant with $p<0.05$, and periods 2004-2006 and 2007-2009 are positive and significant with $p<0.01$, thus indicating increasing environmental costs with respect to the beginning period in our sample. Lastly, we use Wald tests of simple and composite linear hypotheses to test that the coefficients of dummy variables of *TIME3* grow significantly period after period. 14 out of 21 combinations in between periods of three years present significant increasing environmental costs.
We rerun fixed effects estimations (not disclosed) for variables included in column C adding a squared term for variable *TIME3*. The non significant coefficient for this squared variable rejects curvilinear relationships with the dependent variable. Therefore, according to our results, environmental cost increase linearly across the period under study.
We perform random estimation with dummies of *TIME3* and obtain substantially same results not displayed. Overall, these results reinforce the support for our hypothesis H2.

5. Conclusions

This study has explored the trends of productivity and environmental costs over time. A review of the literature suggests that increasing intensification of agriculture requires increasing volumes of energy, pesticides and fertiliser. It is proven and widely researched that these practices are causing serious environmental issues and, thus, these expenditures represent environmental costs. Furthermore, the law of diminishing marginal returns claims that an additional unit of input keeping constant the other inputs might even cause negative marginal product in the long term. This law is particularly appropriate for agriculture given that the earth´s amount of land is constant, while fertile soil is diminishing. Addressing economic and ecological sustainability of agriculture requires paying attention to increasing environmental costs required to achieve a hypothetically increasing productivity.

We use a sample of farms across European regions over the years 1989-2009 considering different measures of time. Results are consistent suggesting that intensification of farming, proved as detrimental to the environment, is also linked with increasing expenditures on energy, pesticides and fertilizers in the long-term. Furthermore, the study reveals that the attainment of additional units of product requires a sustained additional expenditure on environmental costs. Additionally, productivity shows a negative trend in the long-term despite increasing environmental costs and increasing size of farms. Finally, results also reveal that advantages of small size prevail over economies of scale.

The results of this study are relevant for farmers, policy makers and researchers alike. This analysis shows that unsustainable practices are not only linked with environmental degradation but also with decreasing productivity and increasing environmental costs in the long term. This is particularly important if we take into account that monetary terms hide environmental impacts valued at zero in traditional accounting. Paying attention to these two indicators could help to achieve a shift not only in production patterns, but also in consumption habits and in a social awareness of the value of natural resources, all essential factors in the fight against environmental impact of food production.

This study is based on a farm accounting database across European regions over the 1989-2009 period. Future research should focus on other regions and/or periods of time. A limitation of this research is that the used database is mostly representative of intensive farms. It would be interesting for future research to model the difference in the trends of productivity and environmental costs between organic and intensive farming. Additionally, this paper only considers the monetary value of energy, pesticides and fertilisers added at the production stage. Future studies should include expenditures of other indirect energy consumption due to the production and transport of agricultural inputs such as purchased seeds, packaging, oils and lubricants and measured. Lastly, the availability of measurement in physical units could retrieve insightful and complementary results.

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TABLE 1

Sample of country/regions considered

Country	**Nº of regions**	**Region-year observations**
Belgium	3	81
Denmark	1	63
France	22	1,477
Germany	14	770
Greece	4	336
Ireland	1	34
Italy	21	1,697
Luxembourg	1	38
Netherlands	1	63
Portugal	6	412
Spain	16	1,061
United Kingdom	6	250
Total	**96**	**6,282**

TABLE 2

Sample: observations per year and type of farming (official classification of EU Reg. 85/377/EEC)

Year	Field-crops	Horticulture	Wine	Other permanent crops	Total
1989	85	64	61	65	275
1990	83	63	60	67	273
1991	82	66	59	68	275
1992	83	70	58	69	280
1993	83	69	58	67	277
1994	85	71	58	69	283
1995	91	73	56	70	290
1996	90	75	57	73	295
1997	91	73	58	74	296
1998	90	77	60	73	300
1999	91	81	59	74	305
2000	90	79	61	76	306
2001	90	79	61	76	306
2002	90	83	63	74	310
2003	90	82	62	78	312
2004	92	83	63	81	319
2005	92	82	63	80	317
2006	93	82	63	80	318
2007	93	84	62	80	319
2008	91	83	61	78	313
2009	90	83	61	79	313
Total	**1,865**	**1,602**	**1,264**	**1,551**	**6,282**

TABLE 3

Mean values for continuous variables across 1989-2009 for each period of TIME3

Variables	**1989-1991**	**1992-1994**	**1995-1997**	**1998-2000**	**2001-2003**	**2004-2006**	**2007-2009**
Output per hectare *(OUTPHA)*	13,753.99	13,466.40	15,120.19	15,400.39	15,471.14	16,404.38	14,346.46
Environmental costs per hectare *(ENVCHA)*	1,469.22	1,504.00	1,825.22	1,844.02	1,797.46	1,922.91	1,913.39
Annual work units *(AWU)*	1.82	1.83	2.07	2.12	2.20	2.30	2.36
Machinery to total assets *(MACHINERY)*	0.16	0.16	0.16	0.16	0.17	0.17	0.16
Economic size units *(ESU)*	29.67	38.19	49.17	52.89	61.46	65.22	68.47
Subsidies on investments to outputs *(INVESUBS)*	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Subsidies for production to output *(PRODSUBS)*	0.01	0.06	0.13	0.14	0.14	0.12	0.12
Agri-environmental payments to outputs *(ENVISUBS)*	0.00	0.00	0.00	0.01	0.01	0.01	0.01

TABLE 4

Pearson correlations for continuous independent variables

	Calendar year 1989-2009 *(TIME1)*	*OUTPHA*	*ENVCHA*	*lnAWU*	*MACHINERY*	*lnESU*	*INVESUBS*	*PRODSUBS*
Output per hectares *(OUTPHA)*	0.0140	1						
Environmental costs per hectare *(ENVCHA)*	0.0375*	-	1					
Annual work units *(lnAWU)*	0.1177***	-	0.4673***	1				
Machinery to total assets *(MACHINERY)*	0.0237*	0.1442***	0.1195***	0.3182***	1			
Economic size units *(lnESU)*	0.2590***	0.2796***	0.3081***	0.7254***	0.4663***	1		
Subsidies on investments to outputs *(INVESUBS)*	-0.0554***	-0.0410**	-0-0338*	-0.0598***	-0.0106	-0.1607***	1	
Subsidies for production to output *(PRODSUBS)*	0.2192***	-0.2505***	-0.2435***	-0.2557***	0.1584***	-0.0081	0.0068	1
Agri-environmental payments to outputs *(ENVISUBS)*	0.2327***	-0.1333***	-0.1414***	-0.1661***	-0.0870***	-0.1332***	0.0466**	0.2283***

TABLE 5

Robust estimations results for equation (1). Analysis of productivity from 1989 to 2009.
(t-statistics in parentheses)

Variables	**(A) Fixed**	**(B) Random**	**(C) Fixed**	**(D) Random**	**(E) Fixed**
Calendar year 1989-2009 *(TIME1)*	-117.51* (-1.89)	-119.90** (-2.02)			
Periods of three years *(TIME3)*			-320.19* (-1.80)	-320.92* (-1.87)	
Period 1992-1994 *(TIME9294)*					-84.92 (-0.11)
Period 1995-1997 *(TIME9597)*					-792.43 (-1.31)
Period 1998-2000 *(TIME9800)*					-563.50 (-0.83)
Period 2001-2003 *(TIME0103)*					-722.59 (-0.92)
Period 2004-2006 *(TIME0406)*					-1380.30* (-1.65)
Period 2007-2009 (*TIME0709)*					-1969.27* (-1.90)
Environmental costs per hectare *(ENVCHA)*	5.66*** (9.34)	6.02*** (8.72)	5.65*** (9.33)	5.18*** (7.45)	5.65*** (9.32)
Annual work units *(lnAWU)*	4,425.87*** (2.66)	4,676.91*** (2.82)	5,117.11*** (2.69)	5,720.34*** (2.66)	5,174.57*** (2.73)
Machinery to total assets *(MACHINERY)*	33,832.48** (2.53)	33,474.37*** (2.59)	33,658.47** (2.52)	33,534.5*** (2.59)	33,297.91** (2.47)
Economic size units *(lnESU)*	-2,237*** (-2.34)	-2,302.78*** (-2.93)	-2,366.64*** (-2.82)	-2,395.75*** (-2.97)	-2,432.36*** (-2.86)
Subsidies on investments to outputs *(INVESUBS)*	-2,169.93 (-1.22)	-2,607.27 (-1.54)	-2,093.69 (-1.18)	-2,856.75 (-1.60)	-2,166.49 (-1.22)
Subsidies for production to output *(PRODSUBS)*	1,344.56 (0.92)	1,465.81 (0.76)	1,173.46 (1.18)	939.94 (0.67)	1151.63 (0.73)
Agri-environmental payments to outputs *(ENVISUBS)*	22,125.20** (2.19)	22,724.94** (2.23)	21,040.42** (2.15)	21,131.20** (2.16)	17,433.09** (2.15)
Field-crops *(FIELDCRO)*		-16,813.92*** (-3.39)		-16,814.25*** (-3.39)	
Wine *(WINE)*		-1,1291.64** (-2.36)		-1,1352.13** (-2.36)	
Other permanent crops *(OPERCROP)*		-12,312.45*** (-2.59)		-12,358.05*** (-2.59)	
R-sq: overall	0.80***	0.79***	0.80***	0.79***	0.80***

Notes: *Significant at a 10% level. **Significant at a 5% level. ***Significant at a 1% level.

TABLE 6

Robust estimations results for equation (2). Analysis of environmental costs from 1989 to 2009.
(t-statistics in parentheses)

Variables	**(A)** **Fixed**	**(B)** **Random**	**(C)** **Fixed**	**(D)** **Random**	**(E)** **Fixed**
Calendar year 1989-2009 *(TIME1)*	23.58** (2.49)	17.03** (2.11)			
Periods of three years *(TIME3)*			68.38** (2.39)	49.65** (2.02)	
Period 1992-1994 *(TIME9294)*					11.71 (0.12)
Period 1995-1997 *(TIME9597)*					147.81 (1.43)
Period 1998-2000 *(TIME9800)*					216.38* (1.85)
Period 2001-2003 *(TIME0103)*					212.70* (1.70)
Period 2004-2006 *(TIME0406)*					314.86** (2.29)
Period 2007-2009 (*TIME0709)*					406.06** (2.48)
Output per hectares *(OUTPHA)*	0.09*** (8.47)	0.09*** (8.99)	0.09*** (8.46)	0.09*** (8.99)	0.09*** (8.43)
Machinery to total assets *(MACHINERY)*	-4772.86*** (-2.94)	-3977.87*** (-2.86)	-4777.92*** (-2.94)	-3984.67*** (-2.87)	-4743.13*** (-2.92)
Economic size units *(lnESU)*	11.84 (0.10)	139.50 (1.50)	23.35 (0.19)	145.17 (1.54)	32.23 (0.26)
Subsidies on investments to outputs *(INVESUBS)*	-166.22 (-0.54)	-147.89 (-0.57)	-174.15 (-1.23)	-152.51 (-0.58)	-177.50 (-0.56)
Subsidies for production to output *(PRODSUBS)*	-249.73 (-1.32)	-197.99 (-1.11)	-228.49 (-1.23)	-182.18 (-1.04)	-244.51 (-1.04)
Agri-environmental payments to outputs *(ENVISUBS)*	-3580.47*** (-2.66)	-3025.63*** (-2.51)	-3476.84*** (-2.61)	-2954.72** (-2.46)	-3403.84** (-2.25)
Field-crops *(FIELDCRO)*		-1126.84*** (-3.94)		-1129.33*** (-3.95)	
Wine *(WINE)*		-1595.52*** (-6.15)		-1593.54*** (-6.13)	
Other permanent crops *(OPERCROP)*		-1497.28*** (-5.65)		-1497.28*** (-5.64)	
R-sq: overall	0.79***	0.83***	0.79***	0.83***	0.79***

Notes: *Significant at a 10% level. **Significant at a 5% level. ***Significant at a 1% level.