Cambiamenti climatici e agricoltura in Italia: un’analisi delle fronterie stocastiche a livello regionale

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Climate change effects and Agriculture in Italy: a stochastic frontier analysis at regional level

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Abstract
Climate changes, associated to atmospheric accumulation of greenhouse gases, could alter level of temperature at the surface, rainfalls and regional water supplies. There are many areas of the Earth that will cope with a rapid increasing of warming the surface and with an extremization of weather conditions. Although many economic sectors are influenced, agriculture is the most susceptible as weather heavily affects crop production trends, yield variability and reduction of areas suitable to be cultivated. Climate change effects represent a “challenge” that European agriculture has to face in the immediate future. The aim of our work is to analyze the economic impacts of climate change on agricultural sector in Italy at regional scale (NUTS2). Using the stochastic frontier approach, we investigate on the Italian Regions technical efficiency in the period 2000-2010. Considering that technical inefficiency could be influenced by two main meteorological factors – rainfall and minimum temperature– we find that the rainfall variable has a positive impact on technical efficiency while the deviation of minimum
temperature from the 1971-2000 mean value reduces the technical efficiency of harvested production.

**Key words:** CC effects, agricultural sector, stochastic frontier approach

**Climate change effects and threats for agricultural sector**

It is very likely that most of the warming since the mid 20th century is due to the observed increase in greenhouse gas (GHG) atmospheric accumulation, as a result of emissions from human activities of production and consumption. Climate changes (CC) have altered the level of temperature at the surface, rainfalls and regional water supplies. CC means rainfall patterns shifting, glaciers and snow melting, and the global mean sea level rising. The global temperature has risen by about 0.8 °C over the past 150 years, and is projected to increase further. Exceeding an increase of 2 °C above pre-industrial temperatures raises the risk of dangerous changes for global human and natural systems. It is expected that these changes will continue, and that extreme weather events resulting in hazards such as floods and droughts will become more frequent and intense.

Many areas of the Earth and many economic sectors are influenced by a rapid increasing of warming and of an extremization of weather conditions. Impacts and vulnerabilities for nature, the economy and human health differ across regions, territories and economic sectors in Europe. Agricultural sector is one of the most susceptible as weather heavily affects crop production trends, yield variability and reduction of areas suitable to be cultivated, as well as in the Mediterranean countries. The historic agricultural vocation of Italy is confirmed since it is the second largest producer of “fruit and vegetable” in Europe after Spain, offering a wide range of high quality products, a lot of typical Mediterranean products officially recognized as IGP and DOP are produced. Thus, Italy could be strongly affected by the negative consequences of CC, leading to inefficiency in the agricultural sector. In the last twenty years, a growing number of extreme weather events and the rising of minimum temperature occurred. Rising shortage of water in several areas of our country during some months of the year threatened crops and areas suitable for cultivation with substantial losses. In some regions of South of Italy, desertification has continued to increase since 1970 forcing the abandonment of local crops and the choice of new cultivations more resistant to the heat in the summer time.

Many studies have investigated the long-term economic effects of CC on agricultural sector (CEDEX, 2000; Christensen and Christensen, 2002; Giupponi and Shechter, 2003 and Xionget et al., 2010). In contrast, few studies have performed short-term analyses at a sub-regional level (Dono and Mazzapicchio, 2010b). In the case of agriculture and water management, models, based on Discrete Stochastic Programming \(^1\) (DSP) model, have been used to forecast the effects on agriculture of changes in water availability due to CC.

The aim of this work is to analyze the effects of CC on Italian agriculture in the period 2000-2010 at regional level, on the basis of data available, considering as production the sum of all the harvests in the agricultural sector. Many of these agricultural products need more water and suitable microclimatic conditions and could suffer for long drought periods

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\(^1\) DSP models allow the representation of a sequence of choices that are made under conditions of uncertainty (McCarl and Spreen, 1997). In particular, it allows the representation of decision-making concerned with production activities conducted at certain times (stages), which are influenced by certain conditions (states of nature) that are not known with certainty.
and “out of season” meteorological events. By using official statistics, mainly produced by Istat, this paper intends to evaluate the economic effects on agriculture of CC in terms of rainfall and minimum temperatures, considered as the main components of CC (IPCC, 2007; Solomon et al., 2007). In particular, we want to consider the effects of CC on the efficiency of agricultural crop harvested in terms of yields and the implications on the agricultural production at regional level (NUTS2) during the last decade.

**Evaluating Climate Change economic effects on Italian agriculture at regional level**

In the last thirty years, the negative effects of CC has been increasing and more valuable. To evaluate climate-related impacts on the agricultural sector across regions of our country long run time series of data should be necessary. Forced by data availability, the focus of our analysis is mainly on the Italian regions’ efficiency during the period 2000 to 2010.

A dataset of CC and agriculture sector at regional level for the period examined has been constructed by using official statistics mainly produced by ISTAT for inputs and output of the production function and some proxies of climate change and water management. In particular, we collected data on: i) agricultural harvested production and production areas, from the Istat survey of Estimate of Crop, Flower and Plot Plant Production and Area, ii) irrigated areas, seeds and fertilizer used, days of work of farm employees, from both Istat Survey on Agricultural Holding Structure and Output and V and VI Agricultural Census, and finally iii) temperatures and rainfall drawn by Meteo-Climatic and Hydrological Istat Survey. In particular, we use the deviation of annual total rainfall average from 1971-2000 rainfall average value and the deviation of annual minimum temperature average from 1971-2000 minimum temperature average value, assumed in the model as proxies of the CC.

It would be consistent with our aim to take into consideration the use of water in the agriculture sector measured by physical units. In the production model, we could have included the variable “volumes of irrigation water used” instead of “irrigated areas” but official statistics on volumes of irrigation water used in Italian agriculture do not exist until Istat Agricultural Census 2010. To show the importance of this variable in agricultural analysis, we compare volumes of irrigation water with irrigated areas and total harvested production, jointly available for Italy only for the year 2010, as in Figure 1.

The chart underlines the multifaceted situation for each Italian region. As regards the volumes of irrigation water required, we note that Lombardy and Piedmont claim for a very large amount of quantity, respectively more than 4.5 billion and 1.8 billion. They are used to irrigate a lot of hectares for the cultivations. The irrigated areas are respectively more than 580 thousands and 366 thousands of hectares for Lombardy and Piedmont. What is the most amazing consideration is that Lombardy uses about the 42.26% of the total of irrigation water used in Italy to obtains only the 4.39% of the harvested production with respect to the total production. More or less is the same for Piedmont in which, using the 16.64% of water to irrigate the land, the harvested production represents only the 2.93% of the total harvested crops produced in 2010. While, in the opposite case, we find Emilia-Romagna and Puglia, where respectively they use only the 6.84% and 5.90% of total volume of irrigation water to obtain a harvested production of 11.17% and 15.13% with respect to the total harvested crops produced in the same year.
Quite certainly, this situation could be the consequence of the different typologies of crops cultivated in each region. Some of which could be more sensitive to longer period of drought due to higher minimum temperature phenomena or to the “out of season” events such as huge rainfalls. Also, it should be taken into consideration the hydrological and geological characteristics of the different areas considered and the ability of adaptation of each region to CC in the short run. In conclusion, to evaluate the CC effects on irrigation water used in the long run we should have analyzed long time series on the impacts of CC on agriculture but unfortunately we are bounded by the availability of data from the national official institutions.

**Italian Regions efficiency in agriculture: a Stochastic Frontier Approach**

Italy, belonging to the Mediterranean area, could be influenced by the CC negative effects in the agricultural sector. To test whether a statistical relation exists between regional technical inefficiency and the CC effects, we apply stochastic production frontier techniques to our sample. According to the neoclassical paradigm, production is always efficient if several hypotheses are stringent. However, it is unrealistic that two regions – even if identical – can have a similar income with the same endowments. The main idea is that the maximum output frontier for a given input set, is assumed to be stochastic in order to capture exogenous shocks beyond the control of individuals. Since all individuals are not able to produce the same frontier output, an additional error term is introduced to represent technical inefficiency. The difference between two regions can be explained through the analysis of efficiency and some unforeseen exogenous shocks (Kumbhakar e Knox-Lovell, 2000). A simple OLS regression is not sufficient to estimate the relationship between output and inputs because it has several limits (e.g. does not discriminate between rent extraction and productive efficiency; does not simultaneously take into account distances from the efficient frontier for a given production function). To measure regional (in)efficiency, we es-
timate individual production functions using the stochastic frontier approach developed mainly by Aigner et al., (1977); Meesun and Van den Bröck (1977). The advantages of this methodology could be summed up in two aspects. First, production inputs and (in)efficiency factors are separated in two distinct functions and second distances from the efficient frontier between those due to systematic components and those due to noise are disentangled.

To separate the effects of production inputs (labour and physical capital) from inefficiency factors which are the main causes of drought, we assume that the production function takes the constant returns-to-scale log-linear Cobb-Douglas form:

\[
\ln(Y)_{it} = \beta_0 + \beta_1 \ln(K_{seed})_{it} + \beta_2 \ln(K_{fert})_{it} + \beta_3 \ln(K_{irrig\_area})_{it} + \beta_4 \ln(L)_{it} + v_{it} - u_{it} \quad (1)
\]

and the inefficiency model:

\[
u_{it} = \gamma_0 + \gamma_1 \text{Rainfall}_{it} + \gamma_2 \text{Temp\_min}_{it} + \gamma_3 \text{North\_west}_{it} + \gamma_4 \text{North\_east}_{it} + \gamma_5 \text{Centre}_{it} + \gamma_6 \text{South}_{it} + \epsilon_{it} \quad (2)
\]

where \(Y\) is the ratio between production harvested and production areas, physical capital is measured by \(K_{irrig\_area}\) which represents the irrigated areas, \(K_{fert}\) which means fertilizers used and \(K_{seed}\) which is seeds used, and labour force is measured by \(L\) which corresponds to days of work in the farms. \(\text{Rainfall}\) is calculated as the deviation of annual total rainfall average from 1971-2000 rainfall average value and \(\text{Temp\_min}\) represents the deviation of annual minimum temperature average from 1971-2000 minimum temperature average value. The Dummy macro-areas are as usual: North-west, North-east, Centre, South.

The stochastic frontier estimation allows us to measure productive efficiency based on harvested production in Italian regions. The technical efficiency of the \(i\)-th region in the \(t\)-th time period is given by

\[
TE_{it} = e^{-u_{it}} = e^{(-z_{it}\delta - \epsilon_{it})} \quad (3)
\]

The technical (in)efficiency values will oscillate between 0 and 1, being the latter the most favourable case. Following Battese and Corra (1977), the simultaneous maximum likelihood estimation of the two-equation system is expressed in terms of the variance parameters \(\sigma^2 = \sigma^2_v + \sigma^2_u\) and \(\gamma = \sigma^2_u / (\sigma^2_v + \sigma^2_u)\) to provide asymptotically efficient estimates. Hence, it is clear that the test on the significance of the parameter \(\gamma\) is a test on the significance of the stochastic frontier specification. (The acceptance of the null hypothesis that the true value of the parameter equals zero implies that \(\sigma^2_u\), the non-negative random component of the production function residual, is zero.)

The SFA model: empirical results

The maximum-likelihood method of the SFA is used in our analysis to estimate the coefficients of the stochastic frontier of production and of the inefficiency model for 20 Italian regions in the period 2000-2010. Results are presented in Table 1 where the Cobb-Douglas production function’s and the inefficiency model’s estimated coefficients are reported. Because, in all specifications, we reject the null hypothesis of the insignificance of the non-negative error component (\(\gamma\)), we conclude that the SFA is a good model to analyse the effect of local environmental spending on the regional economic performance. Moreover, the parameter (\(\gamma\)) also indicates the proportion of the total variance in the model that is ac-
counted for by the inefficiency effects. This parameter, which is significant at the 1% level in all estimations, is 0.98 indicating that 98% of the variance is explained by the inefficiency effects, confirming that the inefficiency effects are important in explaining the total variance in the model.

Results compare three different estimations. In the first and the second estimation, Rainfall and Temp_min are considered separately, while in the last column the two variables are included jointly. The production function performs rather well. Physical capital measured by fertilizers used (Kfert) and irrigated areas (Kirrig_area) shows always a positive and significant sign, while physical capital measured by seeds used (Kseed) shows a negative sign albeit insignificant. Labour force measured by days of work in the farms (L) shows a negative and significant coefficient.

As regards the inefficiency model coefficients, Rainfall variable shows a negative and significance sign, meaning that the more is the rainfall the less inefficient or the more efficient is the agricultural production on cultivated area for the Italian regions. The positive sign of the minimum temperature variable implies that the more is the minimum temperature the more inefficient or the less efficient is the agricultural production.

The geographical location of regions is not relevant, because all macro-areas have positive effects on efficiency.

Table 1 – Results of the production and inefficiency model

<table>
<thead>
<tr>
<th>Dependent variable: Prod/L</th>
<th>Model 1</th>
<th></th>
<th>Model 2</th>
<th></th>
<th>Model 3</th>
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<tr>
<td></td>
<td>coeff</td>
<td>t-value</td>
<td>coeff</td>
<td>t-value</td>
<td>coeff</td>
<td>t-value</td>
</tr>
<tr>
<td>Const</td>
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<td>-2.87</td>
<td>-1.15***</td>
<td>-2.79</td>
<td>-1.17***</td>
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<td>-1.39</td>
<td>-0.02</td>
<td>-1.08</td>
<td>-0.02</td>
<td>-1.03</td>
</tr>
<tr>
<td>Kfert</td>
<td>0.27***</td>
<td>6.94</td>
<td>0.26***</td>
<td>7.08</td>
<td>0.26***</td>
<td>6.89</td>
</tr>
<tr>
<td>Kirrig_area</td>
<td>0.08*</td>
<td>1.94</td>
<td>0.09**</td>
<td>2.21</td>
<td>0.08*</td>
<td>1.83</td>
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<tr>
<td>L</td>
<td>-0.95***</td>
<td>-23.01</td>
<td>-0.95***</td>
<td>-22.79</td>
<td>-0.95***</td>
<td>-22.27</td>
</tr>
<tr>
<td>Const</td>
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<td>8.44</td>
<td>1.29***</td>
<td>7.27</td>
<td>1.31***</td>
<td>7.02</td>
</tr>
<tr>
<td>Rainfall</td>
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<td></td>
<td></td>
<td>-0.01*</td>
<td>-1.78</td>
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<tr>
<td>Temp_min</td>
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<td></td>
<td>0.19</td>
<td>1.10</td>
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<td></td>
<td></td>
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<tr>
<td></td>
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<td>Neg. sign</td>
<td>Yes</td>
<td>Neg. sign</td>
<td>Yes</td>
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<tr>
<td>Sigma squared</td>
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<td>6.28</td>
<td>0.41***</td>
<td>6.89</td>
<td>0.41***</td>
<td>5.77</td>
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<tr>
<td>Gamma</td>
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<td>160.87</td>
<td>0.97***</td>
<td>139.77</td>
<td>0.97***</td>
<td>119.73</td>
</tr>
</tbody>
</table>

Note: *, ** and *** indicate significance at 10%, 5% and 1% levels

Source: our estimations are based on ISTAT - Annual Agricultural Crops Survey, V and VI Agricultural Census, Structure and Production of Agricultural Farms SPA sample Survey, Annual Census Survey on fertilizers allocation and ISTAT - Survey of Seasonal climate-weather trend in Italy

To deepen our analysis, we estimate technical inefficiencies for each region, using the model described in the third column. We report the technical inefficiencies of Italian regions for three separate years - 2000, 2004 and 2009 -which represent three non-missing data year among regions. We then rank the Italian regions according to the level of inefficiency reached in 2000.

The results show that the inefficient regions are Sardinia and Valle d’Aosta as we expected because these two regions are the less agricultural-sector-oriented. On the other extreme we find Veneto, Friuli-Venezia Giulia and Emilia Romagna, in which agriculture is relevant. Among the South regions, Sicily is the less efficient meaning that it should be more influenced by the negative effects of climate change.
Conclusions

In these last decades climate change effects, associated to atmospheric accumulation of greenhouse gases, have altered the level of temperature at the surface, rainfalls and regional water supplies. A rapid increasing of warming at the surface joined with an extremization of weather conditions have influenced agriculture production because it is the most susceptible to climate variability and extreme weather events. While some of the envisaged consequences could be beneficial for agriculture in the Northern areas of Europe, it is not the case for the Mediterranean countries. For all these reasons, CC effects represent a “challenge” that European agriculture has to face in the immediate future. In our empirical analysis, we consider the economic impacts of climate change on agricultural sector in Italy at regional scale (NUTS2) in the light of mitigation policies undertaken by Italy in accordance with the commitments made by the EU Policy in the struggle against climate change. Using the stochastic frontier approach, we investigate on the Italian Regions efficiency in the period 2000-2010. Considering that inefficiency could be influenced by two main meteorological factors – rainfall and minimum temperature– we find that rainfall variable has a positive impact on efficiency while minimum temperature variable reduces the efficiency of harvested production. Our analysis is bounded by the availability of long time series data. The amazing reaction to CC could be seen as a short run response. This does not exclude that, in the long run, the extremes of weather could lead to serious irreversible damages in the agricultural sector.

Having in mind all these limitations, we think that more and deepen analyses should be carried on such as using the value of the harvested production disaggregated according to the main typologies of plantations in each Italian region or considering in a better way the mitigation policies undertaken by Italy in accordance with the commitments made by the EU Policy in the struggle against climate change.
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