Effects of Drought on the Agricultural System.

An Analytical Approach Based on the Production Function

M. Lanfranchi, C. Giannetto and A. De Pascale

University of Messina, Department S.E.A.M.
Via dei Verdi, 75, 98122 - Messina, Italy

Abstract

Desertification is one of the most serious environmental priorities that affect the Mediterranean territories. The Mediterranean climate, typically characterized by an irregular rainfall pattern with hot, dry summers, may constitute a further element of imbalance. This study is focused on the measuring of temperature increases, as a consequence of climate change and as a crucial environmental factor. The methodology proposed is an attempt to give measurements of drought in the valuation of an agricultural production function. A close examination of agronomic sciences reveals that agricultural output is influenced more by heat wave distribution than by the average temperature of the heat wave. In this analysis, the probability of distribution (frequency of occurrence) of local average temperature anomalies, was conducted taking into consideration the changes of seasonal temperature in units of standard deviation (σ).

Keywords: Drought, Mediterranean basin, Agricultural production function, Climate change, Farm

1 Introduction

Urban sprawl and concentration of people and activities in coastal areas of the Mediterranean basin, in particular the Region of Sicily, considered as one of the most drier areas of southern Europe and characterized by an intensive agricultural
land use, determines water requirements that exceed the actual availability (Cooper, and Arblaster, 2007). Climate change may exacerbate this process and, in some cases, could represent one of the conditions that reduce production. In order to define the concept of drought, this analysis takes into consideration a study conducted by Wilhite and Glantz in which a review of many of the definitions of drought is carried out identifying six overall categories: meteorological, climatic, atmospheric, agricultural, hydrologic and water management (Wilhite, and Glantz, 1985). All categories seem to agree that drought is a condition of insufficient moisture caused by a deficit of precipitation over a given period. In this study the definition of drought was considered in agricultural terms, in particular, it examines the risks in terms of yield, linked to a drought condition (Lanfranchi M., Giannetto C., Puglisi A., 2014). In this light, it is regarded as the process that leads to an irreversible reduction of the soil's ability to produce resources due to limitations of the climate.

2 Materials and methods

The nature of agriculture and farming practices are strongly influenced by the long-term average climate state, the experience and infrastructure of local farming communities are generally appropriate to particular types of farming and to a particular group of crops which are known to be productive under the current climate (Lanfranchi, 2010). Changes in the average climate different to current conditions may require adjustments to current practices in order to maintain productivity, and in some cases the optimum type of farming could change (Lanfranchi M., Giannetto, C., De Pascale A., 2014). Higher growing seasonal temperatures can influence agricultural productivity, farm income and food security. Another aspect regards water resources, which is considered vital to plant growth and a variation in precipitation patterns can have a significant impact on agriculture. In order to evaluate the impact of environment as a factor in food production the classic production function was considered, taking into consideration a fourth factor of production (M) in accordance to agricultural economics literature:

\[ Y = f(K, H, L, M) \]  

(1)

Where, \( Y \) = physical product , \( K \) = capital, \( H \) = labour, \( L \) = land, \( M \) = that can be described as the farmers’ management capacity in order to maximize the organization of the productive factors. Nevertheless, these elements cannot be considered as an exhaustive model to represent the different variables that affect the agricultural production. This model shows its limits when up against environmental issues. In fact, as production is itself dependent on natural resources, the physical production and labour decrease with the running out of natural resources (Colby, 1989). The consideration of natural capital refocuses the theoretical debate on sustainable development (Batie, 1989; Piriou, 1997). Thus,
natural capital must be considered in the explanation of agricultural production just like physical and human capital. In this model, other factors had to be included, in particular: endowments of basic factors of production (and the resulting substitutability or elasticity); agro-ecological factors (including loss of agricultural land and scarcity of water); access to modern know how and production inputs (including fertilizers and nutrients); sea level rise; structure and diversity of production activities; aging farm population and other personal characteristics; institutional agreements (e.g. CAP which reduced economic incentives for farmers) (Lanfranchi M., Giannetto C., 2014). In addition, the environment has been included (including factors such as rainfall, soil type, humidity, temperature, erosion and vegetation). In this light, the production function is defined as a function of land \( (L) \), environmental effect \( (E) \) and management effect \( (M) \):

\[
Y = f(L)g(E)h(M)
\]

(2)

### 3 Methodology and Analytic Approach

In order to evaluate the impact of climate change on the production function this analysis is used on the negative effects that drought can determine in the agriculture sector. In this study the measuring of the incidence of drought frequency in agricultural production function is conducted by the introduction of the standard deviation of drought, it is presumed, according to the studies on climate change, that there is an increase in temperatures, in particular in the coastal areas with a consequent increase in the days of drought (Lanfranchi M., et al, 2014).

To this end, the analysis takes into account the following assumptions: the analysis of daily temperature data of seasons in a specific country/region over many years; the calculation of the average of the daily temperature of a given year; the calculation of the intra-annual variation of the temperature (days of drought) within a given year represented by the standard deviation of temperature. The intent is to identify a potential measure to set the vulnerability of the territory to the risk of desertification and consequently on the yield of the agricultural sector (Lanfranchi, M., Giannetto, C., Zirilli, A., 2014). This feature becomes important in order to examine other indicators connected to the territory such as water quality, socioeconomic aspects (such as depopulation or migration), soil fertility, forest fires, erosive phenomena, etc. which can affect the productivity of the whole sector. Drought is one of the main natural causes of agricultural, economic, and environmental damage (Burton et al, 1978; Haley, 1994). A reduction in precipitation due to climate change will affect the severity of droughts. However, climate change scenarios also show a temperature increase during the twenty-first century, undoubtedly this increase will have consequences for drought conditions (Lespinas et al, 2010). In this regard a drought index can be defined as a dynamic
index because it is based on the temporal variability of the differences that arise between the average of extremely hot days in a definite period and those pertinent to each year, or month, taken into consideration. This is done usually by comparing the current situation to the historical average. This analysis has the purpose of describing the variability of the observed seasonal temperature as abnormal in respect to the average temperature in a control period and it can be applied to a period of thirty years, which is considered, by several climatic indices and studies, as an appropriate control period to observe both the variability or stability of temperatures and the range of time over which humanity and other planetary life are able to adapt.

4 Results of Study on the Calculation of a Drought Variability Index

Drought is a protracted period of deficient precipitation resulting in extensive damage to crops and loss of yield. It is an insidious hazard of nature and its impacts vary from region to region. In this light, is presumed that in a given country/region, there are \( p \) agro-ecological areas \( A_i \), with \( i = 1, \ldots, p \) and \( S^i_\bar{z} \) seasons in a given zone \( z = 1, \ldots, k \), it can be shown that the average number of days of drought of \( p \) zones in a given period (in accordance with the literature on climate changes) in a given country is:

\[
\bar{m} = \frac{\sum_{i=1}^{p} m_i}{p}
\]

In which \( m_i \) is the average of all the areas \( A_i \), \( i = 1, 2, \ldots, p \). Where:

\[
m_i = \frac{\sum_{z=1}^{k_i} m_{iz}}{k_i}
\]

In which \( m_{iz} \) denotes the average of the given season \( S^i_\bar{z} \) (\( k_i \) seasons) in the area \( A_i \), with

\[
m_{iz} = \frac{\sum_{j=1}^{d_{iz}} D_j^i}{|S^i_\bar{z}|}
\]

In which \( d_{iz} \) denotes the total number of heat wave peaks during the season \( S^i_\bar{z} \) in the area \( A_i \), \( |S^i_\bar{z}| \) is the total length of the season \( S^i_\bar{z} \) in days and \( D_j^i \) the quantity of daily maximum temperatures relative to the \( l \)-th day during the season \( S^i_\bar{z} \). After that, by substituting the formula in the equation, it is possible to show that the average days of drought in the country or region during a certain growing period (i.e. a year) is equal to:
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\[
\bar{m} = \frac{\sum_{i=1}^{p} \sum_{z=1}^{k_i} m_{iz}}{p} = \sum_{i=1}^{p} \frac{1}{p} \left[ \sum_{i=1}^{k_i} \sum_{z=1}^{d_i} D_{iz} \right] = \sum_{i=1}^{p} \frac{1}{p} \sum_{i=1}^{k_i} \sum_{z=1}^{d_i} D_{iz} \quad (6)
\]

it follows:

\[
\bar{m} = \sum_{i=1}^{p} \sum_{z=1}^{k_i} \frac{D_{iz}}{k_i} \quad (7)
\]

The average of variation of daily maximum temperature (or heat wave peaks) \(V_i\) of \(p\) areas \(A_i\) in a given year in a given country is:

\[
v = \frac{\sum_{i=1}^{p} V_{iz}}{k_i} \quad (8)
\]

With \(A_i = A_1, A_2, ... A_p\) and given \(V_i = V_1, V_2, ... V_p\). The variation of daily maximum temperature in the Area \(A_i\) is calculated as follows. Given \(k_i\) seasons in the area \(A_i\) if \(V_{iz}\) is the variation of daily maximum temperature calculated over one season \(S_i\) in the area \(A_i\), it follows:

\[
V_{iz} = \sum_{i=1}^{k_i} \frac{V_{iz}}{k_i} \quad (9)
\]

Where \(V_i\) is the average of the daily maximum temperature variation of \(k_i\) seasons \(S_i, S_2, ... S_k\) in the area \(A_i\). In order to calculate \(V_{iz}\), \(m_{iz}\) was considered as the daily maximum temperature average over the season. The following was taken into account:

\[
V_i = \frac{\sum_{i=1}^{k_i} (D_{iz} - m_{iz})^2}{|S_i|} \quad m_{iz} = \frac{\sum_{q=1}^{d_i} D_{iq}}{|S_i|} \quad (10)
\]

And

\[
V_{iz} = \frac{\left( D_{iz} - \sum_{q=1}^{d_i} \frac{D_{iq}}{|S_i|} \right)^2}{|S_i|} \quad (11)
\]

Then, it can be shown that:
The standard change of daily maximum temperature (or heat wave peaks) as the index of drought variability in a given year in a given country/region is:

\[ \sigma = \frac{1}{\sqrt{v}} \quad \text{or} \quad DGT = \frac{1}{\sqrt{v}} \]  

In conclusion, the theoretical model can be expressed as follows:

\[ Y_t = \alpha_0 + \alpha_1 Z_1 + \alpha_2 Z_2 + \alpha_3 Z_3 + \alpha_4 Z_4 + \alpha_5 CF + \alpha_6 NE + \alpha_7 RF + DGT + \varepsilon \]  

In which, \( Y \) is the agricultural production index, it determines the crop yield in a site in a given period of time (t); \( Z_1 \) is the index of cultivated area in Km\(^2\) per capita; \( Z_2 \) is the index of irrigated agricultural area on the total of all the agricultural areas and represents the investment in rural infrastructures; \( Z_3 \) is the quantity of fertilizers and nutrients index per hectare and represents the level of agricultural technology; \( Z_4 \) is the employment index, it is important because of the increased number of elderly people and the migration phenomenon; \( CF \) represents the constraining factors (such as water, seeds, fertility, etc.); \( NE \) denotes the negative externalities (in particular the production of methane and nitrous dioxide) \( RF \) is the total precipitation in the period; \( DGT \) is the index of drought variability; \( \varepsilon \) is the error term. All the variables being expressed in logs and the coefficients obtained are the elasticities.

5 Conclusions

The agricultural production index is the result of a model which includes management and climate variables and can be used to estimate whether the drought phenomenon affects the crop yield in a specific site in a specific period of
time. A review of the literature showed that temperature rise affects the severity of droughts. The Mediterranean Region is likely to suffer global warming significantly over the next century, as well as rising concentrations of greenhouse gases (Costantini et al, 2010). In this light, the agricultural production function can be used to optimize the technological inputs as an adaptation response to climate variations (Tudisca, S., et al., 2014). Climate risk can be managed by altering decisions before and during the growing season, such as the level of inputs (low levels of fertilizers in dry seasons and developing patterns of crop rotation or through a greater use of natural fertilizers e.g. biomass), irrigation regimens, in addition to alternative strategies to manage agricultural production in coastal areas with water difficulties.

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