Economic Implications of Climate Change for Agricultural Productivity

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Abstract: - The agriculture sector is highly exposed to climate change and, consequently, to its risks. The climate risk is capable of altering other risks such as asset depletion (damage and loss to assets as a result of extreme climate events), price risks (risk of falling or rising prices) and financial risk (from possible increase of interest rates). Based on the assumption that climate changes indirectly affect the level of income through losses in capital, a Cobb-Douglas production function has been employed, using the different forms of capital as inputs. In particular, using a Cobb-Douglas production function and the marginal rate of technical substitution, the possibility to replace the use of irrigation water with the use of other inputs has come to light. The knowledge of these connections allows both a better use of water resources, and a more efficient use of other productive resources.

Key-Words: - Agricultural Economics, Climate Change, Agricultural Productivity, Production Function, Elasticity, Vulnerability, Adaptive Capacity.

1 Introduction

The agricultural sector, with its dependence on weather conditions, is likely to be the sector most affected by climate changes. In this paper the phenomenon of climate changes will be discussed in terms of mitigation or reduction and adaptation, and not in terms of a solution. In particular, this study will evaluate the capacity to adapt of farmers in order to cope with the risks and the negative effects of climate changes (Smith *et al.*, 2003). It is noticeable that the climate system responds to changes in greenhouse gas concentrations with a certain delay and, therefore, mitigation measures need to be combined with adaptation measures. Consequently, there are two challenges for the agricultural sector. The first one is to reduce greenhouse gas emissions and the second is to adapt the agricultural sector to the changes caused by the impact of climate change (Chang, K., Wang, S.-S., 2013). In relation to the production of carbon dioxide, it can be said that agriculture produces less greenhouse gas emissions than other economic sectors (Kralj, D, 2009). If on one hand, the main greenhouse gases associated with agricultural activity are methane and nitrous oxide, which are largely connected with fertilizer use and stock raising, on the other hand, agriculture can help to mitigate the negative effects of climate changes thanks to its important function of an active carbon basin, forests and more generally plants have a unique ability to reduce, at the same time, greenhouse gas emissions, capture carbon, and reduce the vulnerability of people and ecosystems to climate changes (Matei, M., Popescu, C., Rădulescu, I.G., 2012). Already, climate change is causing a large variation in crop yields. This will particularly affect small holders and subsistence farmers, as they may not have the means to adapt to these new conditions (Lanfranchi M., Giannetto C., 2013). This could lead to land abandonment and the movement of people from the affected rural areas, thereby disrupting rural development. The direct impacts of climate changes on agriculture can also be seen in soil fertility, the increased vulnerability of soil organic matter and higher risks of soil erosion caused by rising temperatures (Lanfranchi M., Giannetto C., Puglisi A., 2014). Taking these considerations into account, it is easy to argue that agriculture is strongly influenced by climate and weather and in particular by climate changes. While farmers are often flexible in the face of weather changes on a local scale, there is not, nevertheless, a high degree of adaptation to the global climate changes in the form of infrastructures, equipment, local farming practice or other significant experiences. Moreover, considering the literature on this subject, it emerges that there are there are many studies and researches focused on the impact of a particular aspect of climate change in a specific location, but there are relatively few studies which provide a global assessment. Moreover, these studies tend to focus more on the direct effects of changes in climate and do not consider changes in extreme or the indirect effects of climate changes such as sea-level rise or the effects of drought.

2 The Research Objective

In this paper the phenomenon of climate changes will be discussed in terms of mitigation or reduction and adaptation, and not in terms of a solution. Most of the impacts of climate changes in agriculture come through the availability of water. Water shortages will undoubtedly have a major impact on agricultural production. In this context, the risk analyzed affects the water resources, and in particular its supply, as a key factor in the success of interventions to improve agricultural productivity. This paper thus examines the possibilities of substituting water with other crop inputs introduced in the production function. On the basis of this assumption, it has been hypothesized that the issue that arises in understanding the impact of climate changes is how the different types of capital are affected, how they recover after these episodes and how each of them has an impact on output at national and regional levels. In accordance with the same authors, it is accepted that the impact of climate changes on output is indirect, that is, their effects affect output through their impact on the different forms of capital (inputs) that make up output. In this regard, the aim of this study is to see how climate changes affect the measures of each type of capital and how these changes in capital then effect output.

3 Research Approach: Risk Posed by Climate Change in the Agricultural Sector

Climate risk in agriculture represents the probability of a defined meteorological hazard which will in time affect the livelihood of farmers. Risk refers to a probability that can be estimated analysing prior information, while uncertainty applies to situations in which probability cannot be estimated. Both risks and uncertainties have to contribute to the choice of appropriate practices to be applied in the agricultural sector. Most of the impacts of climate changes in agriculture come through the availability of water. Water shortages will undoubtedly have a major impact on agricultural production. In this context, the risk analyzed affects the water resources, and in particular its supply, as a key factor in the success of interventions to improve agricultural productivity (Bulearcă, M., Popescu, C., Sima, C., Ghiga, C., Neagu, C., 2011). In this light, many areas, notably in southern EU countries which have practiced irrigation for hundreds of years as part of their farming tradition, probably need to review their irrigation techniques. Agriculture must also improve its water use efficiency and reduce water loss. Climate change is considered an important impact factor on the water resources, both directly through changing flow and temperature patterns, and indirectly through patterns of land management and use. Furthermore, climate changes will probably increase competition for scarce water resources amongst domestic, industrial, agricultural and conservation needs and uses. Other risks likely to affect competition for water resources during times of scarcity, can be identified in hydroelectricity production and drinking water. Unusual weather patterns, such as drought, or a prolonged rainy season, may lead to considerable morphological changes and modify ground and surface water flow and soil moisture content. Taking into account these considerations, the risk can be defined in economic terms as the amount that the farmer is willing to pay in order to avoid the risk of income losses as a consequence of climate variations.

4 Vulnerability and Adaptive Capacity

We can describe the vulnerability of a system in the face of climate change, in socio-economic and environmental terms, as a function of a system's exposure to the effects of climate changes and its adaptive capacity to those effects. In other terms, the more exposed a system is to a climate change, the more the system is vulnerable; on the contrary, the greater the adaptive capacity of the system to a given climate event, the less it is vulnerable. Some authors (Smith *et al.*, 2003) express this relationship as:

$$V_{it}^{s} = f(E_{it}^{s}, A_{it}^{s}) \tag{1}$$

In which: V_{it}^{s} = vulnerability of system *i* to climate change *s* in time *t*; E_{it}^{s} = exposure of system *i* to climate change *s* in time *t*; A_{it}^{s} = adaptive capacity of system *i* to face climate change *s* in time *t*. The application of the "vulnerable" approach coincides with the assumption that the resilience to existing climate stress is an important element for future adaptation. Regions with high historic climatic variability can be particularly important examples of adaptation capacity and climate resilience. From this point of view, a literature review (Polsky and Easterling, 2001) highlighted some examples, of agricultural adaptation to climate variation, in the U.S. Great Plains using a Ricardian study that included an index of historic climate change. In the conclusions it emerges that farmers and institutions in districts with high historic climate change were more resilient to climate variation, but that the underlying reasons and sustainability of these adaptations were unclear and needed to be investigated with field-level study of the individual farms, farmers and the institutions affecting agriculture. Some authors explained that the concept of resilience is to acquire the adaptive capacity to move from actions that attempt to control the changes, to managing the capacity of social ecological systems to adapt to the changes (Folke *et al.*, 2003). Some important elements that interact across temporal and spatial scales and that seem to be required in dealing with natural-resource dynamics during periods of change were identified: learning to live with changes and uncertainty; combining different types of knowledge and creating opportunity for self-organization.

5 Adaptive Capacities of Farmers To Cope With Climate Change

To describe the capacity of the farmers to adapt to climate changes, the assumption formulated by Klein will be used (Klein, 2002) in which the ability of a system or of an individual to adjust to climate change or climate variation so as to minimize the potential damages or cope with the consequences is described. Consequently, capacity to adapt is the ability to plan and use adaptation measures to minimize the effects of climate changes. It is assumed that farmers are rational and as such they adapt to climate changes in order to reduce the consequences and furthermore, that some farmers have more ability to adjust to climate changes than others.

6 The Production Function for Studying Inputs Substitution

Inputs substitution has been an active research topic in production and resource economics, starting with the estimation of the substitution elasticity by Hicks (Hicks, 1932). In this paper the concepts of substitution initially presented by Hicks (Hicks, 1938) are considered. Assuming that a single product firm employing two variable inputs: x_1 and x_2, if the output (Y) is held constant, convexity to the production isoquants it guarantees that x_1 and x_2 are net substitutes. However, as y varies in response to input price changes, substitution between x_1 and x_2 usually results in different levels of outputs. This is referred to as “gross substitution”. Instead “net substitution”, refers to equivalent crop yield or production through various combinations of inputs. In general, in small scales, such as the field, farm, or even district level, the concept of net substitution may apply, since at such scale changes in input quantities will typically not affect input prices. In larger scales, changes in input quantities can affect prices, unless subsidies are targeted at maintaining original input prices. Changes in water availability upstream can change outcomes for input substitution downstream. Similarly, increased use of nutrients upstream to substitute for declining water availability, for example, can degrade water quality and thus reduce water availability and substitution options for downstream users. Economic incentives, such as water use rights can make input substitution more attractive for some demand sites and less attractive for others, depending on the elasticity of substitution, which varies from one location to another. This paper thus examines the possibilities of substituting water with other crop inputs introduced in the production function.

In production economics, a production function is the basis for both theoretical and empirical input substitution studies. The issue is related to one of the main problems in production economics, the “aggregation” of a production function from a micro scale such as farm district to a macro scale such as a region. In economics, this has been referred to as the problem of “aggregation”, one of the neoclassical economic study issues bought about by the theoretical complexity of production function aggregation. For aggregation purposes, a study conducted by Houthakker (Houthakker, 1955) shows that the aggregate production function is Cobb-Douglas: if all units use the same production technology, and face the same price factors, use inputs efficiently, and work under conditions of perfect competition, then the aggregate production function can be a true version of the individual production functions. However, it is important to note that a major concern for empirical studies, using production functions, is the insufficient theoretical knowledge on elasticity of substitution. In particular, although many indicators have been developed to represent elasticity of substitution, “none of these is the one true elasticity of substitution, which one is useful depends on what we wish to measure” (Stern, 2004) and “for different problems, different demand functions may be pertinent and consequently different measures of substitution"(Mundlak, 1968).

7 Research Methodologies. Pragmatic Approach in Order to Evaluate the Capacity to Adapt to Climate Changes

Some works at the World Bank and elsewhere have emphasized the importance of different types of capital in determining a country's productive potential (World Bank, 2006). In particular it distinguishes physical (produced) capital from human, natural and social capital. Each is an important component of wealth and in time, as development takes place, the relative roles of different types of capital change.

Markandya and Pedroso-Galinato (Markandya and Pedroso-Galinato, 2007), provided empirical estimates of the impacts of natural disasters (in this case Global Warming) different forms of capital (with a focus on human and intangible capital and natural capital), and on real gross domestic product per capita. On the basis of this assumption, it has been hypothesized that the issue that arises in understanding the impact of climate changes is how the different types of capital are affected, how they recover after these episodes and how each of them has an impact on output at national and regional levels. In accordance with the same authors, it is accepted that the impact of climate changes on output is indirect, that is, their effects affect output through their impact on the different forms of capital (inputs) that make up output. In this regard, the aim of this study is to see how climate changes affect the measures of each type of capital and how these changes in capital then effect output. As expected these impacts will have a dynamic profile and it will be sought to understand this as much as possible. In this light and as assumed by Markandya and Pedroso-Galinato (Markandya and Pedroso-Galinato, 2007), the production function at the national level was based on four types of capital:

- Produced or physical capital (K) an aggregate of the value of equipment, machinery, structures (including infrastructures) and urban land;
- Human capital (H) there are two alternative measures: human capital related to educational accomplishments (HS), and human capital as part of the intangible residual capital (HR). The intangible residual capital consists of human capital and the quality of formal and informal institutions. It is measured as the difference between total wealth and the produced and natural capital (World Bank, 2006).
- Production and net imports of non-renewable energy resources (E) sum of the values of oil, natural gas, hard coal and lignite.
- Land resources (L) aggregated value of cropland, pastureland and protected areas.

However, a close scrutiny of agricultural economics literature in the past fifty years reveals that most of the estimation of production functions has been based on neo-classical growth models that emphasized physical and human capital accumulation. These models have shown their limits when faced with the environmental issues. In fact, as production is itself dependent on natural resources, the physical and labour productivity decreases with the running out of natural resources (Gillis *et al.*, 1998). The consideration of natural capital refocuses the theoretical debate on sustainable development (WCED, 1987; Colby, 1989; Batie, 1989; Piriou, 1997, Lanfranchi M., 2010). Thus, the natural capital has to be considered in the explanation of agricultural production just like the physical and human capital in the evolution of this study. In addition, it is assumed that a relatively high elasticity of substitution between different types of capital; for example, loss of natural capital can be made up relatively easily by increases in human and physical capital (e.g. technological change in the adaptation strategies), and that the efficiency of all capital is significantly influenced by changes in economic indicators (trade openness and private sector investment). For this analysis, the data on the four types of capital has been simplified and put together in order to adapt this study to agriculture production. In order to evaluate the impact of environmental factors on production, a neoclassical production function proposed by Solow and Swan represented the theoretical framework (Feebairn, 1994; Frisvold and Ingram, 1995). The simple representation of the model is:

$$Y = f(K, H, T) \tag{2}$$

Where, Y = physical product (output) , K = capital, H = labor, T = all the other factors including technology and environmental factors.

Then it is possible to define and to explicit the production function (Y) as a function of land (or herd size) L, environment effect E, and management effect G (which, in this case, includes the labor factor H, as the ability of farmer to organize input factors, and the achievable technology used for this aim. This, we assume, can be helpful to understand the ability of the farmer to cope the effects of climate change) represented as:

$$Y = f(L)g(E)h(G) \tag{3}$$

Where *f, g, h* are functions relating L, E, and G, respectively to Y. And where the Environment (E) includes factors such as rainfall, soil type, humidity, temperature, erosion and vegetation. In this light and in order to investigate the impact of climatic changes on Production (Y) of the agriculture sector in a specific Country or Region, we assumed that the productivity of the agriculture sector depends on the inputs used in production, the characteristics of the farmer and the adaptation strategies adopted to minimize the damages caused by climate change indicators (temperature, relative humidity, sunshine duration, rainfall and so on). According to Koutsoyiannis (Koutsoyiannis, 2003) and Musu (Musu, 2000) there is a technical relationship between the endogenous inputs and output expressed in the following production function:

$$Y = f(N,P,K,H,T) \tag{4}$$

In the production function there are four types of productive factors: the produced capital (K) which includes the factor (E). The human capital including the labour factor (H) measured in terms of farm employment and hours worked. The natural factors of production (P and N), that include Land resources (L) where L includes not only the site of production but natural resources above or below the soil; materials and energy are considered secondary factors in classical economics because they are obtained from land, labour and capital (Lanfranchi M., 2012). In particular, P represents the environmental exploitation and N the environmental quality. In the end, (T) is an indicator of technology which can be connected to the other factors of production (Musu, 2000).

Taking these considerations into account, we can say that the production function represents the technology of the farmer who transforms inputs into outputs at any given time. In this light, it can, also, be assumed that the environmental quality is a factor of production because it affects productivity.

The natural input P regards the flow of use of natural resources and of the environment, but also the production of pollution and refuse. In this group, in the agricultural sector, the irrigation water use and the use of fertilizers and nutrients are considered. Then, it is necessary to note that there are some factors, such as weather, that are out of the control of the farmer. Unusual weather patterns, such as drought, a prolonged rainy season, early or late frosts, and other factors, can ruin crops and bring productivity down. The capacity of a given farm is also an important factor. Soil cannot be forced to produce beyond capacity, although there are methods that can be used to improve production capacity, such as fertilizing to add nutrients to the soil so that it can support more crops, in that sense we consider T as the adaptive capacity of farmers. Pests can be another concern. In addition to spoiling crops, pests can also add significantly to the costs of producing a crop. Controlling them may require measures such as fences, chemical treatments, or companion planting, all of which change the ratio of inputs to outputs and contribute to increase the share of greenhouse gases.

A Cobb-Douglas production function which shows a technical relationship between input and output, with the intent of showing the relationship between the output and input including adaptive capacity, can be specified as:

$$Y_i = \beta_0 K_i^{\beta_1} H_i^{\beta_2} e^{u_i} \tag{5}$$

Where Y_i is the total output for i_{th} Country or region, β_0 is the constant, K_i is the capital input for i_{th} country or region, H_i is the labour input for i_{th} Country or region, μ_i is the error term for i_{th} Country or region and β_1 and $\beta 2$ are the slope coefficients for capital and labour respectively.

An enlarged Cobb-Douglass production is then specified as shown in the equation by including variables such as water (W_i); fertilizer (it represents the level of agricultural technology) (F_i); and land (L_i). Where for any Country *i* at time *t*, the Output (Y) is a function of a number of inputs:

$$\begin{aligned}\log(Y_{it}) &= \beta_1 + \beta_2 \log(H_{it}) + \beta_3 \log(W_{it}) + \beta_4 \log(F_{it}) + \\ &+ \beta_5 \log(K_{it}) + \beta_6 \log(L_{it}) + \beta_7 \log(R_{it}) + B_8 \log(M_{it}) + \\ &+ \eta_t + \mu_i + \varepsilon_{it}\end{aligned} \tag{6}$$

If in that formula it is assumed that the Output (Y) represents the Agricultural Output (Yeld) it can be assumed that the inputs H, W, F, K, and L are labour, water, fertilizer, capital, and land, respectively. Moreover rainfall, R, and temperature, M, as auxiliary climatic factors that may affect agricultural production are included.

8 Final Results Obtained

In order to investigate the capacity to adapt of farmers, a specific analysis regarding a particular productive factor and its relative elasticity to substitutability with another factor was conducted. In particular, for the aim of this study relative to the effect of climate changes, the factor investigated was the water, in relation to its scarcity and to its substitutability with another factor considered in the Cobb-Douglas production function, for example the technological factor (T) or land use factor (L), according to the study conducted by Moore et al. (Moore *et al.*, 1993). The purpose is to show how managerial policies (in this case capacity to adapt) aimed at saving water production a factor certain to affect the yields of agricultural crops.

To analyze this issue, attention is centred on the yield, i.e. the relationship between the volume of output and the utilized agricultural area (UAA), while the classical production function is expressed, as known, only in terms of output. The first step is, in this case, to rewrite the production function in terms of yield. The following production function Cobb-Douglas is considered:

$$Y = \beta W^{\alpha} R^{\psi} C^{\gamma} L^{\omega} \tag{7}$$

Where: Y= total output; β= k; W= amount of irrigation water or irrigated agricultural area (it represents the level of investment in rural infrastructures); R = amount of rainfall; C =average daily temperature; L = amount of land.

The sum of the exponents $\alpha+\psi+\gamma+\omega$ represents an indication of the return to scale. The parameters α, ψ, γ, ω can be interpreted as elasticity of the output with respect to the inputs included in the production function. Introducing the natural logarithm function it is possible to derive:

$$\log Y = \log\beta + \alpha\log W + \psi\log R + \gamma\log C + \omega\log L \tag{8}$$

and partial derivatives:

$$\frac{\delta\log Y}{\delta\log W} = \alpha; \frac{\delta\log Y}{\delta\log R} = \psi; \frac{\delta\log Y}{\delta\log C} = \gamma; \frac{\delta\log Y}{\delta\log L} = \omega \tag{9}$$

subsequently the relationship between percentage changes, which is the elasticity, is given by:

$$\frac{\delta\log y}{\delta\log x} \cong \frac{\Delta y / y}{\Delta x / x} \tag{10}$$

Then, it can be observed, for example, that the parameter α will indicate that an increase of 1% point in the distribution of water, will generate an increase of output equal to α percentage points. Similar considerations can apply to the other coefficients included in the formula, showing the elasticity. In order to convert the production function into a relationship between yield and quantity of inputs obtained by utilized agricultural area, both members of the production function should be divided by L.

$$\frac{Y}{L} = \frac{\beta W^{\alpha} R^{\psi} C^{\gamma} L^{\omega}}{L} = \beta W^{\alpha} R^{\psi} C^{\gamma} L^{\omega-1} \tag{11}$$

On the left of the expression there is the yield, which is the quantity of output produced per unit of area. The variables on the right are expressed in levels. These variables can also be expressed in terms of quantity produced per unit of utilized agricultural area. To this end, we divide and multiply each factor on the right of the equation for the following:

$$\frac{Y}{L} = \beta \frac{W^{\alpha}}{L^{\alpha}} N^{\alpha} \frac{R^{\psi}}{L^{\psi}} L^{\psi} \frac{C^{\gamma}}{L^{\gamma}} L^{\gamma} L^{\omega-1} = \\ = \beta \left(\frac{W}{L}\right)^{\alpha} \left(\frac{R}{L}\right)^{\psi} \left(\frac{C}{L}\right)^{\gamma} N^{\alpha+\psi+\gamma+\omega-1} \tag{12}$$

We can now define the production function in terms of share of total utilized agricultural area:

$$y = \beta w^{\alpha} r^{\psi} c^{\gamma} L^{\delta} \tag{13}$$

Where, y, w, r, are expressed in terms of volume of input per the amount of cultivated area, with the exception of the variable N which is the total utilized area. It is important to note that the exponent of the L is an indicator of the return to scale. In fact:

1. If $\delta = \alpha+\psi+\gamma+\omega-1>0$ we will have increasing returns to scale;

2. If $\delta = \alpha+\psi+\gamma+\omega-1=0$ we will have constant returns to scale;

3. If $\delta = \alpha+\psi+\gamma+\omega-1<0$ we will have decreasing returns to scale.

To this end, in order to obtain empirical results it is necessary to have reliable data on the following elements: yields related to specific agricultural crops; the amount of water for irrigation distributed measured in inch-acres; the amount of utilized agricultural area (in acres); average temperature in degrees Celsius; technology used in irrigation (Lanfranchi, 2010) (T). On the basis of this data it is possible to calculate the marginal rate of substitution (MRS). The MRS also known as the marginal rate of technical substitution (MRTS), represents the slope of an isoquant, which is a set of combinations of inputs that produce a constant product:

$$MRS = \frac{dW}{dL} = \frac{Pm_L}{Pm_W} \quad (13)$$

In which: Pm_L = is the marginal productivity of land; Pm_W = is the marginal productivity of irrigation water. To complete the analysis and to determine the optimum amount of water and the optimum amount of cultivated land it is necessary to enter the price levels of these two factors. The optimization of their use requires the realization of the condition:

$$MRS = \frac{dW}{dL} = -\frac{Pm_L}{Pm_W} = -\frac{p_L}{p_W} \quad (14)$$

Where p_L and p_W represent the prices of land and water respectively.

The realization of this condition will allow to compare the quantities of inputs actually used and those deductible through the process of cost minimization in the use of production factors.

9 Conclusions and Discussion

Greenhouse gas emissions and climate change have a number of implications on agricultural productivity, but the aggregate impact of these is not yet known and indeed many such impacts and their interactions have not yet been reliably quantified, especially on a global scale.

An increase in average temperature can be expected, but the impact on productivity may depend more on the magnitude and timing of the extreme events. Water availability is crucial, but predictability of precipitation is highly uncertain and there is an added problem of lack of clarity on the relevant quantifying of drought. Agricultural impacts in some regions may arise from climate changes in other regions, owing to the dependence on rivers fed by rainfall, snow melting and glaciers far away. The most pragmatic insight that can be highlighted by these results requires additional knowledge of the degree of exposure to climate.

The combined information of the capacity to adapt and exposure to climate stress provides an understanding of vulnerability. But the future evolution of this phenomenon is uncertain especially at a large scale. So there is a need for continuous monitoring of underlying climate parameters that signal stress and shock and the capacity to adapt.

A wide range of measures to adapt ranging from technological options on-farm to improved farm managerial practices and political tools (e.g. adaptation action plans) need to be taken into account. To cope with projected changes in climate conditions, farmers can change their crop rotation to make the best use of available water, adjust sowing dates according to temperature and rainfall patterns, use crop varieties which are better suited to the new weather conditions (e.g. more resistant to heat and drought), or to plant hedgerows or small wooded areas on arable land that reduce water run-off and act as wind-breaks. However, a literature survey showed that adaptation measures are unlikely to come without cost and it concludes that adaptation costs (as opposed to net costs of damages) are not reported in most impact studies, especially in agriculture. Yet transition costs (e.g., to retrain farmers in new practices) and balance costs (e.g., to develop additional irrigation or apply more fertilizer) may be considerable.

The absence of an in depth benefit-cost calculus for agricultural adaptation is a key deficiency. An extensive body of economic research has studied the benefits and costs of agricultural research and has found that institutions that are responsible for agricultural research adapt agricultural technology only in response to the relative resource scarcity. Moreover, some authors argue that changes in fixed capital for farm infrastructures may be the most significant cost associated with adaptation to climate changes (Lanfranchi, 2012).

Nowadays, it is very difficult to monitor, with certainty, the real implication of climate changes and global warming on the agricultural sector.

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References:

[1] Batie SS, Sustainable Development: Challenges to Profession of Agricultural Economics, *American Journal of Agricultural Economics*, 71 (5): 1083-1101, 1989

[2] Bulearcă, M., Popescu, C., Sima, C., Ghiga, C., Neagu, C., Models for natural resources management, *WSEAS Transactions on Business and Economics*, Volume 8, Issue 2, May 2011, pp. 50-65.

[3] Chang, K., Wang, S.-S., Constant vs. time-varying hedging effectiveness comparison for CO_2 emissions allowances: The empirical evidence from the EU ETS, *WSEAS Transactions on Business and Economics*, Volume 10, Issue 3, 2013, pp. 158-169.

[4] Colby ME., The Evolution of Paradigns of Environmental Management, *Development Strategic Planning and Review*. Discussion Paper 1. 1989, World Bank, Washington D.C.

[5] Feebairn J., Cross-country empirical Studies of economic growth: A review of results and methodology, *Agricultural Competitiveness: Market Forces and Policy choice*. XXII International Conference of Agricultural Economists, 1994, IAAE.

[6] Folke C, Colding J, Berkes F., Building Resilience and Adaptive Capacity in *Socialecological Systems. In Berkes F, Colding J, Folke C (eds.) Navigating Social-Ecological Systems*., 2003, pp. 352–387. Cambridge University Press, Cambridge, UK .

[7] Frisvold G, Ingram K., Sources of Agricultural Productivity Growth and Stagnation in Sub-saharan Africa. *Agricultural Economics*, vol. 13, 1995, N. 1, IAAE, Elsevier Science, New York.

[8] Gillis M, Perkins DH, Roemer M, Snodgrass DR., *Économie du développement*, 1998, Nouveaux Horizons. De Boeck.

[9] Hicks JR., *Theory of Wages*. Macmillan Press. London, 1932.

[10] Hicks JR., *Value and Capital*. Oxford University Press. New York, 1938.

[11] Houthakker HS., The Pareto Distribution and the Cobb–Douglas Production Function in Activity Analysis. *The Review of Economic Studies* 23 (1), 27–31, 1955.

[12] Klein RJT., *Climate Change, Adaptive Capacity and Sustainable Development*. OECD informal Expert Meeting on Development and Climate Change, Paris, France, 2002.

[13] Koutsoyiannis A., *Modern Microeconomics*. Macmillan Press, London, 2003.

[14] Kralj, D, Green environmental business, *WSEAS Transactions on Business and Economics*, Volume 6, Issue 5, May 2009, pp. 219-228.

[15] Lanfranchi M., Giannetto C., Puglisi A., A cost-benefits analysis for risk management in a biological farm, *Applied mathematical sciences, ISSN 1312-885X (print)/ISSN 1314 - 7552(online) Vol. 8, no. 16, 2014, pp.775-787*.

[16] Lanfranchi M., Giannetto C., Analysis of the economic evaluation of an Italian farm in response to the economic financial crisis that the EU is going through, *Quality - Access to Success*, Volume 14, Issue SUPPL.2, 2013, pp. 119-124.

[17] Lanfranchi M., Economic analysis on the enhancement of citrus waste for energy production, *Journal of Essential Oil Research*, vol. 5, 2012, pp. 1-9.

[18] Lanfranchi M., Sustainable technology as an instrument of the enviromental policy for the attainment of a level of socially acceptable pollution, *World Futures: Journal of General Evolution* Volume 66, Issue 6, 2010, pp. 449-454.

[19] Markandya A, Pedroso-Galinato S., How Substitutable is Natural Capital? *Environment and Resource Economics*, Vol 37, 2007, pp. 297-312.

[20] Matei, M., Popescu, C., Rădulescu, I.G.., The consequences of climate change and social responsible behavior, *WSEAS Transactions on Business and Economics*, Volume 9, Issue 1, January 2012, pp. 29-38.

[21] Moore M, Gollehon N. Negri D.H., Alternative Forms of Production Functions of Irrigated Crops, *The Journal of Agricultural Economics Research*, vol.44, n.3, 1993, pp.16-32.

[22] Mundlak Y., Elasticities of Substitution and the Theory of Derived Demand, *The Review of Economic Studies Vol* 35, 1968, pp. 225–236.

[23] Musu I., *Introduzione all'Economia dell'Ambiente*, Il Mulino, Bologna, 2000.

[24] Piriou JP., *Lexique des Scieences Economiques et Sociales*. Nouvelle Edition, Repères, Editions La Decouverte, Paris, 1997.

[25] Polsky C, Easterling W., Adaptation to Climate Variability in the US Great Plains: A Multi-Scale Analysis of Ricardian Climate Sensitivities. *Agriculture, Ecosystems and Environment* Vol.85, 2001, pag.133–144.

[26] Smith B, Pilifosova O., From Adaptation to Adaptive Capacity and Vulnerability

Reduction. In Smith JB, Klein RJT, Huq S. (eds.) *Climate Change, Adaptive Capacity and Development.* Imperial College Press, London, UK, 2003.

[27] Stern DI., Elasticities of Substitution and Complementarity. *Rensselaer Working Papers in Economics*, Rensselaer Polytechnic Institute, Department of Economics, New York, 2004.

[28] WCED. 1987. *Our Common Future*. Oxford University Press, Oxford, 1987.

[29] World Bank, *Where is the Wealth of Nations: Measuring Capital for the 21st Century*. World Bank, Washington DC, 2006.