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Full Length Research Paper

Climate change and agricultural productivity

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Agriculture is the economic sector that is most vulnerable to climate change. According to the latest estimates, farmers' adaptation of farm production to climate change is inevitable. The climate attributes that are expected to have the most direct impacts on agricultural productivity are the rise in temperature, the change in the frequency and intensity of precipitation and of extreme weather phenomena, and the increase in the level of CO_2 available for photosynthesis. This paper analyzes the economic costs of climate change in Greek agricultural productivity during the last thirty years and discusses the implications for policymakers and for agricultural research. Empirical evidence suggests that climate change is already present and has a significant impact on agricultural productivity. Farmers need to adapt to the expected impacts of climate change in order to maintain their standard of living. The adaptation of agriculture to climate change involves both the restructuring of crops, as well as changes in cultivation practices. Policies must take into account the multidimensionality of modern agriculture and the importance of sustainable agricultural development.

Key words: Climate change, agricultural productivity, newey-west, sustainable development.

INTRODUCTION

Generally, agriculture is the primary sector that mostly depends on climate change (Mendelsohn and Dinar, 2009). The choice of the optimal crops cultivated and the choice of the optimal planting and harvesting times depend directly on the weather conditions prevailing in each region. This implies that the impending climate change due to increases in greenhouse gases will have direct effects on agricultural production and productivity and, consequently, on farmers' income.

Climate change is already evident in Europe, as noted by a comparison of the frequency of draughts and other extreme weather phenomena in the last half century (Olesen, 2006; Olesen and Bindi, 2002). More specifically, for Greece, a decrease in droughts in North-western Greece and an increase of droughts in Central and South Greece, by up to 30%, have been reported. In addition, the average summer temperature (June-August) has been steadily increasing since the mid-seventies, with an average increase of one degree Celsius per decade for the capital, Athens (Founda, 2011). It is therefore obvious that climate change has already been occurring during the last decades and, according to the latest estimates, will continue to an even greater extent during this century, as manmade carbon dioxide emissions continue to increase (Bank of Greece, 2011). These forecasts have created significant pressure to the agricultural sector and question its sustainability (Nastis and Papanagiotou, 2009). According to the latest estimates, the most probable scenario for Greece (A2) forecasts an average temperature increase of 4.5°C for the entire year by 2100, ranging between 3.9°C in winter and spring, 5.4°C in summer and 4.7°C in autumn. Average rainfall is expected to decrease by the end of the century by 17% for the entire year 2100, ranging between 16% in winter, 19% in spring, 47% in summer and 10% in autumn (Bank of Greece, 2011). These predictions are

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Table 1. Climate stabilization scenarios.

Stabilization level (ppm CO_2-eq)	Average temperature increase over pre-industrial levels (°C)	Year of highest CO_2 emissions	CO_2 emissions decrease by 2050 compared to 2000 (%)	Year CO_2 emissions return to 2000 levels
445-490	2.0-2.4	2000-2015	-85 … -50	2000-2030
490-535	2.4-2.8	2000-2020	-60 … -30	2000-2050
535-590	2.8-3.2	2010-2030	-30 … +5	2020-2060
590-710	3.4-4.0	2020-2060	+10 …+60	2020- >2100
710-855	4.0-4.9	2050-2080	+25 … +85	>2090
855-1130	4.9-6.1	2060-2090	+90 … +140	>2100

Source: IPCC (2007).

based on the Global climate models (GCM) developed by the scientists participating in the Intergovernmental panel for climate change (IPCC) (Nakicenovic et al., 2000).

Climate change is occurring very rapidly. Compared to the gradual change in temperature during the last ice age, estimated to have been 5.0°C lower than today's temperature (Duncan, 2009). Predictions for the current century illustrate the urgency of the matter. Immediate actions are therefore needed to reduce the effects of climate change as well as the adoption of climate change mitigation measures by the agricultural sector.

The objective of this paper is to analyze whether climate change has already affected agricultural productivity in a measurable way. Evidence from tropical climates suggests that the effect of climate change on the agricultural sector may already be measurable (Barrios et al., 2008), and this may also be the case for temperate climates. However, to our knowledge, no such study exists. Using data for the last three decades for Greece, the effect of climate change already has on agricultural productivity is estimated and policy measures to mitigate these negative effects are proposed based on evidence from previous studies. Subsequently, the paper presents a literature review of climate change and its economic damages on Greek agriculture. Following, the data and methodology along with the results and discussion sections are presented. Finally, conclusions are drawn.

CLIMATE CHANGE PREDICTIONS AND ITS ECONOMIC DAMAGES ON GREEK AGRICULTURE

Climate change is a global issue, since it depends on the total concentration of carbon dioxide and other gases (carbon dioxide equivalents) related to the greenhouse effect. Therefore, only an international common policy of emissions reduction can successfully address the problem. However, even if global concentrations of carbon dioxide equivalents could be stabilized, scientists predict that temperatures will continue to increase for several years. The scientists participating in the IPCC have estimated a number of climate stabilization scenarios, using target values for the concentrations of carbon dioxide equivalents in the atmosphere (IPCC, 2007). Table 1 summarizes the scenarios of climate stabilization following the least cost trajectory.

Even under the most optimistic scenario, which assumes that carbon dioxide emissions can be successfully reduced immediately, the planet is facing a trajectory of increases in the average global temperature that will deem the adaptation of the agricultural sector inevitable, across the globe, if the aim of maintaining the current level of agricultural production and the current level of farmers' standard of living is to be maintained. We proceed by providing estimates of the economic damages of climate change in Greek agriculture during the 21st century.

According to the most widely acceptable climate change scenario (A2), the most recent estimates of the impact of climate change on agricultural productivity predict that global food production is not threatened by the expected climate change, in contrast to previous forecasts (IPCC, 2007). However, there will be an increase at the percentage of the world population that will become more vulnerable to hunger, due to regional agricultural productivity differences caused by climate change (FAO, 2009; Easterling et al., 2007).

The latest estimates from the IPCC predict that there will be both positive and negative effects on agricultural productivity due to climate change, depending on the region and type of cultivation (IPCC, 2007). There will, thus, be different effects at the regional, national, and international level. However, damages in the world's driest tropical regions are expected to be ameliorated through international trade (European Commission, 2009).

Increase in the atmospheric concentration of CO_2 will positively affect agricultural productivity (Taub, 2010). Estimates for Greece suggest that productivity will increase by approximately 15% (Cline, 2007). However, at the same time other agricultural inputs, such as irrigation water and soil nutrients will become the constraining factors of agricultural productivity. It is estimated that until 2080, without taking into account the positive effect of increased atmospheric CO_2 due to photosynthesis, agricultural production in Greece will decrease by 7.8% or approximately €610 million (in 2003 prices), while taking into account the positive effect of

Table 2. Economic impact of climate change in Greek agriculture by 2080.

Agricultural output (in million € 2003)	Without CO_2	With CO_2	Change in agricultural output without CO_2 (in million € 2003)	Change in agricultural output with CO_2 (in million € 2003)
7,817	-7.8%	6%	-610	469

Source: Cline (2007).

Table 3. Summary statistics.

Variable	Mean	Std. Dev.
Agriculture gross output (million € in 2003 prices)	1.88	1.66
Labor (number of workers in agriculture)	936071.40	165577.50
Education (percent of tertiary education)	42.97	24.16
Capital (number of tractors in thousands)	221555.50	36374.32
Fertilizers (in metric tons)	551425.10	93459.41
Animal stock (number of animal units in billions)	102.14	2.70
Land (agricultural land in square kilometers)	89190.36	3623.67
Rain (Annual precipitation in mm)	508.89	100.33
Temperature (Average annual temperature in °C)	17.75	0.66

increased atmospheric CO_2, agricultural production will increase by 6% or approximately €469 million (Table 2) (Cline, 2007). These estimates take into account the direct effects on agricultural supply, without however taking into account changes in prices and the adaptation due to international trade. Moreover, they do not take into account constraints in inputs such as water and soil nutrients, as well as farmers' compensatory actions.

Finally, they do not take into account the effect that the 2010-todate debt crisis and the subsequent macro-economic realities it has created will have on the agricultural sector. The economic costs at the farm level suggest changes in the productivity of different crops and livestock types, and, therefore, a change in the ranking of the most profitable crops and livestock types for each region.

The Greek Biodiversity Institute predicts the extinction of certain crops and the adoption of crops currently cultivated in Northern Africa (Karamanos, 2009). Moreover, small-scale farms and farms cultivating marginal land are expected to have the highest reduction in productivity compared to medium- and large-scale farms, questioning the sustainability of small-scale farms (Moretti et al., 2010). This is due to the inherent difficulties of achieving the required investments in capital and education, resulting in increased costs of production and reduced farm income.

The predictions for the Greek agricultural sector by the end of the century are bleak. However, it should be noted that the GCM used by the IPCC and by previous studies to estimate the economic costs of climate change on Greek agriculture do not have the resolution required to estimate changes in agricultural productivity at the regional level (Antle, 2008). Therefore, it is difficult to derive detailed regional results using GCM and only general results can be derived, using such global models. An alternative method to directly estimate the cost of climate change on agriculture would be to estimate a production function for a region or country, taking into account inputs under the farmers' control, but also weather attributes that can affect agricultural output, but are beyond the farmers' control. This is the methodology employed in the present study and presented subsequently.

DATA AND METHODOLOGY

The data set employed in the present study is a time series covering 28 years, between 1980 and 2007, regarding agricultural production inputs and output, and climate variables. More specifically, data were obtained from the FAO and World Bank databases on Greece's agriculture gross output, labor, education, land, fertilizers, machinery, and animal stock. Data on precipitation and temperature were provided from the National Oceanic and Atmosphere Administration (NOAA-USA), which collects worldwide data from over 20,000 stations worldwide. Meteorological data are averages of the monthly climate temperature data and annual precipitation averages (Table 3).

The model assumes that aggregate agricultural output for each time period depends on land, education-augmented labor, machinery, fertilizers and animal stock:

$$Y_t = f(L_t E_t, K_t, A_t, F_t, S_t) \tag{1}$$

where L is labor employed in agriculture, E is an education proxy, K

Table 4. Regression results with Newey-West standard errors.

Variable	Coefficient	Newey-West Std. Error
Labor*education/land	0.1536	0.0954
Capital/land	-3.8969	0.2455
Fertilizers/land	0.3718	0.2792
Animal stock/land	3.4059	1.0676
Precipitation	0.2088	0.0824
Temperature	-0.7584	0.3150
Constant	16.0518	4.2511
F (6.20)	1016.64	
Number of observations	28	

Variables are first differences in logarithms. Coefficients depict the relative elasticities.

is capital employed in agriculture, *A* is total cultivated area, *F* is fertilizers, *S* is animal stock per time period *t.* We assume, following the literature, that labor's productivity is improved through time by education, thus education has a multiplicative effect on labor (Becker and Murphy, 1992; Griliches, 1988). In what follows, the *t* subscript is suppressed for expositional clarity, since all variables are per time period. Dividing by *A*, Equation (1) can be written in yield terms expressing agricultural productivity per unit of land as:

$$Y / A = f(LE / A, K / A, F / A, S / A) \quad (2)$$

or, by substituting small capitals for the per unit of agricultural land quantity of each variable, as:

$$y = f(le, k, f, s) \quad (3)$$

Two weather variables, annual precipitation and average annual temperature are included to capture the effect of climate on agricultural productivity. These variables are typically not included in a production function because they are assumed constant, and outside the farmers' control, however this is not the case if climate change is present. Thus, Equation (3) can be written as:

$$y = f(le, k, f, s, prec, temp) \quad (4)$$

where *prec* is annual precipitation and *temp* is average annual temperature. Equation (4) expresses average income per hectare as a function of labor per hectare, capital per hectare, fertilizers per hectare, animal stock per hectare, precipitation and temperature. Assuming a Cobb-Douglas functional form, Equation (4) takes the following specification:

$$\log(y) = \alpha + \beta_1 \log(l*e) + \beta_2 \log(k) + \beta_3 \log(f) + \beta_4 \log(s) + \beta_5 \log(prec) + \beta_6 \log(temp) + \varepsilon_t$$

The estimated beta coefficients represent the respective elasticities, α is the intercept and ε is white noise error with zero mean and constant variance.

We first proceed by testing for the presence of unit root in the time series prior to the empirical analysis. An augmented Dickey-Fuller test is carried out for each variable, with two lagged first differences included in the equation. We first test the null hypothesis that the log of the variables aforementioned contains a unit root. They are all accepted, since the *p*-values are greater than 0.05. Next, we test the null hypothesis that the first differences of these variables contain unit roots. All null hypotheses are rejected. Thus, these results suggest that all variables are I (1), integrated of order one.

Newey and West (1987) and Gallant (1987) have developed nonparametric kernel estimators that are consistent even when there is serial correlation and conditional heteroskedasticity of unknown forms. These estimators were further elaborated by, among others, Andrews (1991), Andrews and Monahan (1992), Hansen (1992) and Newey and West (1994), to the Newey-West estimator, as it is usually referred to in the econometrics literature. It should be noted that, despite its strengths, the Newey-West estimator is considered somewhat arbitrary, in that its performance may depend on the choice of the kernel function and truncation lag. These choices may affect the resulting test statistics and render testing results fragile; therefore a number of kernel functions and truncation lags should be tested for consistency of the estimates.

We proceed by estimating coefficients by ordinary least squares (OLS) regression with Newey-West standard errors, where the error structure is assumed heteroskedastic and possibly auto-correlated up to some lag. We have estimated the coefficients for different lags, for consistency, and the coefficients do not differ. Therefore, we proceed by reporting only the results for four time lags.

RESULTS AND DISCUSSION

Results of the OLS regression with Newey-West standard errors show that temperature appears statistically significant with a *p*-value of 0.026 (Table 4). More specifically, the elasticity of temperature on aggregate agricultural output is -0.77. This implies that climate change, through an increase in average temperatures have resulted in a decrease in agricultural productivity in Greece, during the past three decades. The cultivated crops in Greece would benefit, on average, from lower average annual temperatures. Thus, as climate change causes further increases in temperatures, crops currently cultivated in more temperate/tropical climates have to be adopted in Greece. In addition, precipitation is statistically significant in predicting average agricultural output for Greece with an elasticity of 0.20.

The other variables have the expected signs, with the exception of capital, which is measured as the number of

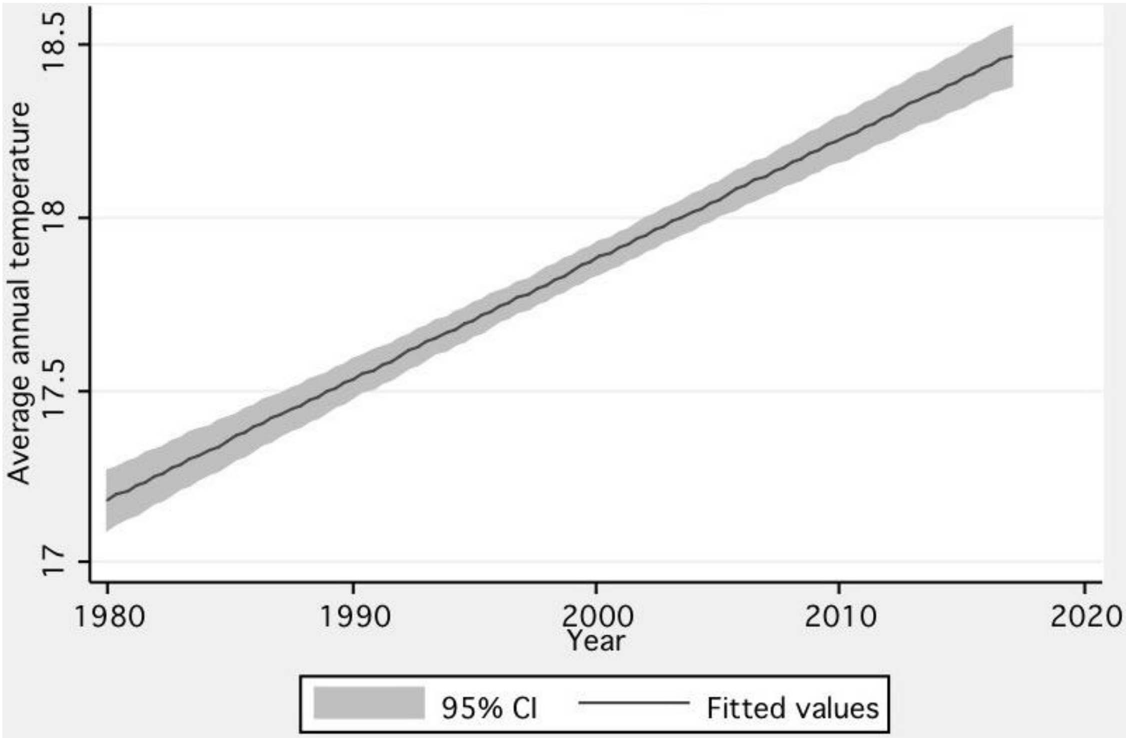

Figure 1. Average annual temperature forecasts.

tractors per square kilometer of agricultural land. A possible explanation to the negative sign is the fact that in Greece there has been an overutilization of tractors. More specifically, agricultural tractors are also a status symbol, resulting in farmers purchasing more tractors, with higher horsepower, than optimal for farm use, a practice that has been amplified during the time period studied from large subsidies after Greece's accession to the European Union in 1980.

Next, we estimate ten year forecasts, for the time period 2008 to 2017, using the Holt-Winters nonseasonal forecasting estimator and draw linear prediction plots with 95% confidence intervals (CI), which are depicted graphically in Figures 1 to 3. These figures clearly show the expected increases in average annual temperatures (narrow 95% CI band) (Figure 1). However, they less clearly illustrate the increases in annual precipitation (wide 95% CI band) (Figure 2). Moreover, forecasts of agricultural productivity clearly illustrate an expected decrease in the following years, if no adaptation strategy is followed (Figure 3).

A number of climate change uncertainties hinder scientists' forecasting ability. More specifically, the availability of irrigation water, the natural resource that is considered the most important limiting factor for agricultural production in Greece, is hard to estimate. Due to increases in temperature, extreme weather phenomena and decreases in precipitation, it is estimated that water available for irrigation will decrease. Estimates based on climate change scenario (A2) predict a decrease in water available for irrigation by 54% on average for the whole country (Bank of Greece, 2011). Therefore, novel cultivation techniques must be adopted that permit more efficient use of the available water in conjunction with investments in water preservation infrastructure.

An additional uncertainty is due to the rate of climate change. A higher rate of climate change requires higher depreciation rates for both manmade and natural capital. This creates a higher adaptation cost for farmers, for the private sector that provides inputs to farmers, and for the institutions that are responsible for agricultural infrastructures and policy making (Antle, 2008). Moreover, the European Union's climate change policies and action plans, included related agricultural subsidies at the national level, may influence costs for farmers. In addition, there is uncertainty regarding population increase and population migration patterns which will create different pressures on land use (Antle, 2008). Finally, there is uncertainty regarding consumers' nutritional preferences. It is well documented, for example, that the production of an equal amount of calories from beef requires approximately 57 times more CO_2 emissions than the production of the same amount of calories from potatoes (Fiala, 2009). On the other hand, both beef and potato production require a huge amount of water, which would be scarce due to the negative impacts of climate change. Therefore, consumers' nutritional preferences

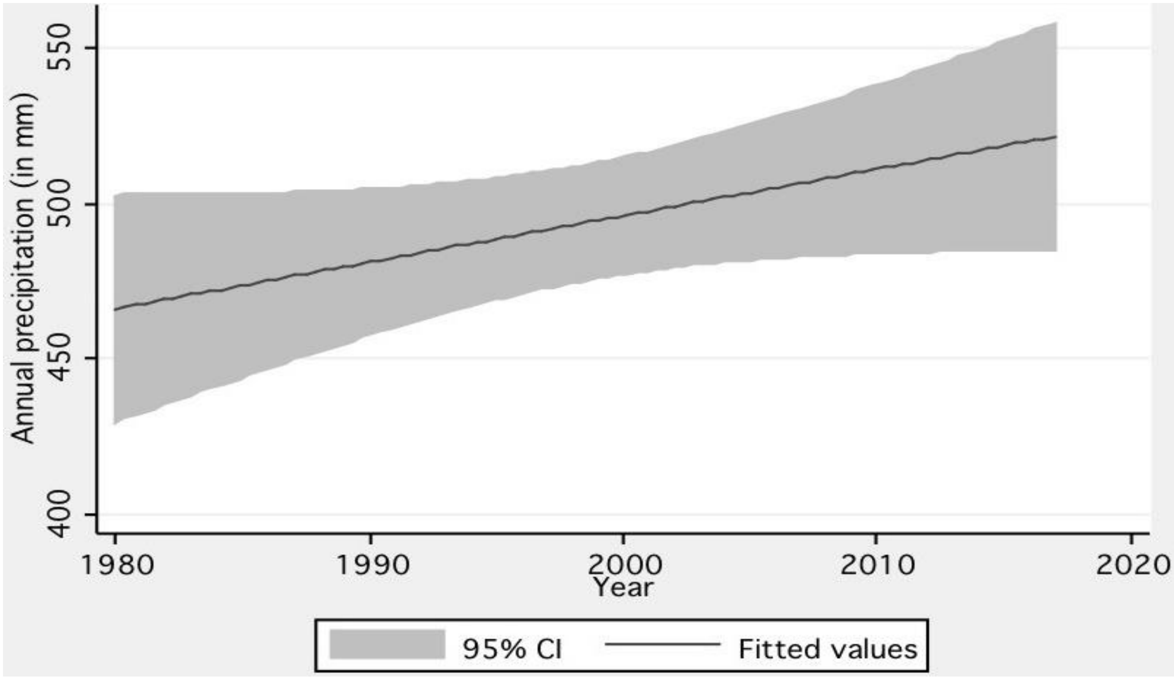

Figure 2. Annual precipitation forecasts.

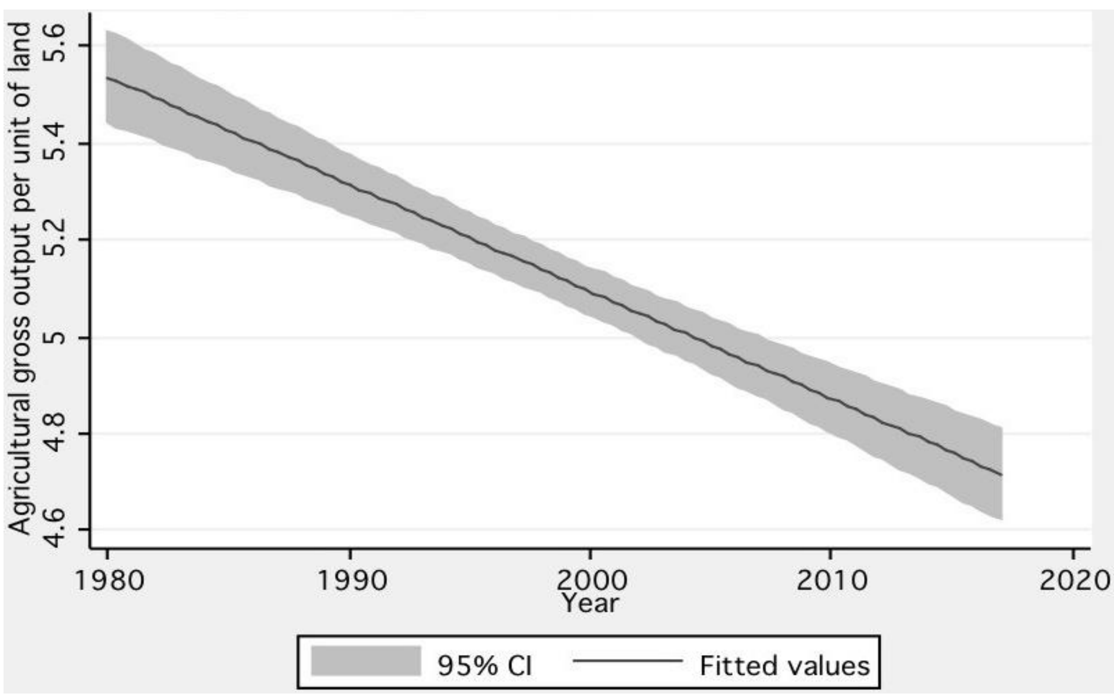

Figure 3. Agricultural productivity forecasts.

will play a crucial part in manmade CO_2 emissions.

Undeniably, Greek agriculture has to adapt to climate change in order to ensure sustainable development, even if there is currently uncertainty in the predictions regarding the speed and the size of the required adaptation. However, adaptation is nothing new to agriculture (European Commission, 2009). Agriculture, since its first appearance on earth, has been constantly adapting to climate that varies greatly between regions both in its long-term attributes and in its short-term annual variability. Therefore, agriculture's adaptation to the environment, policies, and economic factors is a continuous process that is required for the survival of the farm sector. Moreover, factors such as invasive species, pest resistance to pesticides, consumers' dietary preferences, competition for water availability, and changes in national and European Union (EU) policies have required farmers' adaptation. Climate change is expected to become an additional long-term trend that has to be taken into consideration during farmers' choices of cultivations in order for them to maintain their levels of productivity and competitiveness.

It is generally expected that farmers' adaptation to climate change will globally be successful. The adaptation efforts of the agricultural sector must mainly focus on the following areas (Rose and McCarl, 2008):

1. Farm management (for example, earlier plantation, use of varieties that ripe earlier or later, adaptation of pesticide and fertilizer use, temperature control in greenhouses and stables, etc.)
2. Crop selection (for example, change of crops cultivated, use of crops resistant to higher temperatures, etc.).
3. Technological innovations, that require additional capital and changes in cultivation practices, as a result of agricultural research and development (for example, development of new cultivars more resistant to higher temperatures, genetically modified crops, water saving irrigation practices, soil fertilization improvements, alternative farming practices, etc.)

The economic consequences of agricultural adaptation have been widely researched in the literature and most researchers conclude that changes in the timing of the major cultivation activities along with the use of more resistant cultivars can significantly reduce the expected economic damages due to climate change. Moreover, with changes in cultivations altogether, it is possible to have benefits instead of damages (Seo and Mendelsohn, 2008; IPCC, 2007; Reilly et al., 2003; Adams et al., 1999). However, farmers in certain regions are expected to face severe economic damages, when they are faced with a limited number of alternatives. For Greece, these areas constitute a large part of the country, mainly in the southern part of the country and in the islands.

Evidence collected by the authors from three other studies in Greece suggest that there are five basic mechanisms that facilitate the farming sector's adaptation to climate change (Charatsari et al., 2011; Michailidis et al., 2010, 2009):

1. Agricultural research and development (R&D), which includes institutes, universities, private companies that develop and improve farm inputs and cultivation practices. More specifically, agricultural R&D can facilitate the implementation of new farm inputs and cultivation practices to the Greek farm, by adopting basic scientific knowledge generated abroad (Bank of Greece, 2011).
2. Agricultural extension and education, which transfers knowledge and facilitates the dissemination of novel technologies and cultivation practices. These include both public extension services and private marketing, are currently underutilized in Greece and thus have a high rate of return (Charatsari et al., 2011).
3. Producers' networks, which facilitate information diffusion among producers and allow observation and imitation of successful farming practices. Such networks have successfully aided in the adoption of new technologies in the Greek farm (Charatsari et al., 2011).
4. Public water planning, with the main priority being water saving irrigation practices, protection of water capacity, water recycling and artificial refilling of groundwater reservoirs (Michailidis et al., 2010).
5. Policies, at the national and EU level, which assist in hedging the business risk of farming and control market forces. These policies must take under consideration the multitude of goals achieved through farming and be consistent with the three pillars of sustainable development: economic development, environmental protection and societal equity (Nastis and Papanagiotou, 2009).

In terms of economic costs, climate change has been cited as an easily solvable problem. More specifically, the cost of reducing greenhouse gas emissions to the desired levels is estimated to cost 1% of global gross domestic product (GDP), with a lower bound of -2% and an upper bound of 5%, given that the optimal policies are implemented (Duncan, 2009; Stern, 2008; Stern et al., 2006). This cost is relatively small, given that the cost of saving the banking sector during the 2007 to 2009 global financial crisis was estimated at 5% of global GDP. However, such a solution would only be feasible if all nations agree to a common framework for the optimal distribution of adaptation costs. For this to be achieved, the following two phases are required: (1) an intergovernmental agreement must take place, such as the one discussed but not agreed upon in Copenhagen in 2009, (2) this agreement must be ratified and implemented by all involved nations. If these two phases are not implemented, the cost will be much higher than the quoted 1%, as is most likely to happen in reality.

Many economists suggest that the best economic instrument for the implementation of the requisite measures in practice is a cap on the price of carbon. It was estimated to be twice as efficient compared to any other policy (Fischer and Newell, 2004).

The price cap gives a clear incentive for the development of cleaner technologies does not require continuous control of the polluting industries, it does not create market distortions, as with subsidies and it is not a burden for consumers. Duncan estimated that a price of approximately €/t 30 is required, when in the EU at the EUA market carbon prices are ranging around €/t 13. Governments have unfortunately chosen to distribute subsidies to promote green technologies, in effect using less efficient policies. Greece is currently within its targets for reducing greenhouse gas emissions, as they have already been reduced to 23% above 1990 levels in the end of 2011, against a target of 25% above 1990 levels in 2012 under the Kyoto protocol. The whole EU has a target of reducing collective emissions in the 2008 to 2012 period by 8% below 1990 levels. Moreover, Greece has developed a roadmap for the transition to a low carbon economy by 2050, following the EU roadmap (www.roadmap50.eu). More specifically, the roadmap includes switching to 100% of energy needs from renewable energy sources, reducing carbon dioxide emissions by 60% of present levels, and containment of total energy consumption in 2050 at the present levels.

Consequently, the reduction of greenhouse gases is feasible both from a technical and an economic standpoint. The problem of climate change is mainly political. It is the most important political problem facing humanity today, much larger than the ongoing debt crisis facing Greece and Europe, and there is no institution in place capable of resolving it.

Conclusions

The results of the economic estimates of climate change generally conclude that the global effect of climate change on the agricultural sector will be small. However, there will be significant economic damages at the regional level, especially in countries such as Greece. Given that the adaptation is slow, most estimates suggest that the viable farm enterprises, with the proper investments, will be able to adapt quicker, by changing their cultivations and cultivation practices.

The results of the present study show that climate change is already occurring and therefore the adaptation of Greek agriculture is paramount. The degree of adaptation depends on the severity of climate change and the ability to mitigate the negative consequences through support from agricultural research institutes, agricultural extension services, education, farmers' networks, and national and European policies. The adaptation efforts will cause differentiations between regions regarding their development rates and their standards of living.

Policy makers should promote actions that assist in changing land use and crops, as well as crop cultivation techniques. These policies should also take into account the need for sustainable development. In addition, Greece's economic development will significantly affect farmers' ability to profit from additional sources of income through the multidimensionality of the rural sector. Finally, policy makers should take into account the importance of sustainable agricultural development through its three pillars, economic development, environmental conservation and social equity, as sustainable development is the essence of why climate change matters.

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