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# Assessment of climate change impact on viticulture: Economic evaluations and adaptation strategies analysis for the Tuscan wine sector

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**Abstract**

Climate change is expected to have a significant impact on various economic sectors (IPCC, 2007) but an especially large one on agriculture because animal and crop growth are heavily influenced by weather conditions during their life cycles. In this paper, a multidisciplinary approach is developed that jointly uses economic and bio-climate models to evaluate the impact of climate change on viticulture in Tuscany (central Italy). Then a model is used to evaluate the likelihood of adoption of various adaptation strategies.


*Keywords:* Wine; Climate change; Adaptation strategies

## 1. Introduction

Many methodological approaches have been proposed in the literature for the identification and evaluation of damage caused by climate change, with the aim of developing adaptation and mitigation strategies and policies. In this paper, following a proposal by the European Commission in a White Paper, "Adapting to Climate Change: towards a European Framework for Action" (Commission of the European Communities, 2009), the risk of damage from climate change is considered as a consequence of two factors: the vulnerability of the examined system and its ability to adapt. *Vulnerability* (IPCC, 2007) refers to the susceptibility of a system to the negative effects of climate change. *Ability to adapt* refers to the ability of a system to implement measures to reduce future potential damage. Overall, the induced changes are destined to alter the ideal environment of vocational production, with effects that not only jeopardise the possibility of continued cultivation of certain products in certain regions but also push farms to introduce organisational and managerial changes to adjust their production systems to the changing conditions. The latter will have consequences on both processes and products that can be summarised, respectively, as follows:

- the adoption of new "ways to produce," often associated with higher production costs;
- the assessment and possible repositioning of products in markets (possibly extending to changes in target markets and a changed view of the competition, as a consequence of changes in the quality and quantity of output).

According to this approach, if production scenarios related to climate change are linked to an objective view of the local conditions that will allow for the cultivation of vineyards and the production of wine in the future,

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adaptation strategies of farms will be linked to the subjective way in which farms respond to external stimuli, according to a personal objective function that inspires their choices.

The assessment of the vulnerability of cultivation has been the object of numerous studies based on eco-physiological models. A review of these studies is found in White et al., 2011. Most of the examined models, however, do not assess the risk of topsoil loss, and they view variations in climate conditions as a source of incremental production variability. Furthermore, these models cannot be applied to different species. More recently, to overcome these limits, risk assessment models based on the effect of bioclimatic variables in relation to agro-habitat cultivation have become more popular (Barney and Di Tomaso, 2010). These models were also applied, to good effect, to cultivation in the Mediterranean area (Moriondo et al., 2008). Models based on bioclimatic variables were also applied to the assessment of quality loss risk in wine production (Grifoni et al., 2006; Jones, 2006).

Regarding adaptation strategies, Antle et al. (2004) propose a theoretical approach for the economic study of production systems related to climate change, based on the probability of endogenous adaptation by farms. Such a model has the advantage of representing spatial variations and interactions of both biophysical and economic variables in adaptation strategies.

Currently, realistic adaptation processes remain poorly understood and hard to quantify (Smit and Pilifosova, 2001). Although some recent progress has been made in this direction (IPCC, 2007), the extreme complexity of relationships and consequent behaviours of farmers are still difficult to fully understand. To identify vulnerabilities of farming systems and to develop ad hoc adaptation policies, it is essential to better understand the processes by which farmers adapt to climate change. Models for understanding and measuring the determinants of farmers' adaptation behaviours remain difficult to formulate, but an important step in this direction is made in Below et al. (2012): in their study, an activity-based adaptation index (AAI), which explores the relationship between socio-economic variables and adaptation behaviours of farmers, is proposed.

Although wide literature has developed in recent years, the evaluation of vulnerability, with or without adaptation of cultivation, with highly defined territorial detail remains difficult. This observation is especially true given the significant uncertainty that exists regarding the impact of climate change on agri-ecosystems, as well as the uncertainty that exists regarding the capacity of the socio-economic system to implement policies and managerial adaptation actions. The toughest challenge in the adaptation process will be how farmers respond "culturally" to changes in the "identity" of certain regions caused by the mutation of the ampelographic base and of quality characteristics (both technical and functional) of the wines. To achieve such adaptations, a crucial role will be played by attitude, managerial dynamism and technical and agronomical skill, attributes not easily incorporated into a statistical and/or deterministic model. Market reactions are also difficult to incorporate into a model because of the unpredictability of consumer expectations and of the behaviour of direct competitors. The aim of this work is to propose an innovative probabilistic methodology that explicitly considers those uncertainty factors, which are inevitable in the assessment of such complex variables. In particular, the approach integrates an evaluation system, coherent from an economic point of view, of models of the vulnerability of the agri-ecosystem and assessment models, based on the new Jøsang subjective probabilistic logic theories; such integration allows us to consider the effect of socioeconomic variables for each farmer on the probability that each will take managerial adaptation actions. The approach will be implemented in a Geographic Information System (GIS) using high-resolution economic, territorial and census data and applied to Tuscan viticulture, in particular to the Siena province.

## 2. The model

Let $v(x_0)$ be the value of agricultural production v per unit of time (year) and land (hectare), with $x_0$ the vector of data that describe the bioclimatic environment of cultivation. The effects of climate change are observed in the mutation of the values in the vector x: $x_0 \rightarrow x_1$ jeopardising the bioclimatic characteristics that guarantee local production potentials and changing the value of production in terms of both quantity and, especially, quality and without adaptation managerial actions being undertaken.

Then let $p(y||x_1)$ be the probability of obtaining a value of wine production at least equal to $v(x_0)$ without adaptation managerial actions being undertaken. In probabilistic terms, the vulnerability, without adaptation, of wine production, *ECVN*, can be expressed in terms of expected value as:

$$ECVN = p(y||x_1)v(x_0) + [p(y||x_1) - 1]v(x_1) \quad (1)$$

In case that the farmer has to stop production as a consequence of an insufficient profitability that is unable to cover fixed and variable costs, the value of production $v(x_1)$ will be equal to 0.

If the wine farmer is able to implement actions to adapt to climate change, these $x{:}x_0 \rightarrow x_2$ actions will result in direct costs, such as higher production expenses, and/or indirect costs in the form of lost revenues equal to $c(x_2)$ and the production value will reach again the level $[v(x_0)–c(x_2)]$. On the other hand, if the farmer is not able to implement actions to adapt to climate change, the expected production value will be equal to *ECVN*. If $p(y||x_2)$ is the probability that the farmer is able to reach again the production level $v(x_0)–c(x_2)$ as a consequence of the implementation of adaptation actions, the vulnerability with adaptation of wine production, *ECVA*, can be expressed in