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# How to assess future agricultural performance under climate change? A case-study on the Veneto region

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## Abstract

In this paper, we have constructed and tested a simple methodology for assessing and predicting climate change effects on agricultural yields. The methodology follows two steps. First, we econometrically estimate the marginal product of key production inputs (e.g., labor and land), through the estimation of production functions. Then, we predict future agricultural sector performance, by assuming a future with climate-induced changes in the land use and in agricultural labor use, under different IPCC scenarios. We also assume that no dramatic technological change in agriculture production will occur in the near future, so that the selected inputs will present the same marginal product. We assume that the agricultural sector might develop differently under different climate change-induced scenarios and that the use of land and labor will change accordingly. In this way, we are able to compute predictions on the agricultural sector performance in the future, under very different circumstances. We apply the methodology for predicting the sector performance of the Veneto region in 2030. Results differ according to the selected IPCC scenario and consequent input use variations. In the selected case study, for instance, land presents a very high productivity and climate-induced changes in the land use might dramatically (positively and negatively) affect agricultural yields under different IPCC scenarios. In this perspective, the climate change adaptation and mitigation policies and options should primarily aim at the preservation of land productivity in Veneto.

**Keywords:** Climate change, IPCC, Cobb-Douglas/translog production function estimation, Production inputs marginal productivity

## Introduction

Agriculture is an economic activity highly affected by both climate change and variability. The general consensus among scientists, scholars, and experts is that changes in temperature and precipitation will result in changes in land and water regimes that will subsequently affect agricultural productivity. Research has shown that the scope of the climate change impacts on agriculture is region-specific. Climate change is, in fact, likely to affect agricultural systems very differently in various parts of the world. In tropical regions, with many of the poorest countries, impacts on agricultural productivity are expected to be particularly harmful. The vulnerability of these countries is especially likely to be acute in light of technological, resource, and institutional

constraints. Experts predict that tropical regions will see both a reduction in agricultural yields and a rise in poverty levels as livelihood opportunities for many engaged in the agricultural sector become increasingly susceptible to expected climate pressures. (Kurukulasuriya and Rosenthal 2013). In northern European areas, on the contrary, climate change may primarily have positive effects through increases in productivity and in the range of species grown, although there may be negative effects of agricultural on, e.g., the water quality of surface waters. In European southern areas, the disadvantages will predominate with lower harvestable yields, higher yield variability, and a reduction in suitable areas for traditional crops (Olesen and Bindi, 2002, 2004; Bindi and Olesen, 2011; Santeramo et al., 2016).

The literature on the economic impact of climate change on the agricultural sector is very transversal with respect to methodologies and applications. In this perspective, we can highlight four main approaches that we survey in what follows.

The seminal paper by Mendelshon et al. (1994) adopts spatial comparisons in modeling the impacts on agriculture from a Ricardian perspective. The authors base their model on the following two assumptions: (i) perfectly competitive markets for both outputs and inputs, and (ii) interest rate, rate of capital gains, and capital per acre are equal for all plots of land. The latter assumption ensures proportionality between land value and land rent. Consequently, it is possible to reduce the profit maximization function to a cross-sectional analysis in which the land value (or, as most recently suggested, the farm's net revenue) is regressed against climate and soil characteristics, and other control variables. The authors, in fact, measure the economic impact of climate on land prices, by using cross-sectional data on climate, farmland prices, and other economic and geophysical data for almost 3000 counties in the USA. Findings show that higher temperatures in all seasons except autumn reduce average farm values, while more precipitation outside of autumn increases farm values. The model is then applied to a global warming scenario. In this context, results suggest that, even without carbon dioxide fertilization, global warming may have economic benefits for agriculture.

Hanemann (2000) contrasts the Ricardian approach pioneered by Mendelsohn et al. (Mendelshon et al. 1994, 2000) with agronomic models that estimate the impact of climate change on crop yields to predict the economic effect on agriculture. The Ricardian approach uses cross-sectional data from different locations to estimate the effect on land values of changes in climate variables such as temperature or rainfall, while controlling for soil types and other geographic and socioeconomic factors. Different scenarios are used by the author, in order to assess the impact of climate change on the value of farmland and, by inference, on agricultural productivity. More recent work by Kurukulasurya and Mendelsohn (2008) seeks to integrate the agronomic and Ricardian approaches by allowing for switching of output choices by African farmers, using a multinomial logit model while distinguishing different agro-ecological zones.

A third set of studies uses a variety of agro-climatic and global climate change models under different emission scenarios that include socio-economic aspects. Applications are both at regional and global level. In this stream of research, we can mention the seminal work by Parry (1990) and Parry et al. (2004) that analyses the global consequences to crop yields, production, and risk of hunger of linked socio-economic and climate scenarios. Potential impacts of climate change are estimated for climate change scenarios developed from the HadCM3 global climate model under the Intergovernmental Panel on Climate

Change Special Report on Emissions Scenarios (IPCC-SRES). Projected global changes in yield are calculated using transfer functions derived from crop model simulations with observed climate data and projected climate change scenarios. The basic linked system (BLS) is used to evaluate consequent changes in global cereal production, cereal prices, and the number of people at risk from hunger. Authors find that the crop yield results corroborate the complex regional patterns of projected climate variables, CO<sub>2</sub> effects, and agricultural systems that contribute to aggregations of global crop production.

Finally, some studies use computable general equilibrium (CGE) models in order to assess the effect of climate change on agriculture. The work of Darwin (2004), for instance, highlights two interesting types of results. First, uncertainty due to variable projections of climate is fairly large for most of the economic effects evaluated in the analysis. Economic conditions at the time of impact influence the direction and size of as well as the confidence in the economic effects of identical projections of greenhouse gas impacts. The economic variable that behaves most consistently is world crop production that may be a fairly robust indicator of the potential impacts of greenhouse gas emissions. The author stresses that improved economic conditions, embodied in the socio-economic scenarios, are not necessarily a panacea to potential greenhouse-gas-induced damages, particularly at the region level. In fact, in some regions, impacts of climate change or CO<sub>2</sub> fertilization (that are beneficial to under current economic conditions), may be detrimental under improved economic conditions (relative to the new economic base). In addition, those regions that rely on agricultural exports for relatively large shares of their income may be vulnerable not only to direct climate-induced agricultural damages, but also to positive impacts induced by greenhouse gas emissions elsewhere. The work of Palatnik and Nunes (2014) illustrates an attempt to economically assess, through the use of CGE models, the potential effects of climate change-induced impacts of biodiversity on the agricultural sector. Such impacts are measured in terms of changes in land productivity, changes in agricultural output, and, ultimately, changes in national GDPs. Economic valuation shows that climate change-induced impacts on biodiversity cause significant changes in GDP. However, the intensity of these changes varies across the economies under consideration. In fact, some countries, and respective economies, show to be less resilient than others and, most of the time, the welfare changes involved clearly signal the presence of winners and losers.

The present paper enters the first stream of research on the microeconomic/micro-econometric analysis of climate change impacts on agricultural yields. It is an original piece of research that is inspired by both the industrial and agricultural economic literature on production function estimations and the economic/climatologic literature on climate change effects, superbly summarized by the IPCC reports. From those backgrounds, the paper builds an original methodology for analyzing the agricultural drivers and predicting the effects of climate change impacts with a regional scope, with an illustrative application to the Veneto region in 2030.

The study is organized as follows. [Section 2](#) contains a description of the proposed methodology. [Section 3](#) presents the main results of the selected application. [Section 4](#) concludes.

### **Methodological framework**

Our proposed methodology is based on two main steps. First, we perform an econometric analysis of regional agricultural production functions. Secondly, we perform

predictions of the main trends and variation in agricultural yields, due to (assumed) variations in the main drivers/production inputs and to selected climate change scenarios.

### Agricultural regional production functions

We model agricultural production functions (both Cobb-Douglas and translog) in order to tackle and measure the marginal product of each factor used in the production of the selected, agricultural yields.<sup>1</sup> We use production functions that, in our setting, simply describe the technical relationship between the (physical) amount of agricultural inputs and the total agricultural yields, in a pure micro-economic fashion. The general empirical form of the agricultural regional production functions can be synthesized as in Eq. (1):

$$y_i = x_i' \beta + \varepsilon_i, \quad (1)$$

where  $y_i$  (yields) and  $x_i$  (agricultural production inputs) are observable variables, and  $\varepsilon_i$  is unobserved and referred to as an error term or disturbance term.

We aim at estimating the technological efficiency through the measurement of each selected input marginal product, and therefore the marginal impact on agricultural production. In our framework production functions are regional, since technologies vary according to the selected socio-economic applications and they are also money independent, (no input/output price is included in the regression line). Finally, production functions are temperature and climate invariant since, by embodying Mendelshon et al. (1994) criticism, we do not “insert” variables like temperature and precipitation levels in the production function specification. The first step of analysis aims at getting a technological picture of the marginal product of each input used for producing selected agricultural output, given a determined production technology in a given period of time and in a given geographical region.

The economic literature presents a large number of theoretical and empirical production functions. In our suggested methodological framework, Eq. (1) is operationalized through the use of two types of production functions. The first one is a Cobb-Douglas, as described in Eq. (2). The regional agricultural total output  $q$  (in logs) depends on a log-linear combination of  $n$  production inputs and an error term.

$$\ln q = \beta(1)_0 + \sum_{n=1}^N \beta_n \ln x_n + u. \quad (2)$$

The regional Cobb-Douglas empirical model is easy to estimate and interpret and requires estimation of a few parameters. Main disadvantages are the (stringent) assumptions that firms operate in a setting of perfect competition, with all firms having the same production elasticities (and that substitution elasticities equal 1).

The regional translog production function is modeled in Eq. (3). In this case, the regional agricultural total output  $q$  (in logs) depends on a log-linear combination of  $n$  production inputs, the  $m$  interactions of  $n$  production inputs, and an error term.

$$\ln q = \beta_0 + \sum_{n=1}^N \beta_n \ln x_n + \frac{1}{2} \sum_{n=1}^N \sum_{m=1}^N \beta_{nm} \ln x_n \ln x_m + u \quad (3)$$

The translog function is very commonly used in the literature, and it is a generalization of the Cobb-Douglas function. It is a flexible functional form providing a second-order approximation and less restriction on production elasticities and substitution elasticities. However, the translog model is more difficult to interpret and requires estimation of many parameters. In addition, it can suffer from curvature violations. Finally, both Cobb-Douglas and translog functions are linear in parameters and can be easily estimated.

#### Prediction methodology and assumptions

We attempt to perform prediction using selected production function-estimated coefficients in the regression model. We want to predict the value for the dependent variable (produced quantity/agricultural yields), given the potential climate change-induced variations of the two main drivers of agricultural productivity: land and labor, at a given value for the selected explanatory variables. Since the model is assumed to hold for all potential observations, it will also hold that:

$$y_0 = x_0' \beta + \varepsilon_0, \quad (4)$$

where  $\varepsilon_0$  satisfies the same properties as all other error terms. The obvious predictor for  $y_0$  is

$$\bar{y}_0 = x_0' b \quad (5)$$

As  $E\{b\} = \beta$ , it is easily verified that this is an unbiased predictor.<sup>2</sup>

The prediction exercise requires some further qualitative speculations and assumptions, since in the future, the world (and every selected agricultural region) might have changed in ways that are difficult to imagine, as difficult as it would have been at the end of the nineteenth century to imagine the changes of the last 100 years. Nonetheless, our key assumptions that drive the variations of the  $x_0'$  are the following:

1. We assume that there is no technological shock in agricultural production, in terms of dramatic changes in machinery that adopt very different technologies with respect to the current ones, e.g., the drones.
2. We assume a future with climate change. We assume that climate change will affect the agricultural sector in different ways, which are summarized by the IPCC-predicted scenarios (see IPCC; 2000, 2007). Each scenario is constructed according to a storyline. Each storyline assumes a distinctly different direction for future developments, such that the four storylines differ in increasingly irreversible ways. Together, they describe divergent futures that encompass a significant portion of the underlying uncertainties in the main driving forces.

They cover a wide range of key “future” characteristics such as demographic change, economic development, and technological changes.

3. According to the (probabilistic, future) occurrence of each scenario, we assume that land (cultivated hectares) and agricultural labor (labor force employed in the sector) will vary. The four main scenarios and storylines are summarized in Table 1.

The quantification of the value/percentage variations of  $x'_0$  under different climate change scenarios is relatively discretionary and needs assistance from other experts. It is important to understand how the world will vary and how the scenarios will implement in order to define a range of possible values that  $x'_0$  can assume, given the occurrence of each IPCC scenarios. Following Ansuategi et al. (2015), we organized focus groups and meetings with experts (for more clarity, see following sections for the applications) that clarify the possible effects of climate change-induced IPCC scenarios on the agricultural sector and the possible range of values that of  $x'_0$  can assume under each scenario. For instance, given all above, it might (probabilistically) be very unlikely to occur that regional agriculture might spur and develop under a B1 scenario in a certain region. Therefore, land and labor will be used in smaller units, with a percentage variations that cover a range that researchers and scientists determine according to the state of the arts of knowledge on climate change and common sense.

**Table 1** IPCC scenarios

IPCC scenario	Story line
A1	The A1 scenario describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B). In this scenario, emissions will affect the global temperature. Temperature increase: 1.4–6.4/1.4–3.8°C
A2	The A2 scenario describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth, and technological changes are more fragmented and slower than in other storylines. In this scenario, emissions will affect the global temperature. Temperature increase: 2.0–5.4 /1.4–3.8°C
B1	The B1 scenario describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives. In this scenario, emissions will affect the global temperature. Temperature increase: 1.1–2.9/1.4–3.8°C
B2	The B2 scenario describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels. In this scenario, emissions will affect the global temperature. Temperature increase: 1.4–3.8°C

Source. IPCC Special Report on Emissions Scenarios

**Table 2** Descriptive statistics

Variable	Mean	Standard deviation	Min	Max
Agricultural yields	2230	9400.716	0	225,000
Machinery	309	1416.609	0	104,000
Labor	732.21	2699.75	0	136,000
Land	12.47	27.35	0	454
Water	196.30	1339	0	400

Note: As defined in the FADN dataset, agricultural yields and seeds are measured in quintals, machinery in hours of use; labor in hours of work; land in hectares; and water in cubic meters

Finally, on the methodological point of view, the different assumed values for  $x'_0$  (according to the selected IPCC scenario) are then multiplied by  $b$ , the translog-estimated coefficients for land and labor marginal products (as in Eq. 5), in order to compute the climate change-induced variations in agricultural yields.

### **An application of to the northern Italian agricultural sector: the Veneto region**

We apply our proposed methodological framework to study possible impacts of climate change on agricultural yields in Veneto in 2030. Veneto is a region located in the North-East part of Italy and is a very productive agricultural territory. The 2015 OUTLOOK (<http://www.regione.veneto.it/web/agricoltura-e-foreste>) of the agricultural activities in the Veneto region reports, in fact, an increase in the number of employees (+ 2% to 61,224 units) and export growth (+ 12.8 with respect to the previous year) that achieved 4.3 billion euro, a record never achieved before by the Veneto primary sector. Evidence shows a particularly encouraging performance of soy and wheat crops. The description of the status quo, however, is an important piece of information that suffers additional analysis, often policy driven and demanded, aiming at explaining causal relationships and future developments and trends, in particular under climate change scenarios. The following paragraphs, therefore, contain an application of the methodology proposed in Section 2.

### **Testing regional agricultural production functions**

We use a rich dataset provided by the Farm Accountancy Data Network (FADN) that contains 8036 observations in the period 2009–2012. The dataset contains broad information on a large sample of Veneto farms and their legal, accounting, economic, and demographic structures and characteristics. The dataset contains a broad variety of information. It spans from purely technological and agricultural data (farms' yields quantity and variety, number/quantities/types of used production inputs) to accounting-economic figures (firms costs, revenues, and profit margins) and from institutional hints (legal status of the farms, property rights definition and attribution, certification standards) to sociological-demographics inputs (family composition, gender of the farmer).<sup>3</sup> Table 2 provides descriptive statistics of the data.

For the case at study, and given available data, we have estimate both agricultural Cobb-Douglas and translog specifications using a pooled OLS regression methods over other methods for estimating such a small panel. In particular, pooled OLS is a more appropriate estimator for randomly sampled cross sections of individuals at different points in time, like in the case at study, and differently from balanced/unbalanced panel

data, which record cross sections of the same individuals at different points in time. Balanced panel data record all different points in time for all individuals. Unbalanced panel data do not record the same/all different points in time for all individuals in the dataset.

**Production function estimates**

After several checks and attempts, Table 3 presents empirical results for both Cobb-Douglas and translog specifications.

**Cobb-Douglas estimates**

Column 2 contains estimated coefficients for the selected Cobb-Douglas specification. A 1% increase in the use of machinery, labor, water, and land respectively produces a 0.03%, 0.23%, 0.16%, and 0.60% increase in the agricultural yields, i.e., has a positive impact on production, even if at diminishing marginal returns. The estimated coefficient for land presents the highest marginal productivity and is statistically significant, as well as the estimated coefficients for labor and water. On the contrary, a 1% increase in the use of machinery only generates a 0.03% increase in the yields. The latter coefficient, however, is not statistically significant. It is worth signaling that the estimated production function (and underlying production technology) presents constant returns, since the sum of all  $b_n$  (the estimated coefficients for  $\beta_n$  is around 1). The estimated “picture” in the selected time frame shows a technology that produces at constant returns, where land is the steering engine of production.

**Translog estimates**

Column 3 contains estimated coefficients for the selected translog specification. For the sake of simplicity, we have selected the main productive inputs (labor and land). The results show that a 1% increase in the use of labor and land respectively produces a 0.31% and 1.15%, increase in the agricultural yields. The translog specification highlights a positive impact of the selected inputs on production, even if with diminishing marginal returns for labor and increasing marginal returns for land. A negative estimated coefficient for the effect of the interaction term (labor\*land) would imply that

**Table 3** Empirical estimates of selected production functions empirical specifications

Dependent variable: agricultural yields (2009–2012)		
Explanatory variables	Cobb-Douglas specification	Translog specification
(Log)machinery	0.03	–
(Log)labor	0.23***	0.32**
(Log)water	0.16***	–
(Log)land	0.60***	1.16***
(Log)labor <sup>2</sup>	–	0.05***
(Log)land <sup>2</sup>	–	0.06***
(Log)labor*land	–	–0.07***
Constant	4.01***	4.15***
Rsquared	0.67	0.68

\*\*\*5% statistical significant, \*10% statistical significant

a marginal increase of the land input reduces the effect of labor on agricultural yields (for a value of 0.07). Similarly, a marginal increase of the labor input reduces the effect of land on agricultural yields (for the same amount).

**Prediction results** The estimated coefficients of translog production functions for land and labor are used for computing predictions on yield variations under the A2, B1, and B2 IPCC scenarios, using the help of experts as explained in Section 2 (see Valentini et al. 2017). Land and labor are the production inputs that might be affected the most by climate change impacts.

Table 4 reports selected results. Column 1 reports possible variations of the selected inputs (land and labor), from - 50 to + 50%, under climate change scenarios. Columns 2 and 3 report the quantified effects of the climate change-driven variations of labor and land on agricultural yields. Column 4 shortly summarizes the selected IPCC scenarios.

We can summarize the results as follows:

- A1 scenario underlying story-line does not provide sufficient information to formulate a hypothesis on the changes of labor and land in the agricultural sector in 2030
- Under the A2 scenario (highlighted in light green), we can assume further development of agriculture and agricultural production, with a consequent increase in people employed in the agricultural sector and more land devoted to cultivation. The magnitude of the variation of the used selected inputs is variable and depends on the realization of future conditions, summarized by the IPCC scenario. Once the variation is quantified, the related impact on agricultural yields depending on land/ labor is also quantified according to the econometric estimates. For instance, we

**Table 4** Agricultural yields % variations in Veneto in 2030 with respect to the effects of the variation of three main drivers' sources

% variations of the $x_0$ ,	Effects on agricultural yields of the variations of $x_0$ , when it is Labor	Effects on agricultural yields of the variations of $x_0$ , when it is Land	Recalling IPCC Scenarios
-50	-16%	-58%	<b>A2 Scenario</b>
-40	-12.8%	-46.4%	Preservation of local identities, global population continuously increases, economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines
-30	-9.6%	-34.8%	
-25	-8%	-29%	
-20	-6.4%	-23.2%	
-10	-3.2%	-11.6%	
-5	-1.6%	-5.8%	<b>B1 Scenario</b>
0	0	0	A convergent world with the same global population that peaks in mid-century and declines thereafter, rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies
5	1.6%	5.8%	
10	3.2%	11.6%	
20	6.4%	23.2%	
25	8%	29%	
30	9.6%	34.8%	
40	12.8%	46.4%	
50	16%	58%	<b>B2 Scenario</b>
60	19.2%	69.6%	Local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. The scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels
70	22.4%	81.2%	
75	24%	87%	

Our elaboration with our estimates and assumptions based on IPCC scenarios

might assume that the favorable conditions to agriculture incentivize agricultural firms to use more labor (5% more). This, in turn, will increase agricultural yields by 1.6%. Alternatively, a 5% increase of the use of land (more land devoted to agriculture), under conditions hypothesized by the A2 scenario, will increase yields by 5.8%, with respect to the present situation

- Under the B1 scenario (highlighted in gray), we assume that less work might be devoted to the agricultural sector, with a decrease in people employed in the agricultural sector and less land devoted to cultivation. This, in turn, might negatively affect the production of agricultural yields. For instance, if we assume that the input labor will decrease by 10% (given the realization of the circumstances hypothesized under scenario B1), the agricultural yields will decrease by 11.6%
- The B2 scenario (highlighted in dark green) could represent the most fertile scenario for agricultural spurring and development, with a robust increase in people employed in the agricultural sector and more land used for cultivation. In this case, if we assume that the input labor will dramatically increase by 60% (given the realization of the circumstances hypothesized under scenario B2 and a strong change toward an agricultural based society), then agricultural yields will increase by 19.2%

## Conclusions

In this paper, we have constructed and tested a simple methodology for assessing and predicting climate change effects on agricultural yields. The methodology follows two steps. First, we econometrically estimate the marginal product of key production inputs (e.g., labor and land), through the estimation of production functions. Then, we predict future agricultural sector performance, by assuming a future with climate-induced changes in the land use and in agricultural labor use, under different IPCC scenarios. We apply the methodology to perform predictions in the Veneto region in 2030. Results differ according to the selected IPCC scenario and consequent input use variations. For instance, land presents a very high marginal product and climate-induced changes in the land use might dramatically (positively and negatively) affect agricultural yields according to the occurrence of different IPCC scenarios. In this perspective, the climate change adaptation and mitigation policies and options should primarily aim at the preservation of land productivity in Veneto.

Our proposed methodology and results need to be scrutinized under different perspectives.

First, the predictions are a conditional scenario based on specific (or implicit) assumptions about the climate change-driven developments in the future. Though methodologically sound, our predictions are not intended to be a forecast of what the future will be, but instead, they are a description of what would be expected to happen under these very specific assumptions and circumstances. As such, they provide a neutral reference scenario that can serve as a point of departure for discussion of alternative results and measures. For this reason, we have constructed a “*menu*” table that should allow policymakers to be presented with very different impacts, according to the state of the world that will be realized in the near future, and that scholars are not able to forecast with absolute certainty.

Second, our proposed methodology combines a very sound methodological part that is based on econometric estimation and a part that is devoted to discretionary and

reliance on different experts and expertise in order to voluntarily acknowledge the high degree of uncertainty on the occurrence of each scenario and on the occurrence of the estimated and predicted figures.

Third and consequential to the previous points, such uncertainty imposes a “*menu*” of policies, each targeted to the probabilistic occurrence of each scenario and computed impact. Climate change, in fact, can generate soil erosion, desertification, changes in plant biomass and productivity, change in land productivity, and dramatic changes on the economy and structure of the farm. Well-targeted agronomic techniques (e.g., the addition of organic substances), for instance, should aim at conserving and restoring land productivity from climate change negative effects (see Esposti, 2013). The latter point, however, is devoted to further research and discussion.

## Endnotes

<sup>1</sup>The (marginal) productivity identifies the amount of product (on the margin) obtained for each additional productive factor unit (be it capital, work, or land) employed.

<sup>2</sup>See Verbeek (2004); Onofri et., al 2012; Onofri et al., 2014.

<sup>3</sup>In the used dataset, it is possible to highlight that:

- The Province more represented is Verona.
- The majority of companies (81%) is active in the plains.
- The majority of companies (80%) is medium- and large-sized.
- The most cultivated products are cereals (approximately 40% of agricultural production), followed by grapes (about 20%). It is worth highlighting that in Veneto, 80% of total production is mostly covered by 4 outputs: grains (43.43%), fruits/vegetables/ tubers (17.78%), hay (11.87%), and silage (6.32%).
- The dataset contains details on the governance and legal form of enterprises. The most frequent legal profile is family company, received by inheritance.
- There is a large variance on the data for production and income.
- Most companies (about 90%) operate in open field.

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## Authors' contributions

VB conceived the study and participated in its design and coordination. FB has created the dataset. LO has conceived the methodological framework, performed econometric analysis, drafted the paper. All authors read and approved the final manuscript.

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