To what extent will climate and land use change affect EU-28 agriculture? A computable general equilibrium analysis

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Abstract

This paper assesses the macroeconomic implications of climate and land use change on agriculture in the European Union, by means of a computable general equilibrium model of the world economy. In this paper, the counterfactual simulations are conducted at the year 2050 under the second Shared Socioeconomic Pathway.

We find that climate and land use change are likely to affect agricultural systems very differently across Europe. Northern countries are expected to benefit from climate change impacts, whereas other areas in Europe will suffer negative consequences in terms of reduced agricultural output, real income and welfare. Surprisingly, Mediterranean Europe is not the most vulnerable region.

Keywords: productivity shock, climate change, land use change, general equilibrium analysis

JEL classification: Q15, Q18, Q54

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1. Introduction

Despite its relatively small geographical extension, the European Union -EU- is one of the world's largest producers of agricultural products (FAO, 2007). According to EUROSTAT (2015)[1], total agricultural production in 2014 amounted to around 1122.4 million tones, about 10% of world total production. Thanks to its varied climatic and topographic conditions, the EU produces a broad range of crops, fruits and vegetables. For example, the harvested production of cereals (including rice) is estimated to be around 334.2 million tones in 2014, about 13 % of global cereal production. Sugar beet accounts for around 50% of the global production, while two third and three quarters of wine and olive oil produced globally come from the European Union.

Unfortunately, climate change is expected to affect dramatically agriculture (IPCC, 2014). Bindi and Olesen (2011) find that the effects of climate change -and increased atmospheric CO2- are expected to lead to overall small increases in European crop productivity, despite technological development (e.g. new crop varieties and better cropping practices) might outweigh the effects of climate change (Ewert et al., 2005). Recently, cereal grain yields have shown considerable slowing of growth in yields, indicating that climate change may play a greater role than technological progress (Kristensen et al. 2010).

The extent and magnitude of the impacts are, however, uncertain, given the great deal of complexity in the climate-land-food systems. According to Alcamo et al. (2007), the consequences of climate change on agricultural ecosystems are likely to vary widely depending on the cropping system (i.e. cereals vs. forage crops vs. perennial horticulture), the hydrological features, water uses and management approaches of each region. The actual effect depends on several factors, which are either country-specific (e.g., the geography, soil type, water conditions and existing forms of food production) or difficult to evaluate ex-ante. Variations in regional temperature, different regional patterns of precipitations, the amount of fertilization due to higher CO2 concentration, the actual level of water available for irrigation, irrigation techniques, adaptation strategies including variety selection, crop rotation and sowing times are all factors potentially modifying crop yields and thus agricultural productivity.

Climate change also affects the total endowment of land available for agricultural purposes through different drivers. First, rapid and extreme events, like floods, are opposed to long-term climate induced events, which have long duration (from months to years) and slow onset. In the latter case, the effect on land use can hardly be reversed (IPCC, 2014). Second, climate change is expected to affect the distribution of vegetation and, consequently, land cover types: stronger patterns related to elevation gradients may emerge in addition to patterns related to latitude gradients (Gobiet et al., 2014). In addition, changes in biodiversity (due to climate change) are expected to increase the vulnerability of regional agriculture and,

[1] http://ec.europa.eu/eurostat/data/database.

consequently, the likelihood of land abandonment in some regions (Rounsevell et al., 2006). The long-term future development of European agriculture will also depend on a combination of factors, including economic strength of farms, pressure on agriculture land, and adaptive capacity of regional systems (Hermans et al., 2010; Greiving, 2011).

In this paper we simulate the structural joint consequences of both climate and land use change on the agriculture[2] of the European Union, at the year 2050. A first novelty of this study is the combination of different modeling frameworks, each delivering key inputs for and output of the analysis. The methodology proposed by Roson and Sartori (2016) is applied to estimate the climate change impact on the country's agricultural productivity. The Land-Use-based Integrated Sustainability Assessment -LUISA-Territorial Modeling platform (Baranzelli et al., 2014) provides the estimates on land use changes. A computable general equilibrium (CGE) model of the world economy is then employed to gauge the overall impact of climate change (through variations in agricultural productivity) and land use change on the agriculture sector of the European Union. The CGE model database is disaggregated into the 28 EU member state and two residual regions (rest of Europe, rest of the world). The economy of each EU member state is "perturbed" with the estimated variations in agricultural productivity and land use change. A second novelty of this study is that the counterfactual simulations are conducted on a 2050 baseline, where the economic structure of the EU28 is consistent with the population and Gross Domestic Product (GDP) levels projected under the "Middle of the Road" Shared Socioeconomic Pathway, SSP2 (Arnell et al., 2011; Kriegler et al., 2012).[3]

The paper is structured as follows. Section 2 is devoted to the description of the methodology applied to estimate the climate change and land use change impacts on agriculture. Section 3 illustrates the results obtained from the economic analysis, while Section 4 reports the results of the sensitivity analysis conducted on climate change impacts. A final section concludes.

2. The impact of climate and land use change on the European agriculture

2.1 Climate change impact on agricultural productivity

The impact of climate change on agricultural productivity is estimated by applying the methodology proposed by Roson and Sartori (2016). In their contribution, the authors define a set of climate change impact functions, relating physical impacts of climate change (typically variations in average temperature, precipitation levels and CO_2 concentration) to economic impacts in various dimensions, for a set of countries, including all European economies. When it comes to estimate the impact on crop yield, two damage functions are defined. One function estimates sectoral productivity variations in the yields of rice, wheat and maize only, and is obtained

[2] Livestock production is excluded from this analysis.

[3] SSPs include a storyline or *narrative*, which describes plausible alternative changes in aspects of society such as demographic, economic, technological, social, governance and environmental factors.

on the base of meta-analyses provided by the IPCC (2014); a second function estimates productivity changes of the aggregated agricultural sector, elaborating on Cline (2007). In both cases, crop yield is expressed as a function of local mean temperatures.[4] As the disaggregation of the dataset used in this study allows to keep "Rice", "Wheat" and the broader category "Cereals" disaggregated, the first crop-specific impact function is applied to these three categories, whereas the second impact function is applied to an aggregated residual category "Other Crops".[5]
Predicted local average temperature at the year 2050 are retrieved from the GAEZ dataset and are shown in Table 1, both in levels and in percentage change with respect to the baseline year.[6] In the European Union, temperatures are expected to rise by +1.75°C, on average. The largest increases will likely be registered in Central-Eastern countries (e.g., Slovakia, Bulgaria, Romania, Slovenia, Poland, Germany).

Table 1. Predicted average temperature (°C) and standard deviation at the year 2050

Countries	*Temp. 2010*	*Avg temp. 2050*	*Dev.St.*	*Variation*	*Countries*	*Temp. 2010*	*Avg. temp. 2050*	*Dev.St.*	*Variation*
Austria	6.99	8.52	2.96	+1.53	**Italy**	13.68	14.47	4.00	+0.79
Belgium	8.96	11.19	0.67	+2.23	**Latvia**	6.16	8.16	0.58	+2.00
Bulgaria	9.67	13.40	2.03	+3.73	**Lithuania**	6.41	8.68	0.29	+2.27
Croatia	12.7	13.36	2.17	+0.66	**Luxemb.**	8.29	10.68	0.49	+2.39
Cyprus	18.89	20.03	1.26	+1.14	**Malta**	18.71	20.19	0.21	+1.48
CzRep.	7.12	9.65	1.04	+2.53	**Netherl.**	9.22	11.05	0.39	+1.83
Denmark	7.59	9.60	0.35	+2.01	**Poland**	7.19	10.06	0.69	+2.87
Estonia	5.53	7.54	0.49	+2.01	**Portugal**	15.88	17.32	1.92	+1.44
Finland	2.72	3.86	2.11	+1.14	**Romania**	8.56	12.08	2.21	+3.52
France	11.3	12.50	2.16	+1.20	**Slovakia**	6.23	10.41	1.81	+4.18
Germany	8.03	10.41	0.81	+2.38	**Slovenia**	8.08	11.17	1.90	+3.09
Greece	16.92	16.26	2.50	-0.66	**Spain**	15.63	15.46	2.89	-0.17
Hungary	10.07	13.09	0.65	+3.02	**Sweden**	4.53	4.33	3.20	-0.20
Ireland	9.78	10.02	0.63	+0.24	**UK**	9.31	9.59	1.42	+0.28

Source: GAEZ database

By applying the percentage variations in average temperature shown in Table 1 to the damage functions provided by Roson and Sartori (2016), estimates of productivity changes in "Rice", "Wheat", "Cereals" and "Other Crops" are obtained and shown in Table 2. The variations in average temperature affects European agricultural productivity differently, depending on the climate zone where countries

[4] For a detailed description of how the damage functions are obtained, the reader may refer to Roson and Sartori (2016), Section 4.

[5] Maize is a cereal, so we applied the resulted productivity change of maize to the whole category "Cereals". The residual agricultural sector "Other Crops" contains oilseeds, fruits and vegetables, plant-based fibres and nuts.

[6] The GAEZ database (http://www.fao.org/nr/gaez/about-data-portal/agro-climatic-resources/en/) collects projections on several climate variables, including average temperature, obtained from a number of General Circulation Models (e.g., Hadley CM3, MPI ECHAM4, CSIRO Mk2, etc.) on the base of some SRES climate scenarios (A1F, A1, A2, B1 and B2), developed for the IPCC Fourth Assessment Report. As the mean value of the models projections are very similar across SRES scenario, results of this study has been produced by using mean temperature projections generated by the Hadley CM3 model, B2 SRES scenario, for the year 2050.

are located, and the crop response to changing local temperatures, which is generally not linear (Schlenker and Roberts, 2009; Lobell and Burke, 2010).

Table 2. Impact of climate change on agricultural productivity by crop category and potential increase of average temperature.

Countries	*Rice*	*Wheat*	*Cereals*	*Other Crops*
Austria	-4.8%	-6.8%	-0.2%	0.3%
Belgium	-5.1%	-7.4%	-0.2%	0.2%
Bulgaria	-4.3%	-5.6%	-0.8%	-0.2%
Croatia	-3.1%	-6.2%	-2.4%	1.0%
Cyprus	-3.5%	-3.9%	-1.4%	-1.4%
CzRep.	-4.1%	-6.9%	-1.0%	0.5%
Denmark	-4.5%	-7.8%	-0.4%	0.6%
Estonia	-1.1%	-0.8%	-1.2%	1.8%
Finland	-7.6%	8.3%	-3.9%	4.0%
France	-4.7%	-6.5%	-0.5%	0.1%
Germany	-4.2%	-7.0%	-0.9%	0.5%
Greece	-3.9%	-4.0%	-0.6%	-0.7%
Hungary	-1.6%	-4.6%	-2.9%	0.3%
Ireland	-5.3%	-7.9%	0.0%	0.0%
Italy	-4.2%	-5.3%	-0.9%	-0.8%
Latvia	-3.4%	-6.8%	-0.9%	1.4%
Lithuania	-3.4%	-6.8%	-1.1%	1.0%
Luxemb.	-5.0%	-7.1%	-0.3%	0.2%
Malta	-3.2%	-4.9%	-2.5%	-2.2%
Netherl.	-5.3%	-7.8%	-0.1%	0.2%
Poland	-4.3%	-7.2%	-0.8%	0.6%
Portugal	-3.0%	-6.0%	-3.1%	-2.5%
Romania	-3.2%	-6.3%	-2.3%	0.3%
Slovakia	-4.1%	-6.7%	-1.1%	0.5%
Slovenia	-3.9%	-6.3%	-1.4%	0.4%
Spain	-3.5%	-5.5%	-2.0%	-1.4%
Sweden	-2.2%	-3.5%	-0.5%	2.5%
UK	-5.6%	-9.3%	0.1%	0.1%

Source: Authors' own elaboration

On average, wheat is the most affected crop, with a predicted average decrease of -6.5%, followed by rice (-3.9%) and cereals (-1.2%). The impact on the residual sector "other crops" is negative for all the countries located in the South, whereas for the remaining countries the impact is small or even positive (0.3% on average). This result may be explained by either the differences between the tow types of damage functions employed to compute the changes in productivity or the composition of the residual aggregate of agricultural good, which is very heterogeneous, with possible opposite-sign impacts averaging out.

Warmer temperature (and higher concentration of carbon dioxide), by altering the crop production cycles, may also turn out to be beneficial through increased growing potential, larger and earlier harvests and extended growing season, especially in the northern countries (Finland, Sweden) and for residual crops, like fruits and vegetables, accounted for in the aggregated category "other crops". On average, the most affected countries are those located in Central and Eastern Europe, characterized by a continental climate and for which larger rises in mean temperature are predicted (see Table 1).[7]

2.2 *Land use change and its effects on agriculture*

Land use change affects agriculture in the sense that more or less land will be available for crop cultivation. Estimates on land use change were retrieved from the LUISA Territorial Modeling platform, built by the Joint Research Centre of the European Commission (LUISA - Land-Use-based Integrated Sustainability Assessment, Baranzelli et al., 2014). These estimates are not available by crop, but only terms of generic "agriculture" land-use class. Therefore, the estimated variations in agricultural land endowment reported in Table 3 are applied uniformly to each crop category.

The LUISA platform integrates a suite of models, considering the demand and supply of resources and socio-economic activities and infrastructures, and merges both top-down and bottom-up dynamics to simulate land use changes (Baranzelli et al., 2014). Scenarios consist of land-use allocation in space and time considering macro drivers as simulated by sectoral models (such as RHOMOLO, GEM-E3, CAPRI, POLES, etc.), through different geo-spatial models (such as TRANSTOOL, LISFLOOD, Regional Climate Models, BIOMA, etc.). The latter models provide thematic physical and geographical layers, while overall long-term demographic (trends and migrations) and economic projections are retrieved from Eurostat and ECFIN (for further detail on the modeling, see EC, 2016). In practice, the "demand" module of LUISA is a set of procedures that capture macro drivers of land-use change (taken from a set of upstream models) and transform them into actual regional quantities of the modelled land-use types.

Specifically, in LUISA, "land demand" is specified for four main groups of land-use classes: urban, industry-commerce, agriculture and forest. The 'agriculture' land-use class includes various types of land used to produce food, feed and fibre, thus comprising arable and pasture land, and permanent crops. Related to the agricultural land-use class is the 'new energy crops' class that covers land used to grow crops to produce energy. Regional land demands for agricultural commodities are taken from the CAPRI model (Britz and Witzke, 2008), which simulates market dynamics using nonlinear regional programming techniques to forecast the consequences of the Common Agricultural Policy. This ensures consistency between the CAP-compliant economic and market assumptions, and the physical space occupied by the commodities grown in each simulated region.

At the year 2050, agricultural land is likely to decrease in the majority of the countries, with the largest absolute reductions occurring in central Europe (Poland, France and Germany). A larger availability of agricultural land is predicted for Northern-Eastern countries, so a shift of agricultural production toward this

[7] Temperature variability is local, but the model cannot provide subnational estimates.

European region is expected to occur.[8] Surprisingly, an increase in the amount of agricultural land is predicted for some Southern economies as well (such as Cyprus, Greece, Portugal and Spain).

Table 3. Actual and estimated changes in agricultural land (km²).

Countries	*2010*	*2050*	*% Var.*	*Countries*	*2010*	*2050*	*% Var.*
Austria	31,286	27,349	-12.6%	**Italy**	160,529	151,954	-5.3%
Belgium	18,547	15,507	-16.4%	**Latvia**	21,164	24,203	14.4%
Bulgaria	59,601	57,817	-3.0%	**Lithuania**	38,267	35,871	-6.3%
Croatia	20,228	20,222	-0.0%	**Luxemb.**	1,458	1,051	-27.9%
Cyprus	4,696	4,883	4.0%	**Malta**	179	163	-8.9%
CzRep.	46,681	43,556	-6.7%	**Netherl.**	23,616	22,029	-6.7%
Denmark	31,898	30,974	-2.9%	**Poland**	201,092	161,428	-19.7%
Estonia	12,894	14,479	12.3%	**Portugal**	35,395	35,676	0.8%
Finland	8,783	18,627	112.1%	**Romania**	149,458	139,781	-6.5%
France	344,444	317,767	-7.7%	**Slovakia**	24,391	23,044	-5.5%
Germany	209,040	185,860	-11.1%	**Slovenia**	6,690	6,216	-7.1%
Greece	61,938	64,219	3.7%	**Spain**	263,391	265,845	0.9%
Hungary	63,599	58,829	-7.5%	**Sweden**	19,742	37,303	89.0%
Ireland	47,330	46,209	-2.4%	**UK**	139,480	128,593	-7.8%

Source: Own elaboration using the datasets produced by the LUISA platform

2.3 *Modeling strategies and the general equilibrium analysis*

The macroeconomic consequences of reduced land availability and lower productivity of agriculture go far beyond a drop in agricultural production (yields). In fact, lower output brings about an increase in the price of domestic products, which become relatively more expensive than foreign products. This change in relative prices may cause the substitution of some domestically produced agricultural goods with imports in both production and consumption processes, bringing about a real devaluation of the national currency and a change in the whole structure of the economic system. Vice-versa, larger availability of land and increased productivity generate opposite effects.

To account for the multiple system-wide economic consequences, a Computable General Equilibrium (CGE) model is the appropriate tool. A CGE model is a large non-linear system that provides a systemic and disaggregated representation of national, regional and multi-regional economies. It fully accounts for circular income flows, inter-sectoral and market linkages, changes in relative competitiveness. The economy is treated as an integrated system, in which markets influence each other, resource are constrained, prices are allowed to vary and demand and supply must balance under behavioral assumptions of Walrasian perfectly competitive market. Model parameters are calibrated using real world data from Social Accounting Matrices (SAM), whereas counterfactual simulations are obtained by changing exogenous variables and parameters. The counterfactual equilibrium computed for

[8] A relatively large area of land will become increasingly available and attractive to agriculture and forestry. For example, in the northern Scandinavian countries (Norway, Sweden and Finland), it is expected that the boreal region will shift some 600 km further North (IPCC 2014).

the global economy is compared to the benchmark/baseline equilibrium, where no shock perturbed the economy.

A major advantage of using a general equilibrium model is that industry prices of *all* possible markets (not only agricultural markets) are endogenous, so that the loss of productivity occurring in agriculture is partly compensated by an increase in the relative price of agricultural products, thus enhancing the value of the reduced output.

The model used in this exercise is the CGE model of the Global Trade Analysis Project (GTAP), whose mathematical structure is fully described in Hertel and Tsigas (2007). A brief summary of the meaning of equations is provided in the Appendix. The model is calibrated on the version 9 of the GTAP Data Base (Aguiar et al., 2016), at the year 2011. The database is disaggregated into the 28 European Union member states[9] and two residual regions, Rest of Europe and Rest of the World.

Figure 1 summarizes the methodology followed to simulate the consequences of both climate and land availability change on agriculture. The counterfactual simulations are conducted at the year 2050 under the second Shared Socioeconomic Pathway, SSP2 (Arnell et al., 2011; Kriegler et al., 2012), termed the "Middle of the Road" scenario. SSP2 is a pathway characterized by a modest overall growth in population and incomes, and a slow pace of overall trade liberalization. Data on projected population and income levels by country are used to obtain a plausible baseline of the whole economy at the year 2050. Percentage changes of GDP and population reported in Table A1 of the Appendix are applied to the corresponding variable in the CGE model, so that the model generates a counterfactual baseline scenario, where the value of the other macroeconomic variables is consistent with the projected population and GDP. The 2050 SSP2 baseline is then "perturbed" to account for the climate change impact on agricultural productivity and the variations in land available for agriculture – land use change. In particular, (i) the productivity of agricultural crops is varied by the percentage changes reported in Table 2, as a result of climate change; and (ii) agricultural land is scaled up or down according to percentages shown in Table 3. A schematic representation is provided in Figure 1.

[9] Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and UK.

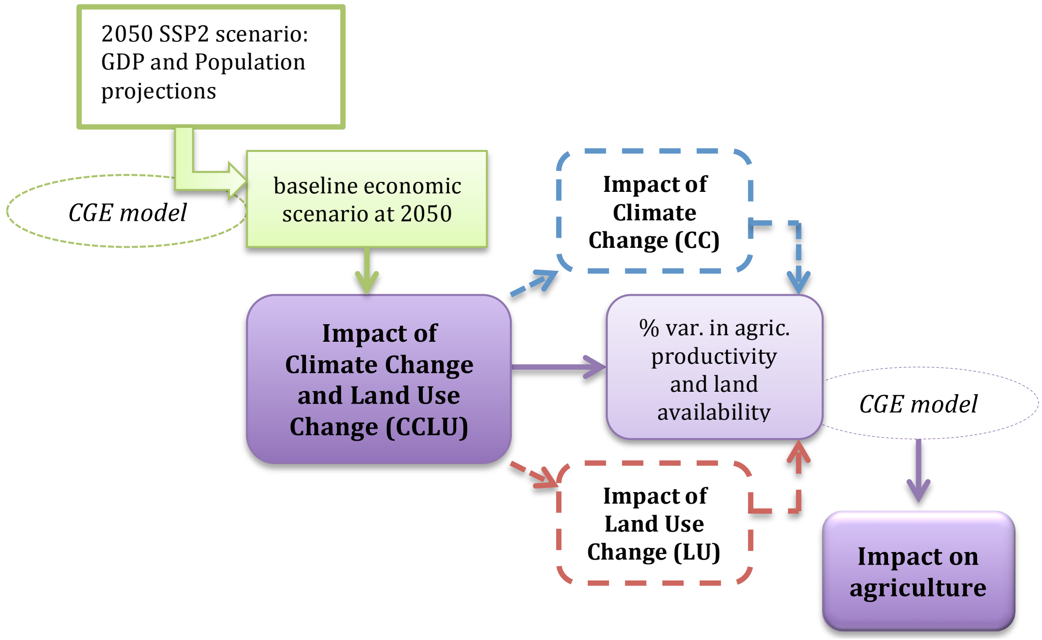
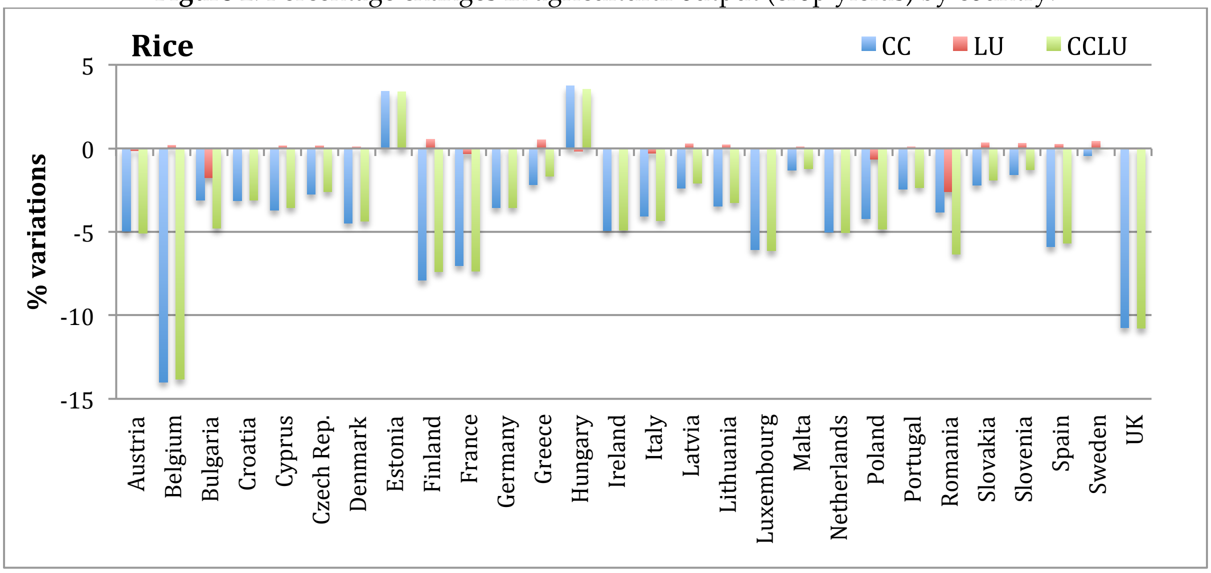


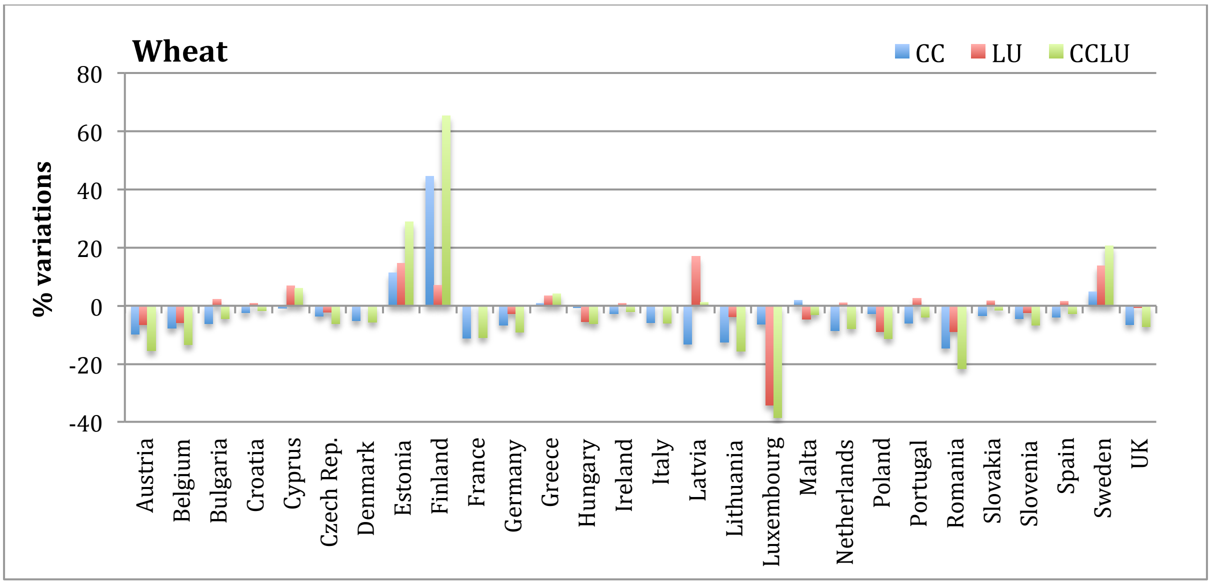
Figure 1. Methodological approach followed in this study.

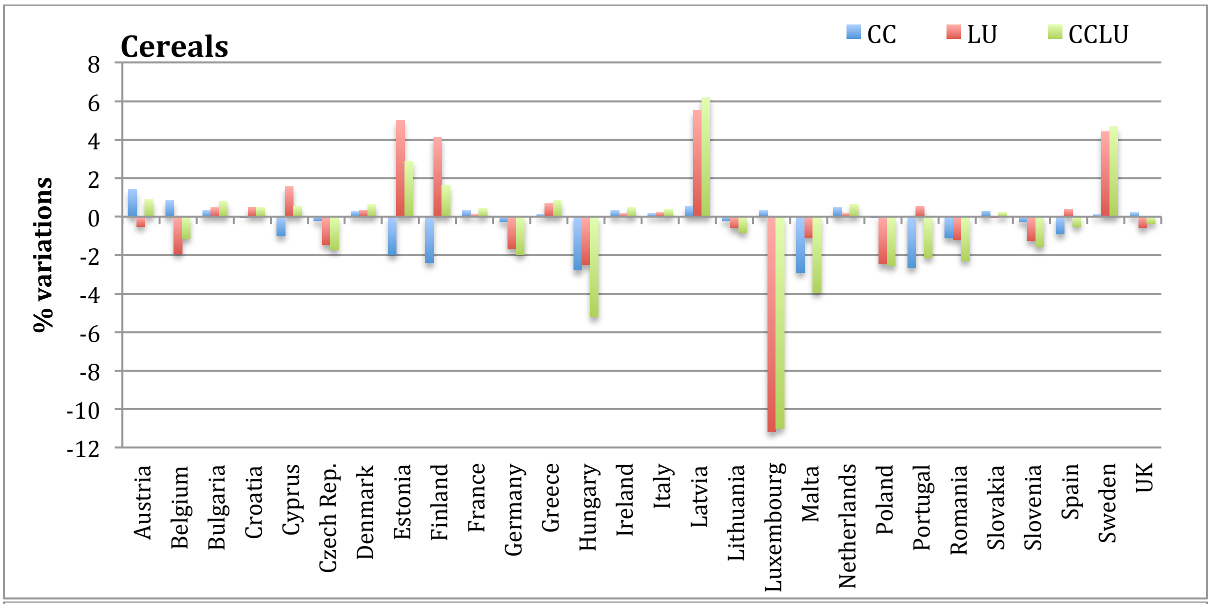
2.4 *Results*

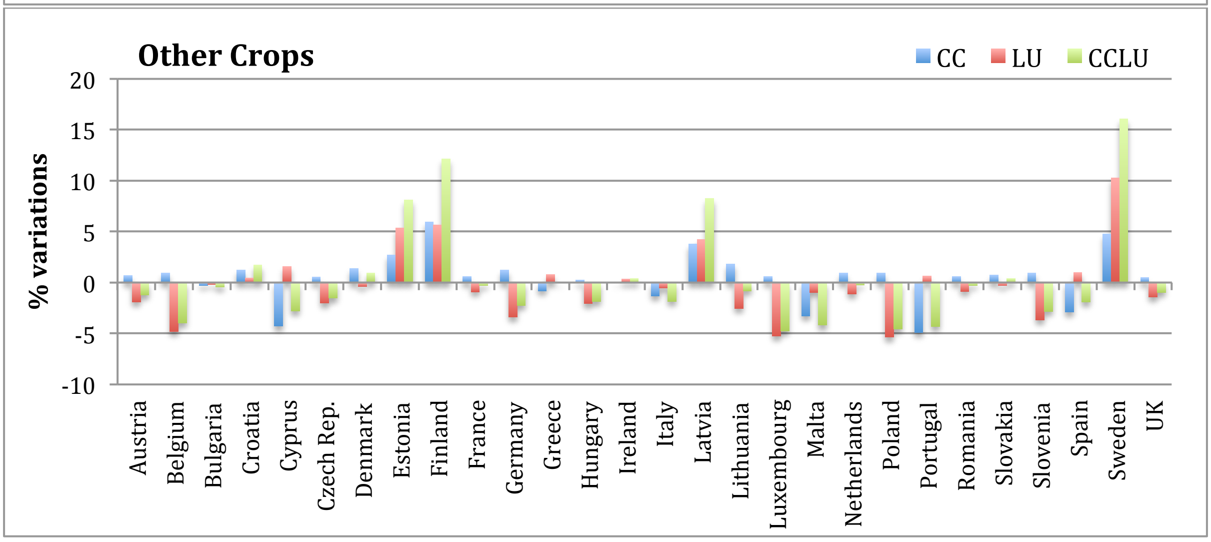
Figure 2 illustrates the percentage variations in total yield by crop category. The impact on agricultural output varies substantial both across countries and crops. Not surprisingly, the impact on agriculture is negative for the countries suffering from loss in land endowment and productivity, and vice versa. However, variations in industrial output are different from changes in productivity, as expected, because the change in relative competitiveness among sectors is fully accounted for in the general equilibrium model. When productivity drops, production volumes fall not only because lower output is obtained with the same factors, but also because higher costs in that sector bring about lower demand.

Figure 2. Percentage changes in agricultural output (crop yields) by country.









Source: Authors' own estimates.

Depending on the crop type and country, the overall impact on crop yield may vary substantially. For example, wheat production is expected to drop by -38.55% in Luxemburg and to rise dramatically by 65.36% in Finland. Climate change drives the result obtained for the latter, land use change for the former.
The overall impact on rice production is negative for all countries, with the exceptions of Hungary (3.53%) and Estonia (3.40%), mostly driven by climate change; rice production in Belgium and UK are the most negatively affected, with a projected decrease of -13.84% and -10.78% respectively.
The expected variations in the crop yield of the various crop categories (with the exception of rice) are qualitatively similar within the same country. For example, agricultural production in Sweden, Finland and Estonia is expected to grow, regardless the crop type under consideration. The reverse holds true for e.g. Hungary, Germany, Spain, Slovenia, UK and Belgium. For other countries, like Italy, France and Cyprus, crop production is expected to be either positive or negative.
Consistently with the literature (e.g., Alexandrov et al., 2002; Ewert et al., 2005; Audsley et al., 2006; Olesen et al., 2007; Richter and Semenov, 2005), climate-related increases in crop yields are expected above all in northern European countries. our Unlike other studies, this analysis reveals that among the countries expected to suffer the largest reductions in wheat and cereals yields we find non-Mediterranean countries, like Lithuania, the Netherlands, Luxembourg, Austria and Belgium.
Other sectors of the economy are indirectly affected by the productivity shocks in agriculture, both positively and negatively. This is another consequence of the full account of changes in relative competitiveness. Indeed, an e.g. negative shock affecting agriculture brings about a real devaluation of national currencies, which is needed to keep the foreign balance in equilibrium. The devaluation makes exported goods more competitive in foreign markets, thereby stimulating production in the other sectors. Table 4 presents the changes in total output for the Manufacture and Services industries. On average, Manufacture is more affected than Services by the change in relative competitiveness (e.g., Estonia, Finland, Malta, Latvia, Poland, Portugal, Spain), as Services are typically not traded internationally.
In general, where agricultural land availability is projected to increase (e.g., Greece, Latvia, Sweden), a rise in agricultural production and a reduction in the output of the other sectors are expected (with possible exceptions) for two reasons. In the CGE model employed in this study factors of production are fixed (their level is exogenous) and fully employed. Therefore, (i) an expansion of agriculture would necessarily generate a contraction of the other sectors, as more factors (not only land) are employed in the former; (ii) the increase in land availability reduces its relative price with respect to the price of labor and capital, in other words, units price in agriculture gets relatively lower.

Table 4. Percentage changes in other industries' output by scenario.

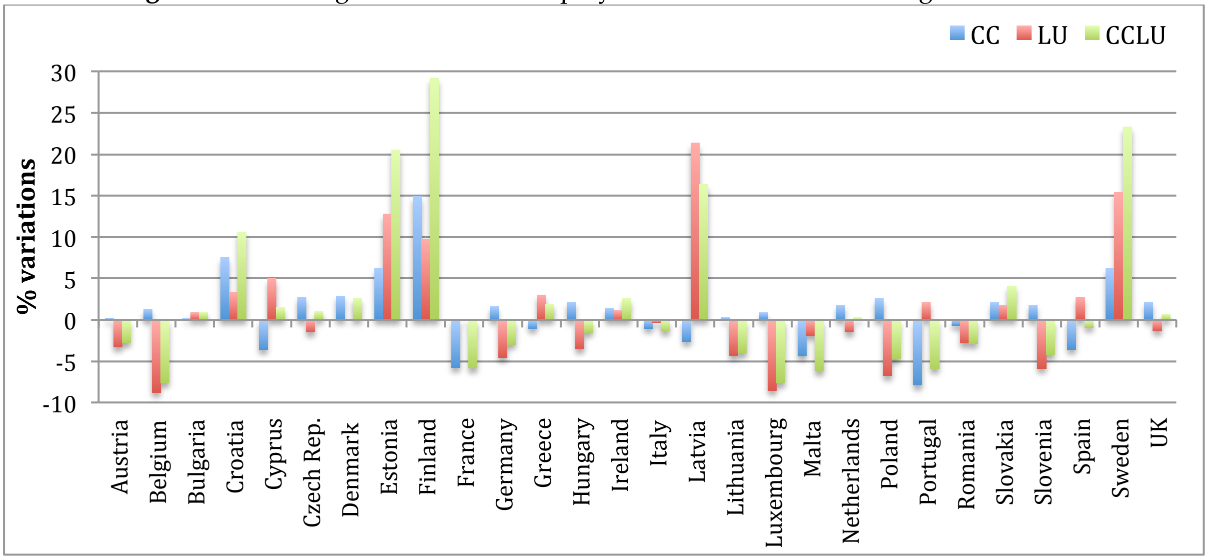
Countris	*CC*		*LU*		*CCLU Scenario*	
	Manuf.	*Service*	*Manuf.*	*Service*	*Manuf.*	*Service*
Austria	0.01	-0.01	0.15	0.01	0.17	0.00
Belgium	0.07	-0.02	0.31	0.06	0.38	0.04
Bulgaria	0.09	-0.04	-0.23	-0.02	-0.12	-0.06
Croatia	-0.01	-0.05	-0.11	-0.03	-0.11	-0.08
Cyprus	0.48	0.01	-0.50	-0.11	-0.02	-0.09
CzRep.	0.00	-0.02	0.17	-0.02	0.18	-0.04
Denmark	0.06	-0.01	-0.07	0.00	0.00	-0.01
Estonia	-0.29	-0.06	-0.62	-0.12	-0.95	-0.20
Finland	-0.17	0.00	-0.36	0.00	-0.55	0.00
France	0.10	0.00	0.02	0.00	0.12	-0.01
Germany	0.02	-0.01	0.18	0.01	0.20	0.00
Greece	0.16	-0.02	-0.23	-0.04	-0.07	-0.06
Hungary	0.09	-0.04	0.40	0.02	0.50	-0.02
Ireland	0.03	-0.04	-0.03	-0.04	0.01	-0.08
Italy	0.11	-0.01	0.01	-0.01	0.12	-0.02
Latvia	0.04	0.00	-0.97	-0.13	-0.89	-0.13
Lithuania	-0.05	-0.03	0.39	0.05	0.33	0.02
Luxemb.	0.00	-0.05	0.54	0.10	0.56	0.05
Malta	0.26	-0.04	0.08	-0.02	0.34	-0.06
Netherl.	0.02	-0.01	0.06	0.01	0.08	0.00
Poland	-0.02	-0.03	0.90	-0.12	0.90	-0.15
Portugal	0.48	0.00	-0.08	-0.01	0.40	-0.01
Romania	0.42	0.00	0.47	0.00	0.84	0.00
Slovakia	-0.02	-0.02	0.00	-0.07	-0.01	-0.09
Slovenia	-0.05	-0.04	0.30	0.04	0.25	0.00
Spain	0.37	0.02	-0.16	-0.03	0.21	-0.01
Sweden	-0.19	-0.04	-0.66	-0.10	-0.89	-0.14
UK	0.08	0.00	0.05	0.00	0.14	0.00

Source: Authors' own estimates.

Employment level in the agricultural sector is also affected by the changes in productivity and availability of land. Figure 3 illustrates the overall impact expected on the employment of the agricultural sector. Clearly, changes in employment levels do reflect the expected percentage variations in crop yields illustrated if Figure 2. A higher agricultural productivity and a larger availability of land bring about an expansion of the whole agricultural sector, which demands additional workers. This is the case of many northern-European countries (e.g., Finland, Sweden, Estonia and Latvia), where the increase in agricultural output pushes up the demand for labor (in agriculture) by 15 to almost 30%. In fact, these increases are not so relevant as they might appear at a first instance, given the small share of labor employed in agriculture (see Table A2 in the Appendix).

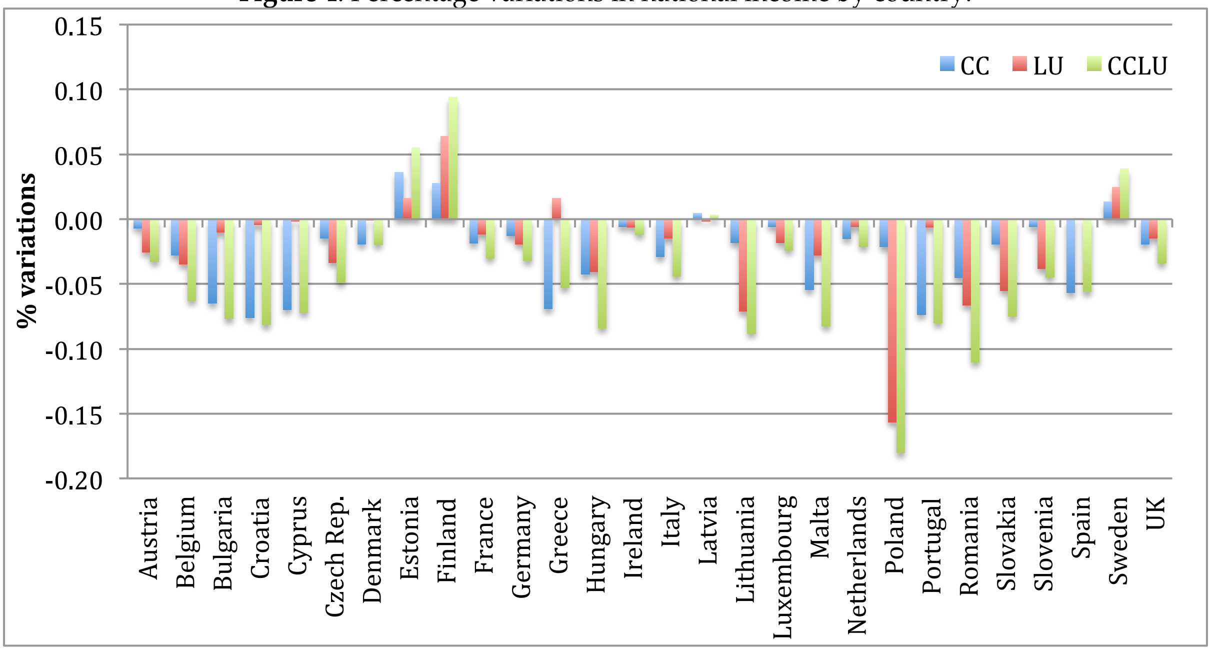
Wherever agricultural land and/or agricultural productivity are expected to decrease, so does the demand for labor (e.g., Luxembourg Belgium, Portugal, Poland, France and Malta). It is worth noting that the most negatively affected countries are those located in central-southern Europe, with some exception (e.g., Croatia, Cyprus, Greece).

Figure 3. Percentage variations in employment level of the overall agricultural sector.



Another important macroeconomic variable it is worth commenting is the national real income, a measure of household purchasing power, thereby accounting for the overall impact on welfare. Lower (higher) productivity in agriculture generates negative (positive) consequences in terms of real income and welfare. Figure 4 illustrates the percentage variations in the national income of the EU-28 countries.

Figure 4. Percentage variations in national income by country.



Source: Authors' own elaboration.

The magnitude of the loss (gain) depends on the amount of the productivity shock, but also on the share of agricultural sector in the economy. A first interesting example is Romania. This country is predicted to suffer the second largest decrease in real national income, even if the reduction in agricultural productivity and agricultural land are not among the largest. Yet, its share of agricultural activities over the total economic activity is the highest among the EU-28 countries (Table A2). A second example is Luxembourg. This country is expected to suffer from large reductions in total agricultural output and employment level. Yet, the negligible share of agriculture on its total value added (1.26%) dampens the impact on national income.

On average, the impact on the national income of the European economies is small, ranging from -0.18% predicted for Poland to 0.09% for Finland under the CLEC Scenario. This modest impact comes with no surprise, as the value added of agriculture represents a small fraction of total GDP in most EU economies (4.72% on average, see Table A2 of the Appendix). Most countries are negatively affected, and it is worth noting that among the largest expected impacts we find non-Mediterranean countries, like (Poland, Romania, Bulgaria, Hungary), whose shares of agricultural value added are among the highest in Europe.

Changes in agricultural productivity due to climate change drive the overall results for half countries, especially in southern Europe. Land use change affects more significantly the national income of central-northern economies, like Poland, Lithuania and, positively, Finland. Estonia and Sweden are also positively affected. Negligible impacts are expected in Latvia, Ireland and central Europe countries. The whole impact of climate change and land use change (CCLU) is not just the sum of the two impacts taken alone (CC+LU), due to the many secondary-order effects at play in the structural captured by the general equilibrium adjustment process.

3. Sensitivity analysis

The software that can be used to perform simulation experiments with the GTAP model (RunGTAP) allows to undertake 'systematic sensitivity analysis' (SSA) on key parameters and exogenous variables, using statistical quadrature techniques (Arndt, 1996). One or more parameters are 'perturbed' on the basis of ex-ante (subjective) probability distributions.[10] For each realization of the random variables, the model computes a general equilibrium state. Results from a series of runs are subsequently processed to infer the statistical distribution –the mean value and standard deviation– for all endogenous variables.

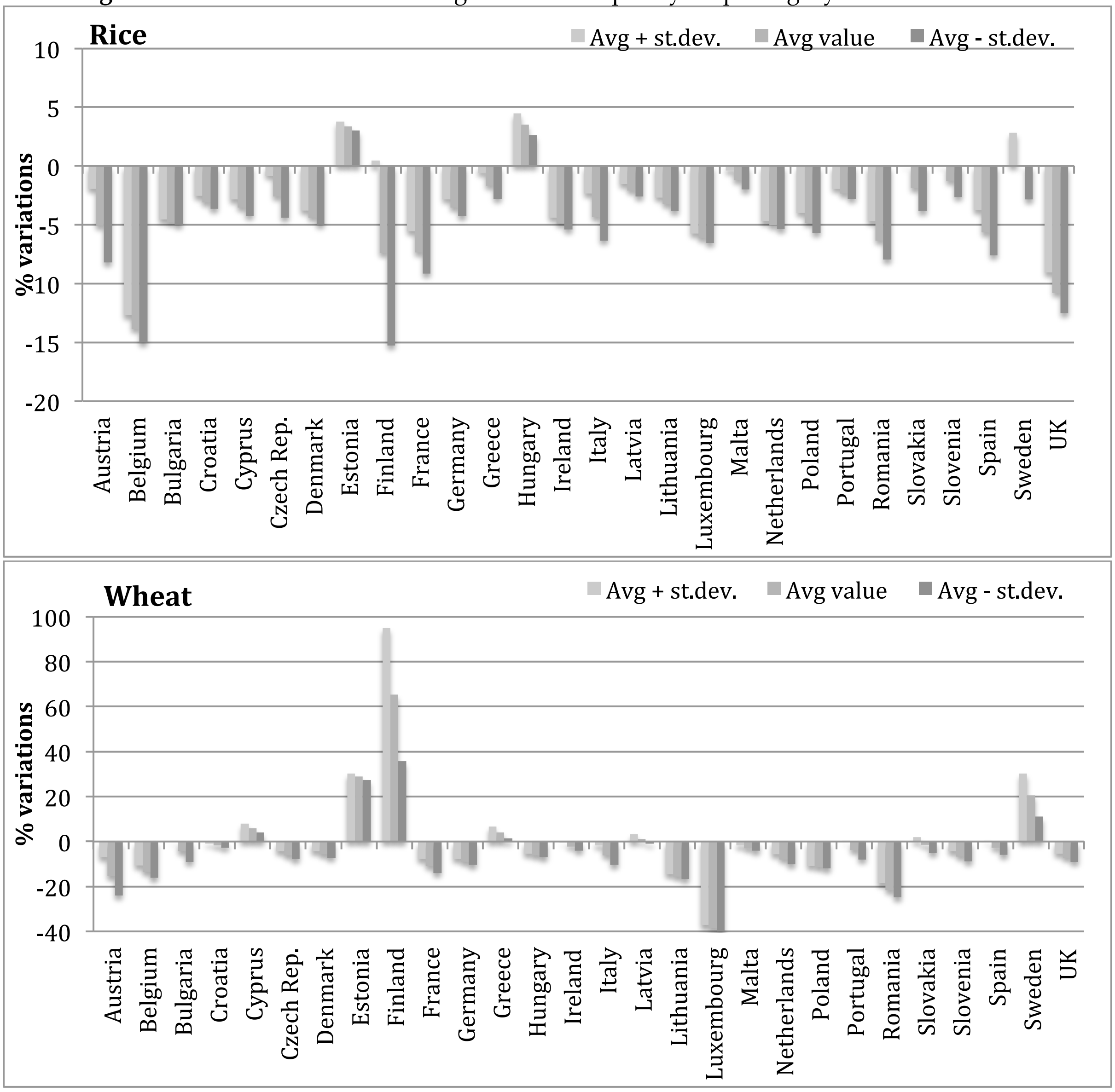
We use this methodology to account for the high degree of uncertainty surrounding the percentage variations of agricultural productivity, reported in Table 2. These percentage variations, representing the economic channel through which climate change affects agricultural output, are indeed estimated on the ground of the predicted average levels of future temperature ("Avg Temp 2050" in Table 1), whose uncertainty is captured the standard deviation of the associated probability distribution ("Dev.St." in Table 1). Elaborating on these data, it is possible to

[10] At present, continuous uniform and symmetric triangular are the two available distributions. In the SSA undertaken in this study, we use the symmetric triangular distribution.

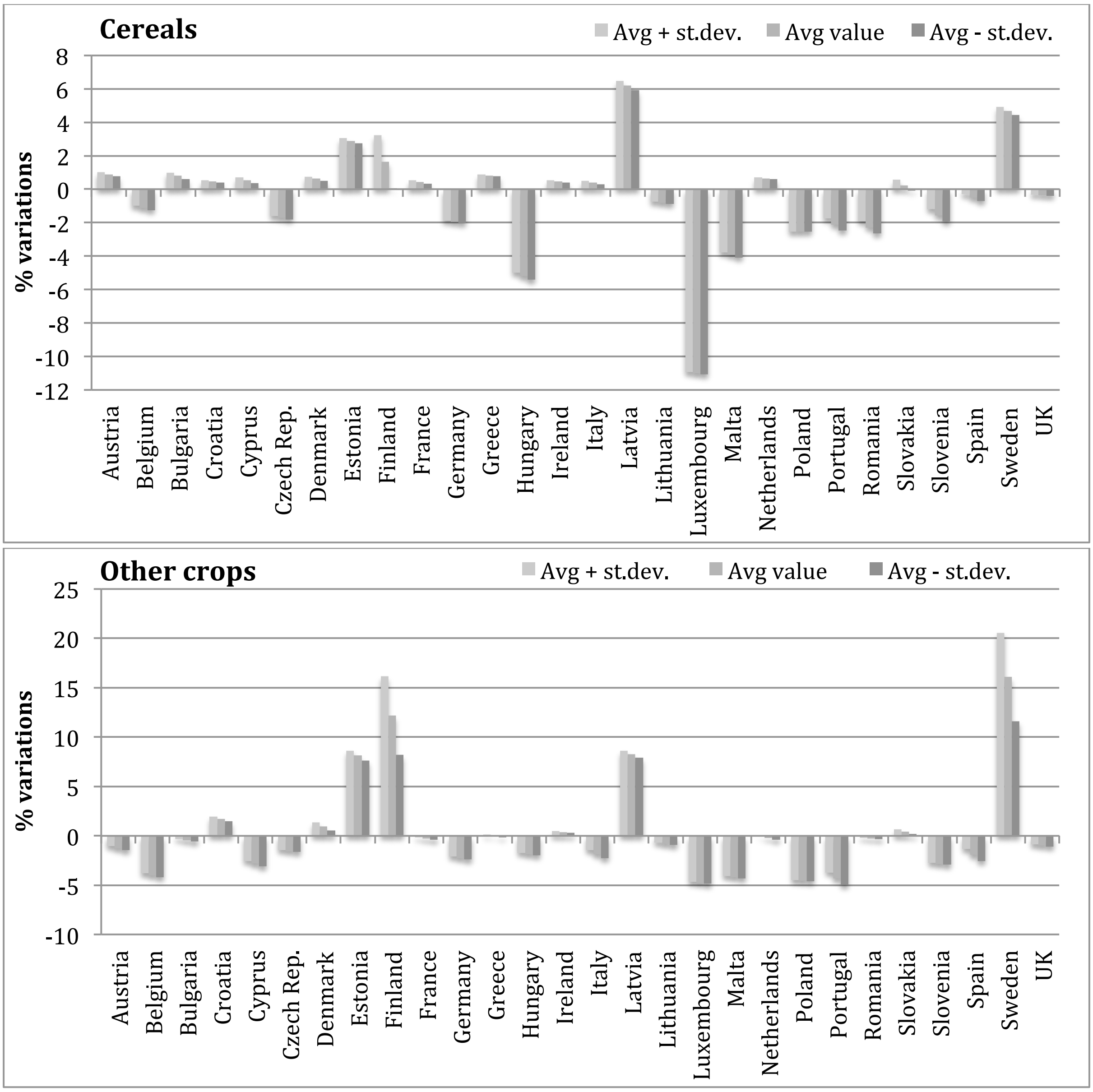
compute the range of variation of the agricultural productivity shocks, used to undertake the SSA.

The results from the SSA calculation are estimates of the mean value and standard deviation for each endogenous variable, from which it is possible to infer information about the likely range of variation the variables of interest, like agricultural output (Figure 5) and employment levels (Figure 6).[11]

Figure 5. Intervals of variation in agricultural output by crop category. CCLUC scenario.



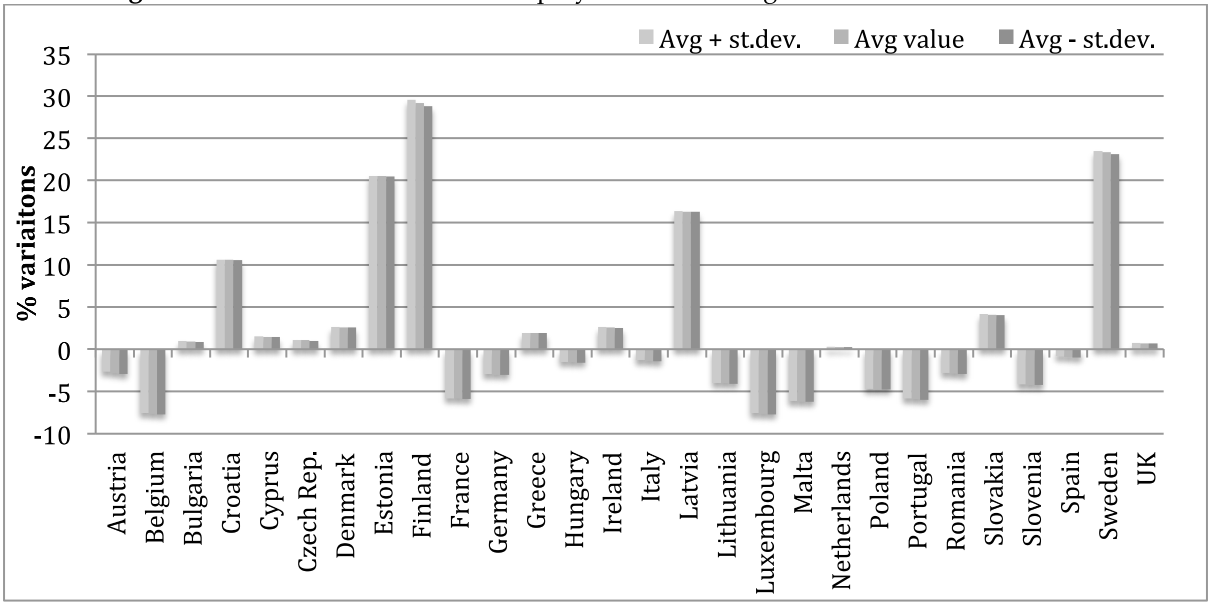
[11] The standard deviation computed by the SSA for the variable "national income" is very low (< 0.0001 for most countries), meaning that the uncertainty surrounding the average values reported in Figure 4 is low. For this reason, results from SSA are not reported.



Source: Authors' own elaboration.

[to be completed]

Figure 6. Intervals of variation in employment level in agricultural. CCLUC scenario.



Source: Authors' own elaboration.

4. Policy implication and concluding remarks

Climate and land use change are likely to affect agricultural systems very differently across Europe. Northern countries are expected to benefit from climate change impacts, whereas other areas in Europe will suffer negative consequences in terms of reduced agricultural output, real income and welfare. Contrary to our expectations, the most vulnerable region is not the Mediterranean Europe.

Agricultural and environmental policies will have to support the adaptation of European agriculture to climate change. Adaptation strategies, like changes in crop species, cultivars and sowing dates, land allocation and farming system, should be introduced not only to reduce negative effects, but also to exploit possible positive effects of climate change.

Furthermore, the development of agricultural strategies to mitigate climate change is necessary.

[to be completed]

Appendix

The GTAP is an international network which builds, updates and distributes a comprehensive and detailed data base of trade transactions among different industries and regions in the world, framed as a Social Accounting Matrix (SAM). The SAM is typically used to calibrate parameters for CGE models, and the GTAP data base is accompanied by a relatively standard CGE model and a package, that can be used to conduct simulation experiments (RunGTAP). The model structure is quite complex and it is fully described in Hertel (1997). We only summarize the main relationships in the model here:

- Production volumes for all industries in all regions equal intermediate domestic consumption, final demand (private consumption, public consumption, demand for investment goods) and exports to all other regions.
- Endowments of primary factors (e.g. labor, capital) are given and match demand from domestic industries. There is perfect domestic mobility for labor and capital (single regional price) and imperfect domestic mobility for land (industry-specific price), but no international mobility. Each sector employs two factors of production, capital and labor, with the exception of agriculture, where a third input, land, enters the production function.
- Representative firms in each regional industry allocate factors on the basis of cost minimization. Production functions are nested CES functions, with calibrated structural parameters and given elasticities of substitution. Intermediate factors and the value added aggregate are not substitutable among themselves (Leontief). Intermediate and final demand is split according to the source of production: first between domestic production and imports, subsequently the imports among the various trading partners. The Armington assumption (Armington, 1969) is adopted: goods in the same industry but produced in different places are regarded as imperfect substitutes. Allocation is based on relative market prices, including transportation, distribution, and tax margins. Unit prices for goods and services equals average production costs, including taxes.
- National income equals returns on primary factors owned by domestic agents, and is allocated to private consumption, public consumption and savings (constant, calibrated shares). Savings are virtually pooled by a world bank and redistributed as regional investments, on the basis of expected future returns on capital. Therefore, there is no equality between domestic savings and investment, which implies the absence of a strict trade balance constraint.
- The structure of private consumption is set on the basis of utility maximization under budget constraint. The utility function is a non-homothetic CDE function and goods have different income elasticities.

Table A1. Projected variations in GDP and population at the year 2050. SSP2.

Countries	*% change in GDP*	*% change in Pop.*	Countries	*% change in GDP*	*% change in Pop.*
Austria	70%	10%	**Italy**	97%	-11%
Belgium	156%	18%	**Latvia**	140%	42%
Bulgaria	146%	-16%	**Lithuania**	122%	2%
Croatia	194%	43%	**Luxemb.**	86%	-18%
Cyprus	123%	12%	**Malta**	205%	64%
CzRep.	44%	-4%	**Netherl.**	117%	-19%
Denmark	74%	18%	**Poland**	172%	6%
Estonia	117%	15%	**Portugal**	101%	12%
Finland	138%	-6%	**Romania**	122%	-8%
France	103%	15%	**Slovakia**	150%	6%
Germany	143%	22%	**Slovenia**	143%	-17%
Greece	158%	23%	**Spain**	139%	-2%
Hungary	127%	-1%	**Sweden**	109%	1%
Ireland	79%	-8%	**UK**	174%	33%

Source: IIASA database

Table A2. Share of agricultural value added on total GDP in the 2011 baseline.

Countries	*% share of agriculture*	*% of labor employed in agric.*	*GDP (M$US)*	*Countries*	*% share of agriculture*	*% of labor employed in agric.*	*GDP (M$US)*
Austria	1.82%	1.00%	415983	**Italy**	2.98%	2.34%	2196333.9
Belgium	1.86%	1.59%	513315.9	**Latvia**	9.20%	2.23%	28480.3
Bulgaria	6.39%	5.25%	53542.7	**Lithuania**	10.34%	8.71%	43083
Croatia	8.86%	5.08%	61520.9	**Luxemb.**	1.26%	1.03%	58009.3
Cyprus	8.06%	1.24%	24851.2	**Malta**	3.16%	2.52%	9302
CzRep.	3.76%	1.97%	216060.3	**Netherl.**	2.88%	1.71%	832751.1
Denmark	2.97%	0.86%	333742.8	**Poland**	6.03%	3.37%	515771
Estonia	4.78%	2.73%	22542.9	**Portugal**	3.13%	1.85%	237888
Finland	2.79%	0.79%	262378.3	**Romania**	16.98%	10.12%	182610.7
France	2.15%	1.81%	2777492.3	**Slovakia**	5.60%	2.74%	95877.2
Germany	1.52%	0.94%	3628098.7	**Slovenia**	5.17%	3.15%	50250.2
Greece	4.40%	6.59%	289886.2	**Spain**	3.46%	3.21%	1454530.2
Hungary	6.50%	5.00%	137451.2	**Sweden**	1.96%	0.71%	535997.4
Ireland	3.14%	1.08%	226033.6	**UK**	1.11%	0.45%	2462478.8

Source: GTAP database

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