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Welfare implications of increasing spatial resolution in national CGE models for climate change impact assessment

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Abstract

Computable General Equilibrium (CGE) models are a widespread tool to assess the economic impacts of climate change because they allow to capture the inter-sectoral and inter-regional interactions of the environmental and climatic shocks in a consistent framework. The geographical resolution adopted in CGE models is usually the country level, however, climate impacts can be heterogenous even within countries as regions located at different latitudes or altitudes respond differently to changes in temperature and precipitations. Our aim in this work is to evaluate the economic implications of increasing the spatial resolution of a CGE model when combined with sub-national level impacts of climatic change on sectoral Gross Value Added (GVA) derived through spatial econometrics. We compare a standard version of a national CGE model calibrated for Italy with its sub-national version (twenty Italian NUTS-2 regions). The objective is not only to show that the aggregated results obtained can differ in terms of national GDP loss but also to provide an economic explanation for these differences. Specifically, we will explain the importance of intra-national trade (flows of imports and exports between sub-national units) and capital/labour re-location across regions. These economic channels are absent in the national version of the CGE.

Keywords: spatial econometrics, CGE models, climate change impacts, sub-national analysis

1. Introduction

Computable General Equilibrium (CGE) models are increasingly used for the economic evaluation of different climate and environmental impacts (Darwin and Tol, 2001; Bigano et al., 2008; Aaheim et al., 2010; Eboli et al., 2010; Ciscar et al., 2011; Bosello et al., 2012). These models provide a dynamic representation of the economy where factors, consumers, and firms adjust their decisions on the basis of market price changes triggered by the impact under examination. CGE models have a more detailed sectoral representation compared to the standard Integrated Assessment Models (IAMs) and allow to capture the inter-sectoral and inter-regional interactions of the environmental and climatic shocks.

The detailed sectoral representation of the CGE models make easier the coupling of the CGE model with bio-physical models or statistical estimations depending on the targeted sector or type of impact. Impacts in the primary sector for example (agriculture, forestry and fishing) are derived from bottom-up crop models such as Globiom and Epic (Havril, 2014). SLR rise impacts also stem form biophysical models like DIVA. Statistical estimations can be used to compute impacts on energy demand or labour producitivy (Shouro).

However, these shocks have so far remained a weakness in the existing literature. A novel contribution of this paper is the use of tailored econometric estimates to feed our CGE model. We use sub-national sectoral (agriculture, industry, and services) GVA data for the Italian regions combined with high-resolution climatic data to investigate the impact of temperature and precipitation. These estimates are then combined with future warming data under Representative Concentration Pathways (RCPs) to compute projections of future climate change impacts on economic productivity in Italy.

The geographical resolution adopted in CGE models is usually the country level, sub-national detail is not common in global CGE models as economic data are often not available at such high spatial resolution, especially in the developing countries. However, climate impacts can be heterogenous even within countries as regions located at different latitudes or altitudes respond differently to changes in temperature and precipitations. Averaging these heterogenous responses to the national level impacts can overlook important intra-national economic channels and introduce bias in the aggregated results. Our aim in this work is to evaluate the economic implications of increasing the spatial resolution of a CGE model when combined with sub-national level impacts of climatic change on sectoral Gross Value Added (GVA) derived through spatial econometrics. We compare a standard version of a national CGE model calibrated for Italy with its sub-national version (twenty Italian NUTS-2 regions). The objective is not only to show that the aggregated results obtained can differ in terms of national GDP loss but also to provide an explanation for these differences. Specifically, we will explain the importance of intra-national trade (flows of imports and exports between sub-national units) and capital/labour re-location across regions. These economic channels are absent in the national version of the CGE.

The structure of the paper is the following. Section 2 describes the database and the theoretical structure of the CGE. Sections 3 explains the econometric estimation. Section 4 lays out the link between the two tools. Section 5 presents and discusses results. Section 6 concludes and offers some ideas for further development.

2. The CGE model

The CGE is calibrated using a Social Accounting Matrix (SAM), a system of economic accounts for different economic agents (firms, households, factors of production) which is internally consistent and balanced. The first objective to construct the sub-national CGE is the regionalization of the national SAM for Italy. To do this, we split the national SAM of Italy in the Global Trade Analysis Project

(GTAP) 8 database (Narayanan et al., 2012) into 20 SAMs, one for each NUTS-2 Italian region displayed in Figure 1. The procedure to get mutually consistent sub-country SAMs takes place essentially in the following steps (Bosello and Standardi, 2018). Fist, we use information on sectoral value added from ISTAT and EUROSTAT to distribute the Italian production across the sub-country units for the year 2007 which is the reference year of the GTAP 8 database. Then, we rely on the so-called Simple Locations Quotients (SLQs) to derive the sub-national domestic and imported demand. The SLQs give a measure of the sectoral specialization in a given region by comparing the national and regional sectoral share and use this information to compute the propensity of a region to import and export the good in that sector. Once we have calculated the sub-national domestic and imported demand, we follow a gravitational approach to obtain the bilateral trade flows across sub-national regions. Finally, an iterative procedure is implemented to adjust and ensure consistency in the regional accounts and the flows of imports and exports across the Italian regions.

The GTAP database is a global database and we aggregate the other countries in the world in two broad elements; Rest of Europe and Rest of the World. We include only three macro-economic sectors in the CGE; 1) agriculture, 2) industry, and 3) services. This is to match the sectoral detail of the econometric analysis.

Figure 1: Italian Nuts-2 regions

The theoretical structure of our CGE is based on the GTAP model (Hertel, 1997). The main assumptions are the competitive structure of the markets, the representative agents (firms and households), and the full use of resources. The representative agents minimize or maximize an objective function subject to a specific constraint. In the case of the representative firm, the objective function is the minimization of costs given a technological constraint while in the case of the representative household the function is the maximization of the consumption utility flow given a budget constraint. In the macro-economic closure, the difference between regional savings and investments is equal to the trade balance and the investments are savings driven.

When an exogenous shock strikes the economic system, relative prices change, and the economic agents re-arrange their min/max problems and adjust their decisions according to the new system of prices. The exogenous shock can a be a tax or a subsidy, a change in the availability of factor endowment (labour, capital, land or natural resources), or a productivity change in a given sector, region, and factor of production.

The focus of the neo-classical CGE is oriented toward the efficient allocation of resources. This, in turn, is driven by the trade mechanisms for the exchange of goods. The interaction between factors and goods market is the key paradigm to interpret the results of a CGE model. Given the Walrasian structure of the CGE, this tool is particularly suitable for the analysis of long run issues such as climate change impacts. From a theoretical point of view, it is worth noting that the national version of the CGE is characterized by perfect mobility of labor and capital across sectors and regions within the country. Moreover, in a given sector and country we have perfect substitutability in the consumption of goods, which means that the national representative consumer does not care the sub-national unit where the good has been produced.

In the sub-national version of the CGE model, we are indeed decreasing the overall mobility of labor and capital and the substitutability of goods within the country. This is because we treat sub-national units as countries. Nevertheless, compared to the national version of the CGE, we modify some assumptions. First, in the national version of the CGE imperfect substitutability is assumed for goods coming from different countries (Armington hypothesis). Equations [1] and [2] show the two minimization problems for the representative consumer. The function g is a Constant Elasticity of Substitution (CES) constraint in Eq. 1 and a Constant Ratios of Elasticities of Substitution – Homothetic (CRESH) constraint in Eq. 2 (Hanoch, 1971):

$$\min_{D_{i,c},I_{i,c}} D_{i,c} \cdot PD_{i,c} + I_{i,c} \cdot PI_{i,c} \qquad [1]$$
$$s.t.\ Cons_{i,c} = g(D_{i,c}, I_{i,c}, \sigma_{ARM\ c}) \qquad \sigma_{ARM\ c} \geq 0$$

$$\min_{IMP_{i,1,c} \ldots IMP_{i,N,c}} \sum_{r*}^{N} IMP_{i,c*,c} \cdot PIMP_{i,c*,c} \qquad [2]$$
$$s.t.\ I_{i,r} = g(IMP_{i,1,c}, \ldots, IMP_{i,N,c}, \sigma_{IMP\ c*,c}) \qquad \sigma_{IMP\ c*,c} \geq 0$$

where *Cons*, *D*, *I*, *PD* and *PI* are total consumption, domestic consumption, aggregate imports, and the associated prices in sector *i* and country *c*, $\sigma_{ARM\ c}$ is the elasticity of substitution between the domestic and imported product. *IMP* and *PIMP* are imports from country *c** to country *c* in sector *i* and the associated price, $\sigma_{IMP\ c*,c}$ is the elasticity of substitution between imports coming from different countries. In the regionalized version of the CGE, the two minimization programs are the same, however, we increase the Armington elasticities by a factor of 10 for goods consumed in one Italian region and coming from another Italian region. This implies that $\sigma_{ARM\ r} = 10 \cdot \sigma_{ARM\ c}$ and $\sigma_{IMP\ r*,r} = 10 \cdot \sigma_{IMP\ c*,c}$ where *r* is the sub-national index. The country level elasticities are based on the GTAP default setting (Narayanan et al., 2012).

Second, in the national version of the CGE model, capital and labor cannot move outside the country but in the regionalized version, an elasticity of substitution (σ) regulates the movements of labor and capital across the Italian regions. If the absolute value of this elasticity is zero, labor and capital must stay in the region they belong to, if the absolute value is greater than zero, they can move outside the region. Equations [3] and [4] formalize the two maximization problems for the representative unit of labor and capital, respectively. The function g is a Constant Elasticity of Transformation (CET) constraint:

$$\max_{L_1 \ldots L_N} \sum_{r}^{N} L_r \cdot PL_r \qquad [3]$$
$$s.t.\ L_{Italy} = g(L_1, \ldots, L_{N,}, \sigma_L) \qquad \sigma_L \leq 0$$

$$\max_{K_1 \ldots K_N} \sum_{r}^{N} K_r \cdot PK_r \qquad [4]$$
$$s.t.\ K_{Italy} = g(K_1, \ldots, K_{N,}, \sigma_K) \qquad \sigma_K \leq 0$$

L, *K*, *PL* and *PK* are the regional supply of labor and capital and the associated prices, σ_L and σ_K represent the elasticity of transformation for inter-regional mobility of labor and capital, respectively.

Given the importance of this parameter, we conduct a sensitivity analysis on the elasticity by using five values for σ_L and σ_K (0, -30, -60, -90 and -120). However, even this increase in factors mobility and goods substitutability for sub-country units does not reach the infinite degree of mobility and substitutability of the national Italian model.

3. Econometric analysis

We conduct an econometric analysis to estimate the impact of climatic variables on total sectoral GVA (agriculture and industry) for the twenty NUTS-2 regions of Italy and combine these estimates with future warming scenarios (RCP8.5) to project the impact of future climate change on sectoral GVA by 2070. We use EUROSTAT data on sectoral GVA in million Euros for these Italian regions for Italy between 2000 - 2017. The three sectors are defined as follows; (1) agriculture, which includes agriculture, forestry, and fishing; (2) industry, which includes mining, manufacturing, construction, and utilities (electricity, water, gas); and (3) services, which includes wholesale and retail trade; transport; accommodation and food service activities; information and communication, financial and insurance activities; real estate activities; professional, scientific and technical activities; administrative and support service activities, and public administration and defense; compulsory social security; education; human health and social work activities; arts, entertainment and recreation, repair of household goods and other services.

We use a fixed-effects panel regression, wherein our dependent variable lny_{rti} is the log of GVA in region r in year t for sector i. *f(C)* includes the non-linear relationship between the temperature and productivity, controlled for by including both the linear and the squared-term of mean temperature; an acclimatization variable, computed as the difference of the mean temperature from a rolling average of four periods prior[1]; total annual precipitation (and its second-degree polynomial); heat extremes represented by the Warm Spell Duration Index (WSDI)[2]. Our specification also includes region (α_r) and year (γ_t) specific fixed-effects, and a quadratic time trend $\theta_{1r}t + \theta_{2r}t^2$ to capture non-linear technological changes.

$$lny_{rti} = f(C) + \alpha_r + \gamma_t + \theta_{1r}t + \theta_{2r}t^2 \quad [5]$$

$$where\ f(C) = \beta_1 T + \beta_2 T^2 + \varphi tdev + \delta_1 prec + \delta_2 prec^2 + \mu WSDI \quad [6]$$

Given the existing findings on the non-linear and inverse *U*-shaped relationship of economic performance and temperatures (Burke et al., 2015; Newell et al., 2018), we expect for the set of coefficients of temperatures that $\beta_1 > 0, \beta_2 < 0$. In this case, the results indicate a non-linear relationship with an "optimal" value of the local temperature computed as $temp_s^{optimal} = |\beta_1/(2*\beta_2)|$ for both the agriculture and industrial sectors.

Using the Moran's I test to test for the presence of spatial correlation, the null hypothesis of spatial independence/randomization is rejected for all the climatic and economic variables, suggesting that the climatic stressors and economic production in a given Italian region is spatially dependent on those in the neighbouring regions. Thus, not controlling for the spatial dependence between regions will likely provide biased results. Hence, we utilize a spatial weight with the distance threshold set to 100 KM based on the greatest Euclidean distance measured between two places on a Cartesian plane. The spatial dependence between regions decays as distance between them increases. By incorporating the spatial weights, we control for spatially lagged climatic stressors and run a Spatial Durbin Model (SDM) model of the following form;

[1] The length of the rolling average is an arbitrary value and was guided by the observable length of a business cycle in EU regions

[2] Annual count of days with at least 6 consecutive days when daily maximum is greater than 90th percentile.

$$lny_{rti} = \omega \boldsymbol{W} y_{rti} + f(C) + \boldsymbol{W} f(C) + \alpha_r + \gamma_t + \theta_{1r} t + \theta_{2r} t^2 \quad [7]$$

where $\boldsymbol{W} f(C) = \beta_1 temp + \beta_2 temp^2 + \beta_3 \boldsymbol{W} temp + \beta_4 \boldsymbol{W} temp^2 + \varphi_1 tdev + \varphi_2 \boldsymbol{W} tdev + \delta_1 prec + \delta_2 prec^2 + \delta_3 \boldsymbol{W} prec + \delta_4 \boldsymbol{W} prec^2 + \mu_1 WSDI + \mu_2 \boldsymbol{W} WSDI$ [8]

$\boldsymbol{W}$ is the spatial weights matrix , ω is the spatial coefficient of the spatial autocorrelated dependent variable, $\beta_3, \beta_4, \delta_3, \delta_4, \varphi_2, \mu_2$ are the spatial coefficients of the spatially-weighted independent variables, and the term $\boldsymbol{W} f(C)$ measures the potential spillover effect that occurs in climatic stressors across the Italian NUTS-2 regions (Baltagi, 2003) while $\boldsymbol{W} y_{rti}$ measures the possible spillover effect in productivity across the regions. The SDM specification is also completely specified and allows us to investigate the impact of both direct (contemporaneous) and indirect effects (spatial lags) of climatic stressors on labour productivity.

In the second step, we combine our spatial non-linear econometric estimates with gridded climate data from four different regional climate models (KNMI RACMO22E, IPSL-CM5A-MR, MPI-ESM-LR, and CNRM-CM5) and future warming scenarios using the Delta method (Dasgupta, 2018) to estimate the loss in productivity due to future climate change. We define current and future climate as the mean of the climatic variables between 1986-2005 (historical) and 2050-2070 (future). We combine the annual mean of the climatic variables with the fitted response from equation (6) to obtain the ratio of future to current sectoral GVA.

4. Linking the regional CGE with econometric estimates

To link the macro-economic model to our econometric estimates, we use the Total Factor Productivity (*TFP*) of the *GVA* function in the CGE model:

$$GVA_{i,r} = TFP_{i,r} \cdot h(L_{i,r}, K_{i,r,}, Land_{i,r,} NR_{i,r,} \sigma_{VA\,i}) \qquad \sigma_{VA\,i} > 0 \quad [9]$$

h is a Constant Return to Scale (CRS) CES function. *L*, *K*, *L*, and *NR* represent labor, physical capital, land, and natural resources used in the production process, respectively. σ_{VA} is the sector-specific elasticity of substitution between the primary factors. Its values are based on the GTAP default setting (Narayanan et al., 2012). In the GTAP framework services use only labor and capital; manufactures use labor, capital and natural resources; the agriculture uses capital, labor, land, and natural resources.

The experiment design has been kept simple and transparent to facilitate replication of the exercise for other countries and scenarios. Essentially, we translate the econometric impacts on sectoral GVA as TFP impacts in the base year of CGE – 2007, thus this is a static comparative exercise. We examine how the economic structure in 2007 has changed as a consequence of the climate impacts. No baseline scenario has been implemented because our aim is mainly theoretical, and we want to understand the fundamental economics behind the experiment. In the national CGE model, the average impact for Italy has been computed as the weighted average of the GVA shares of the Italian regions in the base year 2007. This has been done to be consistent in terms of TFP shocks between the national and the regionalized version of the CGE model.

We should stress that we are analyzing long-run impacts of climate change which have permanent effect on the economy. In our opinion this kind of effect is better modelled as a change in the productivity and not as a change in the endowment of the primary factors.
This is for different reasons. First, the slow onset variations of climatic conditions mainly affect the productivity of a given factor rather than its amount. Extreme events affect both the productivity and stock of the primary factors, but these effects are usually temporary.
Second, labor and capital are by definition geographically mobile and react to a negative climate impact by moving to locations less negatively impacted. The CGE captures these aspects of mobility

endogenously through the connection between returns of factors and TFP and in general through the system of the relative prices which change according to the productivity shocks.
Moreover, taking a large sample of half million Chinese manufacturing plants, Zhang et al. (2017) find a strong correlation between productivity and temperature and precipitations while the correlation between the amount of inputs and the climatic variables is dubious.
Finally, the TFP is the variable usually adopted in the IAMs and other general equilibrium spatial models (Nordhaus, 2011; Hope, 2011; Anthoff and Tol, 2009; Bosetti et al, 2006; Desmet and Rossi-Hansberg, 2015).

5. Results

Our econometric estimates (Table 1) suggest a non-linear impact of temperature and total precipitation on sectoral GVA in Italy. The results also show that the optimal spatially lagged temperatures maximizing productivity in the agricultural and industrial sectors are 12.3°C and 16.2°C, respectively. As expected, the optimal temperature in the agricultural sector is relatively lower as workers in this sector are relatively more exposed to the elements. While the spatially lagged variables capture the indirect effects, our regression is also able to provide direct effects on GVA. We find that agricultural and industrial GVA is maximized at 13.5°C and 19.5°C, respectively. We find statistically significant direct effects of temperature for the services sector, but the indirect effects are not statistically significant. Furthermore, the optimal condition maximizing GVA in this sector is out of sample at 24.1°C. For these reasons, we do not consider the climate change impacts on TFP from the service sector.

Table 1: Main regression results

	(1)	(2)
	Agriculture	Industry
Spatial lag of agricultural GVA	0.789***	
	(0.000)	
Spatial lag of industrial GVA		0.899***
		(0.000)
WSDI	0.001***	0.001**
	(0.000)	(0.036)
Temperature deviation	-0.027**	-0.054***
	(0.031)	(0.001)
Total precipitation	0.116***	0.153***
	(0.004)	(0.004)
Total precipitation-squared	-0.019***	-0.024***
	(0.006)	(0.008)
Mean temperature	0.054***	0.078**
	(0.004)	(0.014)
Mean temperature-squared	-0.002*	-0.002***
	(0.084)	(0.009)
Spatial lag of WSDI	-0.003***	-0.003***
	(0.000)	(0.000)
Spatial lag of temperature deviation	0.004	0.016
	(0.812)	(0.422)
Spatial lag of total precipitation	0.018	0.015
	(0.755)	(0.850)
Spatial lag of total precipitation-squared	-0.006	-0.006
	(0.605)	(0.684)
Spatial lag of mean temperature	0.049**	0.097*
	(0.034)	(0.096)
Spatial lag of mean temperature-squared	-0.002**	-0.003*
	(0.021)	(0.052)
Constant	-5.453***	-6.875***
	(0.000)	(0.000)
Observations	360	360
R-squared	0.691	0.703
Number of regions	20	20

The impacts of future warming on the Italian regions are reported in Table 2. The results suggest that the highest negative impacts on the agricultural sector will be on Basilicata (-20.43%), Molise (-19.2%), and Abruzzo (-18.6%). In the case of the industrial sector, the highest negative impacts will be in the regions of Puglia (-19.9%), Basilicata (-19.6%), and Sicily (-19.2%). The overall impact on Italy due to unmitigated climate change is estimated to be 15.2% and 12.4% in the agricultural and the industrial sectors, respectively.

Table 2: Percentage change in GVA due to climate change in 2070 under RCP 8.5

Regions	Agriculture	Industry
Piemonte	-13.68	-8.40
Valle d'Aosta	10.80	17.37
Lombardia	-13.26	-9.00
Trentino-AA	0.31	5.73
Veneto	-14.40	-11.17
Friuli-VG	-11.79	-7.59
Liguria	-12.63	-11.85
Emilia-Romagna	-16.47	-15.64
Toscana	-16.69	-16.06
Umbria	-18.05	-15.90
Marche	-16.46	-16.09
Lazio	-15.94	-15.79
Abruzzo	-18.60	-14.82
Molise	-19.20	-17.65
Campania	-16.69	-16.52
Puglia	-14.82	-19.90
Basilicata	-20.43	-19.64
Calabria	-15.36	-17.61
Sicily	-18.54	-19.17
Sardegna	-15.78	-18.70
Italy	-15.16	-12.39

The results from the regionalized CGE simulations (Table 3) show that in the aggregate national model the GDP loss is approximately 5.3% under RCP8.5 by 2070. These estimates are shown to be robust in the sub-national version of the CGE when we exclude the possibility for labor and capital to relocate to the regions least affected by climate change ($\sigma = 0$). As we progressively decrease the elasticity regulating the degree of mobility of capital and labor within the country, GDP loss due to climate change declines from 5.3% to 0.9% ($\sigma = -120$).

Table 3: Equivalent Variation (EV) and GDP loss in the different versions of the model (national vs regional) and for different values of the elasticity regulating the mobility of primary factors within Italy

	National CGE	**Regional CGE**	**Regional CGE**	**Regional CGE**	**Regional CGE**	**Regional CGE**
		($\sigma_L = \sigma_K = 0$)	**($\sigma_L = \sigma_K = -30$)**	**($\sigma_L = \sigma_K = -60$)**	**($\sigma_L = \sigma_K = -90$)**	**($\sigma_L = \sigma_K = -120$)**
EV (2007 Mil $)	-116706	-118625	-21814	-88567	-57752	-36134
% GDP loss	-5.30	-5.31	-4.18	-2.71	-1.63	-0.89

The explanation for these outcomes is that if the productivity impact is averaged uniformly on the Italian territory, as in the national CGE model, the primary factors (labor and capital) cannot relocate to the Italian regions least affected by climatic impacts. The regionalized version of the CGE allows a more efficient geographical re-allocation of the primary factors as the impacts are differentiated across the Italian territory. It is important to note that this re-allocation takes place through the price signals the economic agents receive in the market. Thus, the intra-national trade is crucial as it allows the regional consumers to shift demand of goods to those areas where products can be produced at a cheaper price. This in-turn results in an increase in the demand for primary factors from firms and an increase in the prices of labor and capital, which attract units of labor and capital to the areas with higher productivity.

We can understand better these economic mechanisms by examining Figure 1 and Table 4[3]. The maps in Figure 1 shows the regional percent changes of GDP. We can notice that in case of no mobility of capital and labor ($\sigma_L = \sigma_K = 0$), the only two winner regions are the Alpine regions Trentino-Alto Adige and Valle d'Aosta where we find positive impacts on TFP (Table 2). When we allow for mobility of labor and capital ($\sigma_l = \sigma_K = -30$), GDP in the Northern Italian regions of Piemonte, Lombardia, and Friuli Venezia Giulia increases despite the fact climate change has a negative impact on TFP even in these regions (Table 2). This is because the capital and labor inflows from Center and South Italy more than compensate the decrease in the TFP (Table 4). Labor and capital move from South to the North as the demand for products and, in turn, the demand for factors shifts Norther increasing wages and price of capital.

For very high level of factors mobility, $\sigma_L = \sigma_K = [-60, -90, -120]$, we find a very strong polarization of labor and capital towards the Alpine regions (Trentino Alto Adige and Valle d'Aosta). This is because these two regions have higher remunerations of labor and capital even within Northern Italy and in case of a very integrated labor and capital market, they are also able to attract the two mobile factors from Piemonte, Lombardia, and Friuli Venezia Giulia. One should be cautious with the results for very high levels of factors mobility, since in such cases we observe rather high and unrealistic movements of labor and capital towards the small Alpine regions of Valle d'Aosta and Trentino-Alto Adige (Table 4). The constraints on land availability for new economic activities are not captured by our CGE model in the current format. Nevertheless, our work stresses the importance of considering intra-national market channels that are usually overlooked in the more spatially aggregated versions of the CGE models.

[3] All the results for regional GDP (percent changes) are reported in the Appendix.

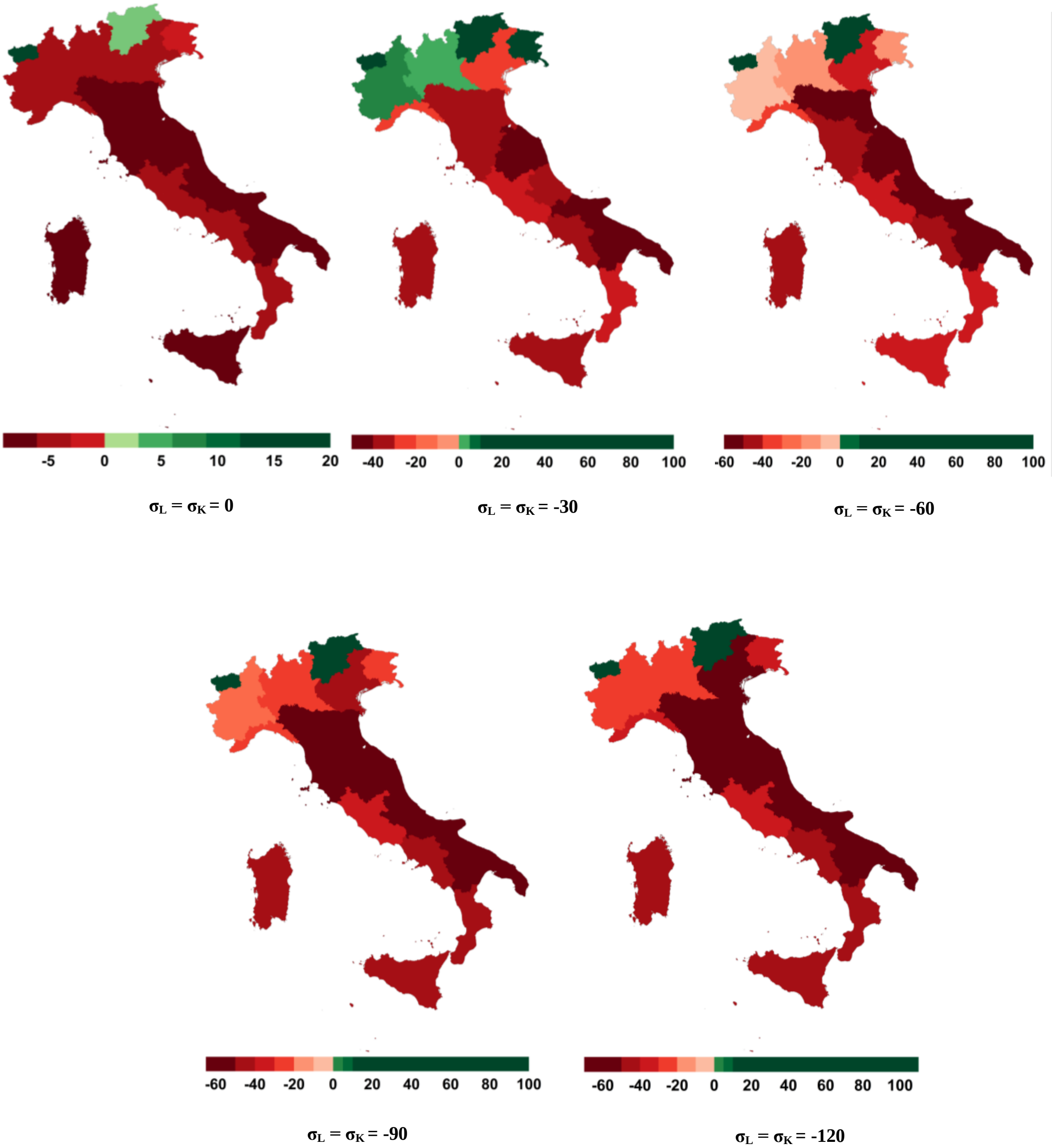

Figure 1: GDP loss (% change) in the regionalized model for different values of the elasticity regulating the mobility of primary factors within Italy

Note: per cent GDP change greater than one hundred per cent has been set to one hundred.

Table 4: % change in the regional supply of labor and capital for different level of factors mobility

	($\sigma_L = \sigma_K = -30$)		($\sigma_L = \sigma_K = -60$)		($\sigma_L = \sigma_K = -90$)		($\sigma_L = \sigma_K = -120$)	
	Labour	**Capital**	**Labour**	**Capital**	**Labour**	**Capital**	**Labour**	**Capital**
Piemonte	13.7	11.7	-2.3	-3.7	-11.9	-13.2	-17.5	-18.7
Valle d'Aosta	2626.4	2408.8	7155.5	6521.2	10546.7	9543.9	12770.8	11501.1
Lombardia	7.8	6.0	-8.1	-9.1	-17.8	-18.6	-23.4	-24.1
Trentino-AA	406.4	383.1	523.7	485.7	496.1	453.3	452.8	409.5
Veneto	-13.8	-14.1	-32.3	-32.8	-42.1	-42.8	-47.5	-48.3
Friuli-VG	16.1	12.8	-6.5	-9.8	-20.5	-23.8	-28.3	-31.5
Liguria	-10.7	-10.7	-19.6	-20.5	-24.6	-26.0	-27.5	-29.3
Emilia-Romagna	-35.4	-34.4	-48.5	-48.6	-54.8	-55.4	-58.3	-59.2
Toscana	-32.7	-31.2	-44.1	-43.9	-49.9	-50.2	-53.2	-53.8
Umbria	-37.7	-36.3	-49.5	-49.1	-55.0	-55.2	-58.1	-58.5
Marche	-38.1	-36.3	-50.7	-50.1	-56.6	-56.6	-59.9	-60.2
Lazio	-20.1	-19.9	-26.9	-28.2	-30.7	-32.7	-32.9	-35.4
Abruzzo	-35.4	-35.0	-49.9	-50.5	-56.7	-57.7	-60.4	-61.6
Molise	-40.9	-40.0	-53.0	-53.5	-58.6	-59.7	-61.8	-63.1
Campania	-27.0	-27.1	-36.9	-38.2	-41.9	-43.8	-44.8	-47.1
Puglia	-36.9	-35.0	-46.4	-46.0	-50.9	-51.3	-53.5	-54.3
Basilicata	-38.4	-39.4	-49.0	-51.2	-54.3	-57.0	-57.4	-60.2
Calabria	-23.7	-25.3	-32.9	-36.1	-37.8	-41.7	-40.7	-45.0
Sicilia	-25.2	-26.0	-33.0	-35.3	-36.9	-40.0	-39.1	-42.7
Sardegna	-29.6	-32.4	-36.5	-40.7	-39.6	-44.5	-41.3	-46.6

6. Conclusions and further research

In this paper, we have tried to provide numeric evidence on the welfare implications of increasing the spatial resolution in a national CGE model when combined with econometric estimates of climate change impacts on TFP. We also explain the theoretical economic reasons of such implications. The main finding from our analysis is that the country-level version of the CGE neglects intra-national market channels that are important in case of asymmetric climate change effects within the national territory. These asymmetric effects of climate are likely to occur not only in large countries such US, China, India, and Russia but also in medium sized countries such as Italy.

As for further development, it would be worthy to increase the sectoral detail along with differentiated impacts between labor, capital, land, and natural resources to capture the inter-factor dimension.

A final comment on the policy implications of this study is that if free markets for both goods and factors are important to achieve an efficient re-allocation of labor and capital within a country as a consequence of climate change, it is likely to be even more important at the global level where the climate impacts are expected to be much more heterogenous. Policymakers should consider the potential benefits that can be achieved by facilitating free markets at the regional and global level for both factors and goods to adapt in the context of climate change. This autonomous and decentralized market adaptation can represent an additional tool to face the climate change challenge.

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Appendix

Table A1: GDP loss (% Ch.) in the different versions of the model (national vs regional) and for different values of the elasticity regulating the mobility of primary factors within Italy

	National model	$\sigma_{L/K}$ **= 0**	$\sigma_{L/K}$ **= -30**	$\sigma_{L/K}$ **= -60**	$\sigma_{L/K}$ **= -90**	$\sigma_{L/K}$ **= -120**
Piemonte	-5.3	-3.6	8.1	-7.2	-16.5	-21.8
Valle d'Aosta	-5.3	15.0	2816.6	7532.5	10989.4	13226.1
Lombardia	-5.3	-4.2	2.1	-12.8	-22.0	-27.3
Trentino-AA	-5.3	5.2	412.7	523.8	492.0	446.9
Veneto	-5.3	-5.7	-18.8	-36.2	-45.4	-50.5
Friuli-VG	-5.3	-3.0	10.7	-11.2	-24.6	-32.1
Liguria	-5.3	-4.0	-14.9	-24.2	-29.3	-32.3
Emilia-Romagna	-5.3	-7.8	-39.7	-52.1	-58.2	-61.5
Toscana	-5.3	-7.0	-36.9	-48.1	-53.7	-56.9
Umbria	-5.3	-6.9	-41.0	-52.4	-57.7	-60.7
Marche	-5.3	-7.9	-42.1	-54.2	-59.9	-63.0
Lazio	-5.3	-4.1	-23.7	-31.0	-35.0	-37.4
Abruzzo	-5.3	-7.1	-39.5	-53.4	-59.9	-63.4
Molise	-5.3	-8.0	-45.1	-56.7	-62.2	-65.2
Campania	-5.3	-5.6	-31.2	-41.1	-46.1	-48.9
Puglia	-5.3	-8.2	-41.4	-50.8	-55.3	-57.8
Basilicata	-5.3	-9.0	-43.3	-53.3	-58.3	-61.1
Calabria	-5.3	-5.3	-28.5	-38.0	-43.0	-45.9
Sicilia	-5.3	-7.3	-31.4	-39.4	-43.4	-45.7
Sardegna	-5.3	-7.7	-36.7	-43.9	-47.1	-48.8
Piemonte	-5.3	-3.6	8.1	-7.2	-16.5	-21.8
Italy	-5.30	-5.31	-4.18	-2.71	-1.63	-0.89