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Sea Level Rise in the Italian Regions: a macro-economic assessment

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SUMMARY The aim of this work is to apply a methodology combining the top-down approach (sub-national CGE model) and the bottom-up approach (DIVA model) to assess the economic general equilibrium effects of Sea Level Rise in the Italian regions by the end of 21st century. Previous macro-economic analyses providing estimates of potential damages occurring from Sea Level Rise for Italy are at country scale. Our approach goes more in detail considering differences in vulnerability across regions, as well as capturing all the economic interactions among the Italian sub-national regions and between each sub-national region and the rest of the world. This assessment allows analyzing how economic agents may respond to change in relative prices following the productivity loss in the resource induced by the climate change impact (market-driven or autonomous adaptation). In order to manage the uncertainty related to the integration's degree across the regional economies, we build both a rigid and a flexible version of the regionalized CGE model. This allows us to control the economic effects of Sea Level Rise when the flexibility in the Italian economy changes. Results show that Emilia Romagna and Veneto are the most affected regions in all the scenarios. In the flexible model we can observe a reallocation of capital and labor from these regions to the landlocked regions.

Keywords: CGE models, Regional economics, Sea Level Rise

JEL: C68, D58, Q50, R11, R12, R13

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1. INTRODUCTION

The Fifth Assessment Report of the *Intergovernmental Panel on Climate Change* (IPCC, 2013) predicts an increase in the global seal level ranging between 25 cm and 1 m by 2100 because of ocean warming and loss of mass from glaciers and ice sheets. It is very likely that this increase will have a strong regional pattern, with some places experiencing significant deviations of local and regional sea level change from the global mean change (IPCC, 2013).

Economic assessment of climate change impacts such as *Sea Level Rise* (SLR) is extremely important to guide policy-makers' actions to cope with such adverse effects. In fact, significant physical impacts could be associated with high economic losses (Bosello et al., 2007; Nicholls and Cazenave, 2010; Ackerman and Stanton, 2011; Hallegatte et al., 2013). Moreover, nearly two-fifths of the world population live in coastal zones, where flooding and storm surges caused from SLR could trigger large-scale migration together with political instability, and could deeply damage homes, businesses, infrastructures, and coastal shallow-water ecosystems (Ackerman and Stanton, 2011).

The economic consequences of SLR can be the direct damages to properties and assets in the affected area but also the indirect effects which spread in the economic system outside the flooded area, both in spatial and temporal terms, by the means of market mechanisms.

Considering only direct economic impacts and ignoring these secondary effects of variations in market prices could give a less realistic picture of the economic consequences (Darwin and Tol, 2001). These indirect effects are usually referred as general equilibrium effects and the best tool to assess them is the *Computable General Equilibrium* (CGE) model.

Italy is an interesting case study. Italian coastline length is about 7911.5 km, and Italy is the 4th and 14th country in Europe and in the World, respectively, for coastline length (CIA, The World Factbook). From the economic point of view Italian GDP measured in *Purchasing Power Parity* (PPP) 2013$ was the 4th and 11th in Europe and in the World (CIA, The World Factbook). In Italy 15 out of 20 sub-national regions have coastline. In 2012 the coastline regions represented the 67% of Italian GDP and 73% of Italian population (ISTAT, Conti Economici Regionali).

For Italy as a whole, the Sixth National Communication to UNFCCC[1] reports the estimates provided by the FP6 Peseta project, amounting to 9-42 billion € per year. However, this estimate does not consider intra-country dynamics. In this work we aim at assessing the long-run economic general equilibrium effects of SLR by 2100 in the 20 Italian sub-national regions. To the best of our knowledge this is the first attempt to carry out a CGE assessment which considers simultaneously all the Italian sub-national regions.

It is worth noting that in this paper we are neither including a cost-benefit analysis nor considering the public adaptation role. Rather, our objective is to compute the maximum level of general equilibrium economic damages when no adaptation is undertaken in terms of raising dikes, nourishing shores and beaches.[2]

Our sub-national CGE model makes it possible to examine not only the economic consequences of SLR in the coastal regions immediately affected by SLR, but also to analyze to what extent the Italian landlocked regions are involved.

In the CGE framework economic agents (households and firms) react to the climate shocks adjusting their decision of consumption, investment and production. This is the typical autonomous (or market driven) adaptation which takes place with no public intervention. We are able to include an additional form of autonomous adaption by our sub-national CGE tool. This is the labor and capital mobility within the Italian territory. The movements of labor and capital in response to climate impacts are usually neglected in the standard CGE models, which are specified at the country level.

The structure of the paper is as follows. Section 2 presents an overview of the literature for economic impact assessment of SLR and the rationale for our contribution. Section 3 illustrates our methodology to build the sub-national CGE tool. Section 4 describes the procedure to couple the CGE model with the *Dynamic and Interactive Vulnerability Assessment* (DIVA) model. Section 5 shows results and their interpretation. Section 6 concludes and sketches some ideas for future research.

[1] http://unfccc.int/files/national_reports/annex_i_natcom/submitted_natcom/application/pdf/ita_nc6_resubmission.pdf

[2] Cost-benefits analysis on SLR and the implementation of adaptation policy have been carried out using bottom-up approaches (Brown et al, 2011), Integrated Assessment Models (IAMs) (Nordhaus, 2010; Hope, 2011) and CGE models (Deke et al., 2001; Bosello et al., 2012; Darwin and Tol, 2001). For a comparison between IAMs and Brown et al. (2011) refer to Hof et al. (2013).

2. METHODOLOGIES FOR ECONOMIC IMPACT ASSESSMENT OF SLR

In the literature, economic assessment of effects caused by SLR has been performed using two main approaches, namely related to direct versus indirect effects.

On one hand biophysical models have been used to assess the direct economic impact of SLR. The direct effect is usually the computation at a very high geographical resolution of lost land and destroyed (or damaged) capital multiplied for a unitary price. Biophysical models are *Bottom-Up* (BU) and very accurate in their spatial detail. Most of them are based on engineering research and *Geographical Information System* (GIS) methods. Several examples can be found in the literature: Nicholls et al. (2007), Hoozemans et al. (1993), Fankhauser and Tol (1996), Tol (2002, 2007), Fankhauser (1994), Yohe et al. (1996), Yohe and Schlesinger (1998), Nicholls and Klein (2005), CEC (2007), Dennis et al. (1995), Volonte and Nicholls (1995), Volonte and Arismendi (1995), Morisugi et al. (1995), Zeider (1997), Gambarelli and Goria (2004), Breil et al. (2005), Smith and Lazo (2001), Saizar (1997), Hinkel and Klein (2009).

On the other hand, economic assessment of indirect effects can be performed coupling the BU approach and CGE models (Bosello et al., 2012; Deke et al., 2001; Darwin and Tol, 2001). First, BU, such as GIS or bio-physical models, determines a climate-related physical impact. Then, the output of BU is used as inputs in the CGE models to determine the indirect economic effects.

CGE models are *Top-Down* (TD), which implies a broad regional aggregation (countries or group of countries). However, they consider all the interactions and feedbacks in the economic system. Even when a specific impact affects one specific region or economic sector, these models keep track of possible reactions of economic agents – households and firms – that can re-allocate their demand for commodities and productive inputs both in domestic and international markets following climate-related price signals. Considering such interconnections among markets can lead to different outcomes than expected through adjustment mechanisms and affect the overall GDP.

One main drawback of CGE approach is the lack of spatial detail, because in general this type of model is at the country level. This requires a scientific effort to increase the resolution of the CGE tool.

Deepening the spatial detail of the CGE is exactly in the main scope of this paper. We build a sub-national CGE model considering at the same time all the 20 Italian NUTS-2 (*Nomenclature of Territorial Units for Statistics*) regions. We control the integration degree of regional economies within the Italian economy by using two versions of the sub-national model: *rigid* and *flexible*. In the latter goods and production factors (capital and labor) can move more easily than in the former within the national territory.

For the economic impact assessment of SLR we follow Bosello et al. (2012). They use the DIVA model (Hinkel and Klein, 2009) to compute the climate physical impacts of SLR in Europe and then apply them into a country level CGE model to assess the economic consequences. We also use the DIVA output to feed the sub-national CGE model. The potential to impose differentiated shocks within a country is one of the main strengths of our approach but it is also interesting to analyze to what extent the economic effects of the physical impact propagate from the coastline to the inland.

3. THE CGE SUB-NATIONAL TOOL

3.1 DATABASE DEVELOPMENT

Building a full-fledged sub-national CGE model is challenging, both in terms of data requirements and modelling capacity.

Our starting point is the *Global Trade Analysis Project* (GTAP) 8 database (Narayanan et al., 2012) consisting of 57 sectors and 129 countries or groups of countries. The reference year is 2007.

The *Italian National Statistical Institute* (ISTAT) provides data on value added, labour and land inputs for the 20 Italian regions and 40 production sectors (Agricoltura e Zootecnia, ISTAT; Conti Economici Regionali, ISTAT; Valore Aggiunto ai Prezzi di Base dell'Agricoltura per Regione, ISTAT). ISTAT also reports bilateral flows in physical volume (tons) by mode of transportation (truck, rail, water and air) for the 20 Italian regions (Trasporto Aereo, ISTAT; Trasporto Ferroviario, ISTAT; Trasporto Marittimo, ISTAT; Trasporto Merci su Strada, ISTAT), but for a smaller number of sectors (just 10 agricultural/industrial sectors).

We integrate the GTAP database with the statistical information from ISTAT to extend the original database by inserting regional details for Italy.

The major effort in building a sub-national CGE database consists in estimating the trade flows across sub-national regions. Due to the lack of data, this is usually done through a gravitational approach (Dixon et al., 2012; Wittwer and Horridge, 2010). By this method, the bilateral trade flows across sub-national regions are computed as an increasing function of the regional production in the origin and destination regions and decreasing function of their geographical distance. The equation is similar to that used for the gravity force in the Newtonian physics.

Given the availability of transport data for the Italian regions we follow a different approach, similar to that used by Dubé and Lemellin (2005) and Canning and Tsigas (2000). Practically, the statistical procedure is the following. First, we split the Italian value added and primary factors in GTAP across the 20 regions using the ISTAT production information. Then we use the shares obtained from ISTAT transport data to distribute the Italian GTAP production in each sector, which is demanded domestically, between domestic regional use and trade flows across Italian regions. Finally, we check if the regional accounts are verified (production = demand + exports - imports). This is done by adjusting the trade flows across regions with the RAS statistical method (Bacharach, 1970; Deming and Stephan 1940) to make these flows consistent with the regional production data.

In our view, combining the transport data and the economic production information in the computation of trade flows across regions is important for three reasons: first, economic dataset has a more detailed sector aggregation; second, we can translate transport data from volumes (tons of carried commodities) in economic values; finally, we use all the available information in a consistent framework.

The final result of this process is a database with 148 geographical units (128 countries or groups of countries and 20 Italian regions) and 57 sectors.

As the focus of the analysis is Italy, the database is re-aggregated as shown in Table 1. For further information we indicate if the region is a coastal or a landlocked region. We keep the sector aggregation in Table 2 as simple as possible because DIVA does not provide physical inputs differentiated by sector and inserting a large number of sectors would complicate uselessly the numerical computation of the economic equilibrium and the interpretation of the results.

Table 1 – Regional detail

CGE geographical units	
Aosta Valley (landlocked region)	**Lazio** (coastal region)
Piedmont (landlocked region)	**Abruzzi** (coastal region)
Lombardy (landlocked region)	**Molise** (coastal region)
Trentino-Alto Adige (landlocked region)	**Campania** (coastal region)
Veneto (coastal region)	**Apulia** (coastal region)
Friuli-Venezia Giulia (coastal region)	**Basilicata** (coastal region)
Liguria (coastal region)	**Calabria** (coastal region)
Emilia-Romagna (coastal region)	**Sicily** (coastal region)
Tuscany (coastal region)	**Sardinia** (coastal region)
Umbria (landlocked region)	**EU**
Marche (coastal region)	**ROW**

Table 2

CGE Sectors
Agriculture
Manufactures
Services

3.2 MODEL SPECIFICATION

The starting point is the GTAP model (Hertel, 1997). It is a widespread CGE model used to evaluate trade and tax policy scenarios but also to carry out climate change economic impact assessment.

The economic structure of the model is neoclassical. In each country, a representative household maximises the consumption utility function subject to a budget constraint. In each country and sector, a representative firm maximises profits subject to a technological constraint. All the domestic markets are perfectly competitive and primary factors are fully employed. Income of primary factors accrues to the representative household. The main primary factors are skilled/unskilled labour, capital and land.

The GTAP model is tailored to countries or group of countries. In order to take into account the different degrees (national and sub-national) of factors and goods mobility we need to modify the theoretical structure of GTAP.[3] In fact, both commodities and factors are expected to move easier within the country than between countries. This implies that additional assumptions have to be made on both factor mobility and trade across sub-national entities.

As to the first point, two opposite options are available: perfect factor immobility at the regional level or perfect mobility between Italian regions. The truth is seemingly in between. At some extent, workers (and capital) can move in other sub-national regions to react to an economic shock. As to the second point, given that trade within a country is larger than trade between countries given the same distance - the so-called border effect (McCallum, 1995) – the product substitution inside the borders should be increased.

This implies additional assumptions and a re-calibration process of some parameters in the model. Turning to the theoretical hypothesis, we use a *Constant Elasticity of Transformation* (CET) function to model the endogenous supply of capital and labor at the sub-national level. In the goods market we assume a different demand structure for the Italian regions with respect to countries to better capture the inter-regional trade relations.

The re-calibration process would require the estimation of two parameters at the sub-national level. The first one is the substitution elasticity regulating capital and labour mobility in the CET function. The second one is the Armington elasticity in the demand of goods faced by households and firms establishing the degree of substitution between domestic and product imported from other sub-national regions.[4]

Unfortunately, to the best of our knowledge, econometric estimations are not available for both the parameters at the sub-national level. In addition, especially for primary factor mobility, it is reasonable to think that these parameters could be not sensitive to the national and regional policy and for this reason they could be not time-invariant.[5]

[3] For more details about the methodology used to change the GTAP model, refer to Standardi et al. (2014).
[4] The Armington elasticity (Armington, 1969) introduces imperfect substitutability between homologue domestic and imported goods. This is a standard assumption in the CGE modelling.
[5] Institutional factors as red tape, contract laws, unions, housing policy and others are likely to play a role in labor/capital mobility.

Therefore, we use two model specifications in order to manage the uncertainty related to the model flexibility. In the first (*rigid* model) workers and capital cannot move outside the Italian region they belong after a shock in the economic system. We also assume the same values of Armington elasticity for both countries and sub-national regions.

In the second specification (*flexible* model) we allow for imperfect mobility of capital and labour within the country (endogenous factor supply at the sub-country level) through the CET function. This opportunity is usually excluded in the standard CGE models where the primary factors are perfectly mobile within the country and perfectly immobile across countries. In addition, we increase the degree of commodities substitutability at the regional level by increasing the sub-national Armington elasticities.[6]

4. COUPLING THE SUB-NATIONAL CGE WITH THE BOTTOM-UP DIVA MODEL

Concerning the geo-physical inputs feeding our CGE model, we use the DIVA software. This tool is a worldwide model, tailored to analyze at high geographical resolution the biophysical and socio-economic consequences of SLR. DIVA allows the quantitative assessment on a wide range of coastal vulnerability indicators according to the different *Intergovernmental Panel on Climate Change* (IPCC) *Special Report Emission Scenario* (SRES) (Nakicenovic and Swart, 2000). However, DIVA does not capture the economic general equilibrium effects of SLR but only physical impacts and direct costs.

It takes into account coastal erosion and submergence, coastal flooding (including rivers), wetland change and salinity intrusion into deltas and estuaries but also number of people affected linked to SLR phenomenon (Hinkel and Klein, 2009; Vafeidis et al., 2008; DINAS-Coast Consortium, 2006).

[6] In this work we arbitrarily double the values of the standard Armington elasticity and set the CET elasticity equal to -2 to allow for capital/labor mobility. Refer to Standardi et al. (2014) for an extensive sensitivity analysis on these parameters.

Our experiment consists in using the output of the DIVA model in 2100 for the six SRES under the assumption that no adaptation in terms of raising dikes, nourishing shores and beaches takes place. A brief description of the SRES is reported.

- **A1** scenario considers a rapid economic growth, a global population that peaks in mid-century and declines thereafter, convergence among countries. The A1 scenario family develops into three groups: fossil intensive (**A1FI**), non-fossil energy sources (**A1T**), or a balance across all sources (**A1B**).
- **A2** represents a more heterogeneous world**,** global population increasing during all the 21st century, and slower convergence among countries. This seems the most pessimistic scenario from an economic perspective.
- **B1** is similar to **A1** but with rapid changes in economic structures toward a service and information economy, with the introduction of clean and resource-efficient technologies.
- Finally **B2** depicts 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**.

For each scenario DIVA provides the land impacted (km^2) and the number of people affected by SLR in every Italian coastal region for the period 1995-2100. For land we have considered these impacts:

1) coastal erosion,
2) submergence,
3) flooding area caused by SLR and associated storm surges for both sea and river floods,
4) change in the coastal wetland area.

For population we take the coastal floodplain population, which is the number of people that live below 1000-year storm-surge level. This indicator gives an idea of people at potential risk of flooding because of SLR.

We use these data as inputs for the CGE analysis. However, this information cannot be inserted directly into the CGE model but need some manipulation to be consistent with CGE theoretical structure. We convert the above-mentioned impacts for land as a change in both land[7] and capital productivity, the latter to consider damages on physical and human-made assets surrounding endangered areas. The impact on population is assumed to work on the supply-side, in terms of reduced productivity of both skilled and unskilled labor.

The choice to shock labor and capital productivity rather than endowments depends on the fact that we want to allow the preexisting SLR stock of labor and capital to reallocate to other regions. Reducing the stock of primary inputs (labor and capital) would not enable us to capture this additional indirect effect. This is the autonomous (market driven) adaptation of primary factors. In general, national-specified CGE models consider the autonomous adaptation driven by trade and production re-allocation across sectors and ignore spatial factor's mobility as they assume perfect factor immobility at the country level. To some extent we extend the opportunities of the autonomous adaptation within Italy. This adaptation takes place instantaneously while in reality it should happen gradually, but this is the constraint of our comparative static exercise.

The computation of the productivity loss is the following. The ratio between the land loss in the region over the period 2007-2100 and the total surface of the region has been used as a proxy to quantify the land productivity loss in the agricultural sector.[8] To model capital productivity loss in agriculture, manufactures and services we assume that the capital lying on all land use classes (agricultural, industrial and urban) is impacted in the same way of land. As a consequence the capital shock is uniform across sectors.

The ratio between the increase in people at risk over the period 2007-2100 and total population in the region for the year 2007 has been used as a proxy to quantify the productivity loss of skilled and unskilled labor for all sectors in the economy. The underlying hypothesis is that the shock is uniform across sectors and between skilled and unskilled labor.

Tables 3 and 4 show the CGE % productivity losses in the last column for the SRES A1B (a very similar regional ranking can be found in the other scenarios).[9] In Table 3 the second and third column report the % regional share of coastline over the total

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[7] By construction, in the model land is only used by agriculture.
[8] We choose 2007 as starting year to compute the impact as this is the base year in the CGE database.
[9] Data for the other SRES are available upon request.

Italian coast length and the % regional share of DIVA impact over the total Italian impact.

Interestingly, we can observe that regions which have high % shares of coastline length, as Sicily and Sardinia, have not high % shares of DIVA impact, as Emilia Romagna and Veneto. This suggests that the shape of the coastline (rocky or flat) plays a key role to determine the SLR physical effect.

A similar behavior characterizes the SLR impact on labor in Table 4. Regions which have high % shares of population, as Sicily, have not high % shares of DIVA impact, as Emilia Romagna and Veneto. This is probably caused by the different coastal urbanization of the regions.

Table 3 – Coastal length, affected coastal areas and computed changes in productivity by region.

SRES A1B	% coastline length	% DIVA impact	CGE % land/capital productivity change
Friuli-V. G.	4.02	2.86	-2.34
Emilia-Romagna	**2.00**	**35.53**	**-10.17**
Liguria	4.36	1.04	-1.24
Tuscany	7.35	9.87	-2.76
Molise	0.45	0.41	-0.60
Apulia	10.87	7.59	-2.50
Campania	5.66	3.68	-1.73
Basilicata	0.74	0.87	-0.56
Calabria	9.00	5.09	-2.15
Sicily	**18.07**	**5.93**	**-1.48**
Abruzzi	1.58	1.19	-0.71
Lazio	4.30	6.51	-2.43
Sardinia	**21.60**	**5.81**	**-1.55**
Marche	2.11	1.54	-1.06
Veneto	**7.87**	**12.06**	**-4.21**
Italy	100.00	100.00	-2.13

Table 4 – Population, affected population and computed changes in labor productivity by region.

SRES A1B	% population	% DIVA impact	CGE % skilled/unskilled labor productivity change
Friuli V. G.	2.05	3.00	-0.98
Emilia Romagna	**7.31**	**21.51**	**-1.97**
Liguria	2.64	0.87	-0.22
Tuscany	6.18	8.91	-0.96
Molise	0.53	0.15	-0.19
Apulia	6.82	5.37	-0.53
Campania	9.70	9.21	-0.63
Basilicata	0.97	0.25	-0.17
Calabria	3.30	2.48	-0.50
Sicily	**8.42**	**4.77**	**-0.38**
Abruzzi	2.20	0.56	-0.17
Lazio	9.26	14.44	-1.04
Sardinia	2.76	2.96	-0.72
Marche	2.59	0.57	-0.15
Veneto	**8.17**	**24.95**	**-2.04**
Rest of Italy	**27.10**	**0**	**0**
Italy	100.00	100.00	-0.67

5. RESULTS

The SLR shocks are cumulative impacts covering the period 2007-2100. The analysis does not consider by now transitional and recursive dynamics. As a consequence, the results should be interpreted as % changes with respect to the economy in the base year 2007. In a nutshell, we carry out a comparative static exercise where all the 2007-2100 cumulative impact is concentrated in the base year 2007 and produces instantaneously the economic general equilibrium effects. We do not consider the role played by technological change, demographic pattern and capital accumulation in this framework.

Table 5 shows that in the *rigid* specification the most affected regions are Emilia Romagna and Veneto – not surprisingly as the physical impact is the highest – because their GDP decreases range from 4.55% to 7.78% and from 2.61% to

6.58%, respectively. Regions which have no coastline, like Piedmont and Lombardy, are essentially not affected in economic terms.

In Table 6 the *flexible* specification triggers an interesting dynamic at the sub-national level. We can notice *amplification* effects for regions which experienced substantial losses in the rigid model. For example, the % GDP decrease ranges from 8.72 to 14.54 in Emilia-Romagna and from 4.41 to 12.06 in Veneto. On the other hand, regions which were not impacted in the rigid version start to gain. Piedmont increases the GDP from 1.71% to 3.43%, Lombardy from 1.32 to 2.61. As the markets become more integrated in the *flexible* model the landlocked regions are indirectly and positively affected by SLR. In addition they gain more in the worst Italian scenario (A2) because compensate the bigger losses of the negatively affected coastal regions.

Tables 5 and 6 report the % real GDP losses in the *rigid* and *flexible* model, respectively. In the last row of both Tables we can observe that the aggregate GDP losses are similar for Italy between *rigid* and *flexible* model. However, in the *flexible* version the GDP decreases less in all the SRES. This is due to the more competitive and integrated markets which allow the economic agents to better respond to the environmental shocks (autonomous adaptation). The worst scenario is A2 for Italy, the best one is B1.

Table 5: % real GDP change in the rigid model

SRES	A1B	A1FI	A1T	A2	B1	B2
Piedmont	**0.00**	**0.00**	**0.00**	**0.01**	**0.00**	**0.00**
Aosta Valley	0.01	0.01	0.01	0.02	0.00	0.01
Lombardy	**-0.02**	**-0.03**	**-0.02**	**-0.03**	**-0.02**	**-0.02**
Trentino Alto Adige	-0.04	-0.04	-0.03	-0.06	-0.03	-0.03
Veneto	**-3.16**	**-3.70**	**-2.71**	**-6.58**	**-2.61**	**-2.64**
Friuli V. G.	-1.66	-2.24	-1.32	-3.31	-1.20	-1.27
Liguria	-0.80	-0.98	-0.65	-0.92	-0.62	-0.65
Emilia Romagna	**-6.23**	**-7.34**	**-4.96**	**-7.78**	**-4.55**	**-4.85**
Tuscany	-1.92	-2.51	-1.37	-2.39	-1.24	-1.34
Umbria	-0.03	-0.03	-0.02	-0.03	-0.02	-0.02
Marche	-0.61	-0.70	-0.51	-0.75	-0.47	-0.50
Lazio	-1.77	-2.25	-1.30	-2.24	-1.16	-1.27
Abruzzi	-0.44	-0.51	-0.38	-0.55	-0.49	-0.37
Molise	-0.41	-0.49	-0.33	-0.50	-0.31	-0.33
Campania	-1.17	-1.50	-0.76	-1.51	-0.71	-0.75
Apulia	-1.50	-1.83	-1.16	-1.81	-1.06	-1.14
Basilicata	-0.36	-0.44	-0.29	-0.45	-0.27	-0.28
Calabria	-1.41	-1.53	-1.29	-1.64	-1.24	-1.28
Sicilia	-0.90	-1.01	-0.80	-1.07	-0.77	-0.79
Sardinia	-1.12	-1.64	-0.92	-1.60	-0.87	-0.94
Italy	**-1.52**	**-1.84**	**-1.21**	**-2.18**	**-1.12**	**-1.18**

Table 6: % real GDP change in the flexible model

	A1B	A1FI	A1T	A2	B1	B2
Piedmont	**2.32**	**2.80**	**1.84**	**3.43**	**1.71**	**1.80**
Aosta Valley	2.51	3.03	1.99	3.65	1.85	1.95
Lombardy	**1.80**	**2.18**	**1.42**	**2.61**	**1.32**	**1.39**
Trentino Alto Adige	1.51	1.86	1.17	1.85	1.07	1.14
Veneto	**-5.13**	**-5.94**	**-4.53**	**-12.06**	**-4.41**	**-4.41**
Friuli V. G.	-2.01	-2.94	-1.63	-5.41	-1.48	-1.56
Liguria	0.27	0.30	0.17	0.89	0.13	0.15
Emilia Romagna	**-11.93**	**-13.95**	**-9.53**	**-14.54**	**-8.72**	**-9.33**
Tuscany	-2.44	-3.38	-1.60	-2.70	-1.41	-1.57
Umbria	1.81	2.18	1.45	2.73	1.36	1.42
Marche	0.36	0.54	0.24	0.93	0.22	0.23
Lazio	-2.04	-2.72	-1.36	-2.19	-1.15	-1.32
Abruzzi	1.11	1.39	0.84	1.91	0.47	0.81
Molise	1.15	1.40	0.91	1.95	0.82	0.88
Campania	-0.72	-1.06	-0.18	-0.55	-0.18	-0.18
Apulia	-1.71	-2.09	-1.31	-1.66	-1.18	-1.29
Basilicata	1.05	1.26	0.84	1.69	0.78	0.82
Calabria	-1.45	-1.34	-1.53	-1.27	-1.54	-1.54
Sicilia	-0.43	-0.34	-0.52	-0.14	-0.55	-0.54
Sardinia	-0.85	-1.71	-0.74	-1.18	-0.72	-0.80
Italy	**-1.51**	**-1.83**	**-1.20**	**-2.16**	**-1.11**	**-1.17**

We can better understand the economic mechanism behind these results in the *flexible* model by analyzing the primary factors movement in Table 7. For example, Emilia Romagna and Veneto experience an outflow of capital (Cap), skilled labor (Sk Lab) and unskilled labor (Un Lab) while Lombardy and Piedmont an inflow of the same primary factors.

The interpretation is straightforward. The SLR impact causes a productivity loss of the primary inputs in the two coastal regions (Emilia Romagna and Veneto). This implies a reduction in the productive capacity of the region. As a result, firms lower their demand of capital and labor. This in turn determines a dip in the factor's price in the two coastal regions. In the *rigid* version no opportunity is given to capital and labor to move towards regions where the factor's remuneration is higher (Piedmont and Lombardy). The *flexible* version makes this possibility feasible and the factors move toward landlocked regions where the wages and the capital's returns have not been negatively affected by SLR and are, eventually, higher compared to coastal regions.

In addition, in each coastal region the representative household partially shifts the demand of goods towards landlocked regions as they produce at relatively lower costs. This tends to strengthen the movements of capital and labor from the coast to inland. The changes in the regional GDP are the natural consequence of this mechanism.

It is worth noting that the movements of primary factors from the coastline to the inland do not involve all the coastal regions. Some coastal regions such as Sardinia, Sicily and others experience an inflow of capital and labor. This probably depends on a smaller SLR impact, trade effects and a winner/loser dynamics which takes place also within coastal regions. However, in general the inflow of capital and labor in the coastal regions does not compensate the negative impact of SLR on GDP.

Finally, we have compared the Italian GDP % change for the SRES A2 (DIVA High Sea level Rise – No Adaptation) between our sub-national CGE model and the national one of Bosello et al. (2012).[10] In Italy the results in terms of % GDP change is **0.0026** in Bosello et al. (2012) and **-2.16** in our regionalized work. We have a different result for both direction and magnitude. We identify some key elements which can explain these different outcomes:

1) in Italy land loss is around 4 times higher than the land loss in Bosello et al. (2.32% against 0.6) because we consider also the land loss caused by storm surges, river floods and change in the coastal wetland area.
2) the land productivity shock is also applied to capital affecting all the sectors in the economy. In Bosello et al. (2012) the shock is applied only to the stock of land used by the agricultural sector.
3) the SLR also hits skilled and unskilled labor; DIVA provides the number of people at potential risk of flooding and this information is used to calibrate the labor productivity shock. In Italy the labor productivity decreases by 1.70 in the SRES A2. Bosello et al. do not consider the SLR impact on labor.

[10] As the labor and capital is perfectly mobile within Italy in the national CGE model of Bosello et. al (2012) we decide to use the *flexible* version of our model as basis for comparison . The comparison between our results for Italy and those of Darwin and Tol (2001) and Deke et al. (2001) is not possible because they use a different BU model and Italy is included in the broader area of European Union or Western Europe.

4) our GDP refers to 2007. Bosello et al. project the GDP to 2085 and compare the baseline scenario with the impact scenario. We do not include capital accumulation, demographic pattern and technological progress in our analysis.

5) differently from Bosello et al., in this case, given the focus on intra-country dynamic, we have not considered impacts outside Italy. If this provides stronger results in the current analysis looking at Italy as a whole, this does not affect distributional effects across regions previously discussed.

Table 7: primary factors mobility

SRES A1B	% Cap Var Rigid	% Cap Var Flexible	% Sk Lab Var Rigid	% Sk Lab Var Flexible	% Un Lab Var Rigid	% Un Lab Var Flexible
Piedmont	**0.00**	**2.48**	**0.00**	**2.18**	**0.00**	**2.18**
Aosta Valley	0.00	2.68	0.00	2.34	0.00	2.26
Lombardy	**0.00**	**1.98**	**0.00**	**1.69**	**0.00**	**1.71**
Trentino Alto Adige	0.00	1.73	0.00	1.42	0.00	1.39
Veneto	**0.00**	**-2.14**	**0.00**	**-2.00**	**0.00**	**-1.84**
Friuli V. G.	0.00	-0.37	0.00	-0.41	0.00	-0.31
Liguria	0.00	1.17	0.00	1.01	0.00	1.00
Emilia Romagna	**0.00**	**-6.50**	**0.00**	**-5.43**	**0.00**	**-5.33**
Tuscany	0.00	-0.59	0.00	-0.56	0.00	-0.42
Umbria	0.00	2.00	0.00	1.68	0.00	1.71
Marche	0.00	0.95	0.00	0.86	0.00	1.09
Lazio	0.00	-0.22	0.00	-0.30	0.00	-0.35
Abruzzi	0.00	1.66	0.00	1.46	0.00	1.48
Molise	0.00	1.66	0.00	1.44	0.00	1.46
Campania	0.00	0.51	0.00	0.37	0.00	0.40
Apulia	0.00	-0.28	0.00	-0.24	0.00	-0.12
Basilicata	0.00	1.63	0.00	1.34	0.00	1.31
Calabria	0.00	-0.01	0.00	-0.08	0.00	-0.06
Sicilia	0.00	0.56	0.00	0.40	0.00	0.39
Sardinia	0.00	0.39	0.00	0.18	0.00	0.15
Italy	0.00	0.00	0.00	0.00	0.00	0.00

6. CONCLUSIONS AND FURTHER RESEARCH

This paper presents the sub-national development of a CGE model traditionally employed for climate change impact assessment. The current analysis focuses on the 20 Italian regions and is applied to the Sea Level Rise occurring by the end of 21^{th} Century.

Main results are as follows. Veneto and Emilia-Romagna are the most affected regions by SLR in terms of GDP loss. The worst IPCC scenario is A2 for Italy. The uncertainty in the Italian overall impact is related to the SRES rather than the version of model (*rigid* and *flexible*), even if the economic general equilibrium effects slightly improve when the markets are more integrated and competitive.

The model flexibility matters for the geographical distribution of economic effects at the sub-national level. Increasing the level of integration in the Italian economy makes the GDP regional patterns more uneven, exacerbating the winner/loser dynamic between coastal and landlocked regions.

In the *flexible* model, regions which have no coastline are positively affected by SLR as labor and capital re-allocate from the coast to inland where remunerations are higher.

Further research will include: a) extending the regionalized database for other European or Mediterranean countries; b) building a baseline scenario to give more realism to our results; c) use the sub-national CGE tool to estimate other climate impacts, such as extreme events and crop productivity.

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26

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