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A Sub-national CGE model for the European Mediterranean Countries

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SUMMARY This paper is the direct development of GEMINA P56 2014. It describes the methodology used to develop a Computable General Equilibrium model with sub-national detail for the Euro-Mediterranean area: Italy, France, Spain, Portugal and Greece. The main purpose of this exercise is to perform economic assessments of climate change impacts with a finer spatial resolution compared to that offered by standard CGE models and, in doing so, to increase the comparability of and the possibility to exchange information across economic and physical impact models. Indeed, aiming to represent the high spatial heterogeneity of climate drivers and environmental impacts, both climate models and physical process models (like e.g. land use, crop growth, flood risk models) are spatially detailed. This is not the case for macroeconomic models that typically feature large geo-political blocks or at best the country as the finest investigation units. Accordingly, when physical and economic models are interfaced to produce integrated assessments of climate change impacts, there is an unavoidable loss of richness both of input and output information. Developing a sub-national resolution for the economic analysis thus offers a first useful step to measure more accurately the economic consequences of climate change, to produce an information more relevant for local planners and businesses, and also to better capture the economic feedbacks between regions which can turn to be as important as the international ones.

The report addresses conceptual and practical issues related to the regionalization process, and presents simple experiments aimed to test the robustness of the regionalized structure and understand the economic implications in terms of market integration.

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1. INTRODUCTION

Computable General Equilibrium (CGE) models represent a popular tool to assess the economic consequences of different policies and social-economic scenarios. Starting from a neo-classical theoretical structure (Johansen, L., 1960; Shoven, J.B. and Whalley, 1992) they are able to capture all the feedbacks in the economic system in terms of inter-sectoral production reallocation, international trade and investments flows. In the recent years an increasing number of works has seen the application of CGE models in the field of environmental and climate change economics. Examples are the assessment of the implementation of carbon and energy taxes for environmental purposes (see e.g. EC 2008; EC 2010; Böhringer et al., 2009, 2010, 2012) or the study of economic consequences of climate change impacts (see e.g. Darwin and Tol, 2001; Bigano et al., 2008; Aaheim et al., 2010; Eboli et al., 2010; Ciscar et al., 2011; Bosello et al., 2012).

The typical investigation unit of CGE models is the country. Sub national differences are very often overlooked. However, on the one hand climate change impacts can be highly differentiated across different areas within the same country. This raises an immediate interest in quantifying their economic consequences with a similar degree of detail, especially to provide information that can be useful to "local" decision makers. On the other hand, countries also present economic asymmetries within them. These can impact for instance factor mobility and trade as importantly as international dynamics. Accordingly, local specificities constitute important determinants not only of how the economic consequences of climate change spread all over the economic system, but also of climate policy effectiveness. Tracing these sub national effects is thus particularly important to gain a better grasp of the distributional implication of a given policy or impact, and to understand the economic implications related to the different assumptions on market integration and flexibility.

In this paper we describe the building process of a sub-national CGE model for the Euro-Mediterranean region: Italy, France, Spain, Greece and Portugal. The Mediterranean area has been identified as one of the main climate change hotspots: that is, one of the most responsive areas to climate change (IPCC, 2014). The area is populated by over 500 million people, distributed in about 30 countries in Africa, Asia, and Europe. This geographical area is also crucial from an economic and socio-political point of view.

As anticipated, there are few CGE multi-country models also featuring a sub-national detail. This is mainly due to the difficulty to create mutually consistent Social Accounting Matrices (SAMs) and reconstruct all the bilateral trade flows for a large number of sub-national regions. Among these: Peter et al. (1996) developed the MRF (*Multi Regional Forecasting*) model to simulate tax/environmental policy for the Australian economy; Jean and Laborde (2004) developed the DREAM-MIRAGE (*Deep Regional Economic Analysis Model – Modelling International Relationships in Applied General Equilibrium*) model for Europe taking into account 119 NUTS (*Nomenclature of Territorial Units for Statistics*) 1 regions; Canning and Tsigas (2000) built a model for eight macro-regions of the USA; recently EU Joint Research Centre (JRC) has created RHOMOLO (Regional HOlistic MOdeL) for 267 NUTS2 European regions and 6 macro-sectors (Brandsma et al., 2015; Potters et al., 2014) for analysing the impact of the European Cohesion policy.

Some CGE models exist which present a spatially resolved description of the agricultural sector. Examples of this type are CAPRI-GTAP (*Common Agricultural Policy Regional Impact Analysis – Global Trade Analysis Project*) (Jansson et al., 2009), CAPSIM (*China's Agricultural Policy Simulation Model*) (Yang et al., 2011), GTAP-AEZ (*Global Trade Analysis Project – AgroEcological Zones*) (Hertel et al., 2009; Lee et al., 2009) and the ICES-AEZ (*Intertemporal Computable Equilibrium System – AgroEcological Zones*) (Michetti and Parrado, 2012).

The model presented here is an extension of the regionalized model for Italy developed by Standardi et al., (2014). That model has been applied to the economic assessment of flood risk (Carrera et al., 2015; Koks et al., 2015), sea-level rise (Standardi and Eboli, 2015) and environmental policies for water saving (Perez et al. forthcoming).

The paper is organized as follows. Section 2 presents the database construction and the estimation strategy to obtain trade flows across sub-national regions within countries. Section 3 describes the main theoretical changes made to adapt the standard country-level CGE model to the sub-national framework. Section 4 reports the results of the experiments developed to test the robustness of the model structure and to highlight the economic interactions between sub-national regions. Section 5 concludes and sketches some ideas for future research.

2. DATABASE DEVELOPMENT

The starting point is the GTAP 8 database (Narayanan et al., 2012). The 8.1 version consists in a collection of Social Accounting Matrices (SAMs) for 57 economic sectors and 134 countries (or groups of countries) in the world. The calibration/reference year is 2007.

In the case of France, Italy, Spain, Portugal and Greece, which the GTAP dataset already represents as singled-out countries, we further reconstruct a database characterizing the 70 sub-national entities represented in Table 1 and the 57 sectors represented in Table 2. An advantage of using a global database such as GTAP is the already existing rich description of international trade flows. In some sense, this facilitates the subsequent endeavor to further regionalize international trade and keep all the information for the other GTAP countries in the world.

Information sources to substantiate the process were the Eurostat (Economic Accounts for Agriculture; Structural Business Statistics) and the National Statistical Offices. Specifically: for Italy we refer to Istituto Nazionale di Statistica - ISTAT (Conti Economici Regionali, Anni 1995-2009; Agricoltura e Zootecnia; Valore Aggiunto ai Prezzi di Base dell'Agricoltura per Regione, Anni 1980-2011); for France to Institut National de la Statistique et des Etudes Economiques - INSEE (Valeurs Ajoutées régionales), for Spain to Instituto Nacional de Estadistica - INE (Contabilidad Regional de España), for Portugal to - Instituto Nacional de Estatística - INE (Gross value added (€) of Enterprises by Geographic localization (NUTS - 2002) and Economic activity) and for Greece to the Hellenic Statistical Authority - HSA (Gross value added by industry).

Operationally the sub national development of ICES followed a stepwise procedure. We started from a country, we regionalize its national database and then we moved to regionalize another country starting from the database obtained in the previous step. The country sequence is the following: Italy, Greece, Spain, France and Portugal.

Table 1: Sub-national characterization of the Euro-Mediterranean region[1]

France (22 NUTS-2)	Italy (20 NUTS-2)	Spain (19 NUTS-2)	Portugal (5 NUTS-2)	Greece (4 NUTS-1)
1. Île de France	1. Piemonte	1. Galicia	1. Norte	1. Voreia Ellada
2. Champagne-Ardenne	2. Valle d'Aosta	2. Principado de Asturias	2. Algarve	2. Kentriki Ellada
3. Picardie	3. Lombardia	3. Cantabria	3. Centro	3. Attica
4. Haute-Normandie	4. Trentino-Alto-Adige	4. País Vasco	4. Lisboa	4. Nisia-Aigaiou-Kriti
5. Centre	5. Veneto	5. Navarra	5. Alentejo	
6. Basse-Normandie	6. Friuli-Venezia-Giulia	6. La Rioja		
7. Bourgogne	7. Liguria	7. Aragón		
8. Nord -Pas-de-Calais	8. Emilia-Romagna	8. Comunidad de Madrid		
9. Lorraine	9. Toscana	9. Castilla y León		
10. Alsace	10. Umbria	10. Castilla-La Mancha		
11. Franche-Comté	11. Marche	11. Extremadura		
12. Pays de la Loire	12. Lazio	12. Cataluña		
13. Bretagne	13. Abruzzo	13. Comunidad Valenciana		
14. Poitou-Charentes	14. Molise			
15. Aquitaine	15. Campania			
16. Midi-Pyrénées				
17. Limousin				

[1] The Nomenclature of territorial units for statistics (NUTS) is a hierarchical system for dividing up the economic territory of the EU (Eurostat, 2015).

18. Rhône-Alpes 19. Auvergne 20. Languedoc-Roussillon 21. Provence-Alpes-Côte d'Azur 22. Corse	16. Puglia 17. Basilicata 18. Calabria 19. Sicilia 20. Sardegna	14. Illes Balears 15. Andalucía 16. Región de Murcia 17. Ceuta 18. Melilla 19. Canarias		

Table 2: sectoral detail of the CGE model

Sectors		
1. Paddy rice	20. Meat products nec	39. Transport equipment nec
2. Wheat	21. Vegetable oils and fats	40. Electronic equipment
3. Cereal grains nec	22. Dairy products	41. Machinery and equipment nec
4. Vegetables, fruit, nuts	23. Processed rice	42. Manufactures nec
5. Oil seeds	24. Sugar	43. Electricity
6. Sugar cane, sugar beet	25. Food products nec	44. Gas manufacture, distribution
7. Plant-based fibers	26. Beverages and tobacco products	45. Water
8. Crops nec	27. Textiles	46. Construction
9. Bovine cattle, sheep and goats, horses	28. Wearing apparel	47. Trade
10. Animal products nec	29. Leather products	48. Transport nec
11. Raw milk	30. Wood products	49. Water transport
12. Wool, silk-worm cocoons	31. Paper products, publishing	50. Air transport
13. Forestry	32. Petroleum, coal products	51. Communication
14. Fishing	33. Chemical, rubber, plastic products	52. Financial services nec
15. Coal	34. Mineral products nec	53. Insurance
16. Oil	35. Ferrous metals	54. Business services nec
17. Gas	36. Metals nec	55. Recreational and other services
18. Minerals nec	37. Metal products	56. Public Administration, Defense, Education, Health
19. Bovine meat products	38. Motor vehicles and parts	57. Dwellings

2.1 SPLITTING THE VALUE ADDED

As quite typical in CGE models, also our model features an upper level production structure which combines a bundle of primary factors with a bundle of intermediate goods by means of a Leontief technology. The two composites of production factors are thus perfect complement. The value of primary factors (in the model: labour, capital, land, natural resources) which coincides with their remuneration, constitutes total value added.

The first step for the sub national development consists thus in detailing the value added, originally available at the country level, to the new regional scope.

To do this, first, we match the sectors of the GTAP database with those of our data sources. Then, for each sector, the regional shares of value added, and accordingly of labour, capital, land and natural resources are computed using the sub-national data. Finally, these shares are used to distribute original country-level data across sub-national units.

National Statistical Offices of Italy and Spain provide information on both capital and labor at the sectoral level. Other countries are not that data rich. In these cases we split the national value of all the primary factors using the same proportion of the regional distribution of value added. For some manufacturing activities we referred to Structural Business Statistics (SBS) of Eurostat because they have a more detailed description of these sectors. To regionalize the agricultural economic components of value added we mainly rely on Economic Accounts for Agriculture of Eurostat because of the rich and already standardized information across EU regions.

2.2 THE DERIVATION OF SUB-NATIONAL DEMAND FOR DOMESTIC AND IMPORTED GOODS: SIMPLE LOCATION QUOTIENTS (SLQS)

One of the most challenging tasks in the database construction is the derivation of the sub-national domestic demand and trade patterns with other regions within and outside the country. This is because these data are often missing and need to be reconstructed using different techniques. The derivation of intra-national trade is particularly important. In our case we rely on the so-called Simple Locations Quotients (SLQs) method (Miller and Blair, 1985; Bonfiglio and Chelli, 2008; Bonfiglio, 2008)[2]. The formula for the SLQs is the following:

$$SLQ_{i,r} = \frac{X_{i,r}/X_r}{X_{i,c}/X_c} \qquad (1)$$

where i is the sector and X the output, r and c represent the regional and national indexes, respectively. SLQ gives a measure of the regional specialization in the economic activity. Two extreme cases are possible: absence of the economic activity i, and perfect specialization. In the first case we have $X_{i,r} = 0$ which implies $SLQ_{i,r} = 0$. This means that the region will need to import i, whether intermediate and final goods, from other regions.

At the other extreme we have $X_{i,r} = X_{i,c}$ and $SLQ_{i,r} = X_c/X_r$. This means that the sectoral regional value added coincides with the national one and that region will tend to export the good for intermediate or final consumption.

Finally in the case of $X_{i,r}/X_r = X_{i,c}/X_c$ the sub-national demand structure will follow exactly the national one and the share of domestic and imported demand will be the same.

[2] SLQs are so called "non-survey" techniques, as they are not based on primary data, but are reconstructed, to derive input-output tables and SAMs. SLQs are not the most precise across non survey coefficients in the literature (Bonfiglio and Chelli, 2008). However they offer the great advantage to be of particularly easy application when large global databases are involved as in our case.

Obviously in almost all the cases the SLQ values will be in between the two extreme cases and not equal to the last one. The sub-country shares of domestic and imported demand will be given by multiplying the national shares times SLQs and then normalizing these shares, as illustrated in the following equations:

$$\mathrm{ShrDom}_{i,r} = \mathrm{ShrDom}_{i,c} \cdot \mathrm{SLQ}_{i,r} \quad (2)$$

$$\mathrm{ShrImp}_{i,r} = \mathrm{ShrImp}_{i,c} \cdot (1/\mathrm{SLQ}_{i,r}) \quad (3)$$

$$\mathrm{ShrDom}^{*}_{i,r} = \mathrm{ShrDom}_{i,r} / (\mathrm{ShrDom}_{i,r} + \mathrm{ShrImp}_{i,r}) \quad (4)$$

$$\mathrm{ShrImp}^{*}_{i,r} = \mathrm{ShrImp}_{i,r} / (\mathrm{ShrDom}_{i,r} + \mathrm{ShrImp}_{i,r}) \quad (5)$$

where ShrImp and ShrDom are the not normalized shares of domestic and imported demand and ShrImp* and ShrDom* the normalized ones. In the extreme case of no economic activity we put ShrImp = 1 and ShrDom = 0 to avoid the infinite numbers.

2.3 ESTIMATION OF BILATERAL TRADE FLOWS BETWEEN SUB-NATIONAL REGIONS

The second step consists in the determination of the bilateral trade flows across sub-national regions. These data are very often missing. To overcome the problem the procedure usually adopted is the so-called gravitational approach as in Horridge and Wittwer (2010) and Dixon *et al.* (2012). By this method, the bilateral intra-country trade flows are estimated using a gravity equation as in the Newtonian physics. It accounts for the sectoral production in the origin region and sectoral demand in the destination regions as attractors and the distance between them as friction.

Some alternative approaches exist. For example, Chintrakarn and Millimet (2006) and Canning and Tsigas (2000) use transport data for United States to obtain trade flows across member States. Dubé and Lemelin (2005) also use transport data to estimate the trade flows across three sub-national regions of Quebec. In addition, they integrate this information with economic data about aggregate sub-national exports and imports and apply a cross-entropy optimisation method to make the two types of information consistent.

We follow the gravitational approach adjusting the trade flows across sub-national regions by the RAS statistical method (Deming and Stephan, 1940; Bacharach, 1970) to make consistent the intra-national trade obtained through the SLQs and the application of the gravitational approach for the bi-lateral trade flows between sub-national regions.[3]

In practice, the procedure is the following. Consider the share matrix **Π** represented in Table 3. Afterwards, vectors and matrices are in bold type. For simplicity, Table 3 features just three hypothetical sub-country regions: North, Centre and South.

In matrix **Π,** the rows represent the origin, and the columns the destination sub-national regions. Its general element π_{od} , where $0 \leq \pi_{od} \leq 1$, is computed through the gravitational criterion, that is the kilometric distance between the capital cities of the origin and destination regions. As our procedure is valid for all the sectors, for sake of algebraic simplicity we do not consider a sector index in the rest of the section.

[3] The RAS abbreviation stems from the names of the vectors (R and S) and matrix (A) used by Bacharach in the original formulation of the algorithm. According to McDougall (1999) RAS is a type of cross-entropy optimization method and it should be preferred in the absence of information about variation in column structure or row structure of the matrix.

Table 3: Components of Matrix Π

	North	Centre	South	Tot
North	π_{11}	π_{12}	π_{13}	$\Pi_{1.}$
Centre	π_{21}	π_{22}	π_{23}	$\Pi_{2.}$
South	π_{31}	π_{32}	π_{33}	$\Pi_{3.}$
Tot	$\Pi_{.1}$	$\Pi_{.2}$	$\Pi_{.3}$	1

Denoting Y_{NAT} the Italian sectoral production sold countrywide that is the value of sectoral production sold domestically, D the sub-national demand (excluded demand for foreign goods), EXP the sub-national exports towards the other sub-national regions, IMP the sub-national imports from the other sub-national regions, EXPAG the aggregate sub-national exports towards the rest of country and IMPAG the aggregate sub-national imports from the rest of country, we compute these variables for, say, sub-national region Centre, applying the following formulas:

$$\begin{aligned}
&(\pi_{12}+\pi_{22}+\pi_{32})\cdot Y_{ITA} = D_{Centre}\\
&\pi_{21}\cdot Y_{ITA} = EXP_{Centre,\,North}\\
&\pi_{23}\cdot Y_{ITA} = EXP_{Centre,\,South}\\
&(\pi_{21}+\pi_{23})\cdot Y_{ITA} = EXPAG_{Centre}\\
&\pi_{12}\cdot Y_{ITA} = IMP_{North,\,Centre}\\
&\pi_{32}\cdot Y_{ITA} = IMP_{South,\,Centre}\\
&(\pi_{12}+\pi_{32})\cdot Y_{ITA} = IMPAG_{Centre}
\end{aligned} \qquad \text{(eq. sys. 1)}$$

We apply the same procedure for each sub-national region.

Now, it well may happen that the regional production and demand that can be inferred for a given sector by applying the SLQs are not consistent with the aggregate imports and exports obtained by the gravitation approach:

$$\begin{aligned}
&Y_{North} = D_{North} + EXPAG_{North} - IMPAG_{North}\\
&Y_{Centre} = D_{Centre} + EXPAG_{Centre} - IMPAG_{Centre}\\
&Y_{South} = D_{South} + EXPAG_{South} - IMPAG_{South}
\end{aligned} \qquad \text{(eq. sys 2)}$$

The required adjustment takes place through the bi-proportional RAS method. Consider the bilateral trade matrix:

$\mathbf{A} = \mathbf{\Pi}\, Y_{ITA}$

of size 3 x 3, where we put $\pi_{11} = \pi_{22} = \pi_{33} = 0$. In matrix **A,** the general element is a_{od} where row *o* represents the origin and column *d* the destination sub-national region respectively. We also have a target vector of row totals **E** (aggregate sub-national exports to the rest of country, size 3 x 1) and a target vector of column totals **M** (aggregate sub-national imports from the rest of country, size 3 x 1). Targets are computed using the National and Eurostat statistical information about economic production (Y_{North}, Y_{Center} and Y_{South}) according to the following equations:

$$\begin{aligned}
E_{North} &= Y_{North} - D_{North} + IMPAG_{North} \\
E_{Centre} &= Y_{Centre} - D_{Centre} + IMPAG_{Centre} \\
E_{South} &= Y_{South} - D_{South} + IMPAG_{South} \\
M_{North} &= D_{North} + EXPAG_{North} - Y_{North} \\
M_{Centre} &= D_{Centre} + EXPAG_{Centre} - Y_{Centre} \\
M_{South} &= D_{South} + EXPAG_{South} - Y_{South}
\end{aligned} \qquad \text{(eq. sys. 3)}$$

The RAS method attempts to find a new matrix **B** such that:

$$\sum_o b_{od} = M_d$$

$$\sum_d b_{od} = E_o$$

where b_{od}, e_o and m_d are, respectively, the general element of matrix **B**, vector **E** and vector **M**.

The new matrix **B** is related to the original **A** via the iterative procedure:

$$b_{od} = (rm)_o \cdot (cm)_d \cdot a_{od}$$

where $(rm)_o$ is the multiplier of row *o* and $(cm)_d$ is the multiplier of column *d*.

For this initial application, we split the national exports and imports using the sectoral sub-national share of value added for exports and a combination of sub-national GDP share and SLQs for imports.

3. CHANGES IN THE MODEL STRUCTURE

Regionalization implies two work phases: one on the database, and another on the model structure. The first phase has been described in the previous section.

The second phase requires modifying the functional structure of the model especially to introduce a different degree of factors and goods mobility for the sub-national regions respect to the national ones. In fact, either goods or factors are expected to move more easily within the same country or the same political and economic union such as EU than between different macro-regions such as Europe and Asia for example.

In our original CGE model primary factors of production like labour and capital are imperfectly mobile across sectors, within the country or the aggregated macro-region, and implicitly also perfectly mobile "spatially" within the country or the aggregated macro-region. They are not mobile across countries. Capital? GTAP also includes land among primary factors. Land does not move physically, but can be used for different purposes, namely to grow different crops. It is a "sluggish" factor of production as there are constraints in land uses captured by an elasticity of transformation parameter which determines the land supply in each agricultural sector. This sectoral mobility of primary input is clearly technological/sectoral rather than spatial. The issue is slightly different for intermediates and final consumption goods. Both can be imported and thus are "mobile" across countries. However, in the CGE framework, to prevent unrealistic specialization phenomena and trade overflows that could warp the results of the model, the Armington assumption (1969) is introduced. It postulates imperfect substitutability between homologue domestic and imported goods. The values of the Armington elasticity are set by econometric estimations, which are carried out at the national level.

When, as in our case, the spatial detail of the CGE model is increased, it would be unrealistic to simply transfer to sub national entities the same parameterization used in the national model.

Both intra national primary factor mobility and goods' and intermediates' substitution require additional assumptions.

As to the first point it is reasonable to assume some, but not perfect, degree of factor mobility across sub-national regions within the same country or EU but this depends also on the policy scenario of the experiment (short, medium or long run).

As to the second point some imperfect substitution between goods produced in different sub-national regions must be introduced. If not, unrealistic full specialization or trade flows could be observed also at the sub-national levels. Following the empirical evidence that trade is bigger within than between countries given the same distance - the so-called border effect (McCallum, 1995) - these Armington elasticities should be higher intra than inter country.

3.1 MOBILITY IN FACTORS MARKET: THE CET APPROACH

The value added in the standard GTAP model originates from five primary factors: land, natural resources, unskilled labour, skilled labour and capital. All the sectors use labour and capital while only some use land and natural resources (agriculture and mining-related sectors, respectively). Land and natural resources supply is sluggish across sectors while labour and capital are perfectly mobile. All the primary factors are spatially immobile. For our sub-national context, we assume the following:

1) Primary factors sectoral mobility does not change.
2) Land and natural resources remain spatially immobile at the sub-national level.
3) Sub-national unskilled labour, skilled labour and capital supply is still immobile with respect to the rest of the world but can be geographically sluggish within the country or the EU depending on the type of experiment and the aim of the research.

The third assumption is new with respect to the standard GTAP model. It is implemented through a CET (*Constant Elasticity of Transformation*) function: as a result, workers and capital can move outside the sub-national region they belong to in response to economic shocks. It is worth noting that the model allows a flexible aggregation scheme. If the focus is on a specific European Mediterranean country, there is the possibility to increase the mobility just within this country.

First order conditions of the CET supply function and the formula to determine the EU price of the endowment (shadow price) are given in the equations 6-11, where QL, QH, QK, PL, PH, and PK represent, respectively, the quantity of supplied unskilled labour, skilled labour, capital and the associated prices. EU and r are, respectively, the European aggregate index and the sub-national index. The parameters σ_L, σ_H and σ_K are the elasticity of substitution of the endowment supply, they are a measure of geographical mobility. Increasing the absolute value of these parameters means increasing the factors mobility within EU.

$$QL_r = QL_{EU}\left(\frac{PL_{EU}}{PL_r}\right)^{\sigma_L} \quad \text{with } \sigma_L < 0 \tag{6}$$

$$\sum_r QL_r PL_r = QL_{EU} PL_{EU} \tag{7}$$

$$QH_r = QH_{EU}\left(\frac{PH_{EU}}{PH_r}\right)^{\sigma_H} \quad \text{with } \sigma_H < 0 \tag{8}$$

$$\sum_r QH_r PH_r = QH_{ITA} PH_{ITA} \tag{9}$$

$$QK_r = QK_{EU}\left(\frac{PK_{EU}}{PK_r}\right)^{\sigma_K} \quad \text{with } \sigma_K < 0 \tag{10}$$

$$\sum_r QK_r PK_r = QK_{EU} PK_{EU} \tag{11}$$

3.2 THE TRADE STRUCTURE OF THE SUB-NATIONAL REGIONS: THE CRESH APPROACH

In the standard GTAP model the demand side is composed by private consumption, government spending and intermediate goods. The demand tree follows a double nest (Figure 1). The first nest links domestic demand and aggregate foreign imports of a specific commodity (irrespective of origin country) for each agent (households, government, firms). The second nest differentiates foreign imports according to the geographical origin.

The second model improvement thus consists in modifying that tree in order to make sub-national products closer substitutes among them within EU.

To achieve this goal we modify the second nest in Figure 2 by using the CRESH (Constant Ratios of Elasticities of Substitution, Homothetic) function (see Hanoch, 1971; Pant, 2007; Cai and Arora, 2015). The CRESH function is very flexible compared to the standard CES function because for every good it allows for differing levels of substitution between any pair of countries/sub-national regions.

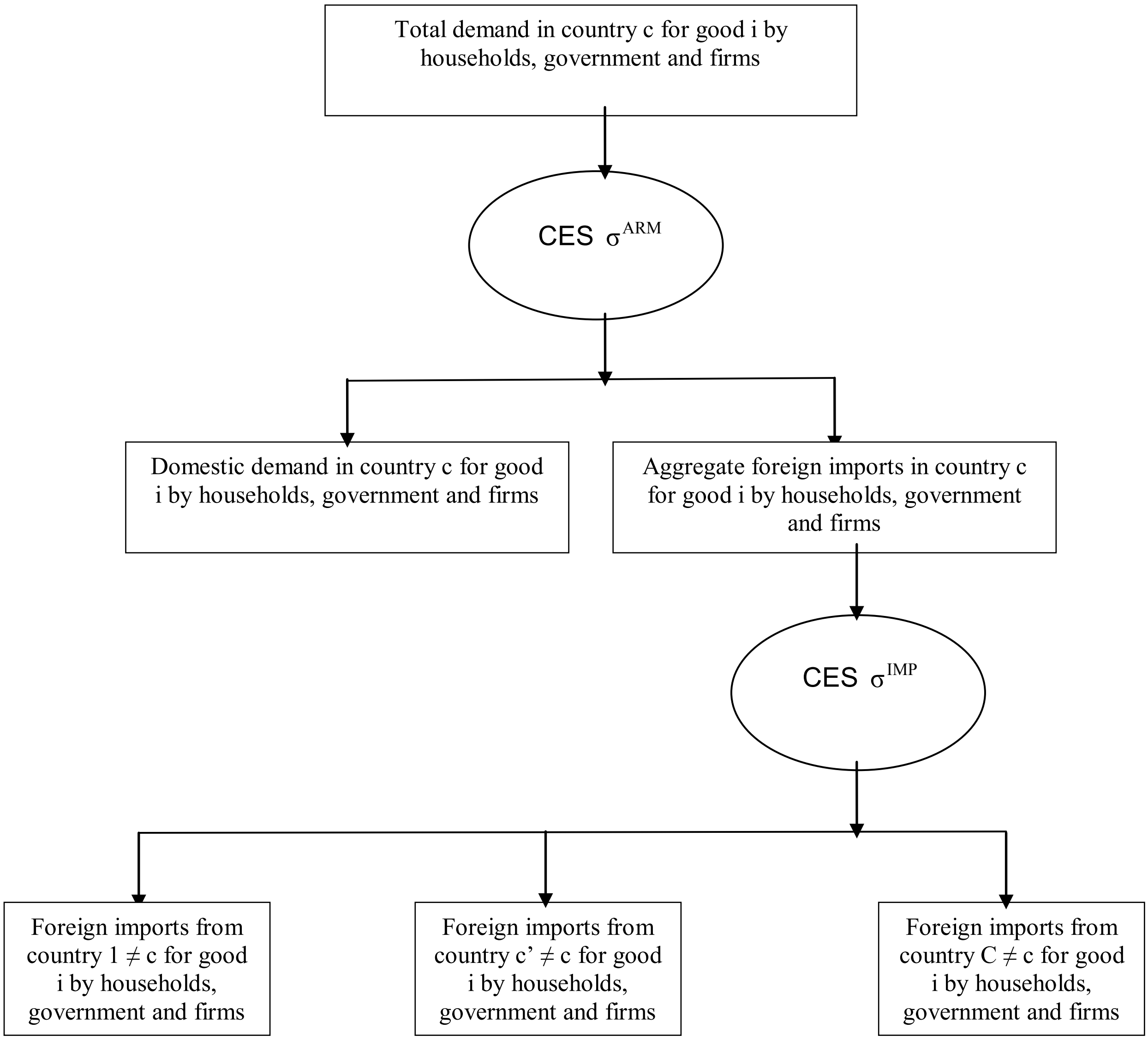

Figure 1 : GTAP standard CES demand structure

Source: Hertel (1997)

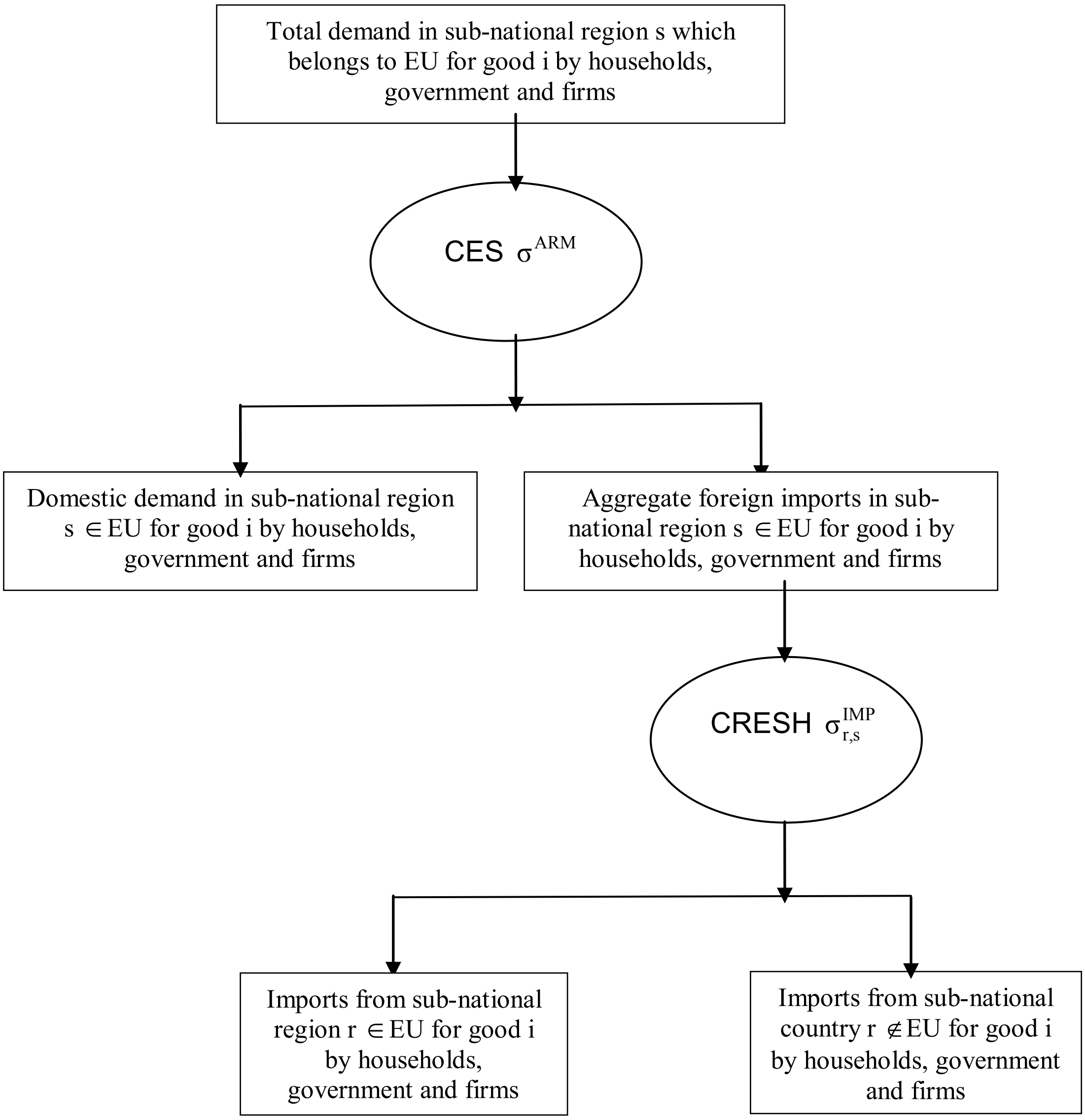

Figure 2: CRESH sub-national demand structure

Source: our elaboration

The equation 12 shows the demand function behind the new trade structure in Figure 2:

$$\sum_r \left(\frac{Q_{r,s}}{QIMP_s} \right)^{d_{r,s}} \frac{D_{r,s}}{d_{r,s}} = \kappa_s \qquad (12)$$

In this equation $Q_{r,s}$ is the trade flow between region r and s and QIMP is total amount of imports in regions s, d is a parameter with a value less than 1 but not equal to zero, each D parameter associated with a particular good is positive, and the values of D and κ are normalized. In the special case when $d_i = d$ for all i the CRESH function collapses to a CES function.

Each agent (household, government and firm) minimizes the expenditure subject to (12). The first order conditions become:

$$Q_{r,s} = \left(\frac{P_{r,s}}{P_s} \right)^{\sigma_{r,s}^{IMP}} QIMP_s \qquad (13)$$

where $\sigma_{r,s}^{IMP} = \frac{1}{1 - d_{r,s}}$, $P_s = \sum_r \sigma_{r,s}^{IMP} S_{r,s} P_{r,s}$, $S_{r,s} = \frac{P_{r,s} Q_{r,s}}{\sum_r P_{r,s} Q_{r,s}}$

The good point of the CRESH approach is that compared to the standard CES Armington elasticities in the second nest, σ^{IMP}, the CRESH Armington elasticities, $\sigma_{r,s}^{IMP}$ have two geographical indexes specifying the origin and the destination of the trade flow. This means that we can set different values for each pair of sub-national regions and/or countries with the maximum level of flexibility.

4. TESTING THE MODEL

This section tests the performance of our sub-national model first for a uniform productivity climate shock across the sub-national regions and then for an asymmetric one. In the first case our aim is to verify the robustness of the economic effects for different assumptions on primary factors and goods mobility within the EU. In the second case we want to measure and understand the distributional economic impacts following an asymmetric climate shock.

4.1 SYMMETRIC SHOCK

In this section, we conduct a sensitivity analysis on the Armington elasticities for trade and the CET elasticities for labour and capital mobility at the sub-national level. These two parameters are fundamental drivers of the model results. Moreover, there is limited quantitative support to their econometric estimation. This is a further motivation to justify a sensitivity test.

Our aggregation scheme is the 70 sub-national regions already cited in Table 1 plus rest of the EU and rest of the world. We keep the sectoral aggregation as simple as possible to make easier the computation of the economic general equilibrium. Three sectors are considered:

1) agriculture, forestry and fishing
2) manufactures and extraction
3) services.

The shock is a uniform 20% decrease in the primary factors productivity of all regions: capital, labour, land and natural resources.

We start with the Armington elasticities. Factor mobility is kept at the reference case ($\sigma_{FAC} = 0$) which corresponds to the case of capital and labour immobility at the sub-national level. Then we progressively increase the substitution across products (i.e., the Armington elasticities $\sigma^{IMP}_{r,s}$) within the European Union. The top graph of Figure 3 represents GDP % changes of EU under three different assumptions on products mobility, implemented varying the elasticity of substitution σ^{IMP} of Eq. 13. The formulas below represent, respectively, low, medium and high mobility in the goods market):

arm_1 $\rightarrow \sigma^{IMP}_{r,s} = \sigma^{IMP}\ \forall r,s$
arm_2 $\rightarrow \sigma^{IMP}_{r,s} = 2\sigma^{IMP}\ \forall r,s \in EU$
arm_3 $\rightarrow \sigma^{IMP}_{r,s} = 3\sigma^{IMP}\ \forall r,s \in EU$

They are depicted on the horizontal axis.

In the central part of Figure 3 we modify the value of σ_L, σ_H and σ_K for the primary factors supply (Eqs. 6-11). For sake of simplicity we assume that $\sigma_L = \sigma_H = \sigma_K = \sigma_{FAC}$. Armington elasticity is kept at the reference case, $\sigma^{IMP}_{r,s} = \sigma^{IMP} \forall r,s$. Factor mobility is increased according to the following scheme:

fac_1 $\rightarrow \sigma_{FAC} = 0$
fac_2 $\rightarrow \sigma_{FAC} = -5$
fac_3 $\rightarrow \sigma_{FAC} = -20$

where fac_1 represents no factor mobility case and fac_3 the highest level of factors mobility.

Finally, we look at the interaction between the two components:

armfac_1 → fac_1, arm_1
armfac_2 → fac_2, arm_2
armfac_3 → fac_3, arm_3

Figure 3 clearly shows that results of EU GDP are very stable for all the scenarios considered. Increasing the economic integration in the goods market, labour market and both does not change substantially the results for EU. The regionalized structure of the model is thus robust to productivity shocks at the aggregate level.

From figure 4 we can understand the sub-national economic dynamics. Results for all the sub-national regions are reported in the Table A.1 of the Appendix. A greater substitutability of sub-national products has almost no effect on the GDP of the 70 sub-national regions while a bigger mobility of primary factors (labour and capital) causes a divergence process across the sub-national regions in a range of less than +/- 2%. Interestingly the flexibility in the goods market slightly reduces this range. The fact that the assumptions on primary factors mobility have deeper consequences than assumptions on goods market integration is not very surprising. In fact Armington elasticities can change the distribution of trade across sectors and regions but they cannot affect the stock of capital and labour in the region. Introducing primary factors mobility across the regions makes this possible and has a direct and stronger impact on the regional GDP.

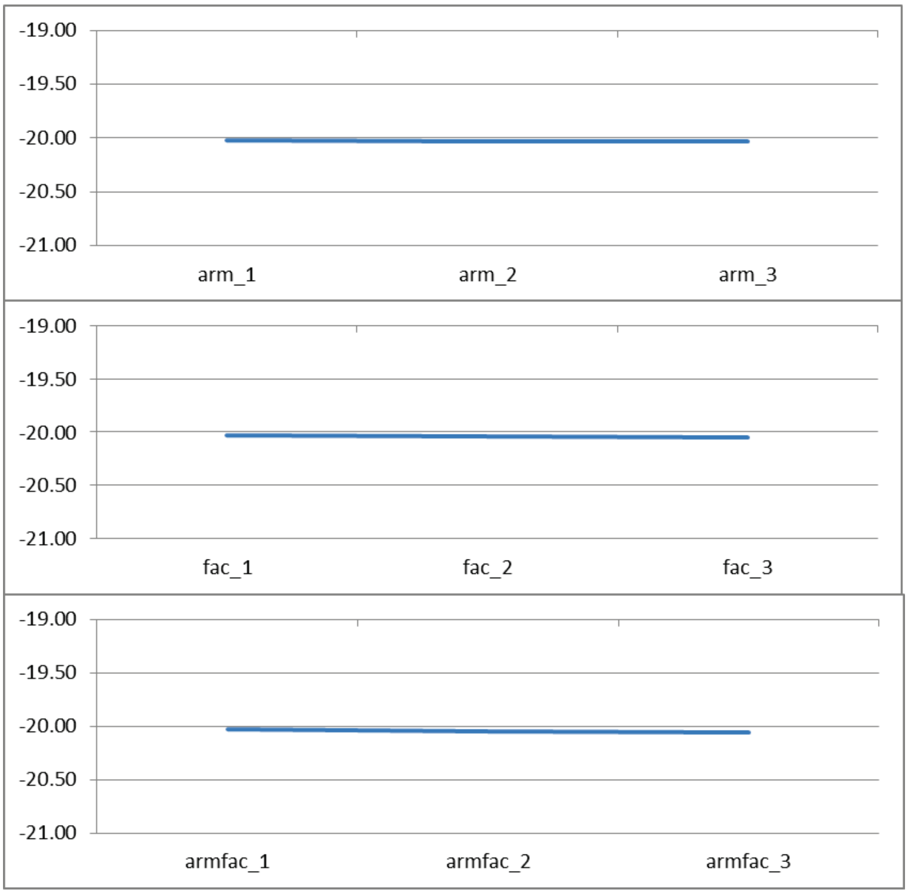

Figure 3: EU real GDP % changes wrt the database (primary factors, Armington and both components)

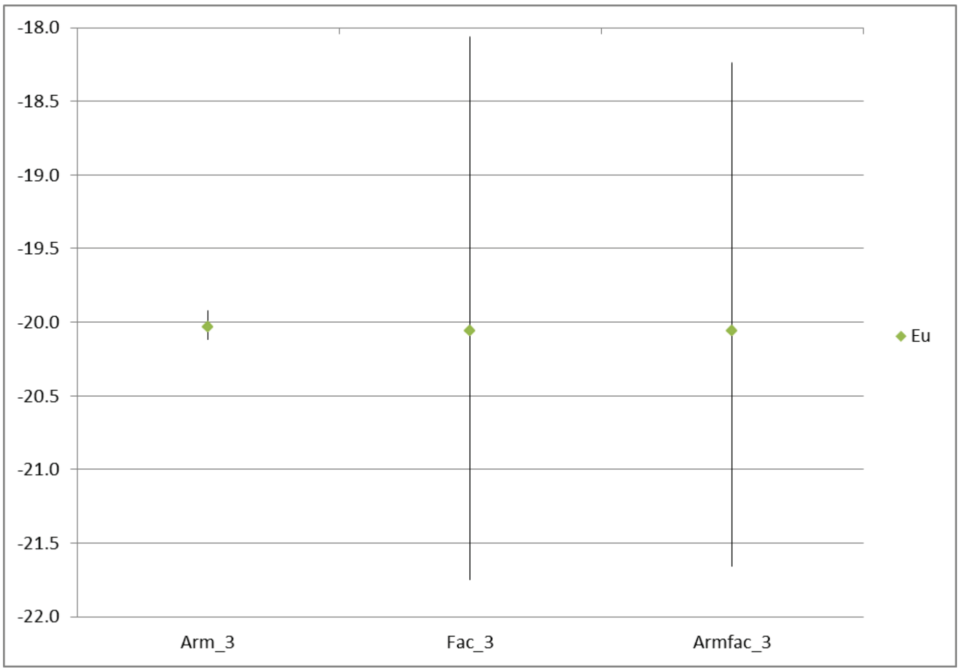

Figure 4: segments representing the lowest and highest GDP % Ch. across the sub-national regions (Armington elasticities , primary factors and both components)

4.2 ASYMMETRIC SHOCK

The above-mentioned dynamics depends also on the type of shock analysed. Affecting uniformly all the primary factors for all the European regions, as we did, is not very realistic for climate change impacts and risk to underestimate the economic potential of labour and capital mobility to re-distribute production and consumption across the sub-country regions.

To test this we impose an asymmetric shock on primary factors productivity. In order to simplify the presentation of the results we take only Portugal (PT) as example for the experiment. A 10% productivity reduction of all primary factors is assumed in the Portuguese Norte region while the other four regions (Algarve, Centro, Lisboa and Alentejo) are not affected. Four scenarios are considered:

1) in the first one labour and capital are immobile at the sub-national level (σ_{FAC} = 0) and Armington elasticities are kept at the reference case ($\sigma_{r,s}^{IMP} = \sigma^{IMP} \forall r,s$).

2) in the second scenario labour and capital are immobile at the sub-national level (σ_{FAC} = 0) and Armington elasticities are doubled compared to the reference case ($\sigma_{r,s}^{IMP} = 2\sigma^{IMP} \forall r,s \in PT$).

3) in the third one labour and capital are mobile within Portugal (σ_{FAC} = -5) and Armington elasticities are kept at the reference case ($\sigma_{r,s}^{IMP} = \sigma^{IMP} \forall r,s$).

4) in the last scenario labour and capital are mobile within Portugal (σ_{FAC} = -5) and Armington elasticities are doubled compared to the reference case ($\sigma_{r,s}^{IMP} = 2\sigma^{IMP} \forall r,s \in PT$).

This also confirms the flexibility of the model in the choice of the regional aggregation and experiment. Results are displayed in Table 4.

Table 4: GDP % Changes wrt database

	1st Scenario: reference	2nd Scenario: bigger products substitution	3rd Scenario: lab/cap mobility	4th Scenario: both components
Norte	-9.86	-9.90	-17.71	-20.46
Algarve	-0.01	0.02	4.69	7.41
Centro	-0.01	0.00	3.86	5.25
Lisboa	-0.03	-0.01	2.91	3.78
Alentejo	0.00	0.03	4.57	6.28
Portugal	-2.89	-2.89	-2.74	-2.69

Also in the case of an asymmetric shock, varying the Armington elasticities does not affect substantially the results (comparison between second and third column in Table 4). However when capital and labour mobility is introduced within Portugal we observe a huge re-allocation of these primary factors across the Portuguese sub-national regions and large GDP changes (fourth column). Results at the aggregate level for Portugal remain stable in all the scenarios. The negative productivity shock in the Norte region reduces the demand for labour and capital because of lower productive capacity and income. This means that remunerations of capital and labour go down and these two factors move towards not affected regions where remunerations are higher. This in turn determines the exacerbation of the looser/winner economic dynamics. Differently from the previous symmetric shock the Armington component amplifies the GDP divergences across regions (fifth column).

5. CONCLUSIONS AND FURTHER RESEARCH

This paper, describes and apply a methodology to develop a sub-national CGE model starting from a global model and database. Eventually a CGE model is built for 70 sub-national regions in the Mediterranean European area. Empirical and theoretical issues are discussed through the paper. The model allows for intra-national trade and factor mobility within each country or EU.

We run a number of simulations to test the robustness of our regionalized structure and understand the potential economic mechanisms behind climate impacts in the context of different levels of market integration. In the case of a symmetric shock on productivity, results for GDP are very stable at the aggregate level for the EU. Diverging patterns of GDP can be observed at the sub-national level when interregional mobility is introduced in the factors market, while different degrees of substitutability in consumption of goods from different sub-national regions play a minor role.

When the shock is asymmetric GDP divergences strongly amplify, exacerbating the winner/looser economic dynamics. Inter-regional factor mobility is crucial in explaining this outcome. Aggregate results for GDP continue to be stable enough.

Further research involves the extension of this first version to the sub-national regions of some African and Asian Mediterranean countries. In particular ongoing work is focusing on three countries: Morocco, Turkey and Egypt. Not surprisingly data constraints become more stringent for countries in the Southern Mediterranean coast.

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APPENDIX

Table A.1: GDP % Changes wrt the database in all scenarios

	arm_1	arm_2	arm_3	fac_1	fac_2	fac_3	armfac_1	armfac_2	armfac_3
Row	-0.06	-0.05	-0.05	-0.06	-0.06	-0.06	-0.06	-0.05	-0.05
REU	-20.02	-20.02	-20.02	-20.02	-20.01	-19.99	-20.02	-19.95	-19.84
Ile de France (France)	-20.09	-20.10	-20.10	-20.09	-19.93	-19.87	-20.09	-20.08	-20.26
Champagne-Ardenne (France)	-20.10	-20.11	-20.12	-20.10	-20.48	-20.63	-20.10	-20.65	-21.28
Picardie (France)	-20.09	-20.10	-20.10	-20.09	-20.36	-20.47	-20.09	-20.50	-20.97
Haute Normandie (France)	-20.03	-20.01	-19.99	-20.03	-19.38	-19.09	-20.03	-19.18	-18.24
Centre (France)	-20.08	-20.09	-20.09	-20.08	-20.17	-20.20	-20.08	-20.35	-20.74
Basse Normandie (France)	-20.07	-20.07	-20.06	-20.07	-19.93	-19.85	-20.07	-19.92	-19.74
Bourgogne (France)	-20.09	-20.10	-20.10	-20.09	-20.28	-20.35	-20.09	-20.44	-20.89
Nord Pas de Calais (France)	-20.07	-20.08	-20.08	-20.07	-20.19	-20.23	-20.07	-20.32	-20.66
Lorraine (France)	-20.08	-20.08	-20.09	-20.08	-20.38	-20.51	-20.08	-20.51	-21.01
Alsace (France)	-20.07	-20.08	-20.09	-20.07	-20.26	-20.34	-20.07	-20.41	-20.86
Franche-Comté (France)	-20.08	-20.09	-20.09	-20.08	-20.44	-20.59	-20.08	-20.56	-21.10
Pays de la Loire (France)	-20.10	-20.11	-20.11	-20.10	-20.18	-20.20	-20.10	-20.32	-20.66
Bretagne (France)	-20.09	-20.11	-20.12	-20.09	-20.08	-20.06	-20.09	-20.33	-20.76
Poitou-Charentes (France)	-20.09	-20.10	-20.11	-20.09	-20.16	-20.17	-20.09	-20.33	-20.72
Aquitaine (France)	-20.08	-20.09	-20.09	-20.08	-20.08	-20.08	-20.08	-20.23	-20.54
Midi-Pyrénées (France)	-20.09	-20.10	-20.11	-20.09	-20.10	-20.09	-20.09	-20.22	-20.49
Limousin (France)	-20.10	-20.11	-20.12	-20.10	-20.28	-20.35	-20.10	-20.47	-20.97
Rhône-Alpes (France)	-20.08	-20.09	-20.09	-20.08	-20.13	-20.13	-20.08	-20.24	-20.49
Auvergne (France)	-20.10	-20.10	-20.11	-20.10	-20.56	-20.75	-20.10	-20.68	-21.29
Languedoc-Roussillon (France)	-20.04	-20.05	-20.05	-20.04	-19.89	-19.82	-20.04	-20.01	-20.10
Provence (France)	-20.06	-20.07	-20.07	-20.06	-19.50	-19.29	-20.06	-19.68	-19.63
Corse (France)	-20.03	-20.07	-20.08	-20.03	-19.00	-18.61	-20.03	-19.33	-19.15
Voreia (Greece)	-20.03	-20.04	-20.04	-20.03	-20.86	-21.25	-20.03	-20.91	-21.50
Kentriki (Greece)	-20.01	-20.01	-20.01	-20.01	-20.83	-21.22	-20.01	-20.82	-21.29
Attiki (Greece)	-19.98	-19.98	-19.98	-19.98	-20.87	-21.25	-19.98	-20.66	-20.86
Nisia (Greece)	-20.06	-20.09	-20.11	-20.06	-19.35	-19.21	-20.06	-19.43	-19.12
Piemonte (Italy)	-20.07	-20.07	-20.07	-20.07	-20.72	-21.10	-20.07	-20.62	-21.05
Valle d'Aosta (Italy)	-20.05	-20.05	-20.05	-20.05	-20.97	-21.49	-20.05	-20.83	-21.40
Lombardia (Italy)	-20.07	-20.07	-20.08	-20.07	-20.72	-21.11	-20.07	-20.65	-21.15
Trentino Alto Adige (Italy)	-20.05	-20.05	-20.06	-20.05	-20.79	-21.20	-20.05	-20.71	-21.23
Veneto (Italy)	-20.07	-20.08	-20.08	-20.07	-20.59	-20.91	-20.07	-20.57	-21.06
Friuli Venezia Giulia (Italy)	-20.05	-20.05	-20.05	-20.05	-21.03	-21.57	-20.05	-20.91	-21.59
Liguria (Italy)	-20.05	-20.05	-20.05	-20.05	-20.53	-20.82	-20.05	-20.40	-20.60
Emilia Romagna (Italy)	-20.05	-20.06	-20.06	-20.05	-20.58	-20.91	-20.05	-20.58	-21.08

	arm_1	arm_2	arm_3	fac_1	fac_2	fac_3	armfac_1	armfac_2	armfac_3
Toscana (Italy)	-20.07	-20.07	-20.07	-20.07	-20.71	-21.08	-20.07	-20.63	-21.09
Umbria (Italy)	-20.05	-20.06	-20.06	-20.05	-20.83	-21.28	-20.05	-20.77	-21.40
Marche (Italy)	-20.07	-20.07	-20.07	-20.07	-20.79	-21.21	-20.07	-20.69	-21.20
Lazio (Italy)	-20.06	-20.05	-20.05	-20.06	-21.21	-21.75	-20.06	-20.96	-21.47
Abruzzo (Italy)	-20.05	-20.06	-20.06	-20.05	-20.74	-21.16	-20.05	-20.69	-21.27
Molise (Italy)	-20.03	-20.03	-20.03	-20.03	-20.86	-21.35	-20.03	-20.77	-21.37
Campania (Italy)	-20.06	-20.06	-20.06	-20.06	-20.98	-21.45	-20.06	-20.82	-21.32
Puglia (Italy)	-20.05	-20.04	-20.04	-20.05	-20.86	-21.29	-20.05	-20.72	-21.18
Basilicata (Italy)	-20.09	-20.10	-20.10	-20.09	-21.01	-21.48	-20.09	-21.01	-21.66
Calabria (Italy)	-20.06	-20.06	-20.05	-20.06	-21.16	-21.68	-20.06	-20.97	-21.48
Sicilia (Italy)	-20.00	-19.98	-19.97	-20.00	-20.62	-20.96	-20.00	-20.30	-20.23
Sardegna (Italy)	-20.04	-20.04	-20.03	-20.04	-20.40	-20.64	-20.04	-20.16	-20.02
Galicia (Spain)	-19.97	-19.98	-19.98	-19.97	-19.12	-18.71	-19.97	-19.42	-19.19
Asturias (Spain)	-19.97	-19.98	-19.99	-19.97	-19.30	-18.92	-19.97	-19.60	-19.51
Cantabria (Spain)	-19.98	-19.98	-19.99	-19.98	-19.19	-18.78	-19.98	-19.47	-19.26
Pais Vasco (Spain)	-19.99	-19.99	-20.00	-19.99	-19.46	-19.12	-19.99	-19.70	-19.58
Navarra (Spain)	-20.00	-20.01	-20.01	-20.00	-19.62	-19.35	-20.00	-19.86	-19.86
La Rioja (Spain)	-19.97	-19.98	-19.99	-19.97	-19.64	-19.41	-19.97	-19.96	-20.18
Aragon (Spain)	-19.98	-20.00	-20.01	-19.98	-18.87	-18.33	-19.98	-19.22	-18.88
Madrid (Spain)	-19.94	-19.95	-19.95	-19.94	-19.02	-18.59	-19.94	-19.28	-18.99
Castilla y León (Spain)	-19.98	-19.99	-20.00	-19.98	-19.26	-18.90	-19.98	-19.57	-19.47
Castilla-La Mancha (Spain)	-19.97	-19.99	-19.99	-19.97	-19.29	-18.92	-19.97	-19.64	-19.63
Extremadura (Spain)	-19.96	-19.98	-20.00	-19.96	-19.12	-18.72	-19.96	-19.48	-19.41
Cataluna (Spain)	-19.97	-19.98	-19.98	-19.97	-19.13	-18.69	-19.97	-19.36	-19.01
Valencia (Spain)	-19.96	-19.97	-19.98	-19.96	-19.05	-18.59	-19.96	-19.37	-19.11
Balears (Spain)	-19.92	-19.94	-19.95	-19.92	-18.62	-18.07	-19.92	-18.95	-18.47
Andalucia (Spain)	-19.95	-19.96	-19.96	-19.95	-18.98	-18.54	-19.95	-19.28	-19.02
Murcia (Spain)	-19.96	-19.97	-19.98	-19.96	-18.98	-18.52	-19.96	-19.32	-19.10
Ceuta (Spain)	-19.94	-19.95	-19.95	-19.94	-19.74	-19.66	-19.94	-19.86	-19.92
Melilla (Spain)	-19.94	-19.95	-19.95	-19.94	-19.53	-19.36	-19.94	-19.72	-19.74
Canarias (Spain)	-19.90	-19.91	-19.92	-19.90	-18.60	-18.06	-19.90	-18.92	-18.48
Norte (Portugal)	-20.00	-20.01	-20.01	-20.00	-20.27	-20.39	-20.00	-20.38	-20.80
Algarve (Portugal)	-20.06	-20.08	-20.08	-20.06	-20.04	-20.05	-20.06	-20.19	-20.44
Centro (Portugal)	-19.99	-20.00	-20.00	-19.99	-19.91	-19.89	-19.99	-20.01	-20.16
Lisboa (Portugal)	-19.98	-19.98	-19.98	-19.98	-20.21	-20.30	-19.98	-20.19	-20.38
Alentejo (Portugal)	-20.03	-20.06	-20.07	-20.03	-19.85	-19.79	-20.03	-20.10	-20.38
EU	-20.03	-20.03	-20.03	-20.03	-20.04	-20.05	-20.03	-20.04	-20.06

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