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Department of Economics

# Working Paper

Wolfgang Britz
Roberto Roson
Martina Sartori

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ISSN: 1827-3580
No. 22/WP/2019

Working Papers
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**Wolfgang Britz**
*Institute for Food and Resource Economics, University of Bonn*

**Roberto Roson**
*Ca' Foscari University of Venice; GREEN Bocconi University Milan; Loyola Andalusia University*

**Martina Sartori**
*European Commission, Joint Research Centre, Seville*

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In this paper we illustrate the development of a modeling framework aimed at producing detailed quantitative estimates for economic variables, consistent with Shared Socio-economic Pathways, and their assumptions about national income and population. Our model not only provides information on industrial production levels, employment, consumption patterns, trade flows and other macroeconomic variables, but disaggregates them further at the sub-national level, for European NUTS2 regions. Estimates are produced by an especially designed dynamic general equilibrium model (G-RDEM), augmented with a regional down-scaling module. The latter takes into account the different sectoral composition of the regional economies, their endowments of primary resources, as well as the possible existence of structural and agglomeration externalities. After describing the methodology, the paper presents an illustrative sample of results produced by the model, focusing on Italian regions and the Shared Socio-economic Pathway 1 in the period 2011-2051.

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Shared Socio-economic Pathways, Regional Economic Growth, Dynamic General Equilibrium Models, Computable General Equilibrium Models, Long-run Economic Scenarios, Structural Change, Economic Growth, Italy

**JEL Codes**
C68, C82, C88, D58, E17, F43, O11, O40

*Address for correspondence*:
**Roberto Roson**
Department of Economics
Ca' Foscari University of Venice
Cannaregio 873, Fondamenta S.Giobbe
30121 Venezia - Italy
e-mail: roson@unive.it



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wp.dse@unive.it

Department of Economics
Ca' Foscari University of Venice
Cannaregio 873, Fondamenta San Giobbe
30121 Venice Italy
Fax: ++39 041 2349210

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In this paper we illustrate the development of a modeling framework aimed at producing detailed quantitative estimates for economic variables, consistent with Shared Socio-economic Pathways, and their assumptions about national income and population. Our model not only provides information on industrial production levels, employment, consumption patterns, trade flows and other macroeconomic variables, but disaggregates them further at the sub-national level, for European NUTS2 regions. Estimates are produced by an especially designed dynamic general equilibrium model (G-RDEM), augmented with a regional down-scaling module. The latter takes into account the different sectoral composition of the regional economies, their endowments of primary resources, as well as the possible existence of structural and agglomeration externalities. After describing the methodology, the paper presents an illustrative sample of results produced by the model, focusing on Italian regions and the Shared Socio-economic Pathway 1 in the period 2011-2051.

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*Institute for Food and Resource Economics, University of Bonn. E-mail: wolfgang.britz@ilr.uni-bonn.de.

†Ca' Foscari University Venice, GREEN Bocconi University Milan and Loyola Andalusia University. E-mail: roson@unive.it.

‡European Commission, Joint Research Centre, Seville. E-mail: martina.sartori@ec.europa.eu

# 1 Introduction

Starting from the 5th Assessment Report (Pachauri et al., 2014), the Intergovernmental Panel of Climate Change (IPCC) has promoted the constructions of two separate groups of scenarios for the analysis of climate change impacts and policies: Representative Concentration Paths (RCP), which are based on physical GHGs concentration targets (Van Vuuren et al., 2014), and Shared Socio-economic Pathways (SSP), which specifically defines assumptions of development in terms of GDP, demographic structure, education and urbanization rates (Riahi et al., 2017). SSP scenarios are increasingly being adopted not only in the context of climate change, but in a variety of other research fields, requiring an extended time perspective, for instance in contrasting economic growth and availability of natural resources, like water (Roson and Damania, 2017), or assessing the future risk of hunger (Hasegawa et al., 2015), land-use patterns (Popp et al., 2017), civil conflicts (Hegre et al., 2016).

The SSPs are based on five narratives describing broad socioeconomic trends that are intended to span the range of plausible futures. They include: a world of sustainability-focused growth and equality (SSP1); a "middle of the road" world where trends broadly follow their historical patterns (SSP2); a fragmented world of "resurgent nationalism" (SSP3); a world of ever-increasing inequality (SSP4); and a world of rapid and unconstrained growth in economic output and energy use (SSP5). The various scenarios are differentiated with respect to two main dimensions: "socio-economic challenges" (adaptation) and "environmental challenges" (mitigation).

To translate these qualitative storylines into quantitative information, to be possibly used in subsequent numerical analyses, some quantitative models are employed under assumptions broadly consistent with the narratives. For instance, Dellink et al. (2017) describe how the OECD ENV-Growth model was used to derive (per capita) GDP projections on a country basis. The methodology is based on a convergence process and places emphasis on some key drivers of economic growth in the long run: population, total factor productivity, physical capital, employment and human capital, and energy and fossil fuel resources (specifically oil and gas).

A data repository is maintained at the International Institute for Applied Systems Analysis (IIASA)[1], containing baseline information, for each SSP and country (until 2100), about: population structure, urbanization rates, and GDP (three estimates generated by different models). Furthermore, an effort was undertaken to feed a set of Integrated Assessment Models[2] with these data, to get additional information about energy, land use, and greenhouse gas emissions (Riahi et al., 2017). The quantitative translation of the qualitative narratives, however, is still insufficient in terms of scale for many policy and impact assessment applications. For instance, estimates about the structural composition of an economy would be needed, in addition to just the average per capita GDP, when assessing the potential future pressure on natural resources. Also, when

[1] http://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about#v2

[2] Specifically: AIM, IMAGE, MESSAGE-GLOBIOM, REMIND, WITCH and GCAM.

analyses are undertaken at sub-national level, nation-wide macroeconomic forecasts may be of little help to shape a scenario for the regional economies.

Two main strategies are being employed when more spatial (and possibly sectoral) detail is required. One strategy focuses on the qualitative side and essentially aims at constructing SSP-consistent regional narratives, through a systematic process of involvement of experts, policy makers and stakeholders (Absar and Preston, 2015; Nilsson et al., 2017). Of course, this methodology is not designed to generate quantitative estimates, although it could be viewed as a preliminary step in this direction. The second strategy is based on forcing results from a detailed macro model, which is often a Computable General Equilibrium one (Fujimori et al., 2017). For instance, GDP levels are imposed from the outside and the model is allowed to endogenously compute parameters, like productivity factors, that will bring about the given GDP target. In this respect, CGE or similar models are employed as "multipliers of scenario variables", since they identify a hypothetical market equilibrium and thus can specify production volumes, trade flows and many other macroeconomic variables.

However, this second approach suffers from two main deficiencies. The first one is that CGE and similar models were not conceived and designed for economic analysis in the medium and long run. Rather, they were intended for short-term policy assessment, like simulating the effects of a fiscal reform, or the implementation of a trade agreement. This explains why most parameters are usually "calibrated" to a relatively recent Social Accounting Matrix (or Input Output Table), such that the observed structure of an economic system is taken as a benchmark, from which counterfactual experiments are conducted. But, of course, when the economy is analyzed at a longer time horizon, the current economic structure, as estimated from some past national accounts, is no more a valid reference.

To overcome this disadvantage, a special type of CGE model, named G-RDEM, has been developed. The G-RDEM model, which is briefly described in Section 2, was specifically designed for the generation of long run scenarios of economic development. It is intended to capture processes of structural adjustment like the changing composition of consumption at higher income levels, the impact of demographic structure on savings rates, and other effects.

Even with these special features, however, the employment of a macroeconomic model like G-RDEM is constrained by the fact that its parameters are estimated on the basis of official national economic accounts. As such, its typical spatial scale is national, and the temporal scale is yearly. If a finer resolution is needed, the macroeconomic model should be used in conjunction with a downscaling module or interfaced with an external model.

This paper describes and discusses how most output variables from G-RDEM can be regionally disaggregated for the European NUTS2 regions (Nomenclature of Territorial Units for Statistics by Eurostat, layer 2). Some economic information for these European regions is available from Eurostat[3], and it is combined with national data in the model. Our methodology is aimed at capturing pos-

[3]http://ec.europa.eu/eurostat/web/regions-and-cities

sible divergences between regional and national economic growth paths, which could be due to differences in the sectoral composition, as well as to specific peculiarities of the regional economies, like agglomeration externalities.

The paper is organized as follows. The next section briefly describes the G-RDEM model and its peculiar characteristics. Section 3 illustrates the regional downscaling module, which is based on a specification of the regional production structure and an econometric estimation of the regional productivity bias. The spatially disaggregated G-RDEM provides a very large amount of data, so that a detailed illustration of all scenario variables would not be feasible here,[4] and likely not even useful. However, we do provide in Section 4 an illustrative sample of results produced by the model, focusing on Italian regions and the Shared Socio-economic Pathway 1 in the period 2011-2051. A final section concludes.

## 2 G-RDEM: a dynamic general equilibrium model for the definition of long-run economic scenarios

G-RDEM is a computable general equilibrium model, designed for the construction of internally consistent and sufficiently detailed scenarios of long-run economic development (Britz and Roson, 2019). The model is a recursive dynamic extension of the GTAP standard comparative static model, with the inclusion of five distinguishing features, meant to capture some key adjustment processes in the long run.

The structure of the GTAP model is fully described in Hertel and Tsigas (1997), although some minor changes have been introduced recently (Itakura and Hertel, 2001; Corong et al., 2017). Most basic assumptions in the model are canonical for a general equilibrium setting: industries are modeled through representative, cost-minimizing firms with constant returns to scale and zero profits; households maximize utility under a budget constraint; revenues are obtained by selling services of primary factors; all macroeconomic identities hold, etc.

Some other assumptions are less common, in particular:

- Utility of the representative household is implicitly defined as a Constant Differences in Elasticity (CDE) function (Hanoch, 1975). This function allows for (rather limited) differences in income elasticities among consumed goods and services.

- Aggregate savings are a constant share of national income. Savings are virtually collected by a global bank and redistributed as physical investments, without the need to match national savings to investments, therefore to have the trade balance in equilibrium.

[4] More detailed information is available on request.

- Trade and transport margins in international commerce are handled similarly, by means of virtual global transport and trade agents.

Although a dynamic variant of the GTAP model does exist (Ianchovichina and Walmsley, 2012), the simplest way of making the model dynamic is by framing it as a chain of temporal general equilibria. This can be simply done by making the (exogenous) capital stock at time $t$ dependent on (endogenous) investments at time *t-1*. When there is no intertemporal optimization, this approach is often termed "recursive dynamics". In general, that extension alone will not generate a realistic path of economic growth.[5] This is why the usual methodology for the calibration of this kind of models entails the generation of a "baseline" path, obtained by imposing GDP levels at each period (obtained, e.g., by a macroeconometric model or by a given scenario), while making endogenous some productivity parameter. Counterfactual simulations are then obtained by setting the resulting productivity parameter back to exogenous, while over-imposing shocks, possibly time-dependent, to other parameters. This means that the model dynamics is partly endogenous (capital accumulation) and partly exogenous (productivity growth).

G-RDEM introduces five additional features into the recursive system:

1. The GTAP CDE utility function is replaced by an AIDADS demand system.[6] The AIDADS is An Implicit, Directly Additive Demand System (Rimmer and Powell, 1992). It can be understood as a generalization of a Linear Expenditure System, where marginal budget shares are not fixed, but are a combination of two vectors, depicting the budget structure at very low and very high utility (income) levels. The reason for replacing CDE with AIDADS is that the latter can account for more effects driven by differences in income elasticity, which is important when variations in per-capita income are large, as it is typically the case in the long run.

2. Total factor productivity is allowed not to vary uniformly among industries and sectors. Indeed, differential productivity growth is one key factor of structural change in the economic systems, and probably the most important one (Swiecki, 2017). In G-RDEM, a function of the GDP growth rate is used, expressing the variation of productivity in Agriculture and Manufacturing relative to the one in the Services. The latter is endogenously computed during the generation of the baseline dynamic path, to get consistency with the imposed trajectory of growth.

3. The national, aggregate saving rate (marginal propensity to save out of the national income) can change over time, mainly as a consequence of variations in the demographic structure. The saving rate is expressed as

[5] There are several reasons for this. One reason, for example, is the assumption of exactly one year lag for the transformation of investments in fresh new capital, which may not hold in the real world.

[6] The parameters of the demand system has been estimated in a cross-sectional analysis by Roson and van der Mensbrugghe (2018); Britz and Roson (2019), based on global data by the International Comparison Network (ICP).

a function of: (a) Population composition by age group; (b) per capita GDP growth and its growth. Parameters for this relationship have been estimated through a cross-section econometric regression.

4. Interest payments on cumulated past foreign debt are considered in the model. To this end, an equation is introduced, which computes the debt stock.[7] The given interest payments on the stock of foreign debt enter the equation defining the regional income, in addition to the factor and tax income. They are positive for a country which was in the past a lender and negative for past debtors.

5. Parameters of the production function, applied to the representative firm in each regional industry, are calibrated on the observed cost structures of the base year SAM, but in G-RDEM they are allowed to vary. This is because, as the economy grows, the average industrial cost structure may vary even if the production technologies for individual goods stay the same. The relevance of the composition effect is a purely empirical question, which is addressed in the model by checking for the existence of a relationship between cost shares and an index of per-capita income[8]. It is found that, out of the 65 input-output coefficients with a cost share of at least 1%, more than 40 turn out to have a highly significant relation with per capita income. The estimates have therefore been introduced in G-RDEM as functions, updating input-output coefficients (parameters of the industrial production functions), from one time period to the next.

# 3 Introducing sub-national economic systems into the G-RDEM model

The estimation of structural parameters in a Computable General Equilibrium model is usually obtained through a calibration process based on a Social Accounting Matrix (SAM). A SAM, which provides a detailed picture of income flows among sectors of an economy (consistent with national accounts) is very expensive to produce, and for this reason it is not generally constructed at the regional level. However, some regional economic data are available, such as employment levels, value added, industrial output volumes. These data are collected and published in Europe by Eurostat.

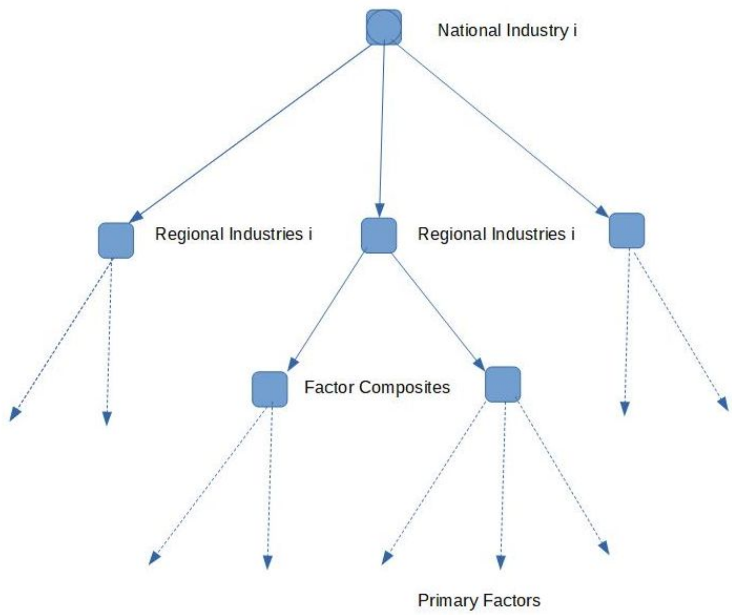
Therefore, to get regional detail in the G-RDEM model, we devise a strategy to exploit the available information without transforming the model into a full-fledged multi-regional CGE.[9] The strategy involves a disaggregation of its supply side, keeping single national components for the final demand, such as household consumption, investments, public expenditure and foreign trade. As

[7] This is usually assumed to be zero in the starting year.

[8] Economies are not closed in our system. Therefore, the index was built though trade weighted aggregation of per-capita incomes.

[9] Actually, the model is a multi-regional one in the sense that regions are countries or aggregations of countries, but not in the sense of explicitly considering sub-national economies.

Figure 1: CES Tree structure in the industrial production function




it is usual in most CGE models, the production function of each representative industrial firm is modeled as a series of nested CES[10] functions. As graphically depicted in Figure 1, we add an additional layer of substitution between regional variants inside the production function of the national composite output of each industry. By doing this, we apply at the regional level the so-called "Armington assumption", which postulates that goods produced in different countries, even when belonging to the same product category, are imperfect substitutes in international trade.[11]

The cost structures, or shares of employed production factors, can be different for the same industry in the various regions. More importantly, endowments of primary resources (labor, capital, land, natural resources) vary, according to regional economic data. Differences in resources drive relative prices and define a sort of comparative advantage at the regional level.

The general equilibrium system expresses a demand for the national goods and services. This demand is allocated down to the regional industries on the basis of their relative competitiveness. Since regional income can be defined as the sum of value added of all regional industries, the model generates income

[10]Constant Elasticity of Substitution: relative factor shares depend on relative factor prices, on the basis of a constant elasticity parameter, assigned to each nest.

[11]For instance, in the standard GTAP model, there are two CES nests in the demand: domestic products are imperfect substitutes with imports, while imports are a composite aggregate of goods of different foreign origin.

differentials: regions with a higher incidence of fast-growing industries will grow more, and vice versa.

Some early tests with this model specification have revealed that the mechanism is insufficient to fully capture the regional income dynamics, though.[12] Indeed, there could be other factors explaining income differentials among regions: agglomeration externalities, external economies (or dis-economies) of scale, inter-industrial knowledge and productivity spill-overs, etc. To account for these additional factors, we follow a modeling strategy akin to the one we used for sectoral productivity growth: we introduced an endogenous total factor productivity shifter at the regional level.

Parameters for the functional relationship defining values for the regional tfp shifters have been estimated econometrically. More precisely, we used a multiple linear regression, based on an unbalanced panel, to explain the ratio between regional and national income per capita. To increase the number of observations, we used data at the finer geographical scale NUTS3 for the years 2000-2016, as available from Eurostat, in total around 24.000 observations. The explanatory variables are Gross Value Added (GVA) shares for sectoral aggregates, their squares, their ratio to the national average share, regional population and its square, as well as the difference between the regional and national population growth rate. An AIC based model selection process (backward and forward) was used to filter out insignificant variables.

Estimates are presented in Table 1. As expected, population growth and density are associated with relatively higher income per capita, although the relationship should be interpreted in terms of correlation, rather than causation. Scenario data provide estimates of population only at the country level. To get regional population, we employ forecasts produced by Eurostat for the year 2050 which, however, do not refer to any SSP scenario and are therefore used here only as regional split factors, applied to the national totals. However, regional population forecasts discount hypotheses of internal migration, which is also driven by income differentials. The inclusion of a productivity shifter based on parameters of Table 1, therefore, ensures some degree of consistency between income and population estimates, by considering the existing correlation.

Interpreting the role of the sectoral composition of the regional economy is somewhat more difficult, because industry shares appear as regressors not only in levels, but also as squares and relative to the corresponding national aggregate. For a better reading of the estimates, we simulated the impact on relative income of a marginal increase in any of the shares, compensated by a reduction in the other ones, to ensures that all shares keep adding up to unity. Results are shown in Table 2, differentiated by country.

[12] When comparing regions in different countries, we noticed that regions belonging to the same nation tend to "move together", as a consequence of the common drivers of national demand.

Table 1: Regression results

| VARIABLE DESCRIPTION | VARIABLE NAME | COEFFICIENT | STD. ERROR |
|---|---|---|---|
| Difference between the regional and national population growth rate | Population | 0.006 | (0.00)** |
| and regional population density | Density | 0.066 | (0.00)*** |
| | Density_sqr | -0.001 | (0.00)*** |
| GVA share of agriculture | Agric | -1.316 | (0.07)*** |
| GVA share of extraction, electricity, gas and water production and distribution | Extr_El_Gas_Water | 0.160 | (0.06)** |
| GVA share of manufacture | Manuf | -1.958 | (0.10)*** |
| | Manuf_sqr | 3.583 | (0.14)*** |
| | Manuf_rel | 0.031 | (0.01)*** |
| GVA share of Information and communication | Commun. | 2.030 | (0.48)*** |
| | Commun_sqr | 12.471 | (1.72)*** |
| | Commun_rel | -0.108 | (0.02)*** |
| GVA share of construction | Constr | -5.173 | (0.27)*** |
| | Constr_sqr | 30.442 | (1.39)*** |
| | Constr_rel | -0.181 | (0.01)*** |
| GVA share of public administration and defence, social security, education | Pub.Services | -2.727 | (0.18)*** |
| | Pub.Services_sqr | 4.231 | (0.31)*** |
| | Pub.Services_rel | -0.252 | (0.02)*** |
| GVA share of financial, insurance, professional, scientific, technical | Prof.Services | -4.792 | (0.19)*** |
| and administrative activities | Prof.Services_sqr | 17.198 | (0.42)*** |
| | Prof.Services_rel | 0.381 | (0.01)*** |
| GVA share of wholesale and retail trade, accommodation and food services | Trade | 0.363 | (0.09)*** |
| | Trade_rel | -0.096 | (0.02)*** |
| Intercept | Constant | 2.018 | (0.05)*** |

We can notice that regions having higher shares of value added in the Communication as well as in Financial, Insurance, Professional, Scientific, Technical and Administrative Services (which are more diffused in urbanized areas) are generally richer. A positive role is also played by Construction, but in this case we are inclined to interpret our findings in terms of reverse causation: dynamic regions attract investments, which stimulates growth in this industry.[13] On the other hand, lagging regions are typically associated with higher shares of Agriculture, Extraction, Public Services and Trade.

Our results appear to be broadly consistent with the literature. For instance, Melitz (2005) revisits the case for infant industry protection when the industry is competitive and experiences dynamic learning effects that are external to firms (as it could be the case for Communication and Technical Services). Inter-sectoral spill-overs and externalities have been studied, among others, by Gemmell et al. (2000), Naito and Ohdoi (2008), Antonelli and Gehringer (2015). Agglomeration (density) externalities are at the core of the "new economic geography" and theories of regional economic growth (Morrison Paul and Siegel, 1999; De Groot et al., 2009; Mariotti et al., 2010; Marrocu et al., 2013). Recently, Bustos et al. (2019) develop a model and test it empirically, to show that industrial composition matters for the regional economic growth, and any shock changing the sectoral structure (e.g., technological improvements in agriculture) can affect the development process.

Parameter values of Table 2 are used in the model to identify a function, which drives a regional parameter of total factor productivity, on the basis of the (endogenous) industrial shares and population projections. The introduction of such a shifter makes the regional paths of economic growth more differentiated.

## 4 Illustrative results

We ran the G-RDEM model to produce detailed results for all European NUTS2 and all SSPs in the period 2011-2051. Of course, the generated datasets are very large, as they include information about trade flows, industrial output, consumption patterns and many other macroeconomic variables, by region, SSP and year. To show what can be achieved from the model, we focus here only on the SSP1 scenario and some Italian regions.

First, consider what is possibly the most relevant variable in terms of economic development: the per-capita Gross Domestic Product (GDP). Figure 2 maps GDP per capita for the 20 Italian NUTS regions in the years 2011 (t00), 2031 (t20) and 2051 (t40). The map of the initial period highlights the well known income imbalance between Northern and Southern regions. In the final period t40, however, we can see a somewhat more homogeneous picture, where lagging regions partly succeed to catch up (with some notable cases, like Sardinia).

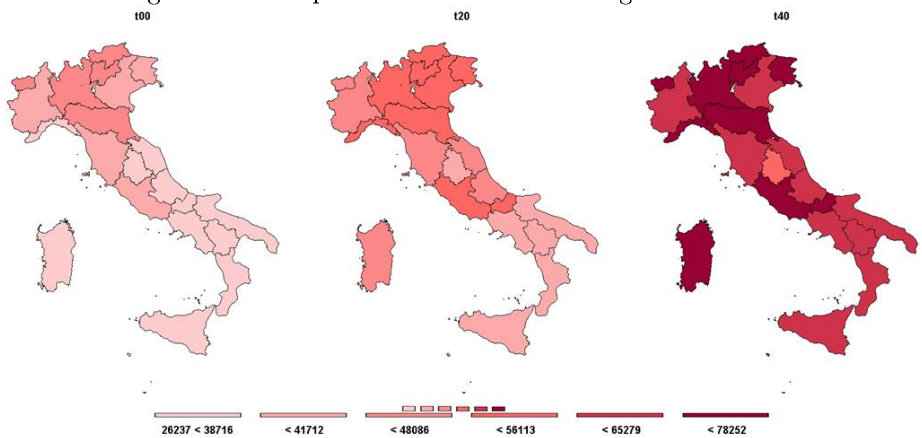
What are the key drivers of this convergence process? Of course, per capita GDP is a ratio: sustained growth takes place when regional GDP increases at

[13] As explained for the case of population, correlation matters, not causation, in this context.

Table 2: Simulated impact on regional income of a change in sectoral share

| Country | Agric. | EEGW | Manuf. | Comm. | Constr. | Pub.Ser | Prof.Ser | Trade |
|---|---|---|---|---|---|---|---|---|
| Austria | -4.45 | -2.95 | -0.99 | 8.53 | 20.71 | -2.80 | 18.39 | -3.17 |
| Belgium | -4.60 | -3.11 | -1.17 | 9.17 | 20.11 | -2.72 | 16.34 | -3.41 |
| Bulgaria | -5.06 | -3.50 | -1.56 | 9.48 | 20.19 | -3.85 | 14.80 | -3.81 |
| Cyprus | -5.12 | -3.60 | -1.44 | 8.09 | 20.45 | -3.07 | 14.18 | -3.81 |
| Czech R. | -4.71 | -3.19 | -1.18 | 9.69 | 20.36 | -3.31 | 18.22 | -3.55 |
| Germany | -4.15 | -2.66 | -0.66 | 9.90 | 19.26 | -2.40 | 19.59 | -3.10 |
| Denmark | -4.35 | -2.85 | -0.92 | 9.71 | 19.34 | -2.30 | 16.95 | -3.17 |
| Greece | -4.65 | -3.11 | -1.17 | 9.71 | 20.90 | -3.26 | 19.86 | -3.36 |
| Estonia | -3.69 | -2.17 | -0.19 | 9.48 | 18.43 | -1.66 | 19.06 | -2.37 |
| Spain | -4.79 | -3.28 | -1.34 | 9.10 | 21.15 | -2.95 | 19.03 | -3.51 |
| Finland | -4.51 | -3.00 | -1.04 | 9.82 | 20.72 | -2.57 | 24.19 | -3.41 |
| France | -4.54 | -3.03 | -1.09 | 9.82 | 20.47 | -2.55 | 19.05 | -3.40 |
| Croatia | -4.81 | -3.26 | -1.33 | 9.33 | 20.29 | -3.29 | 15.58 | -3.56 |
| Hungary | -4.21 | -2.66 | -0.68 | 10.28 | 18.89 | -2.56 | 18.56 | -3.03 |
| Ireland | -4.73 | -3.23 | -1.22 | 11.05 | 11.21 | -3.12 | 14.54 | -3.66 |
| Italy | -4.43 | -2.92 | -0.98 | 9.34 | 20.18 | -2.70 | 17.48 | -3.22 |
| Lithuania | -4.20 | -2.67 | -0.70 | 8.54 | 21.08 | -2.87 | 24.58 | -2.76 |
| Luxemb. | -7.09 | -5.61 | -3.47 | 7.86 | 17.41 | -5.73 | 11.73 | -5.95 |
| Latvia | -4.32 | -2.79 | -0.85 | 9.58 | 20.61 | -2.81 | 19.79 | -2.94 |
| Malta | -4.85 | -3.35 | -1.41 | 10.03 | 18.96 | -2.75 | 15.20 | -3.61 |
| Netherl. | -4.73 | -3.23 | -1.29 | 9.45 | 19.56 | -2.82 | 15.19 | -3.54 |
| Norway | -4.03 | -2.48 | -0.51 | 9.38 | 20.43 | -2.25 | 20.61 | -3.06 |
| Poland | -5.00 | -3.47 | -1.51 | 8.18 | 21.51 | -3.60 | 18.32 | -3.66 |
| Portugal | -4.55 | -3.04 | -1.10 | 8.82 | 19.98 | -2.65 | 15.89 | -3.26 |
| Romania | -4.65 | -3.07 | -1.02 | 9.24 | 21.12 | -3.34 | 22.08 | -3.85 |
| Sweden | -4.57 | -3.07 | -1.12 | 9.98 | 20.18 | -2.69 | 19.39 | -3.44 |
| Slovenia | -4.53 | -3.02 | -1.04 | 9.16 | 20.31 | -2.86 | 17.66 | -3.32 |
| Slovakia | -5.20 | -3.67 | -1.70 | 8.76 | 21.48 | -3.79 | 18.55 | -3.94 |
| U.King. | -5.00 | -3.51 | -1.55 | 9.80 | 19.80 | -3.14 | 14.95 | -3.89 |

Figure 2: Per-capita GDP in the Italian regions 2011-2051




a faster rate than regional population. To see this in a clearer way, Figure 3 presents the population growth rates at the middle (t20) and at the end (t40) of the time period considered.

By comparing Figure 2 with Figure 3 we can easily see that most of the convergence process is determined by changes in the relative population growth rates: most Southern regions catch up not because of a strong economic growth, but because in our scenario they are supposed to relatively lose population.

However, it should be stressed that we do not possess SSP-specific projections of regional population, whereas information on national population is available in the qualtivative characterization of Shared Socio-economic Pathways. We therefore apply regional shares of national population, varying by year but not by SSP.[14]

To see how the productive structure of the regional economies varies over time, we consider in the following three "representative" regions: Lombardy (Milan) in the North, Lazio (Rome) in the Centre and Sicily (Palermo) in the South. Lombardy is the largest and most developed regional economy in Italy. Although the Services sector now covers 59% of the regional value added, Manufacturing still plays an important role (28%). Lazio, where the capital Rome is located, has an economy where Services (mainly Public Administration and Tourism) is the dominant sector. Sicily has a similar share for Services (again mainly Public Administration and Tourism), but a much larger share than the other two regions in Agriculture (8%).

In our model, regions may grow at different speeds because the various industries do: dynamic regional economies are those where the weight of fastest growing industries is larger. At the same time, as explained in the previous section, the structural composition affects the regional total factor productivity

[14]These regional shares have been estimated through elaboration of Eurostat projections (Eurostat Regional Yearbook, 2016 edition, chapter 14).

Figure 3: Regional population growth rates (2031 and 2051)

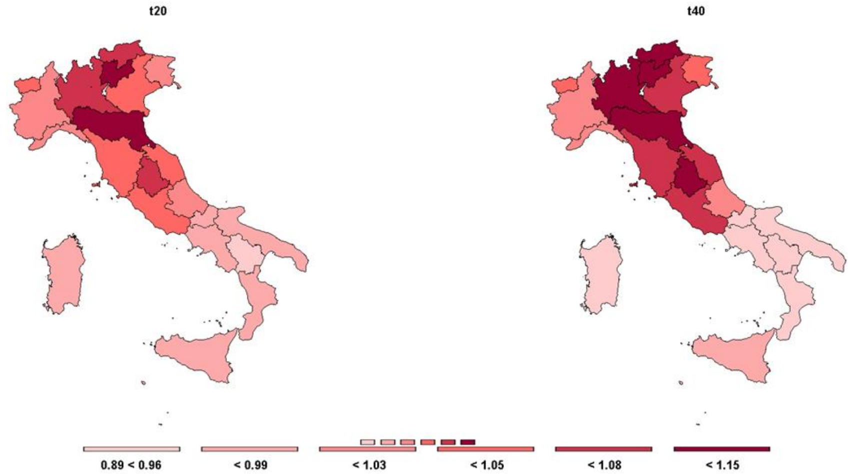



Figure 4: Productive structure of the three regional economies in the base year 2011

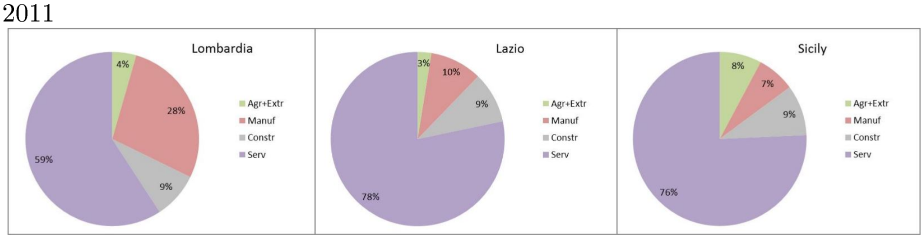


Figure 5: Agricultural share of value added over time, by region

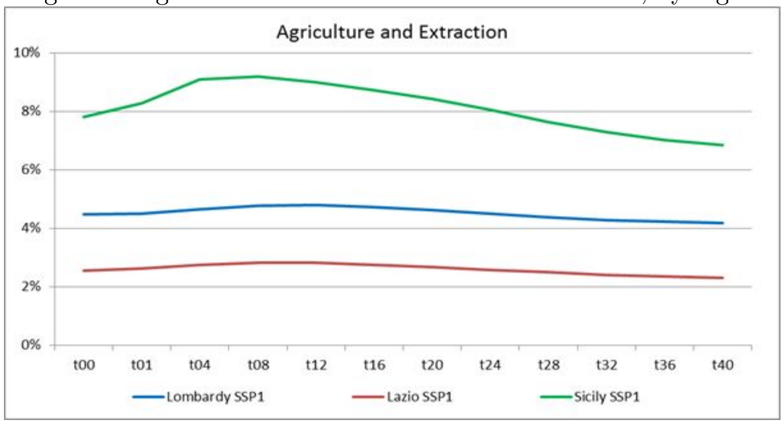
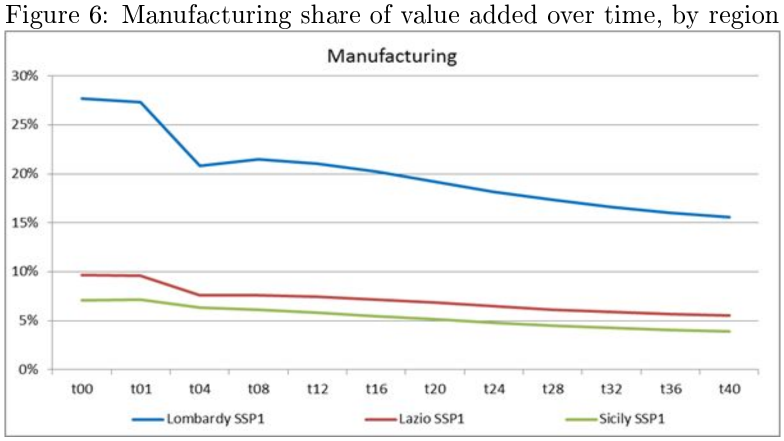



Figure 6: Manufacturing share of value added over time, by region




shifter. Therefore, it is important to analyze how the four aggregate sectors considered here evolve over time.

Figure 5 displays the time evolution of the agricultural (and mining, extraction, etc.) share of value added in the three regions. The share, after a slight increment in the first year, is gradually reduced, the more significantly so in Sicily, where the share was initially highest.

Figure 6 depicts the corresponding evolution in the share of Manufacturing. Even in this case, the three regional shares get closer over time, and the decline is most significant where the share Manufacturing was initially highest (that is, in Lombardy).

Figure 7 shows the case of the Construction industry. Contrary to the previous two sectors, the initial regional shares are here quite similar, and around 9%. The plot highlights that, after some periods of decline, the shares stabilize, actually with a minimal divergence and the lowest value in Sicily.

Figure 7: Construction share of value added over time, by region

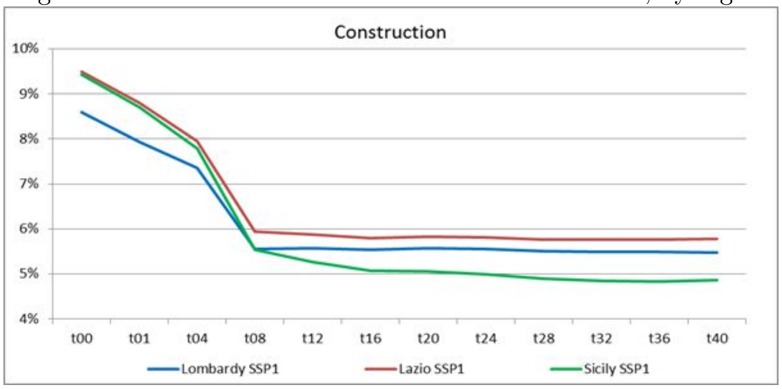
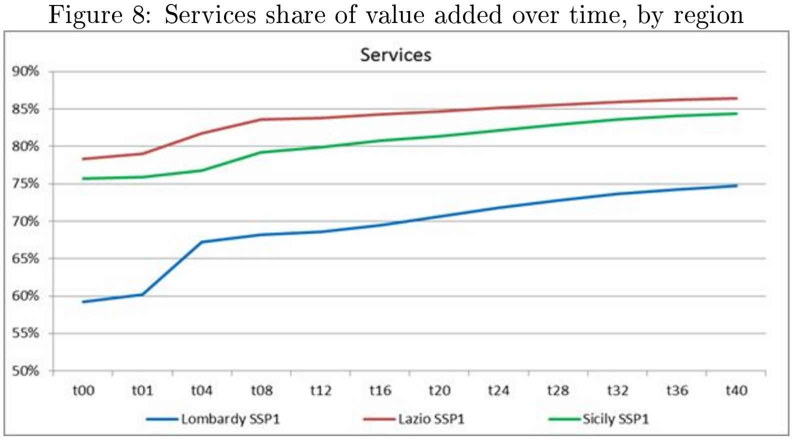


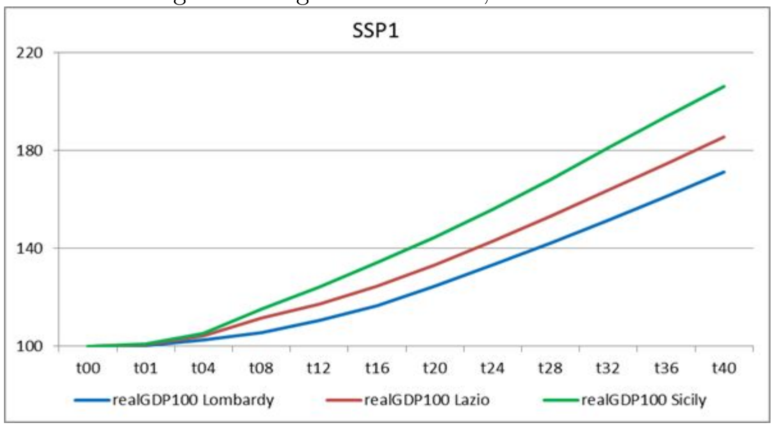

Figure 8: Services share of value added over time, by region




Perhaps the most relevant phenomenon is the rise of the Services economy in the three regions, as displayed in Figure 8. All shares are increasing and slightly converging. Of course, Services is a broad sector, and an aggregated picture like this one may hide important differences. For instance, services in Sicily could be dominated by tourism, whereas in Lombardy the biggest component could possibly be professional or financial services. These differences may have implications in terms of regional growth and intersectoral externalities.

Nonetheless, the four figures combined together suggest that our model is generating a scenario where, in the future, the three regional economies get "structurally more similar". Since we are assuming that total factor productivity depends on the composition of the regional economy, this implies that productivity shifters would also get closer over time. Indeed, this is confirmed by Figure 9, showing the time evolution of real GDP in the three regions, with initial values normalized to 100. Sicily is the lagging region. However, as its economy becomes structurally a little more similar to the one of the leading

Figure 9: Regional real GDP, normalized




Lombardy, even the productivity gap is narrowed.

Therefore, the income per capita convergence highlighted in Figure 2 cannot be only attributed to variations in regional population, although the latter may still remain the dominant driver.

# 5 Conclusion

This paper has introduced a methodology and a model, capable of downscaling Shared Socio-economic Scenarios, in terms of macroeconomic variables, at the level of single industries and sub-national regions. Such a tool is much needed in a variety of different contexts, where aggregated information on national GDP and population (or urbanization rates, etc.) is just insufficient. On the other hand, as SSP are increasingly being used in fields other than climate change, so it increases the demand for more detail in the definition of scenario variables.

By way of illustration, we briefly presented a sample of results, focusing on SSP1 and Italian regions. Of course, a discussion about the realism of the scenario, as well as about the dynamics of regional convergence, is much beyond the scope of this work. We can therefore leave it, as it is usual to say in these cases, to future research.

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