Regional economic resilience in the European Union: a CGE analysis

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Abstract. We analyse regional economic resilience in the European Union using a numerical general equilibrium model. We study the various aspects of resilience identified by the recent literature on the subject: vulnerability, resistance, robustness, and recoverability. We simulate three different types of shocks and we look at the GDP and employment impacts. Then, we investigate the recovery in order to look at how the European regions adapt and adjust post-negative shocks. We find and highlight significant and interesting differences among the regional responses as well as among the various types of shocks.

Keywords: CGE modelling, regional economic resilience, policy analysis

JEL codes: C68, R13

Disclaimer: The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.
1. Introduction

Regional economic resilience is a term used to broadly describe how regional economies respond to undesired external disturbances. Essentially, the notion of regional resilience emphasises the ability of regions to resist and recover from shocks. It has recently gained popularity among both academics (see for example Fingleton et al. 2015) and policy makers (Šucha et al., 2015, Alessi et al. 2018). Despite the attention drawn to the topic, there is no unique definition of economic resilience in the context of regions (Christopherson, S. et al., 2010). Rather, the concept has been expanded and analysed along a number of dimensions including the following, (see Martin and Sunley, 2015, and Giannakis and Bruggeman, 2017): vulnerability (sensitivity to different types of shocks), resistance (sensitivity to economic shock impacts), robustness/structural reorientation (how firms, workers, and institutions respond and adapt to shocks), and recoverability/renewal (about the extent and nature of recovery).

The existing literature offers several contributions exploring one or more of these aspects of regional economic resilience, mostly using case studies. Fingleton et al. (2012) and Martin et al. (2016) study resistance and recoverability in the UK regions after the four major recessions of the last four decades concentrating on employment and on the role played by the industrial structure, respectively. The main finding is that a diverse economic structure may confer greater regional resistance to shocks than more specialized ones. Crescenzi et al. (2016) analyse the determinants of economic resilience of European regions investigating both national and regional factors. Giannakis and Bruggeman (2017) focus on the Greek regions and on the differences between rural and urban ones.

This paper explores the regional economic resilience of the NUTS2 (European Nomenclature of Territorial Units for Statistics at level two) regions of the European Union (EU) using the spatial computable general equilibrium (CGE) model RHOMOLO (Lecca et al. 2018). Such a general equilibrium modelling framework solves a number of issues posed by the use of case studies for the analysis and investigation of regional resilience (Sensier et al. 2016). First, there is no need to identify a reference state against which to measure the impact of a shock, as in a CGE model there is a baseline equilibrium ready to be shocked for scenario analysis purposes. Second, the identification of an economic shock can be challenging in a case study (when does a crisis start? What type of shock triggered it?), but it is straight-forward in a CGE model. And finally, in a modelling framework the time period given for resilience outcomes to be revealed can be easily controlled, while in case studies additional shocks and disturbances at a later stage can blur the recovery path of the economies hit by the crisis in the first place.¹

We simulate three different scenarios each one with a different type of negative shock hitting all the European NUTS2 regions featured in the RHOMOLO model. The first involves a temporary fall in TFP; the second implies a temporary reduction in the demand for exports to the Rest of the World (ROW); and the third shock consists of an increase of the user cost of capital through a temporary increase in the risk premium. The distinctive feature of this experiment is that in each case we analyse the response of the economy under alternative external disturbances triggering different economic mechanisms. In particular, a TFP shock changes immediately the economic structure of

¹Rose and Liao (2005) offer an early example of modelling applied to the study of resilience although in a fairly different framework, that is water service disruptions.
regions by directly affecting the supply-side of the economy; a change in exports to ROW implies direct demand-side effects; and a change in the risk premium entails a combination of demand- and supply-side shock. As for the analysis of the results, we firstly study how the EU regions react to various types of shocks, thus looking both at the vulnerability of the EU regions and at their resistance when concentrating on the magnitude of the initial short-run impacts of the shocks. In the second part of the analysis, we study both robustness and recoverability by looking at the time required for each regional economy to return back to its original steady-state. Finally, we look for the macroeconomic variables capable of affecting the various dimensions of resilience analysed in the first two parts of the analysis.

Our results suggest that the nature of the shocks matters for the different effects on the regional economies of the EU. In particular, the negative peak in GDP is reached immediately in the case of the TFP shock, while it takes between 4 to 7 years for the other two types of shocks. We highlight important regional differences regarding the impact of the various shocks, as well as in the recovery paths after the negative GDP peaks. We also document qualitative differences in the evolution of GDP and employment during and after the shocks. On average we found that soon after the negative pick is reached, the legacy effects on employment are less pronounced than those of GDP in all cases under examination. This implies that GDP adjusts less rapidly than employment in the EU reflecting the higher flexibility of capital during the recovery. We also identify a number of macroeconomic variables that appear to be related to the economic resilience of the European regions, such as the industrial structure in the case of a TFP shock, the capital intensity in the case of a risk premium shock, and trade openness in the case of a demand shock related to exports.

The remainder of the paper is as follows. Section 2 briefly presents the RHOMOLO model and section 3 illustrates the strategy adopted for the regional resilience analysis. Section 4 presents the results organised in three sub-sections: one for vulnerability and resistance; one for robustness and recoverability; and the third one looking at the determinants of resilience. Section 5 concludes.

2. The RHOMOLO model

CGE models nowadays are a standard tool to analyse the economic impact of policies whose effects are transmitted through the multiple inter-related markets of the economy. The main data used in a CGE model is the so-called "Social Accounting Matrix" which represents a snapshot of the economic transactions between the economy's sectors and agents (households, firms and government) in a particular year, with all the markets being in equilibrium. A CGE model represents a decentralised market economy based on the assumption that producers maximize their profits and consumers maximize the utility derived from their consumption, with market prices adjusting endogenously so as to keep supply and demand balanced in all markets. Substitution elasticities are employed in functional forms describing the agents' technology and preferences and define how easily different goods can be replaced with each other as prices change. A CGE model is calibrated to replicate the base year data so to allow for scenario analysis. The introduction of a policy shock leads to a new counterfactual and the analysis of the results is based on the comparison between the values of the variables of interest before and after the shock. Thus, simulating a policy change in a CGE model allows for a “what if” comparison of two equilibrium states of the economy.
Spatial CGEs have been acknowledged as key instruments to examine the geographic features of the economic activity such as factor mobility (see Di Comite et al., 2018), and regional price differentials, influencing the speed and extent of economic development. These models allow for a geographical disaggregation of country-wide policy impacts and also for the evaluation of regional policies. Model results help to identify the territories where the benefits or losses are concentrated, and clarify which effects can be attributed to a specific policy intervention and which others are due to spillover effects. This helps identifying priority areas for investment and policy interventions, and also provides a basis for comparing net welfare benefits with prospective investment costs.

RHOMOLO is a spatial CGE model of the European Commission developed by the Joint Research Centre (JRC) in collaboration with the Directorate-General for Regional and Urban Policy (DG REGIO) to support the EU policy makers providing sector-, region- and time-specific simulations on investment policies and structural reforms. The RHOMOLO model has been used for the impact assessment of Cohesion Policy and structural reforms (see for example European Commission, 2018a), as well as for the impact assessment of the EU investment policies involving the European Investment Bank (European Commission, 2018b).

The statistical unit of the multi-regional CGE model RHOMOLO is NUTS2, that is the basic administrative entities identified for the application of regional policies in the EU. The inter-regional social accounting matrices for the year 2013 were constructed following the procedure explained by Thissen et al. (2018). Transport costs are specific both to sectors and to region pairs and are based on the transport costs estimation developed by Persyn et al. (2018).

The model features 10 sectors (agriculture, forestry, and fishing; energy; manufacturing; construction; trade and transport; information and communication; financial activities; R&D; public administration; other services). Goods are consumed by households, governments and firms. Among different ways of modelling imperfectly competitive commodity markets, the model can deploy both a simple monopolistic competition framework à la Dixit-Stiglitz (1977) and different forms of oligopolistic competition with endogenous number of firms. Labour is disaggregated into high, medium and low skilled groups. Unemployment is modelled through a wage curve (Blanchflower and Oswald, 1995) that negatively relates real wages to the unemployment rate.

Due to the high dimensionality implied by its extensive regional disaggregation, the dynamics of the model are kept relatively simple: expectations of economic agents are assumed to be myopic, as they optimize within a one-year period, and the model is solved recursively year by year.

### 2.1 A condensed description of the RHOMOLO model

In the following we outline the main equations and adjustment governing the model to help the reader to identify the main drivers and determinants of the spatial outcomes generated by the model.\(^2\) More details on the RHOMOLO model can be found in Lecca et al. (2018).

\(^2\) For a full description of the RHOMOLO model and its equations, the technical documentation can be found on [http://rhomolo.jrc.ec.europa.eu/about](http://rhomolo.jrc.ec.europa.eu/about).
Consumers

In each period, consumers in each region $r$ receive utility from consumption $C_r$. The household problem consists in the maximisation of the utility (1) subject to the budget constraint (2):

$$U(C_r)$$

$$P_r^c C_r \leq (1 - s_r) Y C_r$$

where $P_r^c$, $s_r$, $Y C_r$ are the consumer price index, the exogenous saving rate, and the disposable income respectively. The disposable income is defined as the sum of labour and capital income adjusted for tax and net transfer of income:

$$Y C_r = \sum_e (1 - \tau_r^w) w_e L_e (1 - u_e) + \psi_r \sum_f (1 - \tau_r^f) K_{r,f} r k_{r,f} + TR_r$$

where $\psi_r$ is the share of capital income paid directly to households and $\tau_r^w$, $\tau_r^f$ are the average rate of labour and capital income tax, respectively. Factor payments are represented by $w_r e$ and $r k_{r,f}$, that is, the wage rate differentiated by skill types $e$, and the rate of return to capital for each type of capital service, $f$. $L_{r,e}$ is the labour force while $u_{r,e}$ is the unemployment rate by skill types. Finally $K_{r,f}$ is the capital stock for each type of $f$.

The first order condition of this problem implies that the aggregate consumption level is directly related to the disposable income $Y C_r$:

$$C_r = \frac{(1 - s_r) Y C_r}{P_r^c}$$

Households consume all varieties of final goods available in the economy. In order to represent love for variety, $C_r$ is assumed to take the form of a CES function defined as:

$$C_r = \left( \sum_{j=1}^{J} \sum_{i=1}^{N_{r,j,i}} \vartheta_{r,j,i} (c_{r,j,i})^{\rho_c} \right)^{\frac{1}{\rho_c}}$$

where $c_{r,j,i}$ is the consumption of varieties $i$ of sector $j$, in region $r$, whilst $\vartheta_{r,j,i}$ is a share of expenditure parameter and $\rho_c = \frac{\sigma_c - 1}{\sigma_c}$, where $\sigma_c$ is the elasticity of substitution. Similarly the consumption price index $P_r^c$ is obtained through a CES index defined over the consumer price for each varieties, $p_{r,j,i}$.

Government

Government expenditure comprises current spending on goods and services $G_{r,j}$ and net transfers to households and firms. Its revenues are generated by labour and capital income taxes, and indirect taxes on production. When a balanced budget is applied, either government consumption or the income tax rates are endogenous. In our default configuration we assume fixed government consumption and no change in tax rates.

For the sake of readability, we omit time indices when describing static equations.
Firms

At the firm level (i.e., for each variety), the production technology is represented by a multilevel CES function. In each sector \( j \) and region \( r \), total production \( X_{r,j} = CES[Y_{r,j}, V_{r,j}] \) is a CES combination of the value added \( Y_{r,j} \) and intermediate inputs \( V_{r,j} \). In turn \( Y_{r,j} \) and \( V_{r,j} \) are defined as follow in equations (6) and (7) respectively:

\[
Y_{r,j} = A y_{r,j} \left[ \delta_{r,j}^Y \cdot KD_{r,j}^{\rho^Y} + \left( 1 - \delta_{r,j}^Y \right) \cdot LD_{r,j}^{\rho^Y} \right]^{\frac{1}{\rho^Y}} - FC_{r,j} \tag{6}
\]

\[
V_{r,j} = \left( \sum_s b_{r,s,j}^v v^v_{s,j} \right)^{\frac{1}{\rho^v}} \tag{7}
\]

In equation (6), \( Y_{r,j} \), is obtained combining capital \( KD_{r,j} \) and labour \( LD_{r,j} \) in a CES function, net of fixed costs \( FC_{r,j} \). Substitution between the two types of primary factors is governed by the parameter \( \rho^Y = \frac{\sigma^Y - 1}{\sigma^Y} \) (where \( \sigma^Y \) is the elasticity of substitution) and the share parameter \( \delta^Y_{r,j} \). The scale parameter \( A y_{r,j} \) represents the conventional hicks neutral technical change parameter in this production function.

The input-output relations are shown in equation (7) where the composite demand for intermediate inputs is again a CES combination of \( v^v_{s,j} \), that is the purchase of intermediate inputs of each sector \( j \) from the supplier sector \( s \). Input substitution between sectors are determined by the elasticity of substitution \( \rho^v \) and the preference parameter related to the share of expenditure \( b_{r,s,j}^v \).

From cost minimization we obtain the demand for capital and labour in each sector \( j \), represented in equations (8) and (9).

\[
KD_{r,j} = \left( A y_{r,j} \delta_{r,j}^Y \cdot \frac{P k_{r,j}}{P y_{r,j}} \right)^{\frac{1}{1-\rho^Y}} \cdot Y_{r,j} \tag{8}
\]

\[
LD_{r,j} = \left( A y_{r,j} \left( 1 - \delta_{r,j}^Y \right) \cdot \frac{w_r}{P y_{r,j}} \right)^{\frac{1}{1-\rho^Y}} \cdot Y_{r,j} \tag{9}
\]

where \( P y_{r,j} \), \( P k_{r,j} \) and \( w_r \) are respectively the price of value added, the price of capital and the wage rate. For each firms, capital and labour are then further disaggregated. \( LD_{r,j} \) is further disaggregated into three types of skills, e: low, medium and high.

Price mark-ups

Goods and services can either be sold in the domestic economy or exported to other regions. On the other hand, firms and consumers can purchase inputs within the region or from external markets. We use a single Armington nest that differentiates between domestic and imported goods and do not differentiate between imports from within the country or within the EU.
\[ x_{r,r',j} = \eta_{r,r',i} \left( \frac{P_{r,r,j}}{P_{r,r',j}} \right)^{\sigma_j} X_{r,j} \]  

\( x_{r,r',i,t} \) is the demand for each goods and services supplied by regions \( r \), to \( r' \), \( \eta_{r,r',i} \) is a calibrated expenditure share, \( X_{r,j} \) is the Armington aggregate of outputs for each firm in region \( r \), while \( P_{r,r,j} \) is defined as a CES price index as over the market price \( P_{r,r',j,t} \).

\[ P_{r,r',j,t} = \left( \sum_{r} N_{r,j} \eta_{r,r',j} P_{r,r',j,t} \right)^{1-\sigma_j} \]  

where the price \( P_{r,r,j} \) set by a firm of region \( r \) (gross of trade cost \( \tau \)) selling to region \( r' \), for a given sector \( j \), is defined as the optimal mark-up \( \left( \frac{1}{\varepsilon_{r,r',j}} \right) \) over the marginal cost \( P_{r,j}^* \), is given as follows:

\[ P_{r,r',j} = \frac{\tau_{r,r',j} P_{r,j}}{1 - \frac{1}{\varepsilon_{r,r',j}}} \]

where

\[ \varepsilon_{r,r',j} = \sigma_{r,j} \]

The marginal cost includes the cost of production factors and the intermediate price index PIN.

\[ P_{r,j}^* = a_{r,j}^Y P_{r,j} + a_{r,j}^{INT} PIN_{r,j} \]

\( a_{r,j}^Y \) and \( a_{r,j}^{INT} \) are the share parameters attached to the value added and intermediate inputs respectively. Where

The configuration of RHOMOLO adopted in this paper uses a Dixit-Stiglitz formulation of the mark-up of firm-level product differentiation with elasticities of substitution equal for all firms and products in the model. The elasticity of substitution \( \sigma \) is the same in each node of the CES function (between home and imported), therefore any possible combination between domestic and imported inputs will collapse to a single nest. Furthermore the mark-up does not dependent from the market shares, therefore a single region sell products to all the other regions at the same fob (first-on-board) price, even if consumers in the importing regions can observe different cif (cost, insurance and freight) prices, including iceberg transport costs.\(^4\)

**Wage setting**

The RHOMOLO model incorporates imperfect competition in the labour market. We assume a flexible framework that allows one to switch from a wage curve to a Philips curve\(^5\). Further

\(^4\) This implies that the relative power of region \( r \) in region \( r' \) is not transferred through changes in the mark-up prices in that region. This means that a region sells their goods and services to all the other regions at the same price. Alternative options are available in RHOMOLO. We can switch to alternative price setting, such as Cournot or Bertrand price behaviour to generate a different mark-up of price over the marginal cost.

\(^5\) According to equation (15), we can easily switch between a wage curve and Philips curve by changing the related parameter of interest. However, the model could also be run assuming a more conventional neoclassical rule that implies perfect competition in the labour market.
parameterization also permits to use a dynamic or a static form of wage setting. The general formulation is expressed in log as in equation (15):

\[ rw_{e,t} = a_e + \alpha r w_{e,t-1} - \beta u_{e,t} + \gamma \Delta p_t - \lambda (r w_{e,t-1} - T_t) - \theta u e_t \]  \hspace{1cm} (15)

The real wage \( rw_{e,t} \) is differentiated by skills, \( f \), and it is negatively related to the unemployment rate, \( u_{e,t} \), the change in unemployment between two subsequent periods \( \Delta u_{e,t} \), and to an error correction element represented by the difference between the lag real wage and the productivity trend \( T_t \). The real wage is also positively affected by past real wages and changes in the price of output. With \( \alpha = \gamma = \lambda = \theta = 0 \) we have the case of a static wage curve where the real wage is solely affected by the unemployment rate, and this is the specification we use for the purpose of this analysis.

**Investment**

The adjustment rule adopted in RHOMOLO to determine the optimal path of private \( I^P \) investments is consistent with the neoclassical firm’s profit maximisation theory (maximising the present value of firms). The aggregated level of investments is defined as the gap between the desired level of capital, \( K^* \) and the actual level of private capital, \( K^P_r \) adjusted by depreciation, \( \delta, K^P_r \):

\[ I^P_r = v [K^*_r - K^P_r] + \delta_r K^P_r \]  \hspace{1cm} (16)

where, \( v \) is the accelerator parameter and \( \delta \) is the depreciation rate. According to this formulation the investment capital ratio (\( \varphi = I^P_r / K^P_r \)) is a function of the rate of return to capital (\( r_k \)) and the user cost of capital (\( uck \)), allowing the capital stock to reach its desired level in a smooth fashion over time:

\[ \varphi = \varphi(r_{k,f}, uck_r) \]  \hspace{1cm} (17)

where

\[ \frac{\partial \varphi}{\partial r_k} > 0; \quad \frac{\partial \varphi}{\partial uck} < 0 \]  \hspace{1cm} (18)

The user cost of capital, \( uck \), is derived from Hall and Jorgenson (1967) and Jorgenson (1963) as a typical no arbitrage condition, where:

\[ uck_r = (r + \delta_r)p^I_{EU} + p^I_{EU} + r p_r \]  \hspace{1cm} (19)

\( r, \delta_r, p^I_{EU} \) and \( r p_r \) denote the interest rate, the depreciation rates, the investment price index and an exogenous risk premium respectively. \( p^I_{EU} \) is the change of the investment price index defined between two subsequent periods.

In equation (19) the interest rate is fixed and equal for each region; \( \delta_r \) is fixed but we allow variations between regions in the base year; \( r p_r \) is a fixed calibrated parameter. Therefore changes in \( uck \) are only driven by changes in the cost of capital in the whole EU, \( p^I_{EU} \). In the long-run, we should then expect changes in capital returns in all regions to equalise. Proceeding in this way means also that the allocation of investments between regions is driven by the differences between regional and EU average return, that mimic a capital flow mobility rule between regions.
Private capital stock in each region updates period by period through investments adjusted by depreciation:

\[
\dot{K}_r^P = \delta_r K_r^P + I_r^P
\]  

Equilibrium and closing the system

The total absorption equation (21) provides equilibrium in the commodity market. This is sufficient to guarantee equilibrium in the payments account since we are not considering money as a commodity (i.e., there is no cash in the economy left unused, it is either saved or consumed):

\[
X_{r,i,j} = \sum_i \sum_j v_{r,i,j} + C_{r,j} + I_{r,j} + G_{r,j}
\]  

As for the capital market, capital demand equals the capital stock (22):

\[
\sum_i \sum_j k d_{r,j,i,z} = K_r^P
\]

The labour market is equilibrated through endogenous changes in unemployment rates as described in equation (23):

\[
\sum_i \sum_j l d_{r,j,i,e} = (1 - u_{r,e}) L_{r,e}
\]

The zero profit condition that link output price and average price determine the number of firms in the system:

\[
f_{c,i} P_{r,i,t}^* N_{r,i,t} = \sum_{r'} N_{r,i,t} x_{r,r',i,t} P_{r',r,i,t}^* - P_{r,i,t}^* N_{r,i,t} (V_{r,i,t} + V_{r',i,t})
\]  

In its default configuration RHOMOLO ensures an unconstrained inflow of capital to sustain investment whenever required (this is a typical regional macroeconomic closure), not imposing any constraints on the balance of payments. Typically, no binding constraints are imposed to regional government balance. However, foreign savings from the ROW in the model are passive, hence maintaining equilibrium in the payment accounts with the ROW.

2.2 Data, model calibration and baseline scenario

All shift and share parameters are calibrated to reproduce the base year data set, represented by the inter-regional Social Accounting Matrix for the year 2013 (Thissen et al., 2018). The selection of year 2013 for the calibration is based on the data availability, as it is the most recent year for which regional Social Accounting Matrices can be built with a sufficient degree of reliability.

The structural parameters of RHOMOLO are either borrowed from the literature (Okagawa and Ban, 2008) or estimated econometrically. The parameters related to the elasticities of substitution both
on the consumer and on the producer side are based on similar models or derived from the econometric literature. Typically, we assume a rather low elasticity of substitution in production (0.4), a relatively higher elasticity of substitutions in consumption (1.2) and a fairly high for trade between regions (4.0). The elasticity of substitution between different types of labour skills equate to 2. The interest rate (faced by producers, consumers and investors) is set to 0.04 while the rate of depreciation applied to the private capital equates to 0.15.

As for the wage curve parameterization, we typically run a long-run wage curve assuming \( \beta = 0.1 \) (Nikjamp and Poot, 2005).\(^6\) However, if dynamics over the wage is introduced we set \( \alpha = 0.1 \). Recent econometric evidence has shown value of \( \alpha \) significantly less than 1 (Montuenga-Gómez, and Ramos-Parreño, 2005). However the debate is still open and the issue currently remain controversial.

The model calibration process assumes the economies to be initially in steady-state equilibrium. This means that the capital stock is calibrated to allow depreciation to be fully covered by investments. The steady-state equilibrium calibration implies that the data observed should provide unbiased information about preferences and technologies in each region and therefore relative magnitudes should not vary in the baseline scenario. We assume that there is no natural population change and we do not make any assumptions about the economic growth of regions due to external factors.

### 3. Methodology and simulation strategy

With the aim of analysing the economic resilience of the EU regions, we separately run three scenarios simulating the following three system-wide shocks capable of triggering recessionary periods:

- 1% reduction in TFP in all regions and sectors (supply-side shock);
- 5% increase in risk premium in all regions and sectors (both supply- and demand-side shock);
- 5% reduction in demand of exports to the ROW in all regions and sectors (demand-side shock).

Each shock lasts for 10 periods but its intensity diminishes over time with a discount rate of 0.25. After period 10, the shocked exogenous variables bounce back to their base year values. Shocks are implemented simultaneously for all sectors and regions, and the main aim is to capture the different regional responses associated to these shocks. We expect regional agents to react differently not only during the perturbation periods but also during the transition towards the steady-state. Our focus therefore is on the so-called 'engineering resilience' (Martin and Sunley, 2015) largely inspired by the work done in physical sciences and engineering, rather than evolutionary resilience (Boschma, 2015). Resilience here is seen as the economic system’s ability to recover from an external disturbance and the speed at which the economy adjusts to the pre-shock steady-state.

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\(^6\) Most of the studies on the relationship between unemployment and wages find an elasticity close to -0.1 as summarized by the meta-analysis carried out by Nikjamp and Poot (2005). This confirms the original studies by Blanchflower and Oswald (1994, 1995).
With our comparative counterfactual analysis we identify the regions that are most likely to be exposed to external shocks and those which can better withstand negative perturbations. To facilitate our analysis and in line with the pedagogical objective of the paper, the implemented shocks do not involve random components. Furthermore, structural and behavioural elasticities are the same for each region and do not feature any error component. This allows us to compare the three simulations independently from the magnitude of the shock, simplifying substantially the interpretation of the results.

To help the reader understanding the mechanism operating in the model under the three scenarios, in what follows we analyse five key macro-economic variables during the first 20 years of the simulations using the Île de France region (FR10) as an illustrative example.

### 3.1 TFP shock

The negative TFP simulation implies a 1% reduction from base year values of the exogenous variable $A_y$ appearing in equation (6). Figure 1 shows the evolution of the five chosen variables during the first 20 years of the simulation in the FR10 region, with the shock affecting the economy from period 1 to 10. The fall in TFP generates an increase in the price of capital and wages that in turn is reflected in an increase in commodity prices (CPI). In the chart we observe an immediate increase in CPI that reduces competitiveness and thus negatively affects exports. Given the nature of the ROW in RHOMOLO, we expect regions to experience a loss in competitiveness particularly towards that specific region. The higher costs of primary factors and the loss in competitiveness reduce the demand for capital and labour making investment and consumption fall below their base year values. After the shock, the TFP returns back to its original steady-state values while the economy gradually adjusts back to the steady state. The legacy effects of a temporary reduction in TFP are quite strong and it requires more than 20 periods before getting to the original equilibrium.

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### 3.2 Risk Premium shock

The immediate impact of an increase in the risk premium is an increase in the user cost of capital defined by equation (19). This makes capital relatively more expensive, generating a fall in the capital/labour ratio. Although in the calibration each region starts with the same risk free return, the market return is different across regions in order to accommodate capital terminal conditions. Therefore, each region has a different risk premium value in the initial steady-state.

The increase in risk premium generates upward pressure in the user cost of capital and immediately reduces the demand for investments. In the first period there are short-run capacity constraints, therefore there cannot be any capital stock accumulation (de-accumulation in this case) and only final demand investment is immediately affected. Thus, the economy responds to the shock as if it were a conventional demand-side negative shock with no direct supply side effects. In the following

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7 The risk premium is a calibrated exogenous variable and it is obtained as the difference between the market return and the risk free rate (interest rate plus depreciation).
periods, the demand side-effect of the shock is also accompanied by a reduction in the capital stock further reducing output. Consider that this combination of demand- and supply-side effects has conflicting effects on prices. The demand-side mechanism puts initial downward pressure on prices, but then capital de-accumulation puts upward pressure on them. This conflicting behaviour is reflected in the evolution of CPI as shown in Figure 2. In the first periods we observe an immediate reduction in CPI; then we observe an alleviated pressure on prices generated by the fall in the capital stock. Our simulation also suggests that, as long as prices are below their initial steady-state, regional competitiveness improves. It is interesting to see that the household consumption curve is below GDP, compensating for relatively higher competitiveness gain effects (mainly with the ROW).

3.3 Demand shock

In this scenario we reduce by 5% the exports to the ROW in all regions and sectors: in this case the variable of interest is $x_{t,ROW,j}$ appearing in equation (10). Figure 3 shows a sharp reduction in prices and a fall in GDP, employment, consumption and total exports. The negative changes in total exports are lower than the negative 5% changes imposed by the shock, suggesting that relative competitiveness gains within other EU regions are unable to fully offset the negative effects of a fall in foreign exports. It is interesting to notice that, except in the first two periods, for the duration of the shock and beyond the change in employment is lower than the change in GDP, meaning that capital is falling less than GDP.

3.4 Some general considerations

One final consideration is that regional responses to external perturbations change depending on the nature of the shock. This can be seen in Table 1 which reports the correlation coefficients measured using regional GDP changes obtained at period 1, 5 and 10 for the three shocks under scrutiny. In period 1 the TFP shock is negatively correlated with the other two shocks, particularly the risk premium one (-0.73), while a small positive correlation is found between the latter two (0.21) suggesting that the immediate regional response to these two shocks is similar. Another interesting feature coming out of the correlation table is how similar is the GDP response to the TFP shock over time. The correlation between period 1 and period 5 is 0.86 while between period 1 and 10 is 0.69. For the remaining two cases the response in period 1 shows a lower correlation with the response in periods 5 and 10. This is especially true for the risk premium shock, where the correlation between the GDP response in period 1 and that of periods 5 and 10 is only equal to 0.23 and 0.19, respectively.
4. Results

In sub-section 4.1 we first look at the sensitivity to different types of shocks and at their initial impact on the regional economies of the EU. In sub-section 4.2 we explore how the regions adjust and adapt in the post-shock period and look at the extent and nature of the recovery. Finally, in sub-section 4.3 we investigate which regional characteristics are related to the various dimensions of resilience.

4.1 Vulnerability and resistance

It is important to look at the GDP behaviour after the beginning of the shocks as the beginning of the recovery period starts immediately after the economies have reached the negative GDP peak. In our analysis we also look at the behaviour of employment, which may differ from that of GDP and being either more or less responsive to the shocks.

GDP of all EU regions reacts negatively to a TFP shock on impact (period 1), while in the case of the demand shock there is one French region (Corse, FR83) in which GDP actually increases. In the case of the risk premium shock, the same happens in a few Eastern Romanian regions as well as in Latvia and Estonia. Employment also increases in a few cases at the beginning of the simulation period. The explanation for this counterintuitive result lies in the existence of spillover effects. Since trade within the EU regions has to balance, meaning that in each sector imports should be equal to exports, there will be some regions experiencing an increase in interregional export in some sectors of the economy. If the sectors enjoying positive effects are those with higher backward linkages, the positive multipliers generated in those sectors could either partially or fully offset the negative impact directly generated by the shock.

It is interesting to notice that the negative peaks in GDP and employment after the beginning of the shocks are reached in different periods depending on the nature of the shock and on the regions involved. Table 2 contains some statistics regarding the distribution of the year of such negative peaks. In the case of a TFP shock, the negative GDP peak is reached in period 1 in all but one Romanian region (București-Ilfov, RO32) where it is reached in period 2. Employment, however, reacts more slowly and on average the European regions start recovering on the occupational side after three or four years from the beginning of the shock. Things are substantially different in the cases of the two other shocks. The negative GDP and employment peaks post-risk premium shock are reached by most regions between periods 6 and 7, with some exceptions as early as period 1 (three regions in Southern Italy) and a couple of others up to period 11, one year after the end of the shock (Latvia, LV00, and Stockholm, SE11). On the other hand, in the case of the demand shock the negative GDP peak is reached by most regions between period 4 and 5 (even though there are some regions in which the peak is recorded in period 1, and one French region, Corse, FR83, in which the peak is in period 13), but on the employment side the peak is reached before on average, between years 2 and 3.
Thus, while the TFP shock intensity seems to be directly related to the GDP response of the affected economies, with the negative GDP peak being almost everywhere contemporaneous to the largest decrease in TFP (in period 1), in the cases of the demand and risk premium shocks it takes more time to get to the negative GDP peak and, consequently, to start the recovery. Turning to the regional differences, Figures 4, 5, and 6 show the cumulative negative impact on GDP from the beginning of the shock to the period in which the negative GDP peak is reached.

The TFP shock is particularly damaging for the core of the EU and for a number of regions in the North of Spain and in the Scandinavian area. The risk premium shock is particularly felt in the Eastern European regions as well as in the Spanish and Irish ones, and the demand shock is similarly distributed but also badly affects the Portuguese regions. Not surprisingly, there is a negative correlation between the period of the negative peak and the magnitude of the cumulative impact on GDP until that period. However, the correlations are only equal to -0.20 and -0.36 for the risk premium and demand shocks, respectively, meaning that there is no strong evidence suggesting that the highest GDP losses are recorded in the regions that start their recovery relatively late.\footnote{Given that the peak is reached in period 1 almost everywhere after a TFP shock, it is not meaningful to calculate this statistic in that case.}

4.2 Robustness and recoverability

While it is important to study the immediate impact of a recessionary shock on regional economies, from a policy making point of view it is also important to analyse the economies' capacity to respond not only during the recessionary shock or just after the shock, but also in the medium term. This is why we analyse the recovery path during the 10 year after the negative peak in GDP and employment after the start of the shock. The recovery rate 10 year after the negative peak post-TFP shock ranges between 33\% (Molise, ITF2) and 100\% (Navarre, ES22) for GDP and between 44\% (North Aegean, EL13) and 90\% (Sicily, ITG1) in the case of employment. The GDP recovery rate after the negative peak post-demand shock lies between 48\% (North Aegean, EL13) and 500\% (North Eastern Scotland, UKM5), where after the negative impact of the shock in period 1 (which also marks the negative peak for this region), there is an immediate recovery and GDP eventually gets higher than before the shock. Finally, the GDP recovery rate after the risk premium shock’s peak lies between the 46\% of North Aegean (EL13) and the 82\% of Molise (ITF2). The lowest employment recovery rate in this case is for Molise (ITF2) and the highest is for Calabria (ITF6).

Looking more into the details of the recovery after each shock, figure 7 shows that the recovery after the TFP shock differs across a few regional clusters. The largest GDP recovery after 10 years is recorded in Western Europe (particularly in Spanish and French regions), while the regions of Southern Italy exhibit the smallest recovery rates. However, looking at the recovery of the
employment we get different results, with higher recovery rates in the South of Italy and lower recovery rates in all Polish regions.

Quite different conclusions can be drawn when looking at the recovery post-demand shock (figure 8). The regions of central Europe and of the UK on average present the best GDP recovery rates, and the more we move towards the European periphery, the smaller is the recovery, with some exceptions. For example, Spanish regions exhibit higher recovery rates than French ones, and most of the Swedish regions recover relatively well. The employment recovery is quite uniform across all European regions, with those of the UK, Spain, Germany, and Italy performing relatively better on average.

The risk premium shock presents fairly homogeneous GDP recovery rates across regions (see figure 9). In general, the best GDP recovery rates from this shock are recorded in the UK and in Italy. A quite different picture comes out when looking at employment, as the regions of England present low recovery rates, and the worst performances are recorded in the central Italian regions.

Looking at the state of the economy 10 years after the beginning of the recovery ignores the differences between the regions that experienced a long crisis (that is, many years passed before reaching the negative GDP peak) and those where the crisis lasted for less periods. In order to take that information into account, we now look at the differences between GDP and employment in period 20 and the initial steady state as well as the cumulated deviations from the steady state up to period 20. This allows us to understand where the regional economies stand 20 years after the beginning of the 10-years long shocks, thus complementing the information above on the state of the economies 10 years after the beginning of the recovery.

The results suggest that in the case of the TFP shock the Eastern European regions, especially the Bulgarian, Romanian and Latvian ones, present the worst GDP values together with one UK region (North Eastern Scotland, UKM5). In other words, these regions exhibit the highest distance from the steady state value of GDP after 20 years from the beginning of the shock. On the other hand, Italian regions, especially the Southern ones, have values very close to zero, that is are almost back at the equilibrium level of GDP. A similar picture arises when looking at the cumulated values of the GDP deviations from the steady state up to period 20. The worst results are recorded in the Eastern European regions and Bulgarian, Romanian, Polish, and Baltic regions are those that accumulated the largest GDP and employment deviations from their steady state levels.

In the case of the demand shock, 20 years after beginning of the shock the Eastern European regions are again those with the highest GDP deviation from the steady state (South-Eastern Romanian and North-Eastern Bulgarian regions are the worst performers). On the other hand, a number of peripheric UK regions show positive values, meaning that they are now above the steady state level of GDP. Looking at the cumulated values the results don’t change substantially. Almost the same picture emerges when looking at employment, but in this case the numbers reveal that also Greek
and Irish regions are among those suffering the most from a risk premium shock in terms of recovery.

The results for the risk premium shock 20 years after beginning of the 10-years long shocks are different than those of the other two scenarios. In this case, Greek regions present the worst values (together with North Eastern Scotland, UKM5), and, more generally, Eastern European, Southern Spanish, and Irish regions all perform worse than the regions of central and Western Europe. The cumulated GDP deviations from the steady state show that Greece is the country with the regions suffering the most from a risk premium shock, together with the South-East of Spain.

4.3 The determinants of resilience

The final part of our analysis deals with the search for the regional characteristics related to resilience. This is one of the main questions that the scientific literature tries to answer, and it is also of major importance from a policy-making point of view. Are the most resilient regions more or less open to trade? Are their economic structures highly specialised or not? Is their labour force skewed towards low-, medium-, or high-skilled workers? While the main aspects of the economic adjustments after each type of shock are by and large common to all regions, the responses to the shocks can differ across regions both in terms of time required to get back to the equilibrium and in terms of the quantitative impact on GDP, employment, and the rest of the macroeconomic variables of interest. This is endogenously determined in the model and it is affected by the regional initial conditions and the calibrated base year steady-state.

In the case of the TFP shock, competitiveness towards the ROW appears to be of crucial importance for regional vulnerability and resistance. Since all regions are hit by an equal TFP shock in the form of Hicks-neutral technical change, factor productivity shocks affect competitiveness through changes in commodity prices and in turn exports of goods and services. Thus, we expect the regions with larger shares of exports to the ROW to be the most affected. We find validation for this expectation in Figure 10 (panel a) where we show the scatterplot of the regional GDP percentage deviations from base year values in period 10 against the log of the share of exports to the ROW with respect to GDP. As expected, there is a significant negative correlation driven by the rise in commodity prices that has caused negative terms of trade effects.

On the other hand, regions with higher exports potential are likely to adjust faster than those with smaller initial shares of export to the ROW. Panel b of Figure 10 plots the average GDP growth between period 11 and period 15 (y-axis), that is during five periods after the end of the shock when presumably the economies are adjusting towards the previous steady-state equilibrium against the share of exports to the ROW (x-axis). The two variables are in fact positively correlated.

In the case of an increase in the risk premium, the reduced expectations of futures profits make both investments and the capital stock to fall. We would expect greater disinvestment effects and therefore greater decreases in capital stock in those regions with higher capital-GDP ratio. Therefore capital intensive regions are likely to suffer relatively more than those regions experiencing lower capital shares in the original equilibrium. In Figure 11 (panel a) we plot the log of the capital share to GDP expressed in percentage against the percentage change in GDP in period 10. We can see that
regions with relatively higher capital intensity experience a bigger drop in economic activities. However, similarly to the case of TFP, the adjustment is faster in those same regions. This is evident from the scatterplot reported in panel b of Figure 11. The share of capital is strongly positively correlated with the 5 year average GDP growth for periods 11-15.

As for the demand shock, a reduction in the export to the ROW determines a reduction of economic activities and since the unemployment rate increases, there is a downward pressure on wages that drives the reduction in the price of all commodities. In our initial equilibrium, export oriented regions are capital intensive regions; therefore we expect a negative correlation between changes in regional GDP obtained from the simulations and the capital shares. On the contrary, a positive correlation is likely to be observed between changes in GDP and the initial share of labour. To validate this intuition in Figure 12 (panel a) we plot the changes in GDP obtained in period 10 against on the y-axis and the log- of the share of capital (red square dots) and the log of the share of labour (blue circles) both on the x-axis. We see a negative strong correlation between the regional GDP impact and the initial calibrated shares of capital however for labour intensive regions the negative impact of GDP is lower. Similarly to the other two cases seen above the regions with higher shares of capital are expected to recover faster than labour intensive regions as suggested in panel b of Figure 12.

This analysis reveals that the regional initial conditions are of extreme importance for the analysis of external disturbance in terms of resistance and recovery. In our modelling exercise we observe that some crucial calibrated parameters can determine the extent of regional resistance and recovery. In all the three cases analysed here we observe that the calibrated parameters dominating the initial model's equilibrium can contemporaneously affect the level of resistance and the speed of recovery after negative shocks.

5. Conclusions

In this paper we study the economic resilience of the regions of the EU. We examine the sensitivity of the regions to various types of shock on impact, as well as the 10-years recovery path. We fill a gap of the literature which mainly concentrates on case studies by producing an analysis made with a spatial CGE model, RHOMOLO. This strategy permits us to avoid a number of issues such as the identification of a reference state against which to measure the impact of a shock, the identification of the shock, and the time period of interest for the analysis of resilience outcomes.

We analyse three different shocks: a temporary fall in TFP, a temporary reduction in exports to the ROW, and a temporary increase of the rate of return to capital through an increase in the risk premium. In each case we analyse the response of the economy under alternative external disturbances triggering different economic mechanisms.

Our results suggest that the nature of the shocks matters for the different effects on the regional economies of the EU. In particular, the negative peak in GDP is reached immediately in the case of
the TFP shock, while it takes between 4 and 7 years for the other two types of shocks. Employment reacts more slowly than GDP in the case of the TFP shock, but more rapidly in the case of the demand shock. We highlight important regional differences regarding the impact of the various shocks, as well as in the recovery paths after the negative GDP peaks. We also document qualitative differences in the evolution of GDP and employment during and after the shocks. On average we found that soon after the negative pick is reached, the legacy effects on employment are less pronounced than those of GDP in all cases under examination. This implies that GDP adjusts less rapidly than employment in the EU reflecting the higher flexibility of capital during the recovery. We also find that different types of shock call for different related macroeconomic variables, with competitiveness playing a crucial role in the case of TFP and demand shocks, and the role of capital in production being important in case of a risk premium shock.

Our analysis opens up a number of interesting possibilities for further research which can be of interest for both scholars and European policy makers. For example, the identification of the more resilient regions may be checked against the existing regional resilience indicators to check whether there is some correspondence, and in case there is any, for which of the shocks simulated in our analysis. Also a similar analysis could be performed on the variables that have been identified as related to the resilience performance of the European regions.

References


Tables and figures

Table 1. Shocks’ correlation Table (GDP)

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Table 2. Statistics on the period of the negative GDP and employment peaks

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Figure 1. The impact of the TFP shock in all regions and sectors on selected economic variables of the FR10 region
Figure 2. The impact of the risk premium increase in all regions and sectors on selected economic variables of the FR10 region

Figure 3. The impact of the demand shock in all regions and sectors on selected economic variables of the FR10 region
Figure 4. GDP difference with initial steady state in the period of the negative GDP peak (TFP shock)

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Figure 5. GDP difference with initial steady state in the period of the negative GDP peak (risk premium shock).
Figure 6. GDP difference with initial steady state in the period of the negative GDP peak (demand shock)
Figure 7. GDP recovery 10 years after the negative peak (TFP shock)
Figure 8. GDP recovery 10 years after the negative peak (demand shock)
Figure 9. GDP recovery 10 years after the negative peak (risk premium shock)
Figure 10 TFP shock. How relative competitiveness towards the ROW affect resistance and recovery.

a) Correlation between changes in GDP at period 10 and the log of the share of exports to the ROW with respect to GDP.

b) Correlation between average growth between periods 11-15 and the log of the share of exports to the ROW with respect to GDP.
Figure 11 Risk premium shock. The importance of capital intensity for resistance and recovery.

a) Correlation between changes in GDP at period 10 and the log of the share of capital with respect to GDP.

b) Correlation between average growth between periods 11-15 and the log of the share of capital with respect to GDP.
Figure 12 Export shock. The importance of capital and labour intensity for resistance and recovery.

a) Correlation between changes in GDP at period 10 on the y-axis and the log of the share of capital (red dots) and the share of labour (blue circle) both on the x-axis.

\[ y = 0.0337x - 0.105 \]
\[ R^2 = 0.3373 \]

b) Correlation between average growth between periods 11-15 on the y-axis and the log of the share of capital (red dots) and the share of labour (blue circle) both on the x-axis.