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Abstract

Using a spatial general equilibrium model, this paper investigates the resilience of EU regions under three alternative recessionary shocks, each of them activating different economic adjustments and mechanisms. Using a theoretical framework, we measure the vulnerability, resistance, and recoverability of regions and we identify key regional features affecting the ability of regions to withstand to and recover from unexpected external shocks. The analysis reveals that the response of regions varies according to the nature of the external disturbance and to the pre-shock regional characteristics. Finally, it seems that resilience also depends on factors' mobility.

Regional economic resilience in the European Union: a numerical general equilibrium analysis

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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.

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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 and 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. et al., 2010) and the existing studies vary wildly in terms of methods, units of analysis, and aspects of resilience analysed.

This paper explores the regional economic resilience of the NUTS-2 (European Nomenclature of Territorial Units for Statistics at level two) regions of the European Union (EU) using the spatial numerical general equilibrium model RHOMOLO (Lecca et al., 2018). It implements a variety of experiments with the purpose of investigating and quantifying the degree of resistance and recoverability of EU regions after an external perturbation.

An economic model is appealing to study economic resilience because it overcomes the limitation of case studies and empirical analyses. Only when a shock arises and is perfectly identified, it is possible to determine whether the evolution of regional adjustments is consistent with a resilience path (Sensier et al., 2016). The simultaneous variety of shocks affecting an economy can be challenging to disentangle and additional shocks and disturbances at a later stage can blur the recovery path of the economies hit by the crisis in the first place. A general equilibrium framework permits to reduce this type of complexity and simplify significantly the analysis.

In a conventional general equilibrium modelling framework, resilience is seen as the economic system's ability to recover from an external disturbance. The speed at which the economy adjusts to the pre-shock steady-state equilibrium is one of the main objects of interest in this context. Various alternative external shocks (for instance, supply-side or demand-side shocks) can be implemented to test whether regions respond differently

to disruptions that are intrinsically different in nature. Essentially, regions are expected to respond differently in relation to the nature of the shock.[1]

In our analysis, we simulate three different scenarios, each one with a different type of negative shock contemporaneously 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. A TFP shock immediately changes the economic structure of 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 effects. We then use the data coming out of the model simulations in order to study regional economic resilience by constructing variables capturing how the regional economies respond to the shocks and how they behave when recovering from them. Finally, we investigate the main regional characteristics influencing the ability of regional economies to resist and recover after an unexpected external shock.

The remainder of the paper is as follows. Section 2 discusses the multi-faceted concept of regional economic resilience. Section 3 briefly presents the RHOMOLO model and section 4 illustrates the strategy adopted for the regional resilience analysis. Section 5 presents and discusses the modelling results in terms of resistance and recoverability of regions. In section 6 we attempt to identify some of the key determinants of resilience, while section 7 explores the potential role played by factor mobility. Finally, section 8 concludes.

2. Regional economic resilience

As noted above, there is no unique and commonly accepted definition of regional economic resilience; rather, this highly complex concept has been expanded and analysed along a number of dimensions. Martin (2012) identified three of them: resistance (sensitivity to economic shock impacts), recoverability (the extent and nature of recovery), and reorientation/renewal (the ability of a region to adapt in response to a shock and return to its long-run growth path). Later works (Martin and Sunley, 2015; Martin et al., 2016; Giannakis and Bruggeman, 2017) postulated the existence of additional dimensions such as vulnerability to describe the sensitivity to different types of shocks, and robustness, that is how firms, workers, and institutions respond and adapt to shocks.

The existing literature offers several contributions exploring one or more of those aspects of regional economic resilience, mostly using case studies and concentrating on two main dimensions: sensitivity to the shock and recoverability from it (for example, Rizzi et al., 2018, define these two dimensions as the shock and recovery phases). Faggian et al. (2018) analyse the resistance and recovery of the Italian local labour systems during and after the Great Recession, claiming that renewal could only be studied with firm-level data (the use of individual-level data offers a number of additional avenues for research

[1] See for example Faggian et al. (2018, p. 396): "A region which might be resilient to a certain type of shock might not be to another type".

as demonstrated by Doran and Fingleton 2015 and 2016). Fingleton et al. (2012) and Martin et al. (2016) study the same two dimensions, resistance and recoverability, in the UK regions during and after the four major recessions of the last four decades concentrating on employment and on the role played by the industrial structure. 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 Greek regions and on the differences between rural and urban ones, while Pudelko et al. (2018) study resistance and recovery after the Great Recession in the regions of Western Germany concentrating on the role played by industrial specialisation. Although this list does not pretend to be exhaustive, it appears that the empirical literature on regional economic resilience is dominated by case studies concentrating on specific regions, shocks, and aspects of resilience (mainly resistance and recovery), while our analysis is based on a different method, that of economic modelling.

We offer a novel contribution to the literature by using a general equilibrium model in order to study the economic resilience of the EU NUTS-2 regions. Modelling has already been used to study resilience, but in other contexts mostly pertaining to ecology and disaster studies. For instance, Rose and Liao (2005) study regional resilience in the case of disruption of water services in the Portland Metro economy in Oregon (USA) using a general equilibrium modelling framework.

Since we adopt a conventional general equilibrium approach, the simulation experiments presented in the paper are grounded on the so called "engineering resilience" approach (Hill et al., 2008; Martin and Sunley, 2015; and Pudelko et al., 2018) largely inspired by the work done in physical sciences and engineering, rather than evolutionary resilience (Boschma, 2015). In a general equilibrium model, the system is bound to get back to its original equilibrium after a temporary shock, therefore providing the perfect framework to study recovery defined as the return to the pre-shock state, rather than a renewal process modifying the economic structure and relationships within the regional economic systems. The latter concept can be referred to as evolutionary resilience (a concept taken from the ecology field) and it involves structural and operational adaptation in response to shocks, with economies bouncing forward rather than bouncing back (Martin and Sunley, 2015). This is something that a modelling framework such as ours is not equipped to study and it is related to the renewal concept introduced above.

Despite its advantages, our approach has some shortcomings. As just stated, regional economies are constrained to adjust towards a stable equilibrium in the long-run, preventing therefore an investigation of the adaptive capacity of regions to move off their equilibrium growth path. Simmie and Martin (2010) and Martin and Sunley (2015) discuss the problems associated with the "equilibrist" interpretation of resilience pointing out that regional economic resilience should be analysed by adopting an evolutionary perspective that intrinsically emphasise the role of the 'multiple phases' of the adaptive cycle of the regional economic evolution. We do believe however that an "equilibrist" perspective should complement alternative methods based on ecological or evolutionary frameworks in order to improve our understanding of resilience under different angles.

We firstly study how the EU regions react to various types of shocks, looking both at their vulnerability and at their resistance by concentrating on the magnitude of the initial short-run impacts of the shocks. In the second part of the analysis, we study the recoverability of regions by looking at the performances of the regional economies in

terms of getting back to the original steady-state equilibrium. As explained above, it is common for economic studies to concentrate on these dimensions of regional economic resilience, and the general equilibrium modelling approach is ideal to do so. Finally, we investigate the main regional characteristics that influence the ability of regional economies to resist and recover after an unexpected external shock. In order to do so, we resort to an econometric analysis of the modelling data building on the existing literature to identify a few key variables as drivers of the resilience outcomes observed in the simulations.

3. A condensed description of the RHOMOLO model

In this section we outline the main equations governing the model to help the reader to identify the main drivers and determinants of the spatial outcomes generated by the model. This presentation is useful to understand the shocks featured in the scenario analysis explained in section 4, and more details on the RHOMOLO model can be found in Lecca et al. (2018). [2]

The 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 to keep supply and demand balanced in all markets.

The domestic economy consists of 267 endogenous regions, those forming the EU Member States. The ROW is an exogenous external sector. The model features ten NACE rev.2 economic sectors (agriculture, forestry, and fishing; energy; manufacturing; construction; trade and transport; information and communication; financial activities; R&D; public administration; other services) in which firms operate under a monopolistic competition framework à la Dixit-Stiglitz (1977).

Consumers

The aggregate consumption level C_r is directly related to the disposable income YC_r:

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

Where P_r^c is the consumer price index and $s_r$is the rate of savings. 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:

$$C_r = \left(\sum_{j=1}^{J} \sum_{i=1}^{N_{r,s}} \vartheta_{r,j,i} \left(c_{r,j,i} \right)^{\rho^c} \right)^{\frac{1}{\rho^c}} \tag{2}$$

where $c_{r,j,i}$ is the consumption of varieties *i=1…N* 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.

Government

[2] Additional documentation can be found at https://ec.europa.eu/jrc/en/rhomolo. The RHOMOLO model has also been used in Lecca et al. (2020), Christensen et al. (2019), Kancs and Lecca (2018), and Di Comite et al. (2018).

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.

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 (3) and (4) respectively:

$$Y_{r,j} = Ay_{r,j}\left[\delta_{r,j}^{Y} \cdot KD_{r,j}^{\rho_j^y} + \left(1 - \delta_{r,j}^{y}\right) \cdot LD_{r,j}^{\rho_j^y}\right]^{\frac{1}{\rho_j^y}} - FC_{r,j} \tag{3}$$

$$V_{r,j} = \left(\sum_{s} b_{r,s,j} v_{s,j}^{\rho^v}\right)^{\frac{1}{\rho^v}} \tag{4}$$

In equation (3), $Y_{r,j}$, 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 $\rho_j^y = \frac{\sigma^y - 1}{\sigma^y}$ (where σ^y is the elasticity of substitution) and the share parameter δ_j^Y. The scale parameter $Ay_{r,j}$ represents the conventional hicks neutral technical change parameter in this production function.

The input-output relations are shown in equation (4) where the composite demand for intermediate inputs is again a CES combination of $v_{s,j}$, that is the purchase of intermediate inputs of each secors *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 $b_{r,s,j}$.

From cost minimization we obtain the demand for capital and labour in each sector *j*, represented in equations (5) and (6).

$$KD_{r,j} = \left(Ay_{r,j}^{\rho_j^y} \cdot \delta_{r,j}^{y} \cdot \frac{Pk_r}{Py_{r,j}}\right)^{\frac{1}{1-\rho_j^y}} \cdot Y_{r,j} \tag{5}$$

$$LD_{r,j} = \left(Ay_{r,j}^{\rho_j^y}\left(1 - \delta_{r,j}^{y}\right) \cdot \frac{w_r}{Py_{r,j}}\right)^{\frac{1}{1-\rho_j^y}} \cdot Y_{r,j} \tag{6}$$

where $Py_{r,j}$, $Pk_{r,j}$ and w_r are respectively the price of value added, the price of capital and the wage rate.

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.

$$x_{r,r\prime,j} = \eta_{r,r',i,}\left(\frac{P_{r\prime,j}}{P_{r,r\prime,j}}\right)^{\sigma_j} X_{r\prime,j} \tag{7}$$

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

$$P_{r\prime,j,t} = \left(\sum_{r\prime} N_{r,j}\eta_{r,r',i,}P_{r,r',j,t}\right)^{1-\sigma_j} \tag{8}$$

where the price $P_{r,r\prime,j}$ set by a firm of region *r* (gross of trade cost τ) 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:

$$P_{\boldsymbol{r,r',j}} = \frac{\tau_{r,r',j}P^*_{r,j}}{1-\frac{1}{\varepsilon_{r,r',j}}} \tag{9}$$

where

$$\varepsilon_{r,r\prime,j} = \sigma_{r\prime,j} \tag{10}$$

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

$$P^*_{r,j} = a^y_{r,j}PY_{r,j} + a^{Int}_{r,j}PIN_{r,j} \tag{11}$$

$a^y_{r,j}$ and $a^{Int}_{r,j}$ are the share parameters attached to the value added and intermediate inputs respectively.

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 σ 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.

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. Further parameterization also permits to use a dynamic or a static form of wage setting. The general formulation is expressed in log as in equation (12):

$$rw_t = a + \alpha\, rw_{t-1} - \beta\, u_t + \gamma\Delta p_t - \lambda(rw_{t-1} - \mathrm{T}_t) - \theta\Delta u_t \tag{12}$$

The real wage rw_t is negatively related to the unemployment rate, u_t, the change in unemployment between two subsequent periods Δu_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_r^P adjusted by depreciation, $\delta_r K_r^P$:

$$I_r^P = v\,[K_r^* - K_r^P] + \delta_r K_r^P \tag{13}$$

where, *v* is the accelerator parameter and δ is the depreciation rate. According to this formulation the investment capital ratio ($\varphi = I_r^P / K_r^P$) is a function of the rate of return to capital (*rk*) and the user cost of capital (*uck*), allowing the capital stock to reach its desired level in a smooth fashion over time.

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

$$uck_r = (r + \delta_r)p_{EU}^I + \dot{p}_{EU}^I + rp_r \tag{14}$$

r, δ_r, p_{EU}^I and rp_r denote the interest rate, the depreciation rates, the investment price index and an exogenous risk premium respectively. $\dot{p}_{EU}^I$ is the change of the investment price index defined between two subsequent periods.

In equation (14) the interest rate is fixed and equal for each region; δ_r is fixed but we allow variations between regions in the base year; rp_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_{EU}^I. In the long-run, we should then expect changes in capital returns in all regions to equalise. Proceeding in this way means also that 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:

$$\dot{K}_r^P = \delta_r K_r^P + I_r^P \tag{15}$$

Migration

The labour supply evolves as follows:

$$L_{r,e,t} = L_{r,e,t-1}(1 + m_{r,e}) \tag{16}$$

The labour forces $L_{r,e}$, in each region and for different type of skills, *e*, evolve according to the net migration rates ($m_{r,e}$) expressing incoming minus outgoing workers, relative to the original size of the labour force, defined as follows:

$$m_{r,e} = \frac{\sum_{r'} s_{r,',r,e} L_{r,e} - \sum_{r'} s_{r,r',e} L_{r',e}}{L_{r,e}} \quad (17)$$

where $s_{r',r}$ is the share (or probability) of workers moving from region *r*' to *r* determined as (see Persyn et al., 2014):

$$s_{r,r',e} = \frac{exp(\Psi_{r,r'}\beta)}{\sum_s exp(\Psi_{r,r'}\beta)} \quad (18)$$

where $\Psi_{r,r'}$is a vector of characteristics of the regions such as, wages, unemployment and distance between regions while β is the vector of coefficients related to these characteristics as estimated in Persyn et al. (2014).

Equilibrium and closing the system

The total absorption equation (19) 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):

$$X_{r',j} = \sum_i^N \sum_j v_{r,i,j} + C_{r,j} + I_{r,j} + G_{r,j} \quad (19)$$

As for the capital market, capital demand equals the capital stock (20):

$$\sum_i^N \sum_j kd_{r,j,i,=p} = K_r^P \quad (20)$$

The labour market is equilibrated through endogenous changes in unemployment rates as described in equation (21):

$$\sum_i^N \sum_i ld_{r,j,i,e} = (1 - u_{r,e}) L_{r,e} \quad (21)$$

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

$$fc_{r,i} P^*_{r,i,t} N_{r,i,t} = \sum_{r'} N_{r,i,t} x_{r,r',i,t} P_{r,r',i,t} - P^*_{r,i,t} N_{r,i,t} \left(Y_{r,i,,t} + V_{r,i,,t}\right) \quad (22)$$

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.

3.1 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 SAM for the year 2013 (Thissen et al., 2019). The choice of year 2013 for the calibration is based on data availability, as it is the most recent year for which regional SAMs can be built with a sufficient degree of reliability.[3]

The structural parameters of RHOMOLO are either borrowed from the literature or estimated econometrically. The parameters related to the elasticities of substitution both on the consumer and on the producer side are either 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 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 β=0.1 (Nikjamp and Poot, 2005).

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. Further details on the calibration and parameterization of the model can be found in Lecca et al., (2018).

4. 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 in the model's economies: 1% reduction in TFP, 5% increase in risk premium, and 5% reduction in the demand of exports to the ROW. All shocks implemented are temporary. In each region and sector, the shock is imposed for the first 10 periods but the intensity diminishes over time with a discount rate of 0.25. After period 10, the perturbed exogenous variables bounce back to their initial steady-state equilibrium, therefore the economy should eventually converge to the pre-shock equilibrium. We expect regional agents to react differently both during the perturbation periods and during the transition towards the steady-state equilibrium.

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. In line with the informative objective of the paper and in order to facilitate our analysis, the implemented shocks do not involve random components. Furthermore, structural and behavioural elasticities are the same for each region. This allows us to

[3] As we will see in the proceeding sections, the shift and share parameters calibrated in the model (defining the initial regional endowments) play a great role in determining the resistance and recoverability of regions. Unfortunately, the only existing interregional dataset at EU NUTS2 level able to cover the full interregional trade flows is only available for the year 2013. This has prevented us to test the model with an alternative reference years.

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, we briefly analyse the dynamic adjustments mechanisms of key macro-economic variables using the Île de France region (FR10) as an illustrative case.

The demand shock entails a 5% reduction of the exports to the ROW in all regions and sectors: in this case, the variable of interest is $x_{r,ROW,j}$ appearing in equation (7). Figure 1 plots the percentage change deviations from the initial steady-states of some key variables. We notice 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, for the first four periods, the changes in employment are lower than the change in GDP. From the medium- to the long-run GDP falls more than employment meaning that capital is falling more than GDP. The legacy effects of the shock linger for at least ten additional periods beyond the termination of the shock for all the five considered variables.

The negative TFP shock implies a 1% reduction from base year values of the exogenous variable Ay appearing in equation (3). Figure 2 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 as explained above. 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 takes the economy more than 20 periods to go back to the original equilibrium.

The immediate impact of an increase in the risk premium is a rise in the user cost of capital defined by equation (14). This makes capital relatively more expensive, generating a fall in the capital/labour ratio.[4] 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 periods, the demand side-effect of the shock is also accompanied by a reduction in the capital stock further reducing output. This combination of demand- and

[4] The risk premium is a calibrated exogenous variable and it is obtained as the difference between the market return and the risk free rate (defined as interest rate plus depreciation).

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 3. 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.

Figure 1. The impact of the demand shock in all regions and sectors on selected economic variables of the FR10 region

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

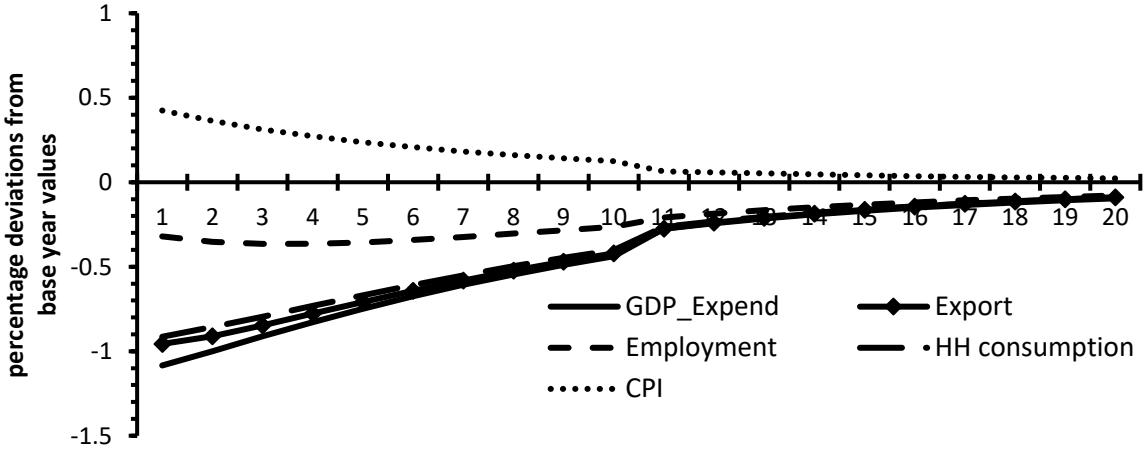


Figure 3. The impact of the risk premium increase in all regions and sectors on selected economic variables of the FR10 region

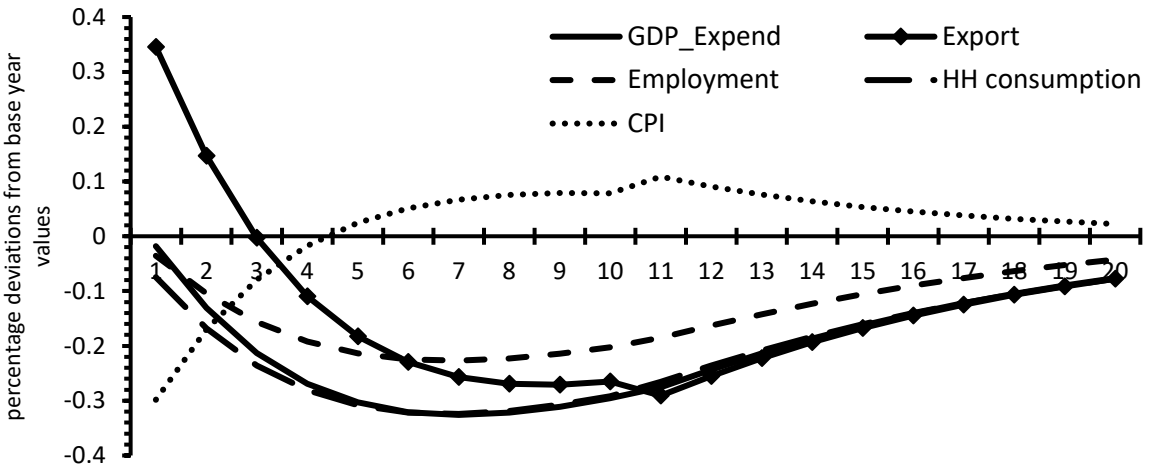


Table 1 shows some descriptive statistics of the periods in which the EU regions reach the negative peak in GDP that is the time at which we detect the largest negative changes in GDP after each shock. We observe that the negative peak is reached immediately in the case of the TFP shock (after one period), while it takes on average slightly more than six periods for the other two types of shocks. Great variation across regions is observed under the demand-shock and the risk premium shock, with the period in which the negative changes in GDP reach their peak varies from a minimum of one to a maximum of 11 periods.

Table 1: EU summary statistics on the period of the negative peak in GDP after the three shocks

	TFP shock	**Demand shock**	**Risk premium shock**
Minimum	1	1	1
Maximum	2	11	11
Mean	1.0	6.5	6.2
1st quartile	1	6	6
Median	1	7	6
3rd quartile	1	7	7

5. The resistance and recoverability of regions

The initial findings presented in the previous section suggest that the regional responses to external perturbation change depending on the nature of the shock. Therefore, it is also likely to expect that the type of shock matters for the capacity of regions to resist to negative shocks and to recover from them. In order to begin investigating how regions react to the shocks defined above, it is useful to compute two measures of resistance and recoverability proposed by Martin et al. (2016) based on the outcomes of our modelling experiments (separately for each shock-specific simulation):

$$Resistance_r = \frac{GDPgrowth_{\mathrm{r}}{}^{\mathrm{contraction}} - GDPgrowth_{\mathrm{EU}}{}^{\mathrm{contraction}}}{\left|GDPgrowth_{\mathrm{EU}}{}^{\mathrm{contraction}}\right|} \quad (23)$$

$$Recovery_r = \frac{GDPgrowth_r{}^{\text{Recovery}} - GDPgrowth_{EU}{}^{\text{Recovery}}}{\left|GDPgrowth_{EU}{}^{\text{Recovery}}\right|} \quad (24)$$

The two measures are constructed in a similar way: they both measure the gap between the average growth in the region and the average growth for the EU as whole. However, they diverge with respect to the time period considered: the contraction and the recovery period. For each region, the contraction period is defined as the time frame from the beginning of the shock (period 1) to the period in which the region reaches its negative GDP peak. The recovery period is assumed to start one period after the peak and to end after six periods. The two measures in equation (23) and (24) are centred around zero. A positive value of *Resistance* indicates that a region is less affected by the contraction relative to the EU average. Similarly, a positive value of the *Recovery* shows that the regions have a high recoverability relative to the EU average. For each shock implemented in the model, the *Resistance* and *Recovery* measures are calculated and plotted in Figures 4, 5, and 6. Each of them results in the EU regions being positioned in one of four quadrants distinguishing between high resistance-weak recoverability (Top-left), high resistance-high recoverability (top-right), weak resistance-high recoverability (bottom-right) and weak resistance-weak recoverability (bottom-left).

A casual inspection of the plots suggests that only in the cases of the TFP and the risk premium shocks we are able to identify a negative correlation between *Resistance* and *Recovery*, albeit small. It is difficult to detect some sort of direct linear relationship in the third scenario. This suggests that recessionary shocks directly affecting the supply-side of the economy will influence the resistance and recoverability of regions in the opposite way: regions able to recover faster (slowly) are expected to be less (more) resistant to external perturbations. Furthermore, the plots suggest that the position of regions across the four quadrants is not always the same and change according to the type of shock implemented in the model. This result is in line with Faggian et al. (2018) according to which a region shows different resilience degrees depending on the type of shock.

It is however possible to identify a small group of regions that constantly maintain their position in one of the quadrants. In particular, 42 regions are likely to experience higher resistance relative to the EU average and 87 regions recover faster than the EU average regardless the type of shock. Interestingly, a group of 28 regions, 22 of which belong to the UK, show high resistance and recoverability regardless the simulation performed and therefore always appears in the top-right quadrant. On the other hand, only three regions retain their position in the left-bottom quadrant across the thre shocks: namely Yugoiztochen (BG34), Languedoc-Roussillon (FR81), and Croatia (HR).

Figure 4. Recovery and Resistance - demand shock

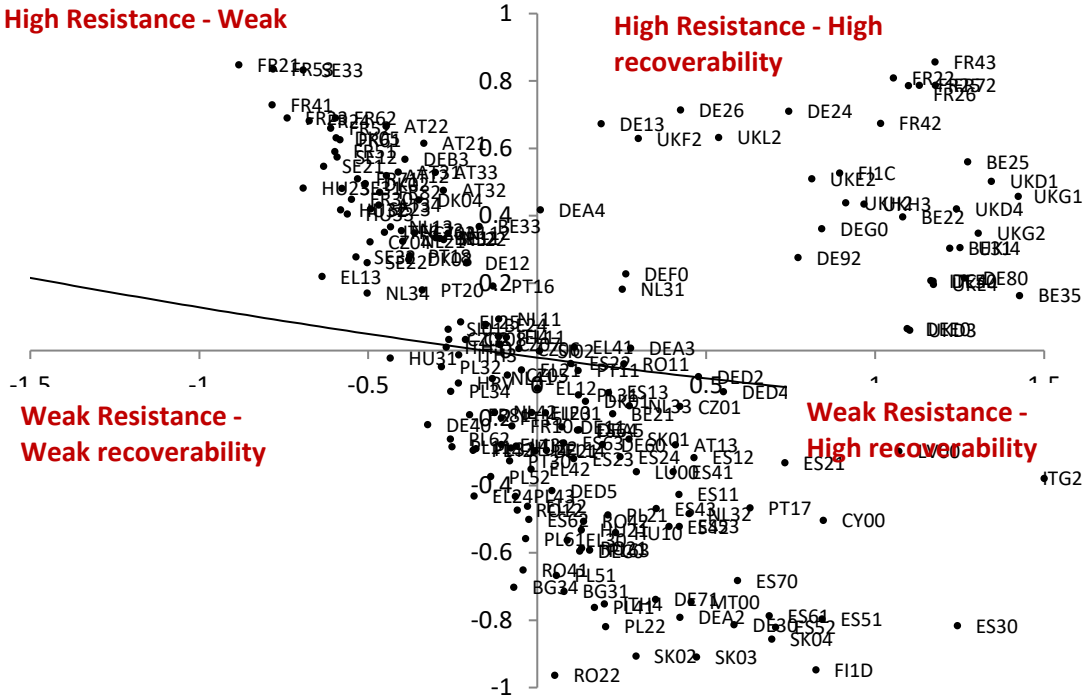


Figure 5. Recovery and Resistance - TFP shock

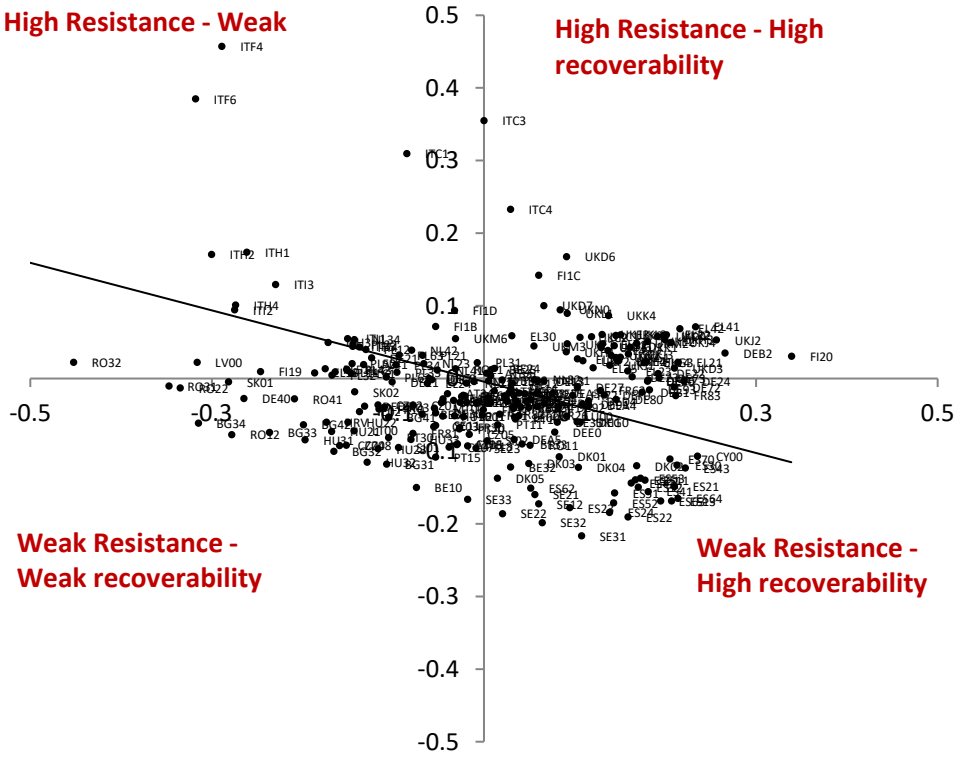
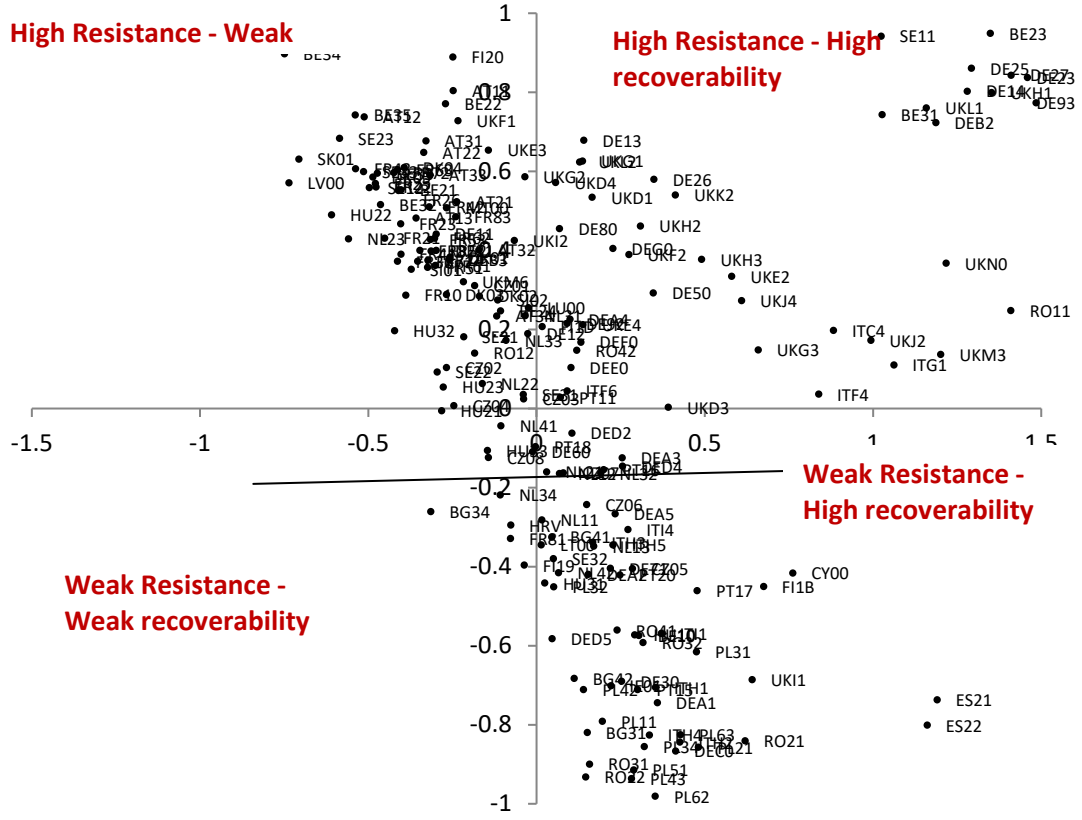


Figure 6. Recovery and Resistance - risk premium shock



Although informative, Figures 4-6 do not shed light on the reasons behind the different economic performances of the EU regions following a negative shock. The next section uses two different econometric models built on the model's simulated data (for which Figures 4-6 constitute an early visual exploration) to study the main drivers and determinants of resistance and recoverability.

6. The determinants of resilience

In this section, we investigate to what extent regional characteristics influence the ability of regional economies to resist and recover after an unexpected external shock. This is one of the main questions that the scientific literature is trying 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? Or, as predicted by some existing studies, the more specialized the regional economic structure, the lower the resistance of regions? These are key questions to understand the phenomenon of regional economic resilience. 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 the quantitative impact during the perturbation period (resistance) and in terms of time required to get back to the equilibrium (recoverability). This is endogenously determined in the model and it is affected by the regional initial conditions and the calibrated base year steady-state.

We resort to two econometric models based on the model's simulated data presented above in order to identify the main drivers of resistance and recoverability. We do this for two main reasons. First, given that we are working with 267 regions with a significant number of endogenous variables, a clear and comprehensible presentation of the results

is problematic. The high dimensionality of the model prevents a more straightforward presentational approach, therefore it is easier to perform appropriate regression analyses on the model's simulated data to gain insights of the average behaviour of regional economies under alternative initial characteristics. Second, the econometric analysis helps to generalize and better summarize the results. Thus, we do not focus on the results of specific regions, but rather on the average effects driven by changes in the initial regional characteristics.

We begin by analysing the regional characteristics that affect the resistance of regions, and subsequently we turn our attention to their recoverability. Both analyses are done separately for the three different kinds of shocks, allowing for the role of each determinant to depend on the nature of the initial perturbation. A set of economic resilience potential determinants have been selected through an initial screening of bivariate correlations involving variables already considered in previous works on economic resilience. This helped us to exclude redundant variables, focusing more on the most promising drivers of resilience. These are listed below.

Factor intensity. It indicates whether the regional production process is more or less capital (or labour) intensive. It is reasonable to expect that regions relatively more capital intensive could experience a bigger drop in economic activities when the recessionary shock directly affects investments and capital adjustments. Variables measuring either capital or labour intensity have been used for similar analyses by, among others, Briguglio et al. (2009) and Rizzi et al. (2017).

Openness. The degree to which an economy depends on foreign trade affect the vulnerability of regions (Briguglio, 1995 and Briguglio et al., 2009). Therefore, regions that are more open can potentially be less resistant to external shocks because of its dependence to external environments. On the other hand, openness might also be a source of strength thanks to the positive role played by international trade.

Specialization. Industrial specialization (diversification) has been widely studied in the context of economic growth (Glaeser et al 1992; Henderson et al., 1995; Harrison et al., 1996; Henderson 2003) and a number of authors have analysed its role as determinant of economic resilience (Frenken et al., 2007, Hill et al., 2008; Fingleton et al., 2012, Pudelko et al., 2018; Faggian et al., 2018; Rizzi et al., 2017 and Lezzetti et al., 2019). Theoretically, highly specialized regions can suffer higher damages when the economic shocks involves the sectors in which they are specialized. It is however unclear what to expect in terms of influence of this variable on resistance and recoverability. For instance, Martin et al. (2016) find that a diverse economic structure may confer greater regional resilience to shocks than more specialized ones.

Our empirical strategy starts with the following model for resistance:

$$\Delta GDP_r^{peak} = \beta_0 + \beta_1 LS_r + \beta_2 Openess_r + \beta_3 SI_r + \beta_5 CD + \varepsilon_r \quad (25)$$

where *r* is the region and ϵ_r is the heteroscedastic random error. The dependent variable ΔGDP_r^{peak} is the change in GDP observed at the time of the negative peak, which is the highest negative change in GDP observed during the period of the shock. Typically, regions experiencing largest negative changes in GDP are showing less resistance to the shock. Although the magnitude and duration of the shock is the same for all regions, the time at which they reach the largest negative impact might diverge, as demonstrated in

Table 1. For example, under the TFP shock, the dependent variable always takes the values of the GDP changes recorded one period after the shock (see Table 1). For the other two shocks, the period at which the largest negative changes in GDP is observed varies widely.

As for the right-hand side variables, LS_r is the initial labour share; $Openess_r$ is equal to the sum of import plus export divided by the gross domestic product; and SI_r is the standard Krugman (1991) specialization index adapted to the EU regional context.[5] CD is a set of country dummies, one of the two alternative ways to control for geographic factors, the other being a regional contiguity variable accounting for the number of shared borders of the 267 regions of the EU (CTG). Table 2 contains some descriptive statistics of the variables used for the estimation of equation (25). The empirical model is estimated using Ordinary Least Square (OLS) with robust standard errors (the results of the Moran's I test of spatial autocorrelation, not reported but available upon request, do not suggest any spatial dependence issue).[6]

Table 2 Summary statistics of the variables used in the econometric model

Variables	N	Mean	SD	Min	Max
ΔGDP					
TFP	267	-1.01	0.12	-1.28	-0.42
Demand shock	267	-0.07	0.26	-1.00	0.00
Risk-premium shock	267	-0.48	0.35	-1.46	0.00
LS	267	0.58	0.10	0.25	0.74
Openness	267	5.60	1.72	3.55	20.56
SI	267	0.40	0.20	0.09	1.12

Table 3 shows the estimated coefficients associated with the three alternative versions of model (25) estimated separately for the three scenarios of the analysis (TFP shock, demand shock, and risk premium shock). Columns (1) contain the results of the baseline model where the set of explicative variables is constituted only by the labour share LS, trade openness $Openness$, and the specialization index SI. The estimates reported under columns (2) and (3) are obtained by adding to the model either the country dummies or the regional contiguity variable, respectively. A first look at the table shows that most of the coefficients are statistically significant and have the expected signs.

Trade openness appears to be negatively related to GDP when either a TFP or a demand shock hits the economy. This means that the higher the initial ratio of exports and imports over GDP, the bigger the loss of GDP caused by the shock. The explanation for this could lie in the more export-oriented regions being more sensitive to these two shocks due to the competitiveness effects of both the change in TFP (through the changes in commodity prices) and of the imposed reduction in the exports to the ROW. On the other hand, the role of openness is not clear in the risk premium scenario as the

[5] SI is calculated with the following formula:

$$Specialization\ Index_r = \sum_i \left| \frac{E_{i,r}}{\sum_i E_{i,r}} - \frac{E_{i,EU}}{\sum_i E_{i,EU}} \right|$$

[6] We did not detect multicollinearity in the regression analysis. The maximum value of the variance inflation factor is lower than 2 in all cases.

estimates of its coefficient depend on the inclusion or exclusion of the country dummies and the contiguity variable.

Table 3: Regressions results of the resistance model

	TFP shock			**Demand shock**			**Risk Premium shock**		
Variables	**(1)**	**(2)**	**(3)**	**(1)**	**(2)**	**(3)**	**(1)**	**(2)**	**(3)**
LS	-0.111	0.186**	-0.117*	0.113***	0.199***	0.112***	2.533***	3.280***	2.495***
	(0.058)	(0.085)	(0.058)	(0.037)	(0.065)	(0.008)	(0.162)	(0.158)	(0.159)
Openness	-0.013***	-0.009***	-0.013***	-0.048***	-0.048***	-0.051***	-0.007	0.016**	0.003
	(0.030)	(0.003)	(0.003)	(0.008)	(0.009)	(0.008)	(0.009)	(0.009)	(-0.009)
SI	0.442***	0.317***	0.460***	-0.071*	-0.081*	-0.052	-0.038	0.013	0.055
	(0.028)	(0.026)	(0.029)	(0.0358)	(0.039)	(0.037)	(0.077)	(0.069)	(0.079)
constant	-1.049***	-1.185***	-1.072***	0.126	-0.062	0.079	-1.982***	-2.282***	-2.096***
	(0.045)	(0.067)	(0.046)	(0.067)	(0.119)	(0.069)	(0.127)	(0.126)	(0.127)
CTG			-0.006*			0.014			0.029***
			(0.003)			(0.007)			(0.007)
Country dummies	no	yes	no	no	yes	no	no	yes	no
No. obs.	267	267	267	267	267	267	267	267	267
R-square	0.49	0.82	0.50	0.22	0.51	0.23	0.52	0.89	0.54

Notes: Standard errors in parentheses; *** indicates significance at the <0.001 level; **<0.01; *<0.05

The coefficients associated with the labour share are positive and significant under the demand and risk premium shock for each of the alternative models estimated. For the TFP shock, the labour share coefficient is positive and significant only when country dummies are included. As for the demand and risk premium scenarios, the estimates imply that the sign of the relationship between the capital share and GDP changes is negative during the perturbation period. This effect is related to the structure of the initial steady-state equilibrium, where export-oriented regions are typically more capital intensive and for this reason will be less resistant than labour intensive regions under external demand shocks. For the case of an increase in the risk premium, the reduced expectations of future profits make both investments and the capital stock to fall. We then observe greater disinvestment effects and therefore larger decreases in capital stock in those regions with higher capital-GDP ratios. This implies that capital-intensive regions are likely to suffer relatively more than those regions with lower capital shares in the original equilibrium.

The estimated coefficient of the specialization index is significant and positive in all three variants of the model in the case of the TFP scenario, signalling that regions that are more specialized are likely to be less affected when the shock hits the economy. The opposite is true in the case of the demand shock, although the coefficient is significant only when the contiguity variable is excluded from the model. Finally, results for this variable are inconclusive in the risk premium scenario.

We now turn our focus on the main factors driving regional recovery by using a probit model based once again on the model's simulated data. The estimated equation is the following:

$$\Pr(Y_r = 1|X_r) = \theta(X_r^T\beta) \tag{26}$$

Y is a regional dummy variable that takes the value 1 if the number of periods required to get back to the steady-state equilibrium after the period of the peak is below the average number periods needed in the EU as whole. It takes the value of zero otherwise.

X^Tindicates the set of explanatory variables. In addition to the variables used for the estimation of equation (25), this model also includes ΔGDP^{peak} as defined in equation (25). This is added to the right-hand side variables in order to evaluate whether regions experiencing higher distress (larger drops in GDP) in the aftermath of a shock are also struggling to readjust and recover. The estimated coefficients and marginal effects of the probit model of equation (26) are reported in Table 4.

Table 4: Regressions results of the recoverability model

	TFP shock		Demand shock		Risk premium shock	
	Coeff.	Change in prob.	Coeff.	Change in prob.	Coeff.	Change in prob.
LS	9.72*** (1.35)	3.11***	10.98*** (2.26)	3.54***	24.42*** (4.13)	2.79**
Openness	-0.04 (0.06)	-0.01	-0.42* (0.17)	-0.14*	0.30 (0.19)	0.03
SI	-0.41 (0.74)	-0.13	-1.06* (0.52)	-0.34*	-1.33* (0.59)	-0.15*
ΔGDP^{peak}	13.46*** (2.12)	4.30***	6.58*** (1.07)	5.92***	4.27*** (0.66)	0.49**
Constant	-0.611*** (0.231)		-2.58 (1.88)		-14.87** (2.98)	
No. obs.	267		267		267	
Pearson χ^2	232.38		188.00		3509.62	
Pseudo R^2	0.35		0.58		0.23	

Notes: Standard errors in parentheses; *** indicates significance at the <0.001 level; **<0.01; *<0.05

In all scenarios, the marginal effect of the GDP change, following the negative shock, is positive and statistically significant. This means that the larger the loss in GDP (in absolute value), the less probable is for the region to recover its steady-state faster than the EU average. The labour share shows positive marginal effects in all cases, thus larger labour shares are associated with a more rapid recovery. The specialization index and trade openness have mainly negative marginal effects, meaning that higher values of these two variables are associated with a lower probability of making a faster recovery after the negative GDP peak. However, the specialization effects are statistically significant only in two cases out of three (demand and risk premium scenarios), and the openness effect is only significant when estimated on the data arising from the risk premium scenario. Thus, it appears that, at least for certain types of shocks, more open and highly specialized regions are less likely to recover faster than the EU average.

The above analysis on the determinants of both regional resistance and recoverability reveals that certain initial conditions are of extreme importance for these two aspects of regional economic resilience. The empirical models built on simulated data suggests that the calibrated shares[7] which govern the initial model's equilibrium can contemporaneously affect the level of resistance and the speed of recovery after negative shocks. Interestingly, but not surprisingly, the legacies effects of the shocks are also related to the magnitude of the impact caused by shock itself.

7. The role of factors mobility

In this section, we assess the sensitivity of the results in relations to some of the model's assumptions.[8] All the results presented so far refer to the model with both capital and

[7] The base year data is therefore of utmost importance in this analysis. Given that alternative dataset are not currently available, the results of the model have been generalized using regression models in order to obtain average predicted behaviour of regions with specific characteristics.

[8] Reporting the sensitivity of the results to alteration of behavioural parameters has undoubtedly a pedagogical benefit. However, it is relatively easier to guess how variables move in relation to changes in behavioural parameters (e.g., elasticity of substitutions) for the three illustrative recessionary scenarios under investigation. Variations in the trade and production elasticities only

labour assumed to be mobile across EU regions. The literature on resilience has highlighted a key role of factor mobility: for example, Yair Grinberger and Samuels (2018) study in a theoretical setting how resilience outcomes change depending on the existence of labour market mobility after a natural disaster. The intuition behind such result is simple: when a region is hit by a shock, factors of productions are likely to quickly leave the region and possibly exacerbate the effects of the initial shock. At the same time, as regions adjust to the shock, new factors of production may flow into the region and help both softening the impact of the shock and accelerating the recovery.

In order to study the role of factor mobility, we run three alternative sets of simulations in which we turn off either capital mobility, labour mobility, or both at the same time. We then compute, and report for the EU as whole, the percentage differences in EU GDP under no factor mobility against the three alternative specifications in which there is some mobility (either capital or labour) or full mobility (which is our default assumption). Figures 7, 8 and 9 show the evolution of the GDP differences between these model's specifications over thirty periods, for the TFP shock, demand shock, and risk premium shock respectively. In terms of interpretation, if the observed difference is positive it means that factor mobility makes the region relatively better off than in the case in which the factors of production are not allowed to move across regions. If the GDP differences are negative, factor's mobility exacerbates the effect of the negative shock.

In the case of the TFP shock, and excluding the firsts two periods, we typically observe that factor mobility makes regions relatively more vulnerable, reducing both their resistance (larger GDP loss after the impact of the shock) and their recoverability (GPD is lower also in the period after it reaches the negative GDP peak). The position of the curves in Figure 7 also suggests that the vulnerability and the adjustment of the economy towards a steady-state equilibrium at least up to period 25 is more affected by labour mobility rather than capital mobility.

Things are different in the demand shock scenario. Capital mobility moderates the negative effects of the shock on EU GDP, while labour mobility exerts the opposite effect for the first 12 periods. When both factors are allowed to move across regions, the negative effects of the shock are exacerbated for the first 20 periods, after which the positive effects of labour mobility dominate the overall impact of factor mobility. In the risk premium scenario, labour mobility moderates the negative effects of the shock on GDP, but its effect is dominated by the negative influence of capital mobility for the first 20 periods when both factors are allowed to move freely. Capital mobility makes the EU economy less vulnerable in the first four periods, but less resilient afterwards.

alter, more or less proportionally, the magnitude of the results but the relative position of regions remain substantially unchanged (detailed results not reported for the sake of brevity but available upon request). For this reason, we thought would have been more appropriate to assess the robustness and sensitiveness of the results in terms of modelling assumptions rather than model parametrizations.

Figure 7. EU GDP evolution under alternative specifications of factors mobility - TFP shock

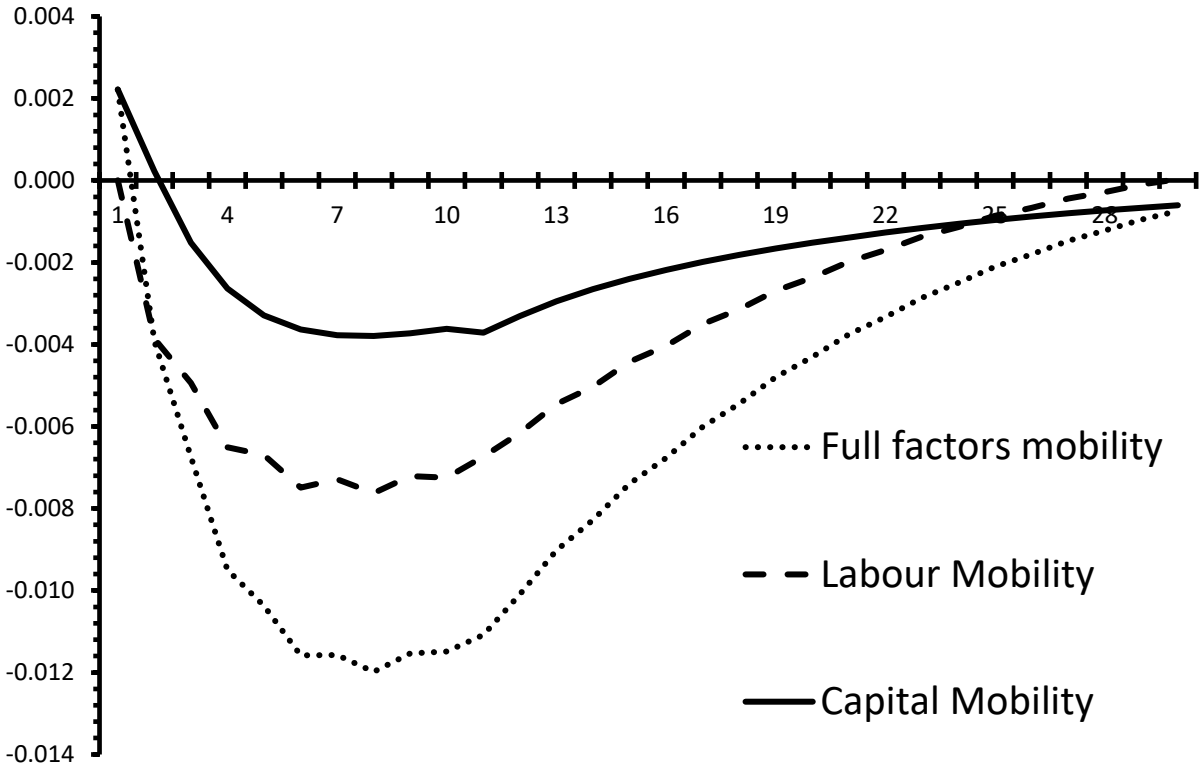


Figure 8. EU GDP evolution under alternative specifications of factors mobility - Demand shock

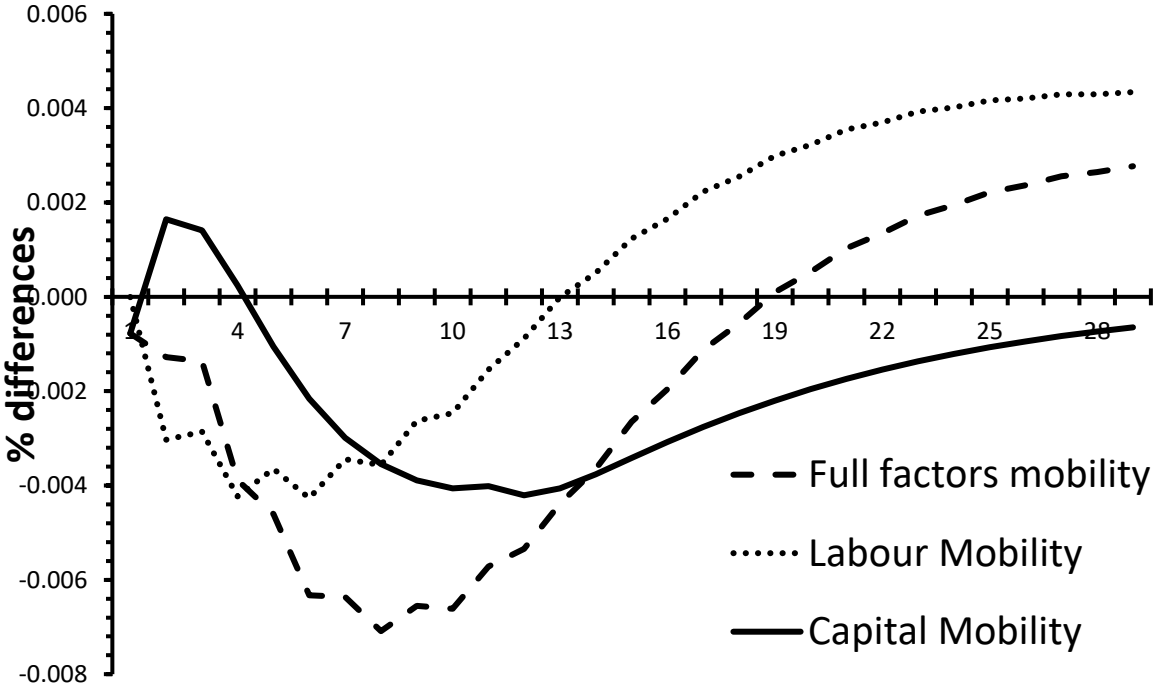
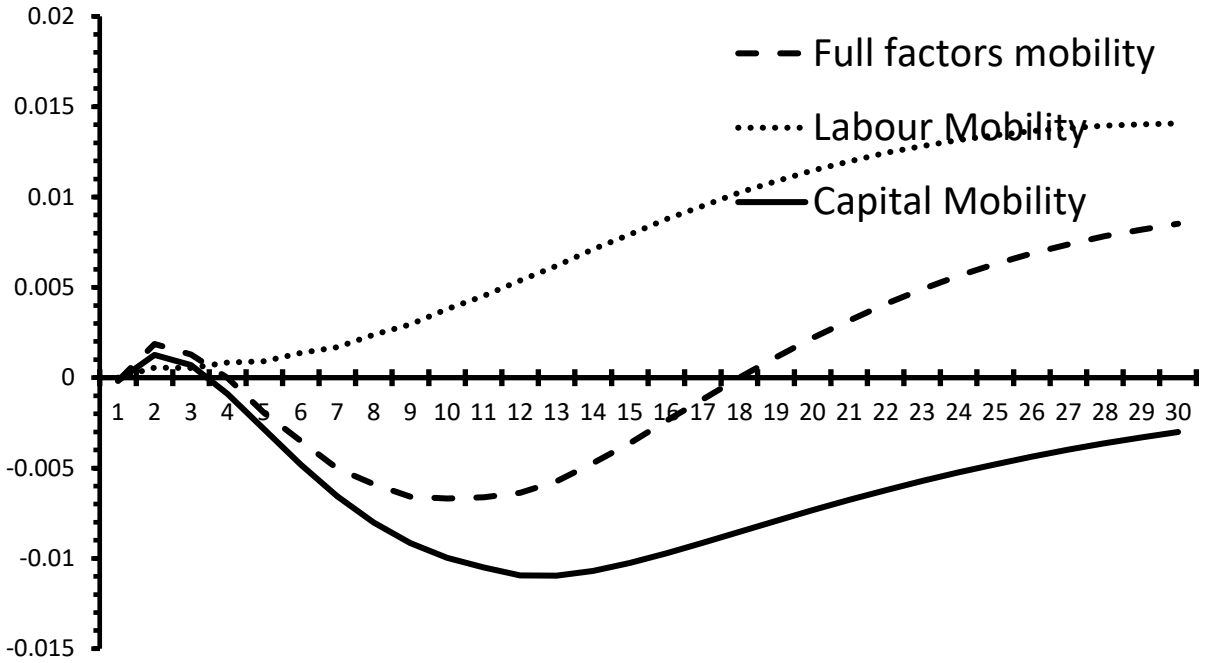


Figure 9. EU GDP evolution under alternative specifications of factors mobility - Risk premium shock



All in all, it appears that capital mobility initially moderates the negative GDP effects of a shock, but as the economy adjusts, it exacerbates the negative effects on GDP and hinders the recoverability of the regional economies. On the other hand, the effect of labour mobility depends on the nature of the shock: it is negative in the event of a TFP shock, positive in the event of a risk premium one, and it's negative for resistance but positive for recoverability when a demand shock hits the economy.

8. Conclusions

This paper investigates the likely response of EU regions to three alternative external disturbances, each of them triggering different economic mechanisms: a fall in TFP, a reduction in demand of exports to the ROW, and an increase of the rate of return to capital through an increase in the risk premium. We found significant differences across regions in both their resistance to and recoverability from unexpected recessionary shocks. Furthermore, our results suggest that the regional responses to external perturbations change depending on the nature of the shock. Regions highly resilient to a supply-side recessionary shock could be weakly resilient to demand-side shocks.

We also look for the regional characteristics driving the resistance and the recoverability of the economies. We found that regions relatively more open are less resistant under either a TFP or a demand shock while capital intensive regions will be less resistant than labour intensive regions under a risk premium shock. Our analysis also suggests that regions experiencing larger recessionary shocks are also struggling to recover. Moreover, it will be unlikely for regions which are highly specialized and relatively more open to experience a faster recovery after a negative shock.

We also analysed the role of factors' mobility finding that capital mobility initially moderates the negative GDP effects of a shock, but then exacerbates its impact a later

stage, thus worsening the recovery of regions and making them less resilient. The role of labour mobility, on the other hand, depends crucially on the nature of the shock.

We do believe that our results enrich the lively debate on regional economic resilience and open up new avenues for resilience analyses in general equilibrium frameworks.

References

Alessi, L., Benczur, P., Campolongo, F., Cariboni, J., Manca, A.R., Menyhert, B., & Pagano, A. (2018). The resilience of EU Member States to the financial and economic crisis: What are the characteristics of resilient behaviour? EUR 29221 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-85746-1, doi:10.2760/840532, JRC111606.

Boschma, R. (2015). Towards an evolutionary perspective on regional resilience. *Regional Studies* 49(5), 733-751.

Briguglio, L. (1995). Small island developing states and their economic vulnerabilities. *World Development*, 23(9), 1615–1632

Briguglio, L., Cordina, G., Farragiua, N., & Vella, S. (2009). Economic vulnerability and resilience concepts and measurements. *Oxford Development Studies* 37(3), 229-247.

Christensen, M., Weiers, G., & Wolski, M. (2019). The 2019 assessment of the macroeconomic effects of the European Fund for Strategic Investments with the RHOMOLO-EIB model. *Investigaciones Regionales - Journal of Regional Research* 2019/3(45), 5-15.

Christopherson, S., Michie, J., & Tyler, P. (2010). Regional resilience: theoretical and empirical perspectives. *Cambridge Journal of Regions, Economy and Society* 3(1), 3-10.

Crescenzi, R., Luca, D., & Milio, S. (2016). The geography of the economic crisis in Europe: national macroeconomic conditions, regional structural factors and short-term economic performance, *Cambridge Journal of Regions, Economy and Society* 9(1), 13-32.

Di Comite F., Kancs D.A., & Lecca P., (2018). Modeling agglomeration and dispersion in space: The role of labor migration, capital mobility and vertical linkages. *Review of International Economics* 26(3), 555-577.

Dixit, A., & Stiglitz, J. (1977). Monopolistic competition and optimum product diversity. *American Economic Review*, vol. 67(3), 297-308.

Doran, J., & Fingleton, B. (2015). Resilience from the micro perspective. *Cambridge Journal of Regions, Economy and Society* 8(2), 205-223.

Doran, J., & Fingleton, B. (2016). Employment resilience in Europe and the 2008 economic crisis: insights from micro-level data. *Regional Studies* 50(4), 644-656.

Faggian, A., Gemmiti, R., Jaquet, T., & Santini, I. (2018). Regional economic resilience: the experience of the Italian local labor systems. *The Annals of Regional Science* 60, 393-410.

Fingleton, B., Garretsen, H., & Martin, R. (2012). Recessionary shocks and regional employment: evidence on the resilience of UK regions. *Journal of Regional Science* 52(1), 109-133.

Fingleton, B., Garretsen, H., & Martin, R. (2015). Shocking aspects of monetary union: the vulnerability of regions in Euroland. *Journal of Economic Geography* 15, 907-934.

Frenken, K., Van Oort, F., & Verburg, T. (2007). Related variety, unrelated variety, and regional economic growth. *Regional Studies*, 41, 685–697.

Giannakis, E., & Bruggeman, A. (2017). Economic crisis and regional resilience: Evidence from Greece. *Papers in Regional Science* 96(3), 451-476.

Glaeser, E.L., Kallal, H.D., Scheinkman, J.A., & Shleifer, A. (1992). Growth in Cities. *Journal of Political Economy* 100, 1126-52

Hall, R.E., & Jorgenson D., (1967). Tax Policy and Investment Behavior. *American Economic Review* 57(3), 391-414

Harrison, B. (1984). Regional restructuring and 'good business climates': The economic transformation of New England since World War II. In *Sunbelt/Snowbelt*, edited by Larry Sawers and William Tabb, pp. 48-96. Oxford University Press.

Harrison, B., Kelley, M.R., & Gant, J. (1996). Innovative firm behaviour and local milieu: exploring the intersection of agglomeration, firm effects, and technological change. *Economic Geography* 72(3), 233-258.

Henderson, V. (2003). Marshall's Scale Economies. *Journal of Urban Economics* 53(1), 1-28.

Henderson, V., Kuncoro, A., & Turner, M. (1995). Industrial Development in Cities. *Journal of Political Economy* 103, 1067-90

Hill, E.W., Wial, H., & Wolman, H. (2008). Exploring regional economic resilience. Working paper 04.

Kancs, D.A., & Lecca, P. (2018). Long-term social, economic and fiscal effects of immigration into the EU: The role of the integration policy. *The World Economy* 41(10), 2599-2630.

Krugman, P. (1991). *Geography and Trade*, MIT Press.

Lecca, P., Christensen, M., Conte, A., Mandras, G., & Salotti, S. (2020). Upward pressure on wages and the interregional trade spillover effects under demand-side shocks. *Papers in Regional Science* 99(1), 165-182.

Lecca, P., Barbero, J., Christensen, M.A., Conte, A., Di Comite, F., Diaz-Lanchas, J., Diukanova, O., Mandras, G., Persyn, D., & Sakkas, S. (2018). RHOMOLO V3: A spatial modelling framework, EUR 29229 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-85886-4, doi:10.2760/671622, JRC111861.

Lazzeretti, L., Oliva, S., & Innocenti, A. (2019). Exploring the role of industrial structure for regional economic resilience. *Papers in Evolutionary Economic Geography* (PEEG) 1917.

Martin, R. (2012). Regional economic resilience: hysteresis and recessionary shocks. *Journal of Economic Geography* 12, 1-32.

Martin, R., & Sunley, P. (2015). On the notion of regional economic resilience: conceptualization and explanation, *Journal of Economic Geography* 15(1), 1-42.

Martin, R., Sunley, P., Gardiner, B., & Tyler, P. (2016). How regions react to recessions: Resilience and the role of economic structure. *Regional Studies* 50(4), 561-585.

Persyn, D., Torfs, W., & Kancs, D.A. (2014). Modelling regional labour market dynamics: Participation, employment and migration decisions in a spatial CGE model for the EU. *Investigaciones Regionales* 29(2014), 77-90.

Pudelko, F., Hundt, C., & Holtermann, L. (2018). Gauging two sides of regional economic resilience in Western Germany - Why sensitivity and recovery should not be lumped together. *Review of Regional Research* 38, 141-189.

Rizzi, P., Graziano, P., & Dallara, A. (2018). A capacity approach to territorial resilience: the case of European regions. *The Annals of Regional Science* 60(2), 285-328.

Rose, A., & Liao, S.Y. (2005). Modeling regional economic resilience to disasters: A computable general equilibrium analysis of water service disruptions. *Journal of Regional Science* 45(1), 75-112.

Sensier, M., Bristow, G., & Healy, A. (2016). Measuring regional economic resilience across Europe: Operationalizing a complex concept. *Spatial Economic Analysis* 11(2), 128-151.

Simmie, J., & Martin, R. (2010). The economic resilience of regions: towards an evolutionary approach. *Cambridge Journal of Regions, Economics and Society* 3(1), 27-43.

Šucha, V., Wahlström, M., Stigson, B., Wijkman, A., Lechner, S., Masera, M., Hubbard, N., Bidoglio, G., Fink-Hooijer, F., Abousahl, S., & Regling, K. (2015). *The Challenge of Resilience in a Globalised World*. EUR 27280 EN, Brussels.

Thissen M., Husby, T., Ivanova, O., & Mandras, G. (2019). European NUTS 2 regions: construction of interregional trade-linked Supply and Use tables with consistent Transport flows. JRC Working Papers series on Territorial Modelling and Analysis No. 01/2019, European Commission, Seville, JRC115439.

Yair Grinberger, A., & Samuels, P. (2018). Labor mobility, trade and urban resilience to natural disasters. Papers presented at the 2018 workshop on regional resilience at the University of Barcelona, November.

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