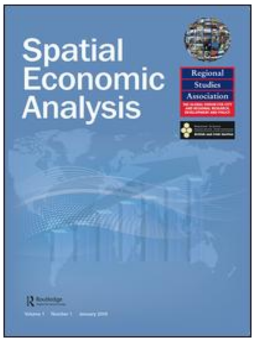

Routledge
Taylor & Francis Group

Spatial Economic Analysis

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rsea20

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

Filippo Di Pietro , Patrizio Lecca & Simone Salotti

To cite this article: Filippo Di Pietro , Patrizio Lecca & Simone Salotti (2020): Regional economic resilience in the European Union: a numerical general equilibrium analysis, Spatial Economic Analysis, DOI: 10.1080/17421772.2020.1846768

To link to this article: https://doi.org/10.1080/17421772.2020.1846768

Published online: 25 Nov 2020.

SPATIAL ECONOMIC ANALYSIS
https://doi.org/10.1080/17421772.2020.1846768

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

Filippo Di Pietro [a], Patrizio Lecca [b] and Simone Salotti [c]

ABSTRACT

Using a spatial general equilibrium model, this paper investigates the resilience of European Union regions under three alternative recessionary shocks, each activating different economic adjustments and mechanisms. We measure the vulnerability, resistance and recoverability of regions and identify key regional features affecting the ability of regions to withstand and recover from unexpected external shocks. The analysis reveals that the responses of regions vary according to the nature of the external disturbance and to the pre-shock regional characteristics. Finally, it seems that resilience also depends on factor mobility. The analysis, although designed before the onset of the Covid-19 pandemic, offers interesting insights into how to use a general equilibrium framework to study resilience in such a context.

KEYWORDS

computable general equilibrium model, regional economic resilience, economic shocks

JEL C68, R13, R15

HISTORY Received 17 June 2019; in revised form 29 October 2020

INTRODUCTION

'Regional economic resilience' is a term used broadly to describe how regional economies respond to undesired external disturbances. Essentially, the notion of regional resilience emphasizes the ability of regions to resist and recover from shocks and it has recently gained popularity among both academics (e.g., Fingleton et al., 2015) and policy-makers (Alessi et al., 2018; Šucha et al., 2015). 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 hugely vary 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 2) 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.

CONTACT

[a] fdi@us.es

European Commission, JRC, Seville, Spain; and Universidad de Sevilla, Seville, Spain.

[b] European Commission, JRC, Seville, Spain; and PBL Netherlands Environmental Assessment Agency, The Hague, Netherlands.

[c] **(Corresponding author)** simone.salotti@ec.europa.eu

European Commission, JRC, Seville, Spain.

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 is it 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 reducing this type of complexity and significantly simplifies 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 (e.g., supply- or demand-side shocks) can be implemented to test whether regions respond differently to disruptions that are intrinsically different in nature. Substantially, regions are expected to respond differently in relation to the nature of the shock.[1]

In our analysis, we simulate three different scenarios, each with a different type of negative shock contemporaneously hitting all the European NUTS-2 regions featured in the RHOMOLO model. The first involves a temporary fall in total factor productivity (TFP); the second implies a temporary reduction in the demand for exports to the rest of the world (ROW); and the third 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 the 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 from the model simulations to construct variables able to capture 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. This framework could be easily adapted to study resilience in the context of the recent Covid-19-related crisis by tailoring the shocks so as to reflect the mix of negative consequences of the pandemic.

The remainder of the paper is structured as follows. The next section discusses the multifaceted concept of regional economic resilience. The third section briefly presents the RHOMOLO model and the fourth section illustrates the strategy adopted for the regional resilience analysis. The fifth section sets out and discusses the modelling results in terms of the resistance and recoverability of regions. The sixth section identifies some of the key determinants of resilience, while the seventh section explores the potential role played by factor mobility. Finally, the conclusions are given in the eighth section.

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 across several 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 studies (Giannakis & Bruggeman, 2017; Martin & Sunley, 2015; Martin et al., 2016) 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 (e.g., 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 several additional avenues for research as demonstrated by Doran & Fingleton, 2015, 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 both employment and 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 specialization. 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 the disruption of water services in the Portland Metro economy in Oregon (United States) using a general equilibrium modelling framework. Recently Allan et al. (2020) analyse the impact of expectations and business confidence on regional resilience after a negative export shock.

Since we adopt a conventional general equilibrium approach, the simulation experiments presented in this paper are grounded on the so-called 'engineering resilience' approach (Hill et al., 2008; Martin & Sunley, 2015; 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 & 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, therefore preventing 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 emphasizes 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 first study how the EU regions react to various types of shocks, looking at both their vulnerability and 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 observing 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.

CONDENSED DESCRIPTION OF THE RHOMOLO MODEL

In this section we outline the main equations governing the model to help readers 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 the fourth section. For more details on the RHOMOLO model, see Lecca et al. (2018).[2]

The model represents a decentralized 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 the 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 10 NACE rev.2 economic sectors (agriculture, forestry and fishing; energy; manufacturing; construction; trade and transport; information and communication; financial activities; research and development (R&D); public administration; and other services) in which firms operate under a monopolistic competition framework à la Dixit and 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 constant elasticity of substitution (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 $i = 1, \ldots, N$ of sector j, in region r; whilst $\vartheta_{r,j,i}$ is a share of the expenditure parameter; and $\rho^c = \sigma^c - 1/\sigma^c$, where $\sigma^c$is the elasticity of substitution.

Government

Government expenditure comprises the 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 in equations (3) and (4), respectively:

$$Y_{r,j} = Ay_{r,j}[\delta^y_{r,j} \cdot KD^{\rho^y_j}_{r,j} + (1 - \delta^y_{r,j}) \cdot LD^{\rho^y_j}_{r,j}]^{\frac{1}{\rho^y_j}} - FC_{r,j} \tag{3}$$

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

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 $\rho^y_j = \sigma^y - 1/\sigma^y$ (where σ^y is the elasticity of substitution) and the share parameter δ^Y_j. 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 sector j from the supplier sector s. Input substitution between sectors is determined by the elasticity of substitution ρ^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):

$$KD_{r,j} = \left(Ay^{\rho^y_j}_{r,j} \cdot \delta^y_{r,j} \cdot \frac{Pk_r}{Py_{r,j}}\right)^{\frac{1}{1-\rho^y_j}} \cdot Y_{r,j} \tag{5}$$

$$LD_{r,j} = \left(Ay^{\rho^y_j}_{r,j}(1 - \delta^y_{r,j}) \cdot \frac{w_r}{Py_{r,j}}\right)^{\frac{1}{1-\rho^y_j}} \cdot Y_{r,j} \tag{6}$$

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 does not differentiate between imports from within the country or within the EU:

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

where $x_{r,r',i,t}$ 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 $P_{r',j}$ is defined as a CES price index as over the market price $P_{r',r,i,t}$.

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

where the price $P_{r,r',j}$ 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 $(1/\varepsilon_{r,r',j})$ over the marginal cost $P^*_{r,j}$, which is given as follows:

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

where

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

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

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

where $a^y_{r,j}$ 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 depend on the market shares, therefore a single region sells products to all the other regions at the same first-on-board (fob) price, even if consumers in the importing regions can observe different cost, insurance and freight (cif) prices, including iceberg transport costs.

Wage setting

The RHOMOLO model incorporates imperfect competition into 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 using a dynamic or a static form of wage setting. The general formulation is expressed in logs 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 maximization theory (maximizing 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:

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

where r, δ_r, p_{EU}^I and rp_r denote the interest rate, depreciation rates, investment price index and an exogenous risk premium, respectively; and $\dot{p}_{EU}^I$ 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; and 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 equalize. Proceeding in this way also means that that the allocation of investments between regions is driven by the differences between regional and EU average return, which 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:

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

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

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

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 by 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):

$$X_{r',j} = \sum_{i}^{N} \sum_{j} v_{r,i,j} + C_{r,j} + I_{r,j} + G_{r,j} \tag{19}$$

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

$$\sum_{i}^{N} \sum_{j} kd_{r,j,i,=p} = K_r^P \tag{20}$$

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

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

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

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

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. Usually, no binding constraints are imposed on the regional government balance. However, foreign savings from the ROW in the model are passive, hence maintaining equilibrium in the payment accounts with the ROW.

Data, model calibration and baseline scenario

All shift and share parameters are calibrated to reproduce the base year data set, represented by the interregional SAM for 2013 (Thissen et al., 2019). The choice of 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 one that is fairly high for trade between regions (4.0). The interest rate (faced by producers, consumers and investors) is set at 0.04, while the rate of depreciation applied to the private capital equates to 0.15. As for the wage curve parameterization, we run a long-run wage curve assuming $\beta = 0.1$ (Nijkamp & 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. For further details on the calibration and parameterization of the model, see Lecca et al. (2018).

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: a 1% reduction in TFP, a 5% increase in risk premium and a 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 paper's informative objective 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 compare the three simulations independently from the magnitude of the shock, substantially simplifying the interpretation of the results.

To help to understand the mechanism operating in the model under the three scenarios, we briefly analyse the dynamic adjustments mechanisms of key macroeconomic 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 gross domestic product (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 10 additional periods beyond the termination of the shock for all the five variables considered.

The negative TFP shock implies a 1% reduction from the base year values of the exogenous variable Ay appearing in equation (3). Figure 2 shows the evolution of the five variables chosen

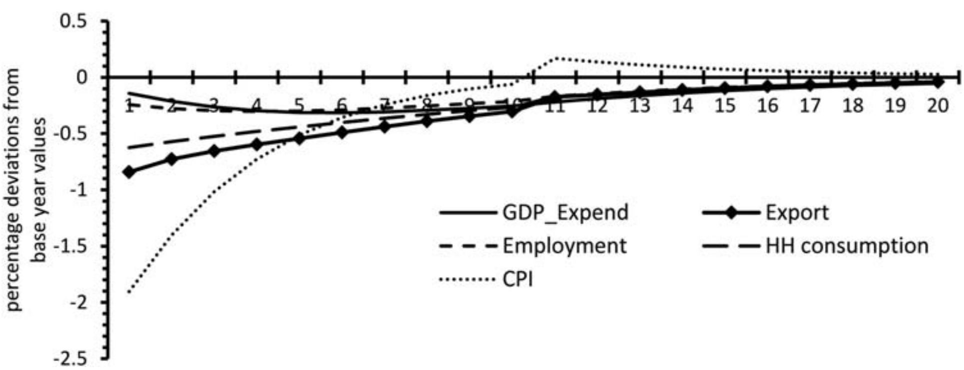

Figure 1. Impact of demand shock in all regions and sectors for selected economic variables of the Île-de-France (FR10) region.

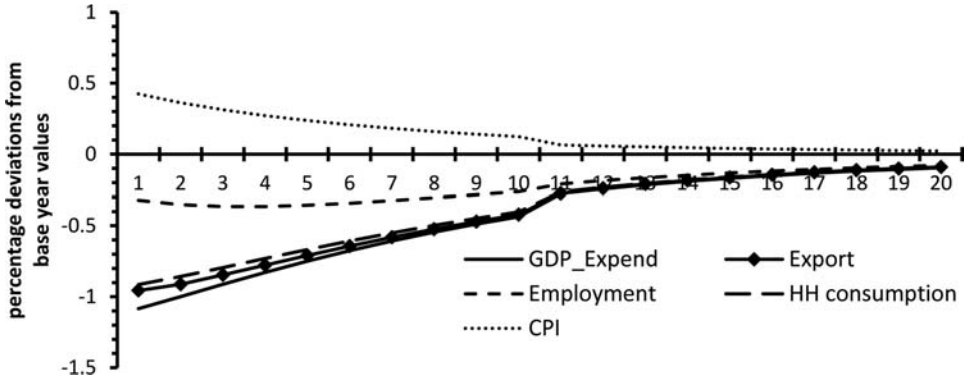

Figure 2. Impact of total factor productivity (TFP) shock in all regions and sectors on selected economic variables of the Île-de-France (FR10) region.

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 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 the risk premium generates an upwards 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 supply-side effects has conflicting effects on prices. The demand-side mechanism puts initial downwards pressure on prices, but then capital de-accumulation puts upwards pressure on them. This conflicting behaviour is reflected in the evolution of the CPI (Figure 3). In the first periods, we observe an immediate reduction in the CPI; we then 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 the GDP, compensating for relatively higher competitiveness gain effects.

Table 1 shows some descriptive statistics of the periods in which the EU regions reach the negative peak in GDP, which 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

Figure 3. Impact of risk premium increase in all regions and sectors on selected economic variables of the Île-de-France (FR10) region.

Table 1. European Union summary statistics on the period of the negative peak in gross domestic product (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

Note: TFP, total factor productivity.

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 varying from a minimum of one to a maximum of 11 periods.

RESISTANCE AND RECOVERABILITY OF REGIONS

The initial findings presented in the previous section suggest that the regional responses to external perturbation change depend 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 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):

$$\text{Resistance}_r = \frac{\text{GDPgrowth}_r^{\text{contraction}} - \text{GDPgrowth}_{\text{EU}}^{\text{contraction}}}{|\text{GDPgrowth}_{\text{EU}}^{\text{contraction}}|} \tag{23}$$

$$\text{Recovery}_r = \frac{\text{GDPgrowth}_r^{\text{Recovery}} - \text{GDPgrowth}_{\text{EU}}^{\text{Recovery}}}{|\text{GDPgrowth}_{\text{EU}}^{\text{Recovery}}|} \tag{24}$$

The measures are constructed similarly: 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 equations (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 4–6. Each 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 are we 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 changes according to the type of shock implemented in the model. This result is in line with Faggian et al. (2018) according to whom 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 of the type of shock. Interestingly, a group of 28 regions, 22 of which belong to the UK, show high resistance and recoverability irrespective of the simulation performed and therefore these regions always appear in the top-right quadrant. On the other hand, only three regions retain their position in the left-bottom quadrant across the three shocks: namely Yugoiztochen (BG34), Languedoc-Roussillon (FR81) and Croatia (HR).

Although informative, Figures 4–6 do not shed a 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.

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 the time required to get back to the equilibrium (recoverability). This is endogenously

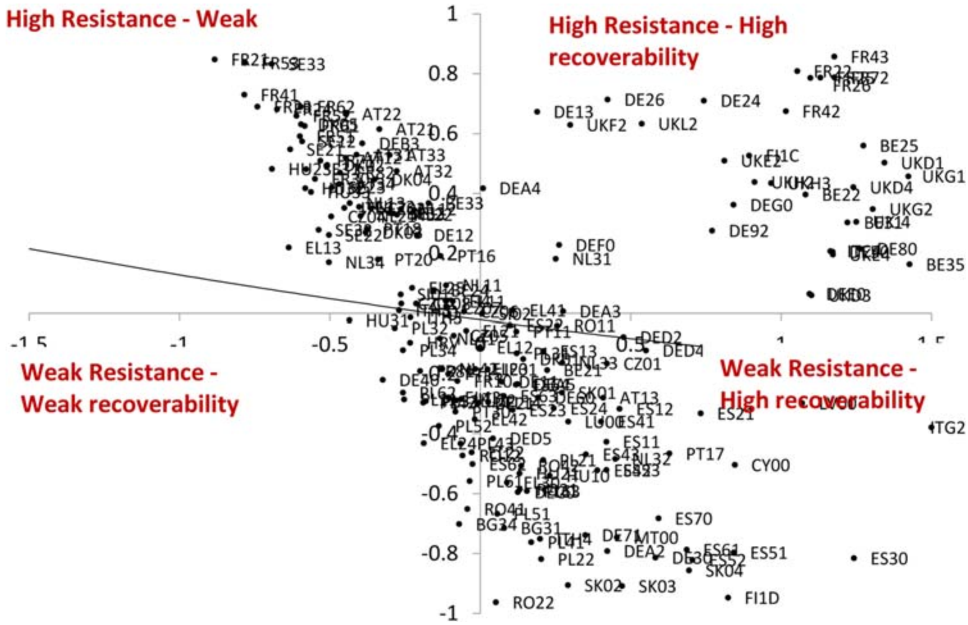

Figure 4. Recovery and resistance: demand shock.

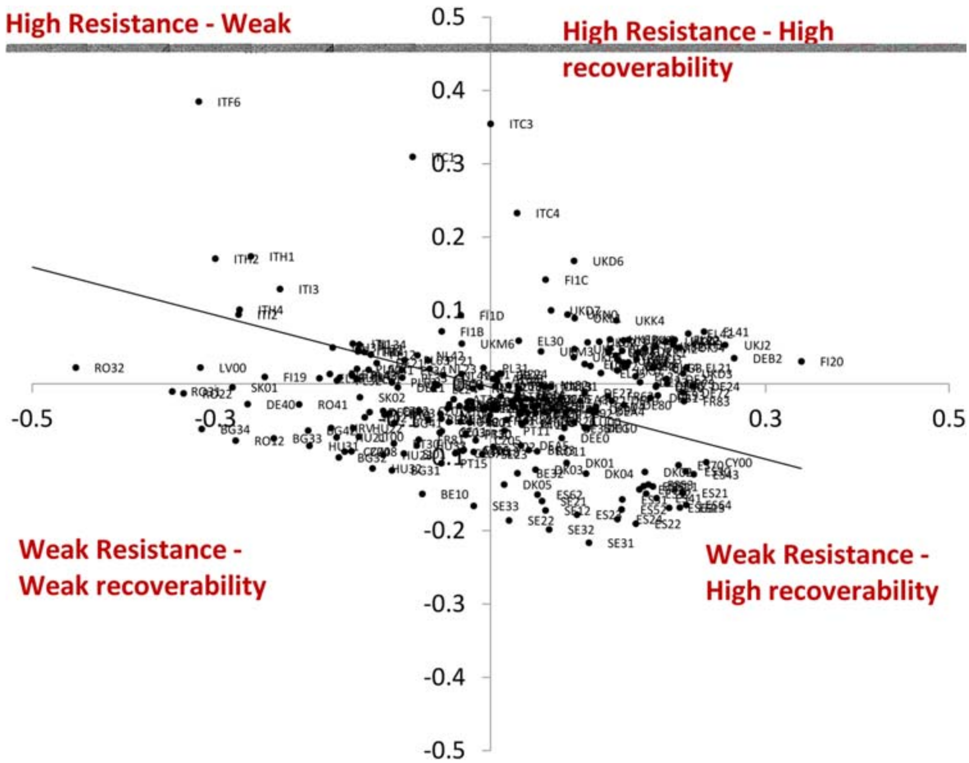

Figure 5. Recovery and resistance: total factor productivity (TFP) shock.

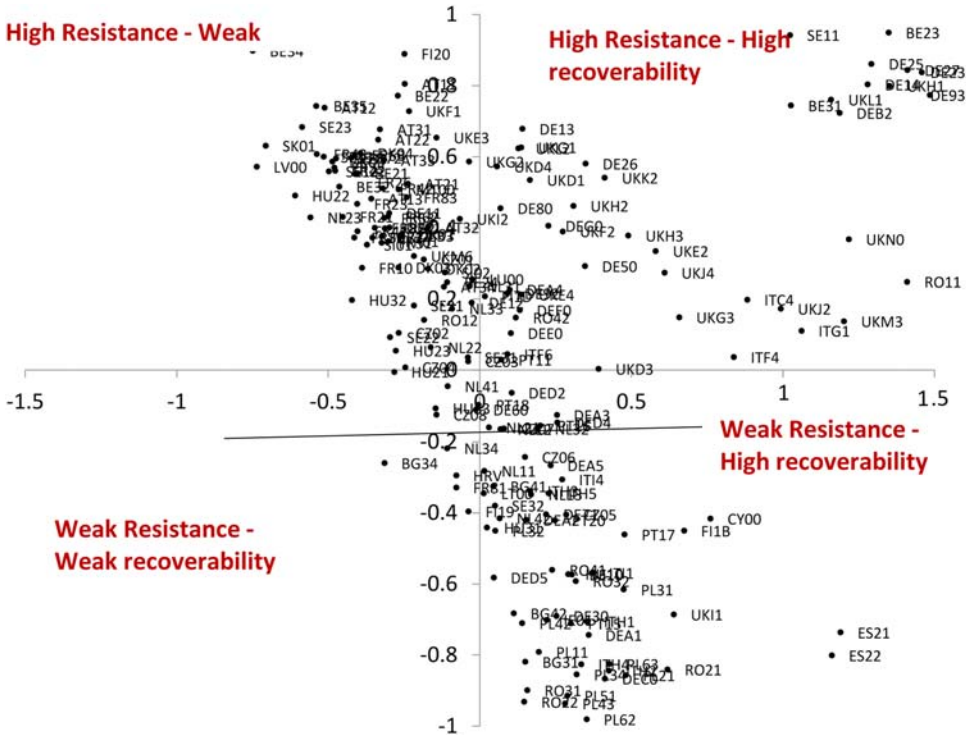

Figure 6. Recovery and resistance: risk premium shock.

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. As the high dimensionality of the model prevents a more straightforward presentational approach, 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 performed 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 has 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:

- *Factor intensity*. This indicates whether the regional production process is more or less capital (or labour) intensive. It is reasonable to expect that relatively more capital-intensive regions 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. (2018).

- *Openness*. The degree to which an economy depends on foreign trade affects the vulnerability of regions (Briguglio, 1995; Briguglio et al., 2009). Therefore, regions that are more open can potentially be less resistant to external shocks because of their dependence on 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, 2003; Henderson et al., 1995, 1996) and several authors have analysed its role as a determinant of economic resilience (Faggian et al., 2018; Fingleton et al., 2012; Frenken et al., 2007; Hill et al., 2008; Lazzeretti et al., 2019; Pudelko et al., 2018; Rizzi et al., 2018). Theoretically, highly specialized regions can suffer greater damage when the economic shocks involve the sectors in which they are specialized. According to Simmie and Martin (2010) and Martin and Sunley (2015), more diversified regions may be less prone to shocks, or at least may be more able to recover from them than more specialized ones. However, Martin (2012) adds that a diversified regional economy reacts to negative shocks also depending on the degree of sectoral interrelatedness, so diversification alone does not necessarily guarantee a high resistance.

The resilience literature has also studied other drivers of resistance and recoverability that we are not exploring in this study. For instance, the general equilibrium modelling framework that constitutes the basis of our econometric analysis does not permit us to investigate the role of regional innovation, nor of agglomeration and dispersion effects.

Our empirical strategy starts with the following model for resistance:

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

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 show 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 (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 imports and exports divided by the GDP; 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 Moran's I test of spatial autocorrelation, not reported but available upon request, do not suggest any spatial dependence issue).[6]

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). Column (1) contains the results of the baseline model where the set of explicative variables is only constituted by the labour share LS, trade openness *Openness* and the specialization index SI. The estimates reported in columns (2) and (3) are

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

Variables	N	Mean	SD	Minimum	Maximum
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

Note: TFP, total factor productivity; LS, labour shares; SI, specialization index.

obtained by adding either the country dummies or the regional contiguity variable, respectively, to the model. A first look at Table 3 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 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 estimates of its coefficient depend on the inclusion or exclusion of the country dummies and the contiguity variable.

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 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 which 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, the results for this variable are inconclusive in the risk premium scenario. Thus, it appears that the prediction of the literature is not respected in the case of the TFP scenario (while they are confirmed, at least weakly, in the case of the demand shock), even though Martin (2012) warns that diversification alone may not lead to high resistance given that other factors, such as interrelatedness, may play a role.

All these results are confirmed by an alternative battery of estimates performed with the dependent variable constructed using the employment series resulting from the modelling simulations rather than GDP (see Table A1 in Appendix A in the supplemental data online).

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
Observations	267	267	267	267	267	267	267	267	267
R^2	0.49	0.82	0.50	0.22	0.51	0.23	0.52	0.89	0.54

Notes: TFP, total factor productivity; CTG, contiguity.
Standard errors are shown in parentheses; ***significance at the < 0.001 level; **< 0.01; and *< 0.05.

Although the magnitude of the coefficients is understandably different, their signs and statistical significance levels are in line with those obtained with the dependent variable constructed using GDP rather than employment (Table 3).

We now 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:

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

where 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 of periods needed in the EU as whole; zero otherwise. X^T indicates 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 A2 in Appendix A in the supplemental data online reports the results obtained with the alternative specifications based on employment rather than GDP).

In all the 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 it is for the region to recover its steady state faster than the EU average. Interestingly, the employment-based regressions only confirm this result in the case of the TFP shock. Thus, it appears that it is especially hard to foster job creation after negative shocks which have particularly harsh consequences on employment, while GDP can recover quickly after big losses. The labour share shows positive marginal effects in all cases, thus larger labour shares are associated with a more rapid recovery, a result which emerges even more clearly from the alternative regressions reported in Table A2 in Appendix A in the supplemental data online based on employment rather than on GDP.

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 (the demand and risk premium scenarios), and the openness effect is only significant when estimated with the data arising from the risk premium scenario. These results suggest 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 latter results confirms earlier literature findings such as those by Martin, 2012; Martin & Sunley, 2015; and Simmie & Martin, 2010). However, the alternative regressions focusing on employment rather than GDP do not confirm this (admittedly weak) finding, as trade openness is associated with positive coefficients in the demand and risk premium scenarios, and specialization has a negative coefficient in the case of the TFP shock and a positive one in the case of the demand shock (Table 2). Thus, the labour share emerges as the main determinant of recoverability according to our analysis.

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 legacy effects of the shocks are also related to the magnitude of the impact caused by the shock itself.

Table 4. Regressions results of the recoverability model.

	TFP shock		Demand shock		Risk premium shock	
Variables	**Coefficient**	**Change in probability**	**Coefficient**	**Change in probability**	**Coefficient**	**Change in probability**
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)	
Observations	267		267		267	
Pearson χ^2	232.38		188.00		3509.62	
Pseudo-R^2	0.35		0.58		0.23	

Notes: TFP, total factor productivity.
Standard errors are shown in parentheses; ***significance at the < 0.001 level; **< 0.01; and *< 0.05.

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 assuming both capital and labour 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 indicates 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 a 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 7–9 show the evolution of the GDP differences between these model's specifications over 30 periods, for the TFP shock, demand shock and risk premium shock, respectively. In terms of interpretation, if the difference observed is positive this 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 mobility exacerbates the effect of the negative shock.

In the case of the TFP shock, and excluding the first 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 (GDP is also lower in the period after it reaches the negative GDP peak). The position of the curves in Figure 7 also suggests that

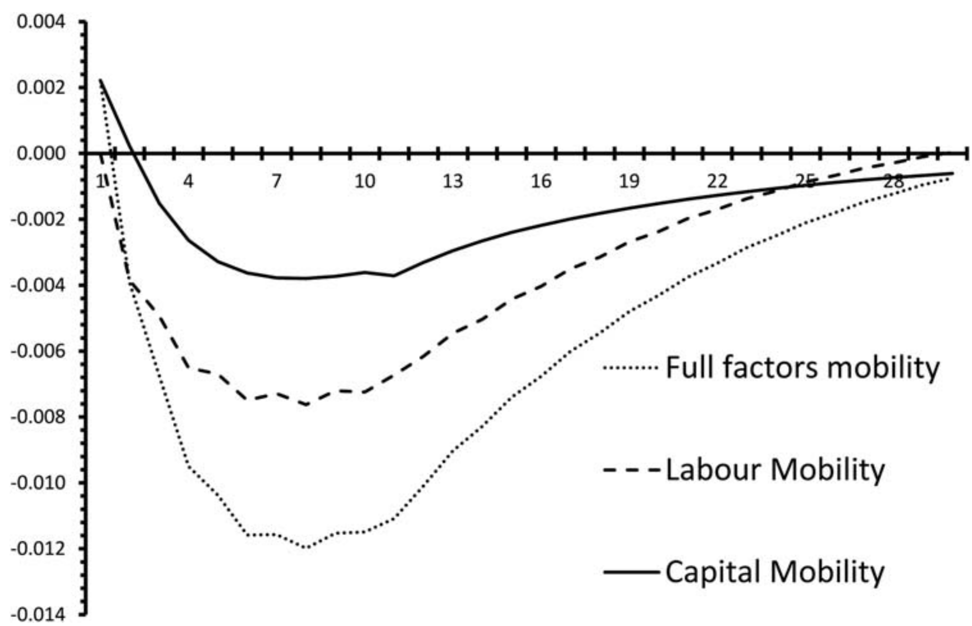

Figure 7. European Union gross domestic product (GDP) evolution under alternative specifications of factors mobility: total factor productivity (TFP) shock.

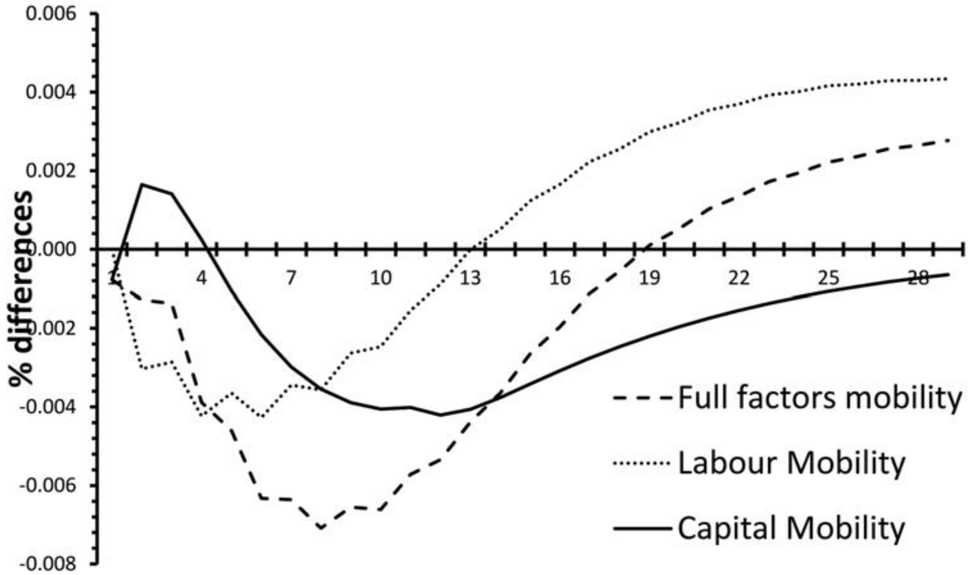

Figure 8. European Union gross domestic product (GDP) evolution under alternative specifications of factors mobility: demand shock.

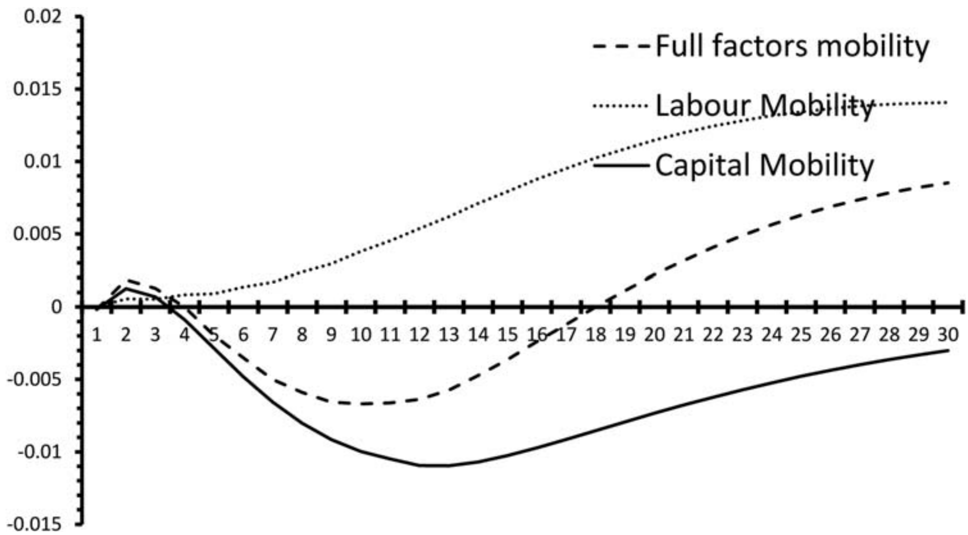

Figure 9. European Union gross domestic product (GDP) evolution under alternative specifications of factors mobility: risk premium shock.

the vulnerability and the adjustment of the economy towards a steady-state equilibrium is, at least up to period 25, more affected by labour mobility rather than by 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.

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 regional economies. During the implementation of the shock, regions experience an increase in the cost of capital that in turns reduces both investments and GDP. The rise in the cost of capital in this period, is lower in the presence of a fully integrated capital market. This implies that, during the perturbation period, capital mobility mitigates the effects of the recessionary shocks. However, in the absence of shocks, the economies gradually adjust towards the original steady states. The responses of the model's variables are therefore driven by the initial calibrated shares governing the adjustment to the pre-shock equilibrium. For the EU as whole, the cost of capital adjusts faster if capital is not fully mobile. In turn, this generates a fall in GDP which is slightly lower under the case of no capital mobility compared to the case of full mobility of capital.

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 is negative for resistance but positive for recoverability when a demand shock hits the economy. This substantially means that the response of the net-migration function incorporated in the model is sensitive to the nature of the perturbation. The risk premium shock hits particularly investments and therefore capital, relatively increasing substitution in favour of labour and in turn reducing the negative impact on employment. Higher probability to find a job in some regions accelerates the adjustments towards the new steady state. A similar mechanism operates under the demand shock. On the contrary, with a full negative supply-side recessionary shock such as the reduction in TFP, net migration exacerbates the negative impact acting as a resistance factor to the adjustment.

CONCLUSIONS

This paper investigates the likely response of EU regions to three alternative external disturbances, each 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 search for the likely determinants of resistance and recoverability of the economies. These variables reflect the initial conditions of regions as represented in our calibrated model. To some extent, this approach has some limitations because it prevents us to explore a larger number of potential drivers of resistance and resilience such as innovation, agglomeration effects, and education.

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 also struggle to recover. Moreover, it will be unlikely for regions which are highly specialized and relatively more open to experience a fast recovery after a negative shock.

We also analysed the role of factor 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, crucially depends on the nature of the shock.

We believe that our results enrich the lively debate on regional economic resilience and open up new avenues for resilience analyses in general equilibrium frameworks. The recent worldwide crisis triggered by the Covid-19 pandemic is a perfect example of a potential application of this framework in order to study resilience related to the pandemic's negative consequences. In fact, the RHOMOLO model has been used to simulate the potential regional impact of the crisis in the EU during the second quarter of 2020 (Conte et al., 2020). Further work on this front, building on the resilience analysis contained in this paper, is currently ongoing.

DISCLOSURE STATEMENT

The views expressed here are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission. No potential conflict of interest was reported by the authors. This work was done when the authors were employed at the JRC, European Commission.

Notes

[1] 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.'
[2] For additional documentation, see https://ec.europa.eu/jrc/en/rhomolo. The RHOMOLO model has also been used by Lecca et al. (2020), Christensen et al. (2019), Kancs and Lecca (2018) and Di Comite et al. (2018).
[3] As will be shown, 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 data set at the EU NUTS-2 level able to cover the full interregional trade flows is only available for 2013. This has prevented model testing with alternative reference years.
[4] The risk premium is a calibrated exogenous variable and obtained as the difference between market return and risk-free rate (defined as interest rate plus depreciation).
[5] *SI* is calculated using:

$$\text{Specialisation Index}_r = \sum_i \left| \frac{E_{i,r}}{\sum_i E_{i,r}} - \frac{E_{i,EU}}{\sum_i E_{i,EU}} \right|$$

.
[6] We did not detect multicollinearity in the regression analysis. The maximum variance inflation factor is < 2 in all cases.
[7] The base year data are therefore of utmost importance in this analysis. Given that alternative data set is not currently available, the results of the model have been generalized using regression models in order to obtain the average predicted behaviour of regions with specific characteristics.
[8] Reporting the sensitivity of the results to the 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 alter, more or less proportionally, the magnitude of the results, but the relative position of regions remains substantially unchanged (detailed results are, for the sake of brevity, not reported but are available from the authors upon request). For this reason, we thought it would have been more appropriate to assess the robustness and sensitivity of the results in terms of modelling assumptions rather than modelling parametrizations.

ORCID

Filippo Di Pietro http://orcid.org/0000-0003-1573-8553
Patrizio Lecca http://orcid.org/0000-0002-1053-3869
Simone Salotti http://orcid.org/0000-0003-1898-6683

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. Luxembourg: Publications Office of the European Union. https://doi.org/10.2760/840532, JRC111606

Allan, G., Figus, G., McGregor, P., & Swales K. (2020). Resilience in a behavioural/Keynesian regional model. Environment and Planning A: Economy and Space. https://doi.org/10.1177%2F0308518X20941775

Boschma, R. (2015). Towards an evolutionary perspective on regional resilience. *Regional Studies*, *49*(5), 733–751. https://doi.org/10.1080/00343404.2014.959481

Briguglio, L. (1995). Small island developing states and their economic vulnerabilities. *World Development*, *23*(9), 1615–1632. https://doi.org/10.1016/0305-750X(95)00065-K

Briguglio, L., Cordina, G., Farragiua, N., & Vella, S. (2009). Economic vulnerability and resilience: Concepts and Measurements. *Oxford Development Studies*, *37*(3), 229–247. https://doi.org/10.1080/13600810903089893

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. https://doi.org/10.1093/cjres/rsq004

Conte, A., Lecca, P., Salotti, S., & Sakkas, S. (2020). *The territorial economic impact of COVID-19 in the EU. A RHOMOLO analysis*. Territorial Development Insights Series, JRC121261. European Commission.

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. https://doi.org/10.1093/cjres/rsv031

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. https://doi.org/10.1111/roie.12313

Dixit, A., & Stiglitz, J. (1977). Monopolistic competition and optimum product diversity. *American Economic Review*, *67*(3), 297–308. https://doi.org/10.7916/D8S75S91

Doran, J., & Fingleton, B. (2015). Resilience from the micro perspective. *Cambridge Journal of Regions, Economy and Society*, 8(2), 205–223. https://doi.org/10.1093/cjres/rsv004

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. https://doi.org/10.1080/00343404.2015.1088642

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*(2), 393–410. https://doi.org/10.1007/s00168-017-0822-9

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. https://doi.org/10.1111/j.1467-9787.2011.00755.x

Fingleton, B., Garretsen, H., & Martin, R. (2015). Shocking aspects of monetary union: The vulnerability of regions in Euroland. *Journal of Economic Geography*, *15*(5), 907–934. https://doi.org/10.1093/jeg/lbu055

Frenken, K., Van Oort, F., & Verburg, T. (2007). Related variety, unrelated variety, and regional economic growth. *Regional Studies*, *41*(5), 685–697. https://doi.org/10.1080/00343400601120296

Giannakis, E., & Bruggeman, A. (2017). Economic crisis and regional resilience: Evidence from Greece. *Papers in Regional Science*, *96*(3), 451–476. https://doi.org/10.1111/pirs.12206

Glaeser, E. L., Kallal, H. D., Scheinkman, J. A., & Shleifer, A. (1992). Growth in Cities. *Journal of Political Economy*, *100*(6), 1126–1152. https://doi.org/10.1086/261856

Hall, R. E., & Jorgenson, D. (1967). Tax policy and investment behavior. *American Economic Review*, *57*(3), 391–414.

Harrison, B., Kelley, M. R., & Gant, J. (1996). Innovative firm Behavior and local Milieu: Exploring the Intersection of agglomeration, firm effects, and Technological change. *Economic Geography*, *72*(3), 233–258. https://doi.org/10.2307/144400

Henderson, V. (2003). Marshall's scale economies. *Journal of Urban Economics*, *53*(1), 1–28. https://doi.org/10.1016/S0094-1190(02)00505-3

Henderson, V., Kuncoro, A., & Turner, M. (1995). Industrial Development in Cities. *Journal of Political Economy*, *103*(5), 1067–1090. https://doi.org/10.1086/262013

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. https://doi.org/10.1111/twec.12637

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

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

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*. Luxembourg: Publications Office of the European Union. https://doi.org/10.2760/671622, JRC111861

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. https://doi.org/10.1111/pirs.12472

Martin, R. (2012). Regional economic resilience, hysteresis and recessionary shocks. *Journal of Economic Geography*, *12*(1), 1–32. https://doi.org/10.1093/jeg/lbr019

Martin, R., & Sunley, P. (2015). On the notion of regional economic resilience: Conceptualization and explanation. *Journal of Economic Geography*, *15*(1), 1–42. https://doi.org/10.1093/jeg/lbu015

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. https://doi.org/10.1080/00343404.2015.1136410

Nijkamp, P., & Poot, J. (2005). The last word on the wage curve? *Journal of Economic Surveys*, *19*(3), 421–450. https://doi.org/10.1111/j.0950-0804.2005.00254.x

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*(2), 141–189. https://doi.org/10.1007/s10037-018-0124-4

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. https://doi.org/10.1007/s00168-017-0854-1

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. https://doi.org/10.1111/j.0022-4146.2005.00365.x

Sensier, M., Bristow, G., & Healy, A. (2016). Measuring regional economic resilience across Europe: Operationalizing a complex concept. *Spatial Economic Analysis*, *11*(2), 128–151. https://doi.org/10.1080/17421772.2016.1129435

Simmie, J., & Martin, R. (2010). The economic resilience of regions: Towards an evolutionary approach. *Cambridge Journal of Regions, Economy and Society*, 3(1), 27–43. https://doi.org/10.1093/cjres/rsp029

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. JRC, European Commission. https://doi.org/10.2788/771635

Thissen, M., Husby, T., Ivanova, O., & Mandras, G. (2019). European NUTS 2 regions: construction of inter-regional 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, October 4). *Labor mobility, trade and urban resilience to natural disasters*. Papers presented at the 2018 workshop on regional resilience at the University of Barcelona, November.