Prace Komisji Geografii Przemysłu Polskiego Towarzystwa Geograficznego
Studies of the Industrial Geography Commission of the Polish Geographical Society

40(1) • 2026

ISSN 2080–1653
DOI 10.24917/20801653.401.1

Jakub Kwaśny
Krakow University of Economics, Krakow, Poland
Arkadiusz Mroczek
Krakow University of Economics, Krakow, Poland
Marta Ulbrych
Krakow University of Economics, Krakow, Poland

Regional resilience and anti-fragility in the EU

Abstract: Supply and demand shocks through the COVID-19 pandemic and the Russia-Ukraine war have underscored the critical importance of the ability of regional economies to adjust to external shocks. The need to increase regional resilience and mitigate their adverse effects has become a subject of discussion among researchers and policymakers. More recently, another concept related to resilience, namely anti-fragility, has entered the debate. The purpose of the article is to discuss the concepts of regional resilience and anti-fragility from a theoretical perspective, as well as to present the results of an empirical analysis which explores regional economic resilience and anti-fragility (measured at the same scale) of EU NUTS-2 regions while including a structural analysis of contributing factors. NUTS-2 GVA data for 225 regions from 19 EU member states were used; the time series ranged from 2013 to 2023. The GVA growth rate for 2013–2019 served as the background period, and the data for 2010–2023 as the crisis period to compute each region's resilience score. In the second part of the empirical analysis, a hierarchical regression model was employed to investigate whether structural factors influence the resilience scores of the regions. The picture of regional resilience in the EU is complex, with several key findings. First, a great many of the vulnerable regions were located in Central Europe, moreover, a significant number of geographically peripheral regions proved to be anti-fragile. While strong manufacturing sectors are often associated with more resilient economies, our findings revealed a surprising result: a higher share of manufacturing in gross value added has a negative impact on resilience. This may be explained by the nature of recent shocks, the interconnections of European industry within global value chains, and energy price volatility. The findings may contribute to the contemporary debate on economic resilience and, given that they were obtained at the regional (sub-national) level, allow for a focus on structural factors rather than the policy issues that were decisive at the national level.

Keywords: anti-fragility, industrial policy, regional economic growth, regional anti-fragility, resilience, regional resilience

Received: 15 December 2025
Accepted: 28 January 2026

Suggested citation:
Kwaśny, J., Mroczek, A., Ulbrych, M. (2026). Regional resilience and anti-fragility in the EU. *Prace Komisji Geografii Przemysłu Polskiego Towarzystwa Geograficznego* [*Studies of the Industrial Geography Commission of the Polish Geographical Society*], *40*(1), 7–21. doi: https://doi.org/10.24917/20801653.401.1

Introduction

In the contemporary world, external economic shocks occur every few years. Financial system crises, pandemics and the results of nearby wars provide examples of those shocks. Different regions respond differently, and this response is an interesting field for empirical study, especially given regional variations in population size, metropolitan character, economic development and economic structure.

From a theoretical standpoint, the relatively new concepts of resilience and, more recently, anti-fragility have emerged as promising tools for studying the outcomes of shocks at various levels. While these concepts are still being refined and their use sometimes lacks precision, a deeper understanding can be achieved through clear definitions. Originally derived from systems theory and applied in ecology and engineering, the concept of resilience has also been adopted by economics. Anti-fragility, a term closely related to resilience, can also be studied within the systems framework, and this paper will draw on its basic concepts. In essence, both terms denote a response to adverse shocks, with resilience often indicating low vulnerability, and anti-fragility signifying the ability to benefit from primarily adverse factors. However, there are instances where the terms overlap, a concern that warrants initial attention.

Rimidis & Butkus (2025) highlight that cascading, or simultaneous shocks, are evident in recent global events, such as the COVID-19 pandemic, supply chain disruptions, and the war in Ukraine, indicating that they are a significant societal phenomenon. Despite their relevance, the systematic literature review found that the analysed papers did not explicitly address cascading shocks. This is noted as a significant research gap. Our study spans a period that allows for the complexity of the situation to be considered, thereby enabling a better understanding of the nature of regional resilience and anti-fragility. The empirical part of the study will present resilience scores for European regions, based on data from Eurostat covering the period 2013–2023. This analysis involves calculating and mapping resilience scores for 225 NUTS-2 regions, distinguishing between the pre-crisis period (2013–2019) and the crisis period (2020–2023), and accounting for the impacts of the COVID-19 pandemic and the Russian invasion of Ukraine. As described previously, the resilience score was derived by comparing average GVA growth rates across these two periods to assess each region's ability to restructure and adapt to external shocks. Covering the recent cascade crisis period (pandemics and full-scale war in Europe) from the resilience perspective is also a distinctive contribution of this study.

In the empirical section, the results of a structural analysis aimed at identifying potential determinants of resilience are presented. This involves examining regional structural features, such as the sectoral composition of gross value added (GVA), including manufacturing, other industries, trade and high-tech employment, as well as indicators of structural diversity and structural change over time. Data from Eurostat's Structural Business Statistics and Regional Innovation Scoreboard were utilised. The hypothesis tested at this stage is that the regional economy's structure affects its resilience.

The empirical analysis aims to uncover relationships between regional resilience and various structural, technological and economic factors, providing insights into what underpins a region's ability to withstand and adapt to external shocks. By integrating quantitative resilience scores with detailed structural indicators, this part of the research contributes to a deeper understanding of the drivers of regional resilience and anti-fragility within the European context.

The paper is organised into three main sections. The first introduces the concepts of regional resilience and anti-fragility, focusing on their definitions, theoretical foundations and relevance. The second section details the research methodology, including data sources from Eurostat (2013–2023), the calculation of resilience scores, and the structural analysis of regional factors such as sectoral composition, diversity, technological sophistication and innovation. It also describes the classification of regions based on these concepts and the statistical approaches used. The third section presents the empirical findings, discusses their implications compared to existing literature, and offers conclusions. Thus, the paper aims to deepen understanding of regional resilience and anti-fragility, with findings that help close the existing research gap in this area.

Literature review

In a constantly evolving global economy that poses new challenges, the concepts of resilience and anti-fragility are becoming increasingly popular and essential for understanding how systems can not only survive but thrive in the face of adversity. Resilience refers to the ability of a system to absorb, adjust and recover from shocks or economic disruptions while maintaining essential functions and continuing on a long-term growth trajectory (Walker et al., 2004). Resilience is a complex and multidimensional notion, initially developed by Holling (1973) as a framework for ecological research. In this article, the concept of economic resilience will be considered closely. It has its roots in broader resilience theory but focuses specifically on the ability of an economic system to cope with shocks while maintaining functionality. A resilient economy better withstands an adverse shock and returns faster to the pre-shock growth rate trend, i.e. minimising the cumulative GDP loss relative to potential output (Sánchez et al., 2015). Regional economies can be thrown off their growth paths through structural change (resulting from global or domestic competition or changes in demand) or other external shocks (like a natural disaster, recession due to their heightened interconnectedness with the global economy) (Hill et al., 2008). The ability of a system to maintain function (e.g. continue production) in the face of a shock is consistent with the fundamental economic problem of efficiently allocating resources and is identical to static economic resilience. A definition incorporating dynamic considerations is that of a system recovering from a severe shock to reach a desired state. This version of dynamic resilience is relatively more complex because it involves the long-term investment problem of recovery (Rose, 2007).

Martin (2012), who proposes a framework for understanding regional economic resilience, advocates a dynamic perspective, recognising that resilience is not just about returning to a pre-shock state but also about adapting to new economic realities and opportunities. He distinguishes between engineering resilience, which refers to the speed of return to a pre-shock state, and ecological resilience, which focuses on the system's ability to absorb shocks and reorganise. Considering this approach and based on the literature review, the essential elements of the analysed phenomenon can be identified. Definitions listed in Table 1 provide a comprehensive view of how economic resilience is conceptualised, covering the essential elements of absorption, adaptation, recovery and sustainable growth.

Table 1. Key elements of a resilient notion based on selected definitions

Key elements	Definition	Authors
Absorption of shocks The ability of a system to endure economic disturbances (equilibrium approach)	"The capability of a system to maintain its functions and structure in the face of internal and external change and to degrade gracefully when it must."	Allenby, Fink (2000)
	"The ability of a region to recover successfully from shocks to its economy that either throw it off its growth path or have the potential to throw it off its growth path."	Hill et al. (2008)
Adaptation The process through which economic entities adjust their strategies or structures in response to changing conditions	"Resilience as the capacity to avoid, withstand or adapt to crises has become a catchword to describe the capabilities to cope with negative shocks and adverse conditions."	Wink (2014)
	"When we say that an ecosystem, or city is resilient, we generally mean that in the face of shock or stress, it either "returns to normal" (i.e. equilibrium) rapidly afterward or at the least does not easily get pushed into a "new normal" (i.e. an alternative equilibrium)."	Pendall (2007)
Recovery The capacity to bounce back and restore economic stability, while potentially improving processes or structures (transformative resilience)	"The ability of regional economies to resist and adapt to or transform in the face of shocks and subsequently recover to maintain or improve their pre-shock economic performance."	Sutton et al. (2023)
	"Adaptability emerges through decisions to leave a path that may have proven successful in the past in favour of a new, related or alternative trajectory."	Pike (2010)
	"The capacity of regions to respond to shocks and crises by pushing an alternative agenda for regional economic development, one that is less oriented towards short-term growth and more focused on environmental sustainability and inclusive development."	Trippl et al. (2023)
Growth sustainability The ability to recover from shocks and sustain and potentially enhance economic development	"Economic resilience encompasses the ability to recover from shocks while ensuring long-term growth and development sustainability, integrating recovery efforts into broader economic advancement strategies."	Martin (2012)
	"Regional resilience is about a long-term capacity to foster structural change… We would stress that the long-term evolution of a regional economy will most likely involve both adaptation and adaptability. Moreover, how they interact over time indicates the differentiation of regional economic resilience."	Hu, Hassink (2019)

Source: authors' elaboration based on references listed in the table

Linking the notion of regional economic resilience with the concept of adaptation and placing the analysis in an evolutionary perspective allows us to distinguish four conceptual frameworks and empirical approaches to the analysed phenomenon (Simmie, Martin, 2009):

- generalised Darwinism, which emphasises diversity, e.g. in terms of economic structure and variability of firm behaviour. Regions with diversified economies are more likely to be resilient in the face of shocks
- path dependence theory, which focuses on historical continuity and the trajectory of socio-economic development
- a theory of complexity that emphasises self-organisation and adaptive growth. The process of self-organisation gives complex systems the potential to adjust their structures and dynamics in response to external shocks or internal co-evolutionary mechanisms
- panarchy, which emphasises resilience and adaptive cycles. It combines key attributes and processes of regional development, such as innovation, capital accumulation dynamics and mechanisms that generate linkages between local firms and institutions.

Among those approaches, the emphasis on diversity can be traced to the work of Jacobs (1969), who argued for stronger innovation capacity and faster adaptation in economically diversified cities. Additionally, in nature, variety is vital to the resilience of ecosystems (Stanley, 2011). Regarding regional economic resilience, variety can take the form of structural (sectoral) diversification and variation in firm behaviour and influence such resilience in several ways (Simmie, Martin, 2009). The degree of sectoral variety is thought to influence a regional economy's vulnerability to shocks, with those regions having a more diversified economic structure being less prone to shocks or, at least, more able to recover than those with an economically specialised structure. Self-organisation, industrial mutation and adaptive growth can, in turn, be linked to the Schumpeterian concept of creative destruction (Martin, Sunley, 2015).

Of course, the mutual penetration of levels of analysis is characteristic. However, this distinction is crucial for understanding the full spectrum of economic resilience, particularly with respect to the operational approach. From this viewpoint, resilience should be regarded as the potential of a given system to preserve its configurations and functions, suggesting that the structure can reorganise itself.

Resilience is generally understood in two basic senses (Chiffi, Curci, 2024). According to the first, narrower, view, resilience aims to restore the system's functions and outputs to pre-shock conditions (bouncing back). However, according to the extended view of resilience, previous functions are restored, and the system may even generate better outcomes than before the shock (bouncing forward). The literature generally defines resilience as the ability to bounce back and move on following a shock (Cowell, 2013; Manyena et al., 2011). Nevertheless, policymakers need to be able to assess potential bounce-forward trajectories and harness the self-organising mechanism that facilitates recovery (Grinberger, Felsenstein, 2014).

In this context, the concept of anti-fragility comes to mind, particularly the possibility of obtaining favourable outcomes after a shock in uncertain conditions (Buhman et al., 2021). Taleb (2012) defines anti-fragility as the property of systems, entities, or units that not only resist damage from shocks but also benefit from them, becoming stronger. At the same time, he notes that "anti-fragility is beyond resilience or robustness. The

resilient are shocked and stay the same; the anti-fragile get better." Anti-fragility characterises the benefit a dynamic system derives from perturbation variability (Axenie et al., 2024) and is exhibited by an ability to change for the better after an impact of initially unfavourable circumstances (Munoz et al., 2021). If the system is not resilient, it cannot sustain its functions under specific stress. However, according to Aven (2015), unlike any other form of resilience, the critical contribution of the concept of anti-fragility lies in the possibility of coping with the future stages of a system in which new functions can emerge. Resilient systems exhibit an ex-post adjustment to "black swans," while an anti-fragile system also shows an ex-ante adjustment to them (de Bruijn et al., 2020).

Summing up and, to some extent, simplifying the above, some authors use a broad concept of resilience, applying it both to the ability of a system to bounce back and to bounce forward. Since Taleb coined the term, other authors have preferred anti-fragility to describe a system that can bounce forward. In this paper, the latter approach will be utilised. From a conceptual point of view, the distinction between staying unchanged and moving forward in the face of demanding conditions is valid. Using just one term would often require sub-terms or describing which meaning applies to a situation. Empirically, as will be shown, it is easy to distinguish between them. Therefore, even though resilience and anti-fragility are parts of the same debate, distinguishing between them brings clarity.

Research methods

In the study, an approach to resilience based on the equilibrium perspective was employed, which conceptualises resilience as the ability of regional economies to absorb shocks and maintain their current equilibrium with minimal structural change. However, an adaptive understanding of regional resilience is also accepted, meaning that resilience is viewed as the region's capacity to recover from shocks or even enhance its core performance by adapting to external shocks (in the latter case, the term anti-fragile can also be used). Such adaptability involves undergoing structural changes in response to changing conditions. In addition, borrowing from systems theory, resilience is a system's ability to regenerate itself in response to external factors. Returning to regional science, it may also be said that a resilient region should have the capacity to return to its previous growth path, and an anti-fragile region should be able to transition to a new, better-performing growth path. Measuring and presenting those concepts with numbers should be possible, because we can say that they exist on a "continuum of fragility," where fragile means degrading with stress, robust stands for unchanged by stress, and anti-fragile represents improving with stress (Johnson, Gheorghe 2013). To operationalise those concepts, a representation of regional performance should be specified, and some factors representing the structure of regional economies should be selected.

The EU NUTS-2 regions were selected for research. Data availability was the basis for this selection and in the first part, data were collected for 225 such regions across 19 member states. This way, most EU regions were included, except those for which data were unavailable. In the second part of the research, which focused on structural factors, 217 regions were included and the structural data collected in 2019 were to best represent the regions under study before the crisis. For the factor representing structural dynamics, the data for 2020 were compared to those for 2019. The lack of further data limited this part of the work as it showed only the initial changes resulting from the crisis

but overall, the European regional data at the NUTS-2 level is rich in terms of both the number of regions and statistical coverage. One can argue, however, that any specific of the EU economy and society can influence the results, and this fact should be included in the interpretation.

Regional economic performance can be represented by unemployment (or employment) and GDP or GVA growth rates; gross value added (GVA) rates were chosen for this study. The reason is that the labour market in Europe currently responds only modestly to shocks, so indicators based on it would not be valid. GVA, on the other hand, is a valuable proxy for the region's economic performance; the data are available, and changes in their value are in response to shocks on a noticeable scale. Based on this, the following indicator was created. First, the data for GVA growth for 225 EU NUTS2 regions for 2013–2023 were collected. In the next step, the time series was divided into the "background" period of relative prosperity (2013–2019) and the "crisis" period (2020–2023). Then, the average values for each region for both were calculated. The crisis period is based on the COVID-19 pandemic, which began in 2020, and a further shock, i.e. the full-scale Russian invasion of Ukraine and its consequences, which started from 2022.

In line with the evolutionary perspective on resilience and path plasticity, the study utilizes a resilience score defined as the divergence between the average regional performance in 2020–2023 and the 2013–2019 baseline. The result of this subtraction is called the resilience score. This methodological choice warrants a brief comparison with alternative approaches prevalent in regional science. A widely adopted framework, proposed by Martin (2012), utilizes resistance and recovery indices to measure a region's sensitivity to shocks relative to a national or supra-national benchmark. While effective for identifying immediate cyclical vulnerability, such indices often focus on short-term deviations rather than long-term structural shifts (Martin, Sunley, 2015). Other scholars advocate for statistical time series models such as VAR to estimate a region's hypothetical growth path in the absence of shock (Doran, Fingleton, 2014). While these econometric techniques offer high precision, they often require longer time series and may struggle to account for the overlapping nature of recent crises.

In contrast, the subtraction method employed here aligns with the evolutionary and adaptive perspective of resilience. By comparing multi-year averages of pre-crisis and crisis-period performance, this approach captures the enduring shift in a region's growth trajectory. This is particularly relevant for operationalizing the concept of "anti-fragility," as it allows for the identification of regions that do not merely return to a previous state but establish a superior performance level following a disturbance (Taleb, 2012)

The resilience score was interpreted as follows: if it was lower than –0.5, the region was described as vulnerable. If the resilience score was between –0.5 and 0.5, the region was classified as resilient; if it was above 0.5, it was considered anti-fragile. Those ranges reflect the understanding of the concept of resilience presented in this work, where resilience means the ability to maintain performance at a previous level (bounce back), and anti-fragility means improving performance after the crisis (bounce forward). Given the substantial number of definitions in the literature, it was hard to find a ready-to-use numerical classification of resilience scores. Therefore, the above approach was taken, and an original classification has been proposed. The results of this classification are then presented, discussed, and used in regression analysis to gain more insight into the possible causes of regional resilience.

Formally, the final resilience score was obtained as follows:

$$R_i = G_{i1} - G_{i0}$$

where Ri is the resilience score for region i, Gi1 is the average growth rate for region i during the crisis period (2020–2023), and Gi0 is the average growth rate for this region during the background period (2013–2019).

In the second part of the empirical research, a hypothesis saying that the regional economy's structure affects its resilience was tested. To do this, a hierarchical regression model was used which was helpful because the regions under study are located in different countries, with different local conditions, and the member states they belong to pursue different policies. This approach allowed for control of those country-level factors. The general hierarchical model can be presented as follows:

$$Y_{ij} = \gamma_{00} + \gamma_{10} X_{ij} + \gamma_{01} Z_j + \gamma_{11} Z_j X_{ij} + U_{1j} X_{ij} + U_{0j} + R_{ij}$$

where: γ00 – global average, γ01, γ10, γ11 – regression coefficients, Xij – individual variable value X for unit i from the group j, Zj – group variable value Z for the group j, U0j – group random component, Rij – individual random term (Więziak, 2007). The very aim of this approach is also its basic strength. It allows for a focus on the structural factors of the regions, and any conclusions drawn from it may relate to those factors. At the same time, this approach does not allow for addressing any anti-shock policy conducted by the EU or the member states.

Results

The general result of a classification of regions according to their resilience score is shown in Table 2.

Table 2. Resilience score of EU regions

	Anti-fragile	Resilient	Vulnerable	Total (N)
No. of regions	48	50	127	225
% of regions	21%	22%	56%	100%

Resilience score: vulnerable < –0.5; resilient > –0.5 and < 0.5; anti-fragile > 0.5

Statistical character of the resilience score: min: –5.5; max: 6.6; mean: –0.7; standard dev: 1.7

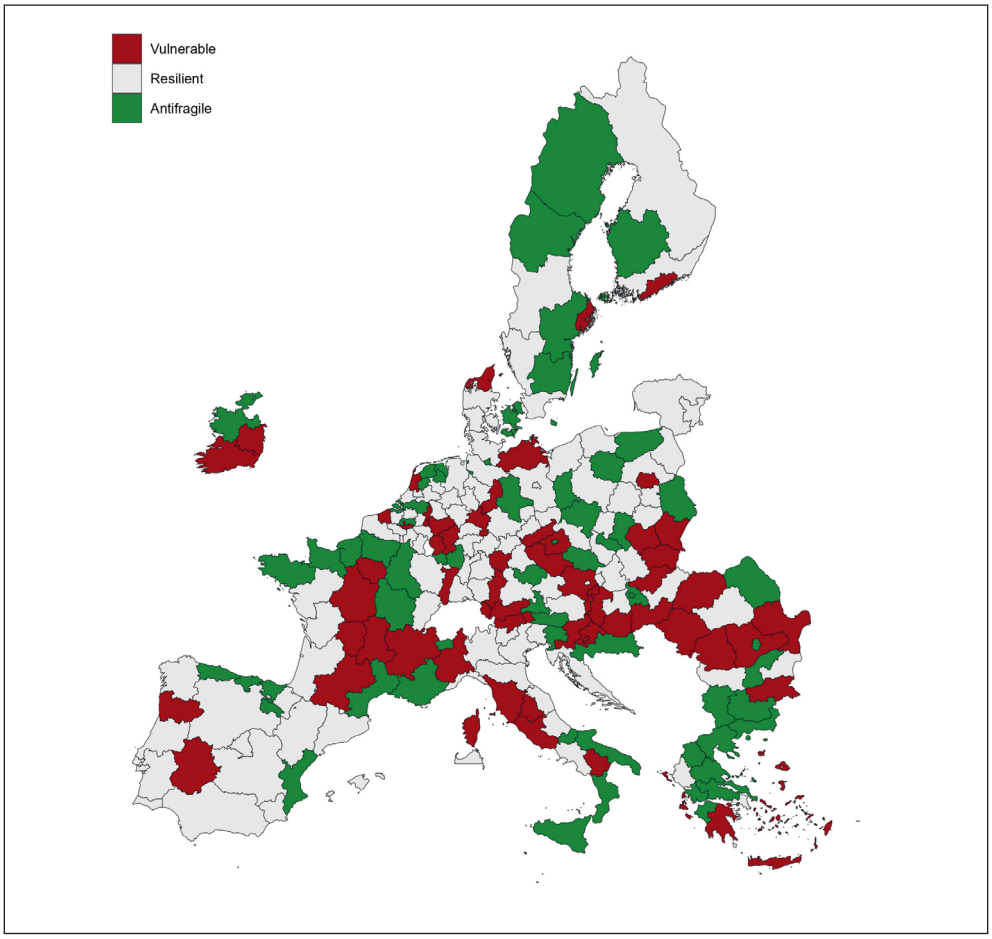
Source: authors' elaboration based on Eurostat data: (nama_10r_3gva__custom_12285674)

Most regions turned out to be vulnerable, meaning their growth slowed by more than 0.5 p.p. during the crisis period compared to the background period. This fact confirms that the crisis is severe from a regional perspective. The three-year period was not enough for the economies of the vulnerable regions to bounce back, let alone bounce forward. The share of regions classified here as resilient was 22%, and those regions can also be called robust if we use systems terminology. The share of regions classified as anti-fragile was lower by just one per cent, corroborating the usefulness of this group from an empirical perspective. Combining anti-fragile and resilient regions into a single

group will account for about 43%, a fraction that can be understood as the share of regions that have emerged from the crises relatively well.

Figure 1 presents the detailed results for the regions graphically and analysing the map may help better understand whether resilience follows any geographic patterns.

Figure 1. Resilience score of EU regions



Source: authors' elaboration based on Eurostat data: (naa_10r_3gva__custom_12285674)

The figure shows that the vulnerable regions can be found mainly in Central Europe, including Germany, Czechia, most of Austria, Poland and Romania. Such regions also appeared in France and Mediterranean member states. Resilient regions appeared in many somewhat peripheral areas, both in the east and the west; however, parts of the European development corridor, often called the "Blue Banana," such as Benelux and Northern Italy, were also classified this way.

The most interesting and complex pattern can be attributed to the anti-fragile regions. They tend to be located peripherally, although some are part of the EU's core. Some of them are also the capital regions of their countries, but most of them are peripheral

in their national context. Such regions can be less prone to international economic disruptions, as their connections to the global economy are weaker. Overall, the map suggests that the regional resilience studied here is a complex phenomenon that warrants further reflection.

Therefore, a regression analysis was conducted to check whether some structural factors may have influenced the resilience factors obtained. Identifying causal pathways and selecting explanatory variables, particularly given their availability at a regional level, is challenging. The set of structural factors is based on the previous literature review (Annoni et al., 2019; Giannakis, Bruggeman, 2017; Sutton et al., 2023) and includes shares of the six sections covering the entire GVA, except for agriculture and forestry excluded because of their negligible share in the economic structure of almost all regions. The sections included: 1. Manufacturing; 2. Industry without manufacturing and construction; 3. Construction; 4. Wholesale and retail trade, transport, accommodation and food service activities, information and communication; 5. Financial and insurance activities, real estate activities, professional, scientific and technical activities, administrative and support service activities; 6. Public administration and defence, compulsory social security, education, human health and social work activities, arts, entertainment and recreation, repair of household. Two other indicators were additionally calculated. The first one shows the structural diversity of the regional economy, which is understood as the share of other sections, excluding the one with the highest share. This factor was obtained based on the Structural Business Statistics section of Eurostat and was calculated using the data for 83 NACE sections, for which the 2019 data were available as the basis for future resilient reactions. Structural diversity is the opposite of structural concentration, understood as the dominance of just one industry. This approach is related to Glaeser et al. (1991). The other indicator was created to depict structural changes in the regions under discussion and aligns with Schumpeter's approach to economic dynamics. It shows the total change in shares across all 74 NACE sections for which data were available in the region's economy between 2019 and 2020, as no more recent data were available.

Innovation as a determinant of resilience is also frequently considered in research, including studies such as Bristow and Healy (2018) which highlight the importance of innovation capacity in explaining regional performance differences in Europe. Three variables were used to control for technological sophistication: human resources in science and technology – percentage of population in the labour force, employment in high-tech sectors – percentage of total employment, and the Regional Innovation Scoreboard overall score. Finally, regional GDP per capita was used to check whether its level influences resilience.

As this work is focused on regional phenomena, it is essential to note that besides regional factors, there are also global, European (EU policy and the general market) and national factors. Global and European factors can be treated as neutral when comparing EU regions, an assumption based on the simple fact that the conditions created by those factors are the same for all the regions. For national factors, however, it is not the same. Different countries can apply different fiscal policies; some EU members conduct their own monetary policy, and national governments have reacted in many ways to the pandemic. A hierarchical model of regression was used to account for this by allowing for the creation of different classes of region, depending on the member state to which each belongs. The results of modelling in terms of statistically significant factors and their influence on the resilience score are presented in Table 3.

Table 3. Structural factors and regional resilience in the EU

Variable	p value	Influence
Manufacturing	0.005	Negative
Public administration and defence; compulsory social security; education; human health and social work activities; arts, entertainment and recreation; repair of household	0.057	Negative
Industry without manufacturing and construction	0.056	Negative

Hierarchical regression model (REML), N = 217, number of classes (countries): 19

Source: authors' calculations based on Eurostat data: (nama_10r_3gva__custom_12285674; nama_10r_2gdp__custom_12191111; tgs00038; tgs00039)

The only statistically significant variable at the level normally used in social science ($p < 0.05$) is the share of manufacturing in a region's economy. The other two variables are also close to this level, so together they can serve as a basis for the conclusion. All three variables are negative, meaning that as they increase, the resilience score decreases. In other words, no factors were identified as positively influencing resilience, and only negative factors were pointed out.

Discussion

Considering the geographical pattern of regional resilience, it is worth mentioning the study by Annoni et al. (2019), which examined regions' ability to recover and return to a path of economic growth and sustain prosperity during the recession and financial crisis between 2008 and 2015, focusing on the factors determining economic growth and resilience. They also investigated whether these determinants are similar across different groups of EU regions and their analysis found that the determinants of regional growth and resilience varied across spatial regimes (core vs. periphery). This division was based on the spatial distribution of GDP per capita in 2008. Regions surrounded by other regions with a higher initial GDP per capita (in 2008) tended to experience faster growth, results consistent with the empirical literature on convergence. In our work, no clear pattern like that was found, and even its opposite seemed true, as the anti-fragile regions were spread across the EU, often surrounded by more vulnerable regions.

The finding that manufacturing negatively influenced resilience may be striking and counterintuitive. It is, however, supported by another finding, showing that other industries also negatively influence resilience. Furthermore, returning to the map, it indicates that many vulnerable regions are those that were traditionally considered industrial. Such results are not unprecedented in the literature, as similar have been found by other researchers, indicating a negative effect of a large manufacturing sector on regions' ability to withstand recessionary shocks (Giannakis, Bruggeman, 2017).

Even if our findings may be unexpected based on some traditional literature, they are, however, explicable, and there may be several justifications for the results obtained. Foremost, the specifics of the pandemic crisis disrupted supply chains and caused a decline in demand for many products, such as vehicles. In addition, other crises whose effects are evident in the data might contribute to the poor performance of the industrial sector in Europe. The increase in energy prices triggered by the Russian invasion and the reaction to it, in the context of an energy transformation that was not going smoothly in many member states, indeed worsened the conditions for a large part of this sector.

Taken together, they formed a cascade of crises in which negative consequences multiplied.

The negative influence of the public sector's share on the resilience score may also be worth discussing. On the one hand, public expenses are traditionally considered to play a stabilising role in the economy. Independent of the business cycle, they may smooth it by providing spending during times when the private sector fails. In the long run, however, the public sector must also cut expenses. Moreover, a relatively high share in the economy may indicate the weak potential of the private sector. The public sector tends to be less adaptable, which is another argument supporting its potential negative influence over resilience.

Conclusions

The pandemic and war in Eastern Europe have increased interest in economic resilience and security, particularly considering disruptions to global value chains and the imperative to strengthen the EU's strategic autonomy. This context provides empirical material to study this concept at a regional level. The geographic pattern of regional resilience in the EU presents no clear picture contrasting with classical studies of regional development. Even though the main development corridor is partly visible, some other anti-fragile regions were positioned in the peripheral parts of the EU. Regions of Central Europe proved vulnerable to shocks, including large parts of the new member states, which had been leaders in European economic growth.

The results of this study also show no universal factor contributing positively to resilience. Negative influence was, however, demonstrated, and a factor contributing to regions' vulnerability was their share of industry, including manufacturing, in the economy. This vulnerability is partly rooted in long-term structural shifts, particularly the accelerated delocalisation of EU industrial capacity since the 1990s, driven by globalisation and cost-efficiency. Multinational corporations systematically offshored manufacturing to Asian economies with lower labour costs, laxer environmental regulations and state-subsidised production ecosystems. This hollowing-out of Europe's industrial base progressively eroded its comparative advantage in energy-intensive sectors, mid- to high-tech manufacturing and value-added production. Energy cost variability remains a separate negative factor influencing industrial regions.

Some of the findings can be interpreted more positively. The lack of relationship between the current level of development and resilience shows that the former offers no particular advantage to a region, and that a crisis may be an opportunity for some poor regions to change their development paths. In general, it must be noted that, from an empirical perspective, resilience remains a complex phenomenon, and research on the factors contributing to it should continue. As more recent data become available, an effort should be made to examine the relationships between structural diversity, structural dynamics and resilience, as this study has found a lack of them, but this may be specific to the current crisis stage.

Policy recommendations should prioritise rebuilding the EU's comparative advantage through endogenous mobilisation, including industrial modernisation and strategic autonomy in critical sectors. Despite industry's vulnerability, it remains vital for long-term economic security, technological leadership and GVC repositioning. The industrial restructuring strategy is crucial for strengthening economic resilience in the face of long-term

challenges (Peng et al., 2025). An EU-wide industrial strategy must address secure and diversified supply chains, competitive energy systems, and the development of human capital in advanced technologies, particularly amid demographic decline. This aligns with efforts to counter decades of offshoring and re-anchor high-value production within the EU, as seen in initiatives such as the European Critical Raw Materials Act.

The limitations of the current study come from data availability. The 2020 to 2023 period provides interesting insight, but further studies with more recent data are necessary. This will allow for the full effects of post-pandemic recovery or the economic results of the war in Ukraine.

Future research could overcome the above obstacles. Because of the complex nature of resilience, studies that focus on a deeper analysis of regions that performed especially well after the crisis could provide insights into the factors that contribute to resilience. Further analysis should investigate regions that successfully leveraged endogenous assets (e.g. local innovation ecosystems or workforce upskilling) to enhance resilience, offering insights for EU-level strategies.

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Acknowledgment:
The article presents the result of the Project no 081/EEG/2024/POT, financed from the subsidy granted to the Krakow University of Economics, and the result of the Project no 082/EEG/2024/POT, financed from the subsidy granted to the Krakow University of Economics.

Jakub Kwaśny, PhD, Krakow University of Economics, Department of International Economics. He is an Assistant Professor at the Department of International Economics at the Krakow University of Economics, Mayor of the City of Tarnów and local government official. His academic interests focus on issues of local and regional development, the European Union's cohesion policy, and international economics. He is the author of numerous publications on local government and regional development, as well as a participant in research projects analysing economic processes in EU countries, with particular emphasis on territorial organizations and urban development.

ORCID: https://orcid.org/0000-0002-0786-304X

Address:

Krakow University of Economics
Department of International Economics
ul. Rakowicka 27
31–510 Kraków, Poland

e-mail: kwasnyj@uek.krakow.pl

Arkadiusz Mroczek, PhD, Krakow University of Economics, Department of International Economics. His research interests focus on urban and regional development, metropolitan economics and the location of the business service sector.

ORCID: https://orcid.org/0000-0003-3736-437X

Address:

Krakow University of Economics
Department of International Economics
ul. Rakowicka 27
31–510 Kraków, Poland

e-mail: mroczeka@uek.krakow.pl

Marta Ulbrych, PhD, Krakow University of Economics, Department of International Economic Relations. Her research interests focus on international economic integration, globalization, industrial policy and energy transition. She is the author of numerous publications on industrial competitiveness and regional development, as well as a participant in research projects analyzing economic processes in EU countries, with particular emphasis on the Visegrad Group.

ORCID: https://orcid.org/0000-0003-3886-371X

Address:

Krakow University of Economics
Department of International Economics
ul. Rakowicka 27
31–510 Kraków, Poland

e-mail: ulbrychm@uek.krakow.pl