Title: *Technological innovation and regional resilience: a Composite Index approach to assess regional vulnerability*

Keywords: Technological innovation; Automation; Artificial Intelligence; Regional disparities; Regional economic resilience; Composite Indicators; Policy evaluation; Difference-in-Differences analysis.

Project summary description

The aim of this research project is to analyse how the introduction of new emerging technologies into the labour market, in particular automation and artificial intelligence, may impact regional economic resilience. Regions are characterised by different economic structures and may respond differently to such an exogenous shock. This study intends to perform a multi-pronged regional vulnerability assessment using a composite index (through PCA analysis) to investigate the impacts of new emerging technologies at the regional level in the main risk sectors. The analysis intends to consider five components within the index: labour market, financial system, governance and institutions, economic performance, and environmental factors and sustainability. Using the derived outputs, the aim is to define a regional vulnerability parameter useful for classifying regions with the aim of expressing the stages of resilience described by Martin and Sunley (2015) for those regions that are lagging behind. The analysis will focus at the European NUTS-2 level and will reveal:

(i) the impact of technological innovation in terms of vulnerability at regional level, taking into account the significant diversity of regions and key sectors
(ii) the importance of cohesion policies adopted at regional level and how can be effective for promoting economic resilience and differentiated guidelines

Overall, this project aims to contribute to the growing literature by exploring:

(i) the economic consequences of new emerging technologies and their impact on the increasing regional inequalities
(ii) the relationship between resilience and vulnerability
(iii) the effects arising from the implementation of public cohesion policies

The expected results will provide concrete recommendations for the design of differentiated and evidence-based adaptation strategies, useful for guiding investments at regional level.

State of the art

Despite many years of social scientific research into innovation and emerging technologies, and their recent rise the public and political 'visibility', key researchers such as Autor (2024), Acemoglu, Restrepo (2019) and Goos (2018) continue to argue that our understanding of the future impacts of new technologies remains limited. David Dorn (2015) questions whether technological progress will continue at the same rate or are we reaching a saturation point in the next years. In this era of constant transitions and transformations, consumer expectations and the ongoing environmental pressure, along with the increasing globalisation, are redefining the competitive environment in which firms operate (Song et. al, 2022). Within this scenario, innovation is no longer an option, it is a necessity. However, in recent years, the increasing spread of new digital technologies has radically transformed the competitive environment in which companies operate (Brynjolfsson and McAfee, 2014). Emerging technologies, such as artificial intelligence and automation, are redefining how we work, learn and relate.

The first studies on the introduction of new technologies and their impact on the labour market have already found evidence in the past. As early as the 16th century, English weavers protested against mechanical looms and the Luddites (between 1811 and 1816) destroyed textile machines in protest against the advent of mechanisation. Later, Keynes (1930) introduced the concept of technological unemployment, the idea that technology could reduce the demand for human labour in the future. Schumpeter (1942) spoke of creative destruction, the idea that technological innovation destroys old sectors in which human labour is replaceable but creates new ones. Leontief (1983) argued that, unlike in the past, the new computer and automatic technologies might not create enough demand for labour to compensate for that lost, especially for unskilled workers. However, the latest technological revolutions have fundamentally transformed the labour market compared to the past by generating a new demand for labour. Zuboff (2019) argues that modern technologies are not just tools for enhancing human physical strength but intelligent systems capable of automating complex decisions. Even professions with advanced skills (such as doctors, lawyers and teachers) are exposed to automation and digital transformation (Susskind, 2015).

These dynamics are highly relevant, as they play a crucial role in both the ongoing economic transformation and efforts to maintain social and territorial cohesion (European Commission). The European Commission, among its main activities, promotes the implementation of cohesion policies in order to stimulate competitiveness, innovation and green and digital transition also at regional level. In this regard, it clearly confirms the existence of significant regional gaps within the European Union, and cohesion policies are one of the main instruments to address them. The idea that regions

develop unevenly is not new (Myrdal, 1957). In fact, regions have always been characterised by different economic and structural systems. These differences are related to many aspects, including employment, environment, infrastructure and so on. This phenomenon has also been amplified by increasing globalisation (Puga, 2002; Autor et. al, 2013). Indeed, Sassen (2001) notes that globalisation favours the concentration of wealth and innovation in large cities and metropolitan areas, creating strong regional disparities. Pike et. al (2006) confirm how globalisation has made inequalities between regions more visible. However, even where cohesion policies act (e.g. EU structural funds), the reduction of regional disparities is slow and uncertain (European Commission, 2024). Alexopoulos et al. (2025) analysed the effects of the EU Cohesion Fund and the results indicate that the positive effects are concentrated in the first seven years after a region's inclusion in the programme, but with an uneven distribution where poorer regions tend to benefit more, while richer ones show smaller effects.

Even though progress has therefore been made in reducing disparities, significant differences within countries persist (OECD, 2016). Within this context, the risk that the process of technological innovation accentuates existing regional gaps, making some areas more vulnerable in terms of innovation and development, must be considered. Meanwhile much of the literature has focused more on the impact of technology at the macroeconomic level (Aghion and Howitt, 1994; Acemoglu et. al, 2000 and others), mainly considering impacts on GDP and employment, this research project aims to provide a more detailed perspective for geographical areas where we already find important foundations of some research (Saxenian, 1996; Boschma, 2005; Moretti, 2012; Rodríguez-Pose, 2013; Iammarino et. al, 2020) expandable for future academic debate.

These presented studies highlight two fundamental aspects. First, new technologies risk increasing inequalities by creating a new "*geography of vulnerability*" in which some regions respond better than others. While in some regions economic and educational progress will provide new opportunities, others may be more affected. Secondly, regional disparities mean that regions respond differently to these external shocks caused by technology (Martin R, 2012). The ability of a region to respond to exogenous shocks is a fundamental concept, referred to as economic resilience, and represents the readiness and effectiveness with which an area is able to absorb, adapt to and recover from unforeseen external events (Martin R, 2011). An authoritative theoretical framework is provided by Martin and Sunley (2015) in which they define the four dimensions of regional resilience: *resilience*, *recovery*, *reorientation* and *renewal*. Numerous works in the literature show how European regions have reacted differently over the years to exogenous shocks and crises (Crescenzi et. al., 2016; Martin et. al., 2016; Bristow and Healy, 2018) and others deepen how regional resilience also depends on institutional, social and local governance factors (Sensier et. al., 2016).

It is therefore evident from the wide research presented in this section that the impact of technological innovation on the labour market remains a central concern within the scientific community, with several critical issues yet to be resolved. Several contemporary scholars point out that there are substantial gaps in our understanding of technological evolution, particularly with regard to artificial intelligence and automation (Acemoglu, 2023; Brynjolfsson, McAfee, 2014; Autor, 2015). Autor (2024) argues that the direction that new technologies take will depend mainly on political, institutional and cultural choices, not necessarily on technological fate. New technologies don't have a predetermined fate and require extensive redevelopment (especially in terms of policies). This is still an open point in the literature as, in general, the academic and institutional debate agrees on the importance of these policies and their evolution, but it remains a discourse that needs to be updated along with assessments of future technological impacts.

Within this debate, a growing literature started integrating dynamics of technological innovation with the subnational dimension, investigating how heterogeneous regional characteristics lead to differential exposure to technology. Within this framework, the concepts of regional vulnerability and resilience have acquired considerable relevance (Martin, 2012; Stanickova and Melecky, 2018; Panori, 2024; Marin et al., 2021; HERIAUD, B et al., 2025). When we talk about (technological) vulnerability, we mean the predisposition of a regional economic system to suffer negative consequences due to digital transformation, unlike resilience that represents the capacity to absorb, adapt, and recover from such exogenous shocks (Martin and Sunley, 2015). To study these concepts, a broad field of research has used composite indicators. These indicators are useful for aggregating multiple dimensions into a single, synthetic measure of regional adaptive susceptibility or capacity. The advantage of composite indicators lies in their ability to condense complex, multidimensional phenomena into manageable metrics, suitable for regional and territorial comparison. Although this methodological choice sometimes presents significant limitations (including sensitivity to normalization techniques and assumptions regarding weights and the selection of constituent variables), composite indicators are considered an appropriate approach to assess vulnerability and its components (Sibilia et al., 2024). Their effectiveness lies in their ability to simplify the multi-dimensionality of vulnerability and the interlinkages between its components by capturing the most significant factors and providing an easily interpretable measure.

However, the existing literature on composite indicators for regional vulnerability has mainly focused on environmental hazards (such as floods, earthquakes and climate extremes), economic crises, or health emergencies. While these contributions are undoubtedly valuable, they do not capture the specific channels through which digital transformation generate differential risks across territories. Moreover, technological vulnerability differs from other forms of regional exposure in at least three

fundamental respects. First, it is mainly driven by the occupational and task composition of the local labour force, rather than by physical or geographic exposure. Second, its effects unfold gradually over time, often without a sudden triggering event, making it less visible and more pervasive. Third, it interacts with regional institutional factors, such as the presence of active labour market policies, educational and training systems and innovation ecosystems, which can either mitigate or amplify its impact.

Considering these aspects and the limited number of studies that have attempted to construct composite indicators specifically designed to assess regional vulnerability to technological innovation (Cappellano et. al, 2021; Martinez A. and Talavera, A., 2026 and others), it is precisely here that the present study intends to position itself. By developing a Regional Vulnerability Composite Index, this research aims to provide a more comprehensive and policy-relevant tool for assessing territorial disparities in order to face the ongoing digital transformation. The proposed index is not intended to replace existing vulnerability measures, but rather to complement them by addressing a critical blind spot i.e. the uneven capacity of regions to withstand and adapt to technology-driven labour market shifts.

Research objectives

The main objective is to analyse how the introduction of new emerging technologies (automation and AI) affects the vulnerability of European regions, developing and applying a Regional Vulnerability Composite Index (RVCI) at the EU NUTS-2 level, in order to provide a comparative tool for analysts and policymakers. Secondary objectives refer to:

- Evaluate the impact of cohesion policies at regional level in reducing regional disparities
- Define a recovery framework for those regions lagging behind (more vulnerable) following the structure of Martin and Sunley (2015) → *Resilience*, *Recovery*, *Reorientation* and *Renewal*

The NUTS-2 level is the administrative level assigned by the European Union for cohesion policies, and regional strategies for technological innovation are designed and implemented at this level. Applying this level will allow the assessment of where technological inequalities emerge. Much of the literature has focused on this level, assessing how regional disparities in Europe are within countries and not only between them. Riccio et. al (2025) consider the exposure of European employment to labour-saving technological change at the NUTS-2 level, finding that low-wage regions and deindustrializing regions are disproportionately vulnerable to technological substitution.

Hernandez de Rojas et. al (2025) find digitalization and competitiveness gaps across 240 NUTS-2 regions, demonstrating that capital regions lead in both, while regional capitals lag behind.

Furthermore, NUTS-2 is the level at which vulnerability and resilience dynamics are measured. The European Commission itself is investing significant resources in developing composite vulnerability and resilience indicators at this level through its Joint Research Centre (JRC). Among the European Commission's key initiatives there is the Regional Resilience Dashboard (RRDB), a comprehensive dashboard that provides an overview of resilience and capacity for 242 NUTS-2 regions in the EU, with the aim of supporting regions in self-assessing and identifying strategic interventions to strengthen resilience. The dashboard includes data on 24 vulnerability and 27 capacity indicators, covering economic, social and environmental dimensions, with data spanning a significant time span, from 2017 to 2023.

The European Commission has therefore recognized the importance of monitoring regional vulnerability. However, its tool addresses the technological dimension only in a residual manner, relying on just four indicators, mainly focused on access and basic use. Beyond this limited technological perspective, the Commission’s framework includes very few indicators specifically designed to capture vulnerability, while using a greater number to assess the aspect of resilience. This imbalance risks overlooking regions that not only lack resilience capacities but are also inherently more exposed and vulnerable to technological risks.

Research questions

- How does the adoption of new emerging technologies (automation and AI) negatively impact economic resilience?
- Which factors most influence regional vulnerability in Europe, and what spatial dynamics emerge?
- Are public policies effectively reducing vulnerability and strengthening resilience?

Methodology and expected results

As Tyler et al. (2010) emphasized, resilience and vulnerability are two sides of the same coin. One cannot understand the former without thoroughly analysing the latter. While much of the literature on regional resilience focuses on the capacity to respond to shocks ex post, this research project seeks to adopt a different perspective. Following the evolutionary approach suggested by Tyler et al. (2010),

the question is: is it possible to identify the conditions of vulnerability that make a region more exposed to technological shocks? In other words, instead of asking *'how to react afterwards,'* the question should be *'how to avoid finding regions in a situation that requires an emergency response?*'

Considering these aspects, methodology involves a four-step process:

[1] *Construction of the Regional Vulnerability Composite Index (RVCI)*. The composite index is a useful measure in this regard that allows for the explanation of a multidimensional concept, which will have to integrate structural and non-structural variables of the regions examined in order to obtain information for a subsequent assessment of regional economic resilience. The index aims to integrate the following dimensions (with their indicators within): labour market (unemployment rate, labor force participation and % routine jobs), financial system (access to credit, bank deposits (% of GDP) and financial regional activity rate), governance and institutions (government efficiency, perceived corruption and the rule of law), economic performance (GDP per capita, labor productivity and disposable income) and environmental factors and sustainability (CO_2 per capita, green employment and exposure to natural hazards).

[2] *Regional ranking → descriptive analysis + cluster*. The second section will present the results of the Regional Vulnerability Composite Index (RVCI) for the 242 NUTS-2 regions of the European Union. The analysis will be divided into three parts. First, there will be the regional ranking in order to identify the most and least vulnerable areas. Second, there will be the analysis of the geographical distribution of vulnerability, with particular attention to the role of capital regions. Third, cluster analysis techniques will be used to identify homogeneous vulnerability profiles, showing that regions with similar aggregate scores could have different vulnerability structures.

[3] *Regression analysis*. After constructing and validating the RVCI, the empirical analysis aims to go beyond description (ranking and clustering), in order to identify the causal factors determining the different levels of technological vulnerability across European regions. The objective is to understand why some regions are more vulnerable than others. To do so, the RVCI will be used as a dependent variable in panel data regression models. This approach, as suggested by Tyler et al. (2010), allows to move beyond static analyses and capture path dependence dynamics and the impact of policies over time.

Specifically, the two main models should be considered:

Model 1: The impact of technology adoption on vulnerability

This model aims to test the impact of technological innovation on regional vulnerability. The equation is as follows:

$$RVCI_{it} = \alpha + \beta \mathbf{X}_{it} + \gamma \mathbf{Z}_{it} + \gamma_i + \delta_t + \varepsilon_{it}$$

where:

Variables	Description
$RVCI_{it}$	Regional Vulnerability Composite Index
α	Intercept
$\mathbf{X}_{it}$	**Vector of technological variables** (such as *Robot Density*$_{it}$, *R&D Expenditure*$_{it}$ and *AI PatentStock*$_{it}$)
β	Coefficients associated with technological variables
$\mathbf{Z}_{it}$	**Vector of control variables (Population density, Trade balance etc.)**
γ	Coefficients associated with control variables
γ_i	Fixed regional effect
δ_t	Fixed temporal effect
ε_{it}	Error term

Model 2: Policy impact assessment

This model aims to assess the effectiveness of European policies in reducing vulnerability. The equation is the same as before, but in this case independent variables of interest are policy variables (CohesionFunds and DigitalFunds). Moreover, the aim here is to add interaction terms because

digital funds are not expected to have the same effect everywhere and the hypothesis is that their effectiveness depends on the region's human capital.

Finally, the inclusion of γ_i (*regional fixed effects*) will allow to control for all the specific and time-invariant characteristics of each region (e.g., history or culture). The same goes for the inclusion of δ_t (*time fixed effects*) where the aim is to control for common shocks that affect all regions in the same year (e.g., a financial crisis).

[4] *Policy analysis to formulate evidence-based policy recommendations*. The aim is to analyse the role of the main public policies adopted at European level through the assessment of both ex-ante and ex-post effects, by using the *Difference-in-Differences* approach widely common in literature (Gentzkow et. al, 2011; Autor et. al, 2013; Acemoglu et. al, 2016). The aim is to define differentiated guidelines to ensure support for regional developments trajectories and innovation.

Research design framework

Regional Vulnerability Composite Index (RVCI)

Regarding what has been realized and provided so far in the literature, the definition of the Regional Vulnerability Composite Index (RVCI) is provided by the following dimensions:

- **Labor market**. This section aims to assess the composition of the labor force and understand its fragility in terms of its vulnerability to technological shocks. In this case, it will be useful to consider indicators such as the unemployment rate, labor force participation and % of routine jobs.
- **Financial system**. The regional financial system contains the set of financial institutions, instruments and services operating in a region, which determines the ability of businesses to access financing, manage risks and invest in innovation. This section aims to highlight the composition of the financial system by examining indicators such as access to credit, bank deposits (% of GDP) and financial regional activity rate.
- **Governance and institutions**. Measuring governance and the impact of institutions at the regional level is important for diagnosing problems, guiding public policies, attracting investment and assessing citizen well-being. Indicators such as government efficiency, perceived corruption, and the rule of law will be considered. These indicators are not primary regional data, but are national indicators attributed to all NUTS-2 regions within a single country. The primary source of this data will be the World Bank's Worldwide Governance Indicators (WGI) dataset.

- **Economic performance**. In this case the aim is to assess how well a regional economic system achieves its key objectives, such as growth, stability, efficiency and well-being. To this end, indicators such as GDP per capita, labor productivity, and disposable income will be considered.
- **Environmental factors and sustainability**. In recent years, environmental factors and sustainability have emerged as central dimensions in the analysis of regional vulnerability and resilience, reflecting a growing awareness of the complex interaction between human and natural systems (Sibilia, A. et. al., 2024). As highlighted by the most recent literature, vulnerability can no longer be conceptualized exclusively in socio-economic terms but must necessarily incorporate the environmental conditions and pressures that shape a territory's capacity to withstand and adapt to multiple shocks. To this end, the assessment will consider indicators such as per capita CO_2 emissions, air quality, green employment and exposure to natural hazards.

RVCI computation

Once data have been organized, the indices within the dimensions will be normalised to allow for a correct assignment of weights. Specifically, the index will be aggregated using the weights calculated through *Principal Component Analysis* (PCA) in order to maximise the variance explained by each component. This technique will capture the most relevant information provided by the index.

RVCI formula (min-max normalization with PCA weights)

$$RVCI_{it} = \sum_{j=1}^{k} w_j \cdot \frac{x_{ijt} - \min(x_j)}{\max(x_j) - \min(x_j)}$$

Where:

Symbol	Description
$RVCI_{it}$	Regional Vulnerability Composite Index for region i at time t
$j = 1, \dots, k$	Index iterating over the k selected indicators

Symbol	Description
w_j	Weight assigned to indicator j (derived from PCA)
x_{ijt}	Observed value of indicator j for region i at time t
$\min(x_j)$	Minimum value of indicator j across the entire sample
$\max(x_j)$	Maximum value of indicator j across the entire sample

Min-max normalization

$$\frac{x_{ijt} - \min(x_j)}{\max(x_j) - \min(x_j)}$$

This transforms each indicator to a scale between 0 and 1, making them comparable regardless of their original unit of measurement. The interpretation is:

- 0 = best performance (lowest vulnerability)
- …….
- 1 = worst performance (highest vulnerability)

PCA weights (w_j)

The weights are derived from *Principal Component Analysis (PCA)*. This method is useful to identify the underlying structure of the data and assign higher weights to indicators that explain more of the variance in the dataset.

Sum across indicators

$$\sum_{j=1}^{k} w_j \cdot (\text{normalized value})$$

The final RVCI is the weighted sum of all normalized indicators. The result is a single composite score for each region-year observation.

However, the standard composite index has limitations relating to the choice of weights w_j and its sensitivity to outliers (Greco et. al, 2018). To improve the reliability of the index, this study will therefore evaluate alternative methods, including sensitivity analysis and robustness checks.

Once the Regional Vulnerability Composite Index will be updated and completed, the information will be used for the assessment of the regional vulnerability and for differentiated policy recommendations.

Conclusions and expected Results

This research project proposes the construction of a Regional Vulnerability Composite Index (RVCI) to assess technological vulnerability (to automation and AI) for 242 European regions at the NUTS-2 level. Even though existing indices treat digitalization as a residual dimension within broader resilience frameworks (such as the European Commission's Regional Resilience Dashboard), the RVCI is designed to capture the multidimensional nature of technological vulnerability along the five dimensions presented.

Based on the theoretical framework proposed and existing literature, four key points can be discussed. First, the RVCI should be treated as a comparative tool for researchers and policymakers, as well as a tool for further geographical studies. Second, considering the previous studies on regional disparities, the RVCI should reveal significant heterogeneity across European regions, where technological adoption increases vulnerability in less-developed areas. Third, cohesion policies are expected to be effective in reducing vulnerability while also finding new dimensions and outcomes that can guide new investments and policy choices. Finally, despite often being studied together, vulnerability and resilience are expected to be imperfectly correlated.

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