CONFLICT SCENARIOS AND TRANSITIONS

Opportunities and Risks for Regions and Territories

edited by
Marco Modica
Davide Piacentino

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FrancoAngeli

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Conflict Scenarios and Transitions. Opportunities and Risks for Regions and Territories

Marco Modica, Davide Piacentino°*

1. Multiple Conflicts, Global Tensions and Transitions

In the last three years, societies have seen an increasing number of challenges worldwide. In order to mention just the most recent events we can report, at global level, a pandemic (COVID-19) followed by a series of international conflicts such as the Russo-Ukrainian war and the Israeli-Palestinian conflict. These tensions have led to an increase of inflation mainly due to three shocks: i) an energy price shock triggered by the disruption of natural gas furniture caused by the Russo-Ukrainian war (Wildauer *et al.*, 2023); ii) demand shocks to the goods sector caused by a combination of geopolitical instability, reduced consumer confidence and lower investments, combined with production delays (Foglia *et al.*, 2023); and iii) supply chain disruption of intermediate goods, that in the end might be considered as the interruptions suffered by firms in the flow of components, raw materials, and other type of inputs that are pivotal for the production of finished goods (Inoue, Todo, 2023). These events have increased the vulnerability of regions and local areas, addressing the attention of researchers and policy makers on the issue of socio-economic resilience.

These disruptions, that mainly operate at firms level and that might be more or less relevant according to the business sectors and structure of the affected firms (e.g. automotive industry), might reverberate on regions in several ways and they are dramatically increased by several local specific factors such as the combination of the effects of pandemic-related challenges (e.g. lockdown measures); the current globalized and complex supply chain (Meier, Pinto, 2024); the always increasing level of trade barriers (Handley *et al.*, 2023); the role played by natural disaster and climate change (Ghadge *et al.*, 2020) but also the local

* Gran Sasso Science Institute, Social Sciences, L'Aquila, Italy, e-mail: marco.modica@gssi.it.
° Università di Palermo, dSEAS, Palermo, Italy, e-mail: davide.piacentino@unipa.it.

characteristics of the territories affected in terms of degree of inequalities and segregation (Bonaccorsi *et al.*, 2021).

Therefore, we could say that the combination of all these multiple conflicts and shocks that caused energy price shocks – as well as demand and supply shocks – creates uncertainty, leads to changes in consumer behaviour and investment decisions, and disrupts the flow of goods throughout the economy. Furthermore, the exacerbate effects of climate change and natural shocks in general add local tension to regional economies as for example the recent flooding events that have affected Italy in May 2023 (or the recurrent droughts in both the North and South of Italy during the summer and in the last months of 2023). All these shocks are therefore reflecting potential criticalities of the territories affected by producing a series of multiple risks while only sometimes they lead to new opportunities.

Summarizing we could say that conflicts, and the relative shocks, produce disruption of economic activities through several channels, for instance by inducing job losses, decreased investment, and economic instability (Marin, Modica, 2021); political instability and humanitarian crisis also in terms of increasing pressure derived from migration flows (Brandano *et al.*, 2023), and environmental degradation due to factors such as increased resource exploitation and/or damage to ecosystems (Donnini *et al.*, 2020).

Nonetheless, conflicts and shocks might be the trigger for new opportunities for instance by removing economic bottlenecks and promoting the condition for the economic revitalization of the areas affected e.g. by stimulating local industries and attract investments (Altay, Ramirez, 2010; Hallegatte, 2008; Wang *et al.*, 2021). Furthermore, these shocks driven by conflicts might fostering innovation and technology adoption in entrepreneurial activities as well as new business formation (Antonioli *et al.*, 2022; Audretsch *et al.*, 2024); but also they can promote a greater social cohesion as people tend to address common unexpected challenges (Townshend *et al.*, 2015).

This edited volume would shed light on the fact that conflicts and shocks present both risk and opportunities for regions and territories. In details conflicts (and shocks) produce different impact on the local economies and this would require a certain degree of adaptation and transition to the new condition created by these multiple threats. Overall, we believe that in-depth analyses are essential to maximize the positive outcomes and minimize the negative impacts on regions and territories.

2. The Impact of Conflicts: Risks and Opportunities

Conflict is a broader concept whose definition depends on the scientific field of application, however, we could generally affirm that '*each kind of social unit,* *having its own range of size, structure, and institutions, will also have its own modes of interaction and thus its own patterns of conflict with other social units*' (p. 423; Fink, 1968). Overall, we could affirm that conflict typically refers to a disagreement of views between different social units and it can be manifested into different ways involving different perspectives on political, social, economic, cultural, or religious matters. However, in a more broader interpretation of the concept conflict we could argue that – especially in the social sciences and particularly in economics – conflict can be considered as a shock, interpreted as an unexpected event that disrupts the normal functioning of a system and leading to significant changes in its dynamics (Marin, Modica 2021) or between social groups.

Therefore, conflicts and shocks might lead to significant impacts on the local economies, by producing challenges and sometimes opportunities. Regarding the major risk we can affirm that, conflicts and shocks, from an economic point of view, can lead to the disruption of economic activities such as production, trade, and investment and also to the reduction in productivity (e.g. scarcity of resources, and labour shortages). Furthermore, they can also weaken the quality of the institutions both in reality and in perception for instance by undermining trust and legitimacy, distorting the decision-making processes and reducing the accountability and transparency of institutions.

Nonetheless, conflicts and shocks can also provide certain opportunities for economies, especially in terms of innovation and technological advancements, because they might be interpreted as adaptive strategies to a numerous series of threats (e.g. medical treatments during the COVID pandemic). Furthermore, governments and research institutions, may invest in R&D to address the challenges posed by conflicts, leading to technological breakthroughs and providing employment opportunities for local labour forces.

However, it is important to recall that while conflicts sometimes may present economic opportunities in particular sectors or areas, we should clarify that overall, conflicts and shocks impose significant economic costs on societies by exacerbating tensions and impeding progress towards e.g. sustainable economic development.

3. Transitions and Local Adaptation

Any conflict and shock has an impact and this event calls for an adaptation to the shock and therefore to a transition. The role of transitions in general refers to the process of shifting from an equilibrium to another one. For instance, when talking about sustainability, transition means to move from unsustainable practices towards more sustainable ones across a series of different dimensions such as the environmental, social, and economic ones. Therefore, transitions can be seen as adaptation strategies, because it is meant as a broader systemic changes aimed at adpting societies and economies to exogenous shocks.

Given these premises we can say that transitions provide both opportunities and risks for regions and territories due to their transformative nature and impact on various aspects of society, economy, and environment. Relatively to the opportunities, transitions, especially those related to the technological advancement, can drive innovation and foster economic growth in regions and territories. In order to provide some non-exhaustive example we could argue that green transition, namely the transition toward renewable energy sources, can lead, in a specific region, to a greater capacity to attract investment in that sector, creating new work opportunities. At the same time, transitions might foster regional diversification promoting regional resilience because they create a more robust and adaptable economic base.

On the flip side, transitioning to new economic models can introduce certain risks. Specifically, these transitions can disrupt the economy, especially in regions heavily dependent on industries undergoing change. For instance, areas with strong ties to traditional manufacturing sectors may see job cuts and economic downturns as these industries shift towards automation or move elsewhere. Moreover, such transitions can worsen social inequalities within these regions, particularly if certain demographics bear the brunt of the economic shifts. Regions undergoing rapid change may find it challenging to offer sufficient assistance and resources to marginalized communities, thus fuelling social tensions and disparities.

Overall, transitions present regions and territories with both opportunities and risks. However, we believe that while these transitions are essential for addressing pressing global challenges such as social inequalities and ensuring the well-being of present and future generations, effectively managing these transitions requires proactive planning and collaboration between institutions in order to mitigate risks and addressing the future challenges.

4. Structure of the Volume

The XLIV conference of the Italian Regional Science Association (AISRe) held in Naples in September 2023, deals with cutting-edge and interdisciplinary topics on current global issues that are affecting regions and territories. In details, it was entitled '*Europe and the Mediterranean between transitions and conflicts. Opportunities and risks for regions and territories*'. This conference, therefore, gave us the possibility to start a reflection on recent conflicts and related transitions that are experimenting many regions worldwide and especially Europe for the presence of a series of tensions in nearby geopolitical relevant areas.

Thus we focus our attention specifically in a broader specification of conflicts that are closely related to the idea of shocks and to transitions interpreted more as sort of adaptation strategies to current challenges. Therefore, this book even if does not cover all global challenges and local responses comprehensively, however it gathers various contributions presented at the conference, with a primary focus on territorial and regional economic systems. In particular, the focus is on highlighting how regions are confronting the profound and often unexpected changes brought about by disruptive challenges. These challenges encompass a broad spectrum, including energy crises, natural disasters, and climate-related shocks. Additionally, the discussion delves into the role played by inequalities and segregation within regions, which can exacerbate the effects of these challenges on different segments of the population. Furthermore, the examination extends to encompass health and safety risks, which can arise as a result of both the direct impact of the disruptive challenges themselves and the subsequent responses and adaptations by regional communities. By exploring these multifaceted dimensions, the book aims to provide a comprehensive understanding of how regions are navigating and responding to the complex array of challenges they face in today's rapidly changing environment.

The book is structured in two parts. The first part presents seven papers dealing with the recent challenges, and the regional responses to such challenges. This section of the book provides a diverse range of contributions that focus on various aspects of regional disparities, geographical inequality, tax evasion, occupational safety and health, polycentric urban regions, gendered sectoral segregation, and the impact of natural disasters on local industrial structures. Each chapter is authored or co-authored by experts from different academic institutions, offering unique perspectives and insights into these topics.

The paper of Fiorelli, Giannini and Martini addresses the disparities among European Union regions, exploring factors contributing to these differences. In details, they analyse income distribution in the EU's 249 NUTS2 regions from 2000 to 2021 to explore the convergence hypothesis. Using three cluster identification techniques, it confirms a marked convergence towards a common long-term path. The data reveal a significant reduction in regional inequality over the last two decades, particularly benefiting the most disadvantaged countries in 2000.

The following chapter of Cartone, Panzera and Postiglione examines geographical inequalities within Italy, offering insights into the spatial distribution of economic opportunities and resources. It extends the analysis to different years and uses fine-scale data at the NUTS 3 level (provinces) from 2001 to 2021. The aim is to provide insight into spatial dimensions of inequality to assist policymakers in addressing economic disparities.

The contribute of Argentiero, Maranzano, Monturano and Pedrini investigates the relationship between tax evasion and local labour market structures in Italian provinces by using a unique dataset merging tax evasion data with labour force characteristics. The analysis includes spatial distribution mapping, correlation studies, and cluster analysis to identify homogeneous groups of provinces based on tax evasion, occupational, and sectoral structures.

Finardi, explores occupational safety and health issues (OSH) from a bibliometric perspective, shedding light on research trends and social implications. The study reveals that external social issues shape research activities in OSH, directing attention to specific subfields and sometimes involving non-research entities.

The next paper of Caporali and Lunardon aims at introducing a new approach to assessing polycentric urban regions (PURs) in Italy, examining their spatial organization and economic dynamics. The study emphasizes the importance of common methodologies for identifying PURs while also advocating for deeper analysis of local dynamics. It aims to revive interest in polycentricity in Italy and contribute to existing studies on Italian urbanization patterns.

Martini discusses gendered sectoral segregation within the European Union, examining how regional specialization influences gender disparities in the labour market. It highlights a significant gender segregation between industries globally, affecting women's employment opportunities and economic development.

The chapter of D'Adda, Di Marcoberardino, Iacobucci and Perugini provides an analysis on the effects of the 2016 earthquake on the industrial structure of the affected regions, offering insights into the resilience and adaptation of local economies in the face of natural disasters. The study employs a difference-in-difference estimation method and finds that, while the per-capita level of local units and employment initially fell after the earthquake, it subsequently recovers in the affected municipalities.

Overall, this section provides a comprehensive exploration of regional dynamics, economic disparities, social issues, and the impact of natural events on local economies, offering valuable insights for policymakers, researchers, and practitioners.

The second part of this book presents eight papers covering various topics related to innovation, ecological transition, digitalization, climate change, and energy transition in Italy and across the Mediterranean countries.

The contribute of Pinate, Dal Molin and Brandano explores the spatial distribution and characteristics of green innovation activities using Italian regional data on green-related patent applications from 2019 and emphasizing the lack of attention to the regional and local viewpoint. The study involves mapping green-related technologies across Local Labour Systems and analyse spatial dependence through measures like the global Moran index and local indicators of spatial association.

Provenzano and Seminara discusses the concept of territorial intelligence innovation in rural areas and its role in fostering ecological transition, highlighting the growing importance of regulating the economy at local and regional levels across European countries and the need for place-based solutions considering the unique needs and potentials of each locality, with particular attention to rural areas. Finally, this contribute concludes with policy implications for fostering sustainable growth in rural regions.

The following chapter of Cipriano, D'Agostino, Longobardi and Regoli examines the impact of the COVID-19 pandemic on the on the integration of ICT in Italian schools by especially looking at the ICT readiness of Italian teachers. The study considers multidimensional factors and evaluates regional differences of ICT readiness, using data from the National Institute for the Evaluation of Education and Training System (INVALSI). It finds that pandemic's significant influence the ICT readiness and especially among teachers in Southern regions, facing the very well-known North-South educational divide in Italy.

The paper of Agnoletti, Ferretti and Piccini investigates the potential capacity of digitalization to revitalize peripheral areas in Italy, with a focus on the post-covid era. In details, it explores the rise of remote activities such as smart working, e-commerce, and distance learning, which reduce travel times and reshape location preferences towards areas offering larger living spaces and healthier environments. The study analyses demographic dynamics in Italian cities, identifying territories affected by depopulation and repopulation trends influenced by digital infrastructure. It concludes by discussing the implications of these structural changes on mobility demand and environmental sustainability.

The next chapter of Allegra, Cortese and Fusaro analyses the main evidence of climate change observed in capital cities, focusing on Italy. The paper explores the historical context of climate change, tracing its trajectory from natural phenomena to accelerated human-induced impacts, particularly since the industrialization era. It emphasizes the urgency of addressing climate change, driven by factors such as industrial activities, energy demands, resource depletion, and population growth. The study highlights the importance of accurate quantitative and statistical data from official sources to understand and manage climate change impacts, especially in vulnerable urban contexts.

The following paper of Turchetti; Ferraresi, Piccini, Ghezzi and Paniccià focuses on assessing the vulnerability of Italian regional food systems to climate change impacts using interregional input-output analysis. It examines the spatial organization of the food value chain and the dependence on imports, evaluating the criticality of food products based on economic, nutritional, and supply chain disruption risks. Additionally, it develops a disaggregated accounting system to assess the exposure of regional food systems to specific climate events, exemplified by the 2023 flood in Emilia-Romagna. The study highlights the importance of integrating spatial information and real-time data to understand and address vulnerabilities in regional food systems.

The chapter of Bosco and Canitano explores the energy transition dynamics in Mediterranean countries, focusing on energy demands and supplies. It examines the Mediterranean basin's pivotal role in global energy supply, particularly concerning trade flows from the MENA region (the Middle East and North Africa to the Sahel countries) to EU member states. It addresses the pressing climate emergency and advocates for transitioning to renewable energy to mitigate global warming. The study investigates energy trade dynamics in the Mediterranean, focusing on fossil fuels and renewable sources.

The final paper of Kanzari, Fazio and Fricano investigates the dynamics of energy stocks in European countries within the context of energy transition. By underlying the undeniable association between energy risk and fossil fuels and emphasizing their environmental, economic, and geopolitical risks. It discusses the challenges and opportunities associated with transitioning towards renewable energy sources, point out the need for diversification and acceleration of this transition. The findings contribute insights into global energy security and market sentiments, underlying the importance of understanding the dynamics between energy stocks and perceived energy risks for policymakers and industry stakeholders.

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Regional Economic Convergence in the European Union

Cristiana Fiorelli, Massimo Giannini°, Barbara Martini°*

Abstract

This chapter examines the GDP per capita of 249 European regions over the period 2000-2021, aiming to identify growth patterns consistent with the "club convergence" theory. This theory suggests that income distribution is multimodal rather than unimodal, like a Gaussian distribution. The literature is mixed on this point. Inspection of the data reveals a significant reduction in regional inequalities over the last two decades, especially in initially disadvantaged countries. In this study, we use three alternative clustering techniques. While all of them identify three clusters, two of them show a strong convergence towards a common long-term path, suggesting that the initial tripartite GDP distribution in 2000 has gradually become more uniform, especially in the last decade.

1. Introduction[1]

Economic convergence is a concept used to describe the process by which regions with the same level of development and similar economic characteristics tend to converge over time.

In Europe, the issue of economic convergence is of great interest due to the significant disparities in income and economic development between regions. Since its establishment, the European Union (EU) has played a crucial role in promoting economic growth, social progress, and political stability across the continent. One of the EU's key policy areas is economic cohesion, which aims to reduce economic disparities between its regions and ensure that all regions can participate in and benefit from the single market. The EU Cohesion Policy is

* Sapienza University of Rome, Department of Economics and Law, Rome, Italy, e-mail: cristiana.fiorelli@uniroma1.it (corresponding author).

° University of Rome Tor Vergata, Department of Enterprise Engineering, Rome, Italy, e-mail: massimo.giannini@uniroma2.it, barbara.martini@uniroma2.it.

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based on the principles of solidarity and convergence (Percoco, 2017). Solidarity refers to the sharing of risks and benefits between Member states, while convergence refers to the process of narrowing the gaps in economic performance between European regions. The policy is designed to support the development of less-developed regions and to promote balanced and sustainable growth across the EU (Rodríguez-Pose, Fratesi, 2004; Capello, Perucca, 2019).

In line with this aim, the EU institutions have been committed to promoting greater convergence and reducing disparities between Member states' economies over time. However, after a period of slow convergence in the 1990s, regional inequality has risen sharply. Recent studies (Hendrickson *et al.*, 2018; Iammarino *et al.*, 2019; Martin, 2021) have shown that certain regions, cities, and metropolitan areas have surged ahead economically while others have been left behind, contributing to increasing regional divergence within countries.

This contrasts with the neoclassical growth theory, as discussed by Solow (1956), according to regions (or countries) that are rather similar in their structural characteristics may show a similar pattern of economic convergence over time. However, if they differ in terms of the initial level of per capita income, regions may move together towards different steady-state equilibria in the long run, leading to many groups of economic convergence. The literature defines this phenomenon as the club convergence hypothesis (Galor, 1996).

Given the heterogeneity of income distribution in the EU, in this chapter, we conduct an explorative analysis that aims to study the convergence hypothesis by considering 249 European NUTS2 regions over the period 2000-2021. Starting from the different initial conditions in terms of per capita income, the goal is to identify the number of "clubs" or clusters within the European regions and to study their dynamics over time.

We use three alternative cluster identification techniques. Although they find the same number of clusters, two of them agree in confirming a marked convergence of clusters towards a common long-term path. The data show that there has been a significant reduction in inequality between regions over the last twenty years, which has mainly affected those countries that were the most disadvantaged in 2000. In fact, while the distribution of GDP per capita in 2000 was undoubtedly characterised by the presence of three clusters of regions, this tripartition has become more uniform over time, especially in the last decade.

The results reflect the effectiveness of European regional development and territorial cohesion policies. In particular, Eastern European regions, which were the furthest behind two decades ago, have recorded higher average growth rates during the observed period. This progress has substantially narrowed their initial economic disparities, contributing to a broader trend of convergence and integration across Europe.

The chapter is organized as follows. Section 2 summarizes the relevant literature and introduces the conceptual framework. Sections 3 and 4 present the data and the methodology used, while empirical results are presented in Section 5. Section 6 concludes.

2. A Brief Literature Review

The distribution of wealth or GDP across EU countries and regions tends to display persistent polarisation between rich regions in the northwest and poor regions in the southeast as well as between western and eastern regions (Ezcurra *et al.*, 2005). The rise of disparities among European regions can be read through the lens of two tendencies. On one side, the strong dynamism of the large urban areas, regions hosting the capital cities that act as attraction poles, and regions close to the core countries' border. On the other side, the decline in old industrialised, rural, and peripheral lagging regions further contributes to increasing regional divergence within countries (Ezcurra *et al.*, 2007; Meliciani, 2006; Chapman, Meliciani, 2018; Borsekova *et al.*, 2021). Other contributions have shown that weak institutions and poor-quality government are a crucial obstacle to development, affecting the returns on EU Cohesion policies (Rodríguez-Pose, Garcilazo, 2015) and the capacity to innovate as well (Rodríguez-Pose, Di Cataldo, 2015). Moreover, regional macroeconomic imbalances are also associated with structural polarization regarding sectoral composition. This can be attributed to differences in technology adoption and firm performance.

The technological process plays an important role in the exogenous growth theory. Solow (1956) argues that countries or regions with initially lower capital per worker grow faster than those with higher initial capital, leading to a convergence in per capita income over time. Regions that are rather similar in their structural characteristics (e.g., production technology, preferences, government policies, etc.) may show a similar pattern of convergence, despite the initial level of income. This concept is known in the literature as *absolute convergence*. The convergence hypothesis gains more support when considering country/region-specific differences and relaxing the assumption of uniform parameters across units (Mankiw *et al.*,1992; Barro, Sala-i-Martin, 1995). Accordingly, regions that show different structural conditions may reach their respective steady states (*conditional convergence*).

Both absolute and conditional convergence imply that convergence does not depend upon initial income per worker. Nevertheless, if regions start the process of economic convergence with different incomes per worker, they will hit different steady states, as the initial income may affect the region's economic growth path. This implies that regions sharing similar evolutions of fundamental variables and long-term growth rates may not converge to the same steady state if they do not have similar initial incomes per worker (Monfort *et al.*, 2013). Hence, within a group of similar economies, a common balanced growth path can only be expected if their initial income is in the basin of attraction of the same steady-state equilibrium. This phenomenon is widely referred to as the *club convergence* hypothesis (Galor, 1996).

The European economy has traditionally been viewed as an interesting case study for empirical examination of the club convergence hypothesis. Indeed, numerous studies in the empirical literature have focused on analysing this hypothesis within the European context.

Earlier research indicated a gradual process of club convergence between EU countries and regions, as pointed out in the studies by Cappelen *et al.* (2003), for instance, or by Del Bo *et al.* (2010). However, more recent investigations have yielded mixed results. Some suggest higher rates of convergence, particularly after the EU's eastward expansion (see Zoega, Phelps, 2019), supporting the idea that access to structural funds leads benefit to the EU's members, while others find that the financial crisis has led to growing regional income disparities (Cutrini, 2019), stressing the differences between urban and remote rural regions (Dijkstra *et al*., 2015).

As regards the number of different clusters identified, existing studies suggest heterogeneous findings. Most of the empirical methods employed belong to the non-linear family models, such as the time-varying factor model, given that linear models have been identified as problematic (see, e.g., Azomahou *et al*. 2011), or semi-parametric and non-parametric techniques, such as quantile regression. In the contribution of Monfort *et al*. (2013), the authors analysed the convergence of GDP per worker in 23 European countries from 1980 to 2009, applying the factor model as in Phillips and Sul (2007). Within the EU-14 Member states, they find the presence of two convergence clubs. Using the same methodology, Bartkowska and Riedl (2009) constructed a sample of 206 European NUTS2 regions between 1990 and 2002. The results show that European regions form six separate groups converging to their steady-state paths. Along the same line, Von Lyncker and Thoennessen (2017) investigated the club convergence in per capita income in 194 European NUTS2 regions, assessing the role of initial and structural conditions, as well as geographic factors. Their results indicate the presence of four convergence clubs in the EU-15 countries and suggest that initial conditions matter for the resulting income distribution. Similarly, the contribution of Cutrini and Mendez (2023), based on the clustering algorithm of Phillips and Sul (2009), shows that the GDP per capita dynamics of European regions are characterized by five convergence clubs. Finally, Cartone *et al*. (2021) used a spatial quantile regression for 187 European regions from 1981-2009. They conclude that European regions are characterised by different convergence rates, finding three groups of regions.

Taken together, the mentioned studies have yielded mixed results, with varying numbers of clusters. These inconsistencies might be attributed to differences in the empirical technique employed or the period under analysis.

3. Data

Our dataset is constructed considering 249 NUTS2 regions of 27 EU countries over the period 2000-2021. It includes all Member states (EU-27) except the United Kingdom.

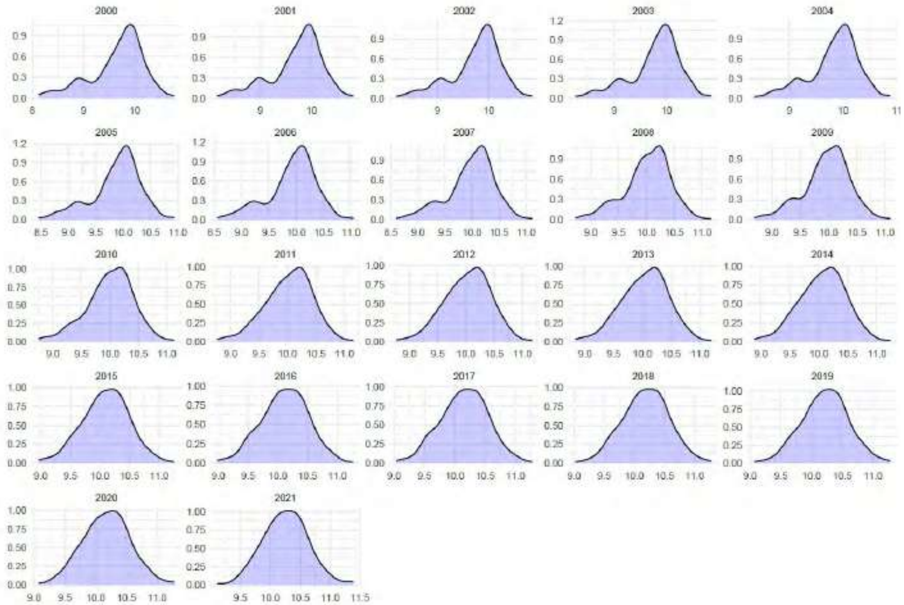
As suggested by the literature, we use a measure that accounts for the economic growth by collecting annual data on gross domestic product (GDP) per capita measured in Purchasing Power Standards (PPS). We apply the logarithm transformation of the series. The data come from the European Commission's regional database (Annual Regional Database of the European Commission – ARDECO).[2]

In Figure 1, we report a series of kernel density plots of GDP per capita for different years, from 2000 to 2021. These plots provide a granular view of how the income distribution has changed year by year. These plots are a powerful visual tool for analysing economic convergence, which can be inferred through the shape and modality of the distributions. In 2000, the distribution exhibited a certain degree of multimodality, with multiple peaks suggesting the existence of several groups of regions converging around different levels of GDP per capita. This multimodality is indicative of the club convergence hypothesis, where subsets of the data converge towards different equilibria. As we progress through the years, the density plots begin to show a gradual shift towards a more unimodal distribution. The transition from a multimodal to a unimodal distribution suggests a movement towards absolute convergence. Absolute convergence is characterized by a single peak, implying that differences in GDP per capita across countries or regions are diminishing over time, and they are starting to converge towards a common growth path. By 2021, the distribution will have significantly fewer peaks and appear more symmetric, resembling a normal distribution. The observation of a single mode in 2021, with its peak closer to the global mean, supports the idea that income disparities are reducing over time.

This is corroborated by the Lorenz curve depicted in Figure 2. The latter shows the distribution of income for two different years, 2000 and 2021. The curve closer to the line of perfect equality (the 45-degree line) represents the year 2021, indicating a more equitable distribution of income in that year compared to 2000. The inequality measures listed in Table 1 confirm the convergence. We calculate the inequality measures, comparing the level of GDP per capita in the last year under analysis (2021) and the initial value of GDP per capita in 2000. The Gini index, a commonly

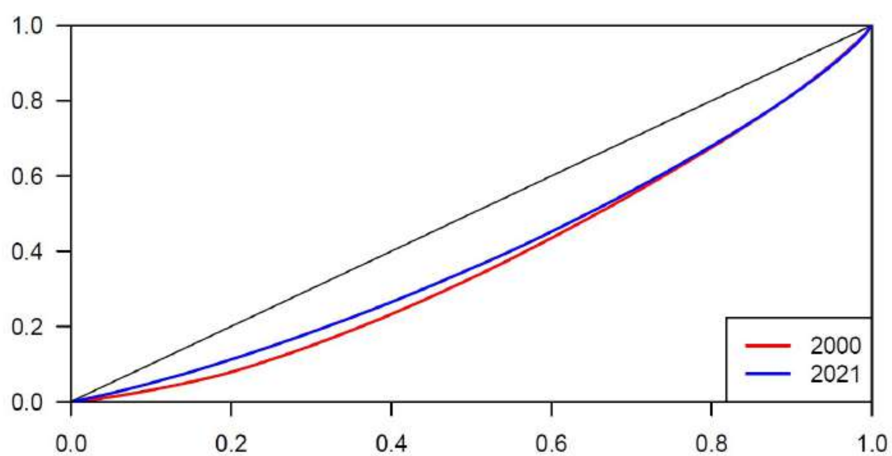
2. We use the 2016 version of the NUTS2 classification.

Figure 1 – Kernel Density Estimation for the Logarithm of GDP per Capita



Source: Authors' elaborations on data provided by the ARDECO database

Figure 2 – Lorenz Curve in 2000 vs 2021



Source: Authors' elaborations on data provided by the ARDECO database

Table 1 – Main Inequality Measures

Measures	*2000*	*2021*
Gini index	0.24	0.21
Theil index	0.10	0.07
Entropy index	0.11	0.07
Coefficient of variation	0.44	0.40

Source: Authors' elaborations on data provided by the ARDECO database

used measure of inequality, has decreased from 0.24 in 2000 to 0.21 in 2021. This indicates a reduction in income inequality, as a lower Gini coefficient suggests a more equal distribution of income. The Theil index, another measure of economic disparity, also shows a decrease from 0.10 to 0.07, which supports the findings suggested by the Gini index. Furthermore, the decrease in the Entropy index from 0.11 to 0.07 complements the other measures, providing a consistent narrative of reduced inequality over the period. The Coefficient of variation, which is a standardized measure of the dispersion of a frequency distribution, decreased from 0.44 to 0.40. This also indicates a contraction in the relative spread of the income distribution.

Overall, although the data on GDP per capita in 2000 are multimodal, suggesting different patterns of convergence, regions tend to converge towards a more equitable income distribution over time.

4. Empirical Analysis

In this Section we formally test the presence of clusters in European regions, using three different econometric approaches.

4.1. The log-t Test

First, we apply the time-varying factor model introduced by Phillips and Sul (2007), which allows for individual and transitional heterogeneity to identify convergence clubs. This model decomposes each variable (x_{it}) in a panel data over t-years and i-observations into two parts:

$$x_{it} = g_{it} + a_{it}, \qquad [1]$$

where g_{it} represents a systematic component and a_{it} a transitory one. To differentiate between common (μ_t) and idiosyncratic (b_{it}) components, the equation is reformulated as:

$$x_{it} = \left(\frac{g_{it} + a_{it}}{\mu_t}\right)\mu_t = b_{it}\mu_t. \quad [2]$$

The common component is removed by creating relative transition paths:

$$h_{it} = \frac{b_{it}}{N^{-1}\sum_{i=1}^{N} b_{it}}. \quad [3]$$

Asymptotically ($t \to \infty$), the cross-sectional variance of the relative transition parameter H_t tends to zero, indicating convergence ($H_t \to 0$). To test the presence of convergence among different economies, we use the *log-t* test. Phillips and Sul (2007) suggest estimating the following equation model through the ordinary least squares method:

$$\log\frac{H_1}{H_t} = -2\log(\log t) = \alpha + \beta \log t + u_t, \; for \; t = [rT], [rT]+1, \ldots, T \quad [4]$$

where H_1/H_t is the ratio between the current and initial cross-sectional variance; β is the speed of convergence parameter of b_{it}; −2log(log*t*) is a penalization function that improves the performance of the test mainly under the alternative. The term [*rT*] indicates the initial observation in the regression, which implies that the first fraction of the data is discarded. A negative and statistically significant slope coefficient β implies a lack of convergence (Phillips, Sul, 2009). If the t-statistic is below −1.65, the null hypothesis of regional convergence is rejected at 5%. For the clustering algorithm, the model performs a recursive process ensuring each group satisfies the convergence test. The *log-t* test may lead to more groups than those really existing. To avoid this overdetermination, we use a club merging algorithm.

4.2. Finite Mixture Model

We compare Phillips-Sul approach with Gaussian finite mixture model. Finite mixture models can be applied to data where observations originate from various groups and the group affiliations are not known. According to Wedel and DeSarbo (1995), this approach is developed that simultaneously estimates the posterior membership probabilities of observations to a number of unobservable groups or latent classes, and the parameters of a linear model which relates the observations to a set of specified covariates within each group. Moreover, it provides approximations for multimodal distributions (Everitt, 2013; McLachlan, Peel, 2019). We consider finite mixture models with *K* components:

$$h(y|x) = \sum_{i=1}^{K} \pi_k f(y|x, \theta_k) \quad \pi_k \geq 0, \; \sum_{i=1}^{K} \pi_k = 1, \quad [5]$$

where y is a (possibly multivariate) dependent variable with conditional density h, x is a vector of independent variables, π_k is the prior probability of component k, θ_k is the component specific parameter vector for the density function f. If f is a univariate normal density, Equation (5) describes a mixture of standard linear regression models; if f is a member of the exponential family, we get a mixture of generalized linear models (Wedel, DeSarbo, 1995).[3] Parameter estimation is performed using the expectation-maximization (EM) algorithm within a maximum likelihood framework (Dempster *et al.*,1977).

The posterior probability that observation (x, y) belongs to cluster j is given by:

$$P(j|x,y) = \frac{\pi_j f(y \mid x,\theta_j)}{\sum_k \pi_k f(y \mid x,\theta_j)}. \quad [6]$$

The posterior probabilities can be used to segment data by assigning each observation to the group with maximum posterior probability. The number of clusters j is determined by assuming $j \in [1,K]$ with K large enough and selecting j which shows the lowest BIC index.

4.3. K-means Clustering

Additionally, we check the classification of regions into different clusters by using the k-means clustering. The basic idea behind k-means clustering consists of defining clusters so that the total within-cluster variation is minimized. There are several k-means algorithms available. The standard algorithm is the Hartigan-Wong algorithm (1979), which defines the total within-cluster variation as the sum of squared Euclidean distances between items and the corresponding centroid:

$$W(k) = \sum_{x_i \in k} (x_i - \mu_k)^2. \quad [7]$$

x_i is an observation belonging to the cluster k, while μ_i is the mean value of the points assigned to the cluster or centroid. Each observation is assigned to a given cluster such that the sum of squares distance of the observation to their assigned cluster centers is minimized.

$$TW(k) = \sum_{k=1}^{k} W(k) = \sum_{k=1}^{k} \sum_{x_i \in k} (x_i - \mu_k)^2. \quad [8]$$

Equation (8) defines the total within-cluster sum of squares that accounts for the goodness of the clustering. The model wants to minimize this measure.

3. For multivariate normal f and $x \equiv 1$ we get a mixture of Gaussians without a regression part.

5. Results

This section presents the findings of the analysis.

Before moving to club convergence, we begin by testing the hypothesis of absolute convergence in per capita income, as depicted by the income distribution over time.[4] Results from the *log-t* test of Phillips and Sul (2007) reject at a 5% of significance level the hypothesis of convergence, with a negative beta coefficient and t-statistic lower than the threshold of -1.65. Differently from what the data suggest (see Section 3), according to the *log-t* test the European regions do not seem to converge to the same steady-state equilibrium in terms of per capita income.

Then, we try to test the club convergence hypothesis, applying the different clustering methodologies. The Phillips-Sul approach performs the clustering algorithm identifying three clubs of convergence. Table 2 reports the estimated parameters, the corresponding standard errors and *t*-statistics, and the number of regions belonging to each cluster. The first cluster, representing the largest group with 144 units, shows a negative and not statistically significant beta coefficient, similar to the third cluster that comprises 60 units. Differently, the second cluster exhibits a significantly positive coefficient (0.22), confirming the income convergence between regions within the cluster.

Table 2 – Results of the log-t Test

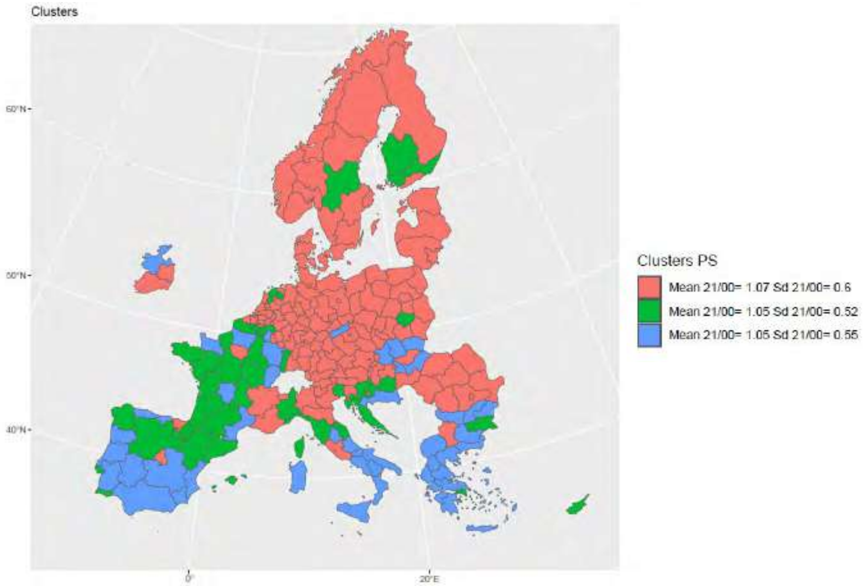
Club	*No. of Units*	*beta*	*s.e.*	*t-value*
1	144	-0.023	0.025	-0.915
2	45	0.217	0.045	4.791
3	60	-0.014	0.024	-0.567

Source: Authors' elaborations

Given the lack of convergence within the first and third clusters, the Phillips-Sul approach may lead to inconsistent club convergence classification. To better explain this concept, we present a visual breakdown of club membership in Figure 3. The clubs are grouped primarily by geographical proximity and less by the economic convergence criteria that one might expect to dominate such a classification. In fact, the clusters are segmented geographically, with high-income central European regions being assimilated in terms of convergence with lower-income eastern European regions. This is observed, for instance, in regions of Poland, Romania, Bulgaria, or

4. To account for the long-run component, we perform cluster analysis on the series filtered by the Hodrick-Prescott (HP) filter.

Figure 3 – Clusters in European Regions (2000-2021) – Phillips-Sul method (PS)



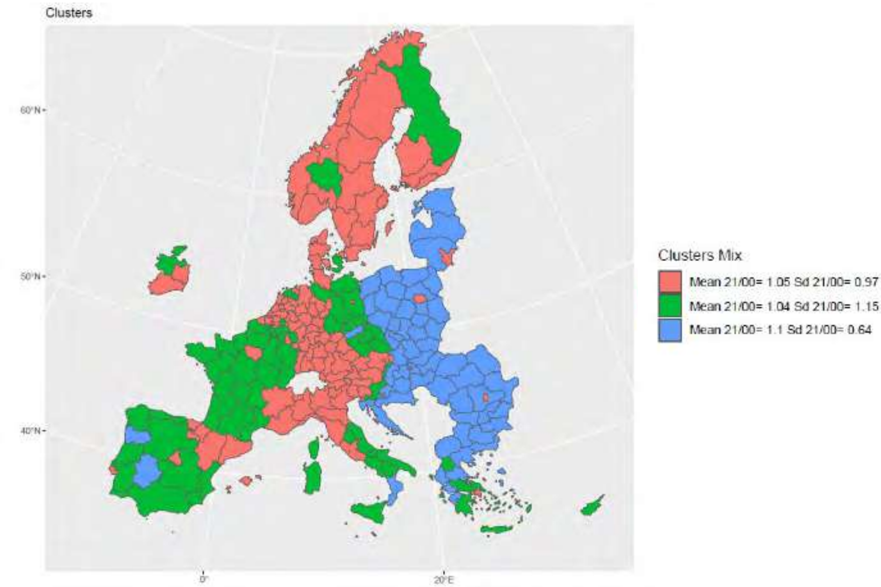
Source: Authors' elaborations

Hungary. Conversely, the composition of the third cluster, which includes southern European regions, seems more aligned with economic similarities between regions.

On the other hand, the clustering exhibits a composition that aligns more closely with economic evidence, using different econometric methodologies. Figure 4 presents the outcome of clustering using the finite mixture model. Despite an identical number of clusters being identified, the allocation of regions to clusters shows significant differences with respect to the first approach and a better cluster composition pointing to varied growth dynamics among the regions. This classification not only separates core European regions from the peripheries in the east but also aligns with the disparate growth rates observed across these areas. Despite lower per capita incomes in eastern European regions compared to their western counterparts, these regions have demonstrated the highest percentage of income growth from 2000 to 2021, as detailed in Figures 1A and 2A in the Appendix. Consistent with this, the ratio of the average per capita income in the latter period (2021) to the initial period (2000) for the Eastern European cluster is 1.1.

To validate the robustness of our clustering, we applied the k-means clustering approach. The partitioning algorithm proposed a selection of three clusters ($k = 3$), mirroring the number identified by the previous methods. The k-means

Figure 4 – Clusters in European Regions (2000-2021) – Finite Mixture Model (Mix)



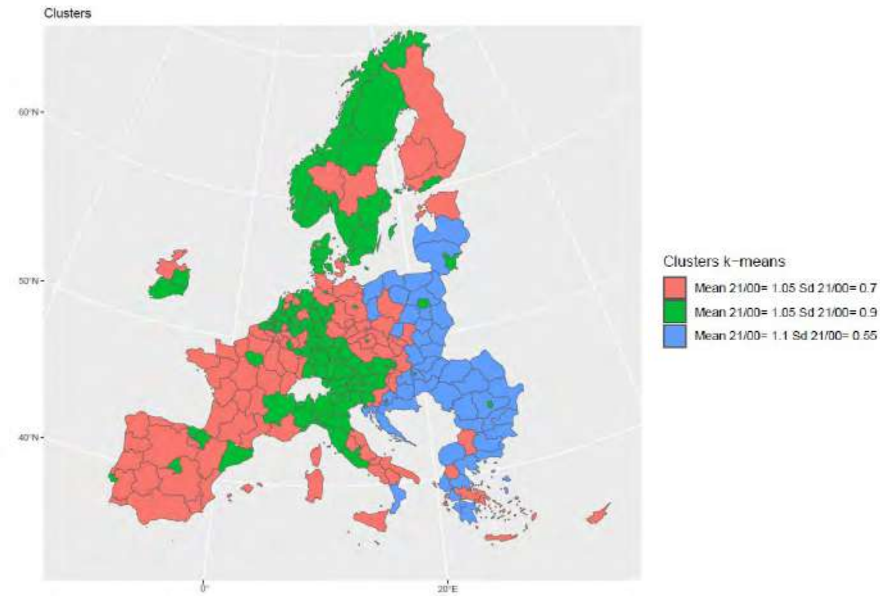
Source: Authors' elaborations

clustering results, as shown in Figure 5, support the previous findings. It presents clusters that exhibit significant differences from those identified by the Phillips-Sul method. The red and green clusters predominantly encompass Western and Central European countries, regions typically associated with higher income levels. The blue cluster consists of peripheral Eastern European countries along with a few Southern regions such as Calabria or the Peloponnese. This cluster reflects emerging economies within the EU that, while starting from a lower base of per capita income, have shown significant growth rates, as indicated by the robust income growth figures from 2000 to 2021 discussed earlier.

Figure 6 shows the average relative transition paths for each club, as determined by the *log-t* test and the finite mixture model. These transition paths are represented by the relative transition coefficient h_{it}, as specified in Equation (3).

In the upper graph, we observe divergent transition paths for the clusters identified by the Phillips-Sul method. Conversely, the lower graph, which utilizes the finite mixture model, shows convergent transition paths. The green line here depicts the second cluster maintaining a steady state, while the red line indicates the first cluster whose relative transition is closely aligned with the average path. The black line suggests a convergence towards the average, albeit starting from a lower baseline. Thus, the finite mixture model suggests that clusters are

Figure 5 – Clusters in European Regions (2000-2021) – K-Means



Source: Authors' elaborations

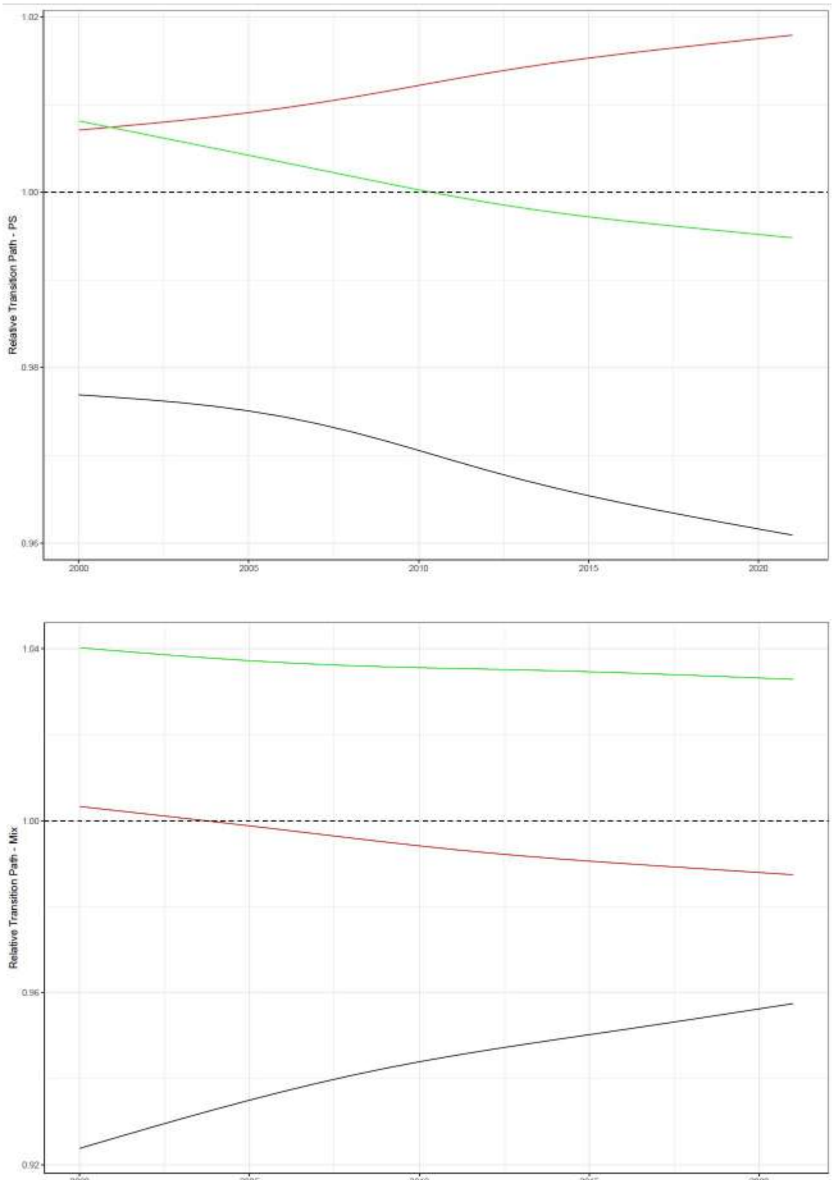
moving towards a common transition path, indicating a reduction in differences and a trend towards convergence among the regions. This convergence process is likely to be driven by EU budget allocations from various development and cohesion funds. Over the years, a significant part of these funds has been directed to the peripheral regions of Europe in order to promote their economic growth. As shown in Figure 3A in the Appendix, the allocation of these funds is strongly correlated to the growth rates of the regions with the most unfavorable initial conditions.[5] Hence, it seems that the EU Cohesion Policy has been instrumental in promoting convergence.

6. Conclusions

The concept of economic convergence remains a relevant issue, especially in the context of the European Union, given the significant income and development disparities between regions. The results of the empirical literature are mixed, depending on the data, the time horizon, and the techniques used.

5. Exceptions are some regions of Spain which, despite receiving more resources on average than the others, do not show high GDP growth rates over time compared to the eastern regions.

Figure 6 – Average Relative Transition Paths for Each Cluster



Note: Clustering by Phillips-Sul method (above) and Finite mixture model (below)
Source: Authors' elaborations

In this study, we shed new light on this issue by testing several techniques and the latest available data to examine the behaviour of GDP per capita of 249 European regions over the period 2000-2021 and to test the club convergence hypothesis within the EU.

A simple data explorative analysis undoubtedly suggests a clear multimodality in the per capita income in 2000 and a clear convergence towards a more symmetrical distribution in the following twenty-one years. Then, more suitable econometric techniques have been exploited to confirm such a result. In contrast to the Phillips-Sul approach, which suffers from several ad-hoc assumptions, semi-parametric methods such as Gaussian mixtures and K-means point to corroborate the idea that European regions are still grouped in three clubs, but the latter are converging towards a single one, especially in the last decade.

The reasons for this convergence are to be found in the growth of the eastern regions. As shown in Figures 4 and 5, the regions close to the Russian Federation form a well-defined cluster, but they had the highest growth rates in our sample over the last twenty years. These regions were also the main recipients of European regional development and cohesion funds, which allowed them to grow faster. In other words, although we do not provide in this paper a clear econometric analysis, we conclude that the convergence process is the result of European policies. Our analysis shows that clusters are still identifiable, but their distance is rapidly decreasing. From this point of view, our results confirm the successful role of European institutions in promoting and fostering the integration of European regions. The introduction of recent measures, such as the Next Generation EU plan, may serve as a further catalyst for convergence. Exploring the effects of these initiatives presents new opportunities for future research on the mechanisms driving the reduction of regional disparities across Europe.

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Sommario

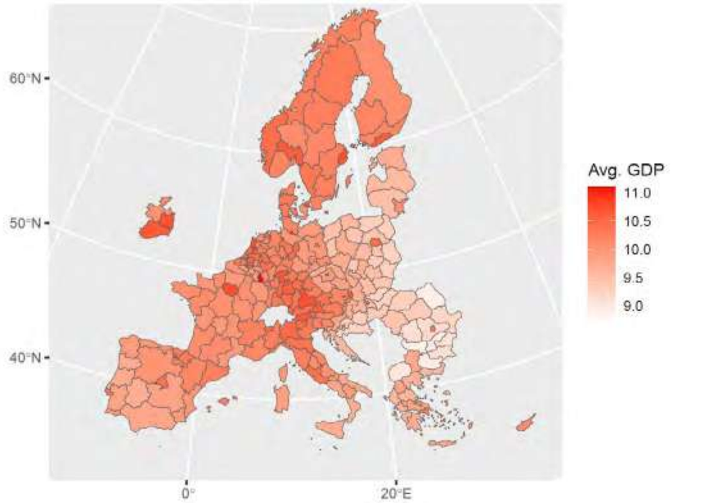
La convergenza economica nelle regioni europee

Questo capitolo esamina le dinamiche del PIL pro capite di 249 regioni europee dal 2000 al 2021, al fine di verificarne la coerenza rispetto alla teoria della club convergence. La teoria postula che la distribuzione del reddito sarebbe caratterizzata da multimodalità, piuttosto che da una distribuzione simmetrica e unimodale. Considerato che la letteratura empirica individua risultati eterogenei, in questo studio si utilizzano tre tecniche alternative di individuazione dei cluster. Sebbene tutte identifichino tre cluster,

due di esse confermano un deciso percorso di convergenza dei cluster verso un percorso comune di lungo periodo, suggerendo che l'iniziale distribuzione tripartita del PIL nel 2000 è diventata gradualmente più uniforme, soprattutto nell'ultimo decennio.

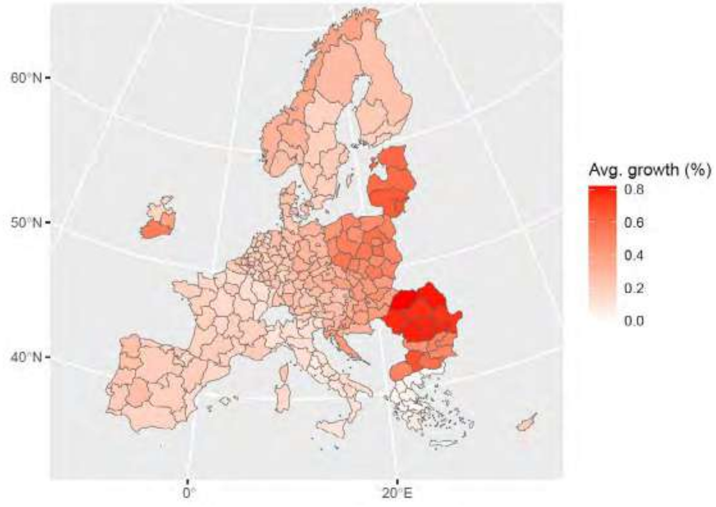
Appendix

Figure 1.A – Average of Logarithm of GDP per Capita over Time



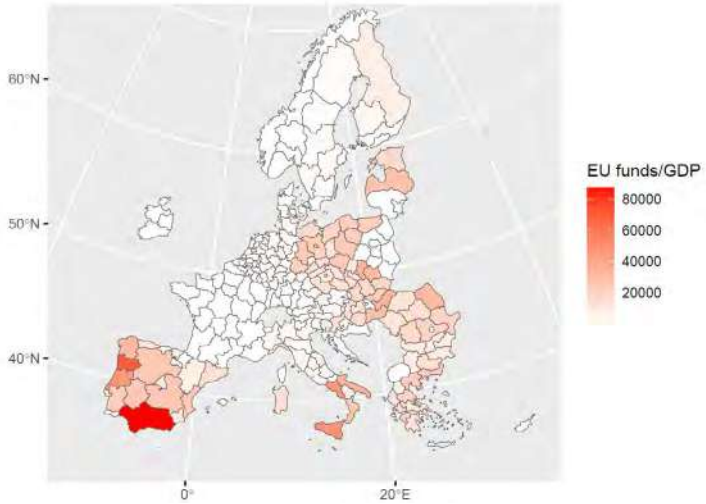
Source: Authors' elaborations

Figure 2.A – Average Growth Rate of GDP per Capita Over Time



Source: Authors' elaborations

Figure 3.A – Average Distribution of EU Funds Over Time



Note: We collect data on EU payments made from the European Regional Development Fund (ERDF), the Cohesion Fund (CF), the European Social Fund (ESF) and the European Agricultural Fund for Rural Development (EAFRD) for the different programming periods. Data are provided by the Cohesion Open Data Platform of the European Commission.

Source: Authors' elaborations

The Spatial Dimension of Economic Inequality in Italy

Alfredo Cartone, Domenica Panzera*, Paolo Postiglione**

Abstract

Traditional inequality measures fail to explain the spatial distribution of economic phenomena. For this reason, a new class of indices have been introduced in the recent years in the literature. In this paper, we estimate spatial components of the overall inequality in Italy exploiting different spatial measures of concentration. Particularly, we ground on recently introduced spatial expansions of the standard Gini index to assess the relevance that spatial distribution may have on income inequality. The aim is to bring more evidence on the spatial dimension of inequality and support policy makers in the evaluation of economic disparities.

1. Introduction

Over the last years, the estimation of income inequality has been fascinating attention from different researchers (Andreano *et al.,* 2021; Barrios, Strobl, 2009; Iammarino *et al.,* 2019; Panzera, Postiglione, 2022, among others).

Inequality indices quantify the variability of data. When we are interested in the evaluation of regional inequality, the units of observation are georeferenced. Regional inequality indicates the unequal distribution of economic and social opportunities among different geographic zones within a country.

In the EU, inequality is a key point that impacts regional policies. In fact, after its enlargement, the EU had to face with large disparity between regions, and the financial and economic crises worsened current disparities.

Also, in Italy the analysis of economic disparities and inequalities is particularly relevant for the presence of a significant north/south divide; here some areas are more economically wealthy and socially developed than others. The growth of the south has represented, for many decades, a missed opportunity for

* University of Chieti-Pescara, Gabriele d'Annunzio, Department of Economic Studies, Pescara, Italy, e-mail: domenica.panzera@unich.it, alfredo.cartone@unich.it, postigli@unich.it (corresponding author).

the entire country. The south of Italy represents the largest and most populous area of economic underdevelopment in Western Europe.

The contributions on regional inequality have mainly concerned standard inequality measures (see, among others, Azzoni, 2001; Akita 2003; Fan, Casetti, 1994). The most popular inequality measures include the Gini index (Gini, 1912) and the Theil index (Theil, 1967). All these measures do not consider spatial information; in fact, they are invariant with respect to location, and thus, they are insensitive to any spatial permutation. This condition of traditional inequality measures is known as anonymity (Bickenbach, Bode, 2008). This indicates that, holding the variable under investigation as constant, different spatial patterns can provide the same global inequality measure.

Because of the anonymity condition, traditional inequality measures, such as the Gini index and the Theil index, fail to capture differences in the geographical position of data. This implies that inequality measures cannot account for relevant interconnections and dependencies between regions. Therefore, it becomes difficult for policy makers to benefit information included into the geographical structure on how regions may influence each other (Arbia, 2001).

Hence, the analysis of regional inequality requires considering additional subjects that are related to the nature of georeferenced observations: data are collected with reference to geographical units that cannot be considered as independent entities and the geographical proximity among regions could cause their economic behaviour to become similar or dissimilar. In the literature, the similarity/dissimilarity of observations of a given phenomenon, that are collected from nearby locations, is known as spatial dependence (Anselin, 1988). The connection between spatial dependence and inequality has been poorly studied in the literature (Rey, Janikas, 2005).

More formally, spatial dependence can be defined as a characteristic of geographical data for which close observations tend to assume similar values (positive dependence) or dissimilar values (negative dependence). Spatial dependence is often caused by significant interconnections between nearby areas. Spatial dependence is also supported by the First Law of Geography, which states that '*everything is related to everything else, but near things are more related than distant things*' (Tobler, 1970).

According to these considerations, the spatial position of data could have a strong influence on the quantification of income inequality. Despite this, the geographical distribution of income is mainly neglected in the measurement of inequality.

The treatment of spatial dependence in the evaluation of inequality is not only relevant from a methodological point of view. Considering the territorial dimension, the interactions among regions, and their differences, is relevant from a policy perspective. In fact, it helps developing interdependent scenarios.

It is worth noticing that spatial techniques offer us a way to interpret many geographical issues linked to inequality, but they cannot be interpreted in a simplistic way. Spatial interactions descend from a cascade of features that go far beyond the mere physical sense (*i.e.* roads, transportation, commuting flows). Similarities and geographical differences happen because proximity leads to cultural similarities (Anselin, 1988). Following this line, the term "spatial" should not be used as a rough attribute that emerges from data.

The analysis of regional inequality is generally based on the evaluation of the differences across regional Gross Domestic Product (GDP) rather than the income differences between individuals or households within a regional economy (Rey, Janikas, 2005).

In the last decades, some contributions in the literature have highlighted the importance of combining measures of inequality with measures of spatial dependence to assess inequality.

Arbia (2001) identifies two different aspects of the spatial concentration of observations: a-spatial variability, which is invariant to permutations, and polarization and refers to the geographical position of data. To summarize these different aspects, the author suggests combining a measure of inequality, such as the Gini index, with a measure of spatial dependence (like Moran's I).

Arbia and Piras (2009) introduce a new measure that accounts for both a-spatial concentration and spatial correlation. The authors also discuss the properties of this statistic and an approximate sampling theory. They also identify some possible extensions of the proposed index, as its use for comparing the concentration of the same variable measured over two different time periods or in two different countries.

Márquez *et al.* (2019) focus their contribution on an entropy-based measure as the Theil index. Just like the Gini index G, this statistic is insensitive to the spatial position of data. Following the idea that spatial dependence is important in modelling inequality, the authors propose a decomposition of the Theil index into spatial and non-spatial components. Specifically, the authors identify a neighbourhood Theil index to illustrate the influence of spatial association on inequality and a specific Theil index that accounts for non-spatial inequality.

Rey and Smith (2013) consider the Gini index in relative mean difference form and propose a decomposition to define a spatial autocorrelation index that is nested in the measure.

Panzera and Postiglione (2020) introduce a new index based on the Gini correlation measure (Schechtman, Yitzhaki, 1987). This new measure considers both inequality and spatial autocorrelation.

In this paper, we aim at measuring spatial components of the global inequality in Italy, using the spatial expansions of the standard Gini index, recently introduced by Rey and Smith (2013) and Panzera and Postiglione (2020) to evaluate the influence that spatial distribution may have on income inequality. In addition, we extend this analysis to different years to observe if there have been variations in the spatial patterns of inequality in recent times.

To give wider evidence, we use data on a fine spatial scale as the NUTS 3 level (provinces) in Italy, and the indicators of spatial inequality are obtained over the 2001-2021 period. The aim is to provide more indication on the spatial dimension of inequality and support policy makers in the evaluation of economic disparities.

The rest of the paper is organised as described in the following. The methods, on which our analyses are based, are presented in Section 2. Section 3 illustrates the main empirical results jointly with a discussion containing some policy indications. Finally, Section 4 concludes the paper.

2. Methods

The Gini index is a widely used measure of economic inequality within a population. It usually measures the degree of distribution inequality among the members of a given group. The Gini index G, in terms of relative mean absolute difference, is defined as:

$$G = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N}\left|x_i - x_j\right|}{2N^2\mu_x} \quad [1]$$

Where x_i is the value of GDP per capita observed on spatial unit

$$i,j = 1,2,\ldots, N,\ \mu_x = \sum_i x_i / N$$

is the mean value of the observations x_i. Hence, the numerator of G is the sum of all the pairwise absolute differences between regional GDPs. It is standardised by the factor $2N^2\mu_x$, so that G is scale invariant. The Gini coefficient ranges from a minimum value of zero (perfect equality, every unit has the same income) to a theoretical maximum of one in which every unit except one has a size of zero (absolute inequality).

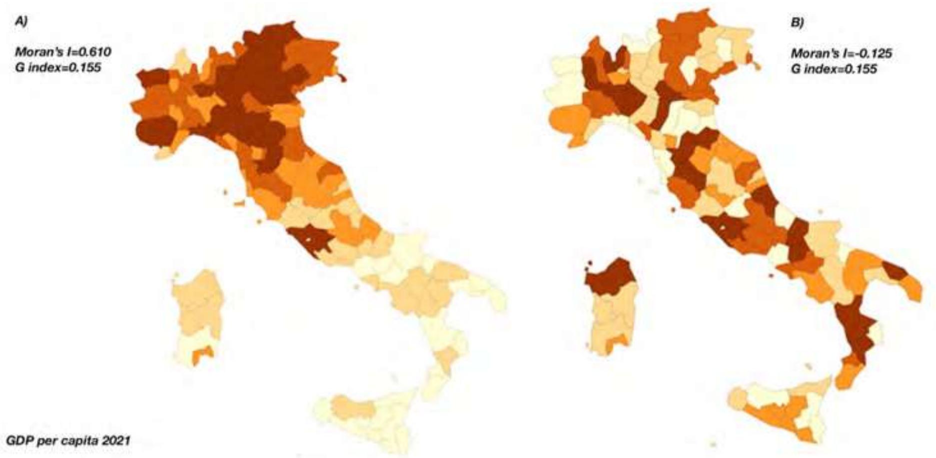
The main drawback presented by the Gini index is that it suffers from the anonymity problem. In fact, different spatial configurations of the phenomenon under investigation provide the same figure of the index.

An illustration of the anonymity condition for Italian provinces is provided in Figure 1. Figure 1(A) presents the observed distribution of regional GDP per capita across the 107 Italian NUTS 3 units (*i.e.* provinces). The values in the map display regional GDP per capita for the year 2021. Darker colours indicate higher values of GDP per capita, while lighter colours evidence lower values of GDP per capita.

Figure 1(B) shows the geographical distribution that is obtained by randomly assigning the values of GDP per capita over the Italian provinces. This spatial distribution is built only for comparison with the actual distribution in (A).

Figure 1 – Inequality and Spatial Dependence of GDP per Capita Across Italian Provinces (2021)

A) Real spatial distribution of regional GDP per capita *B) Random spatial distribution of regional GDP per capita*



Source: Authors' elaborations on ARDECO database

For the two different spatial configurations are calculated: the Gini index G and the Moran's I, a measure of spatial dependence, calculated as:

$$I = \frac{N}{\sum_i \sum_j w_{ij}} \frac{\sum_i \sum_j w_{ij}(x_i - \mu_x)(x_j - \mu_x)}{\sum_i (x_i - \mu_x)^2} \quad [2]$$

where w_{ij} is the element of the matrix W expressing the proximity between NUTS 3 geographical units. Moran's I is an index that measures the similarity (dissimilarity) of values across space. Positive values of I indicate that the observations of the variable under consideration present positive spatial autocorrelation, *i.e.* similar values tend to cluster together in space. On the other hand, negative values of I indicate the presence of negative spatial autocorrelation, *i.e.* high (low) values of the variable are surrounded by low (high) values of the same variable. In the current illustration, for each regional unit, we identify the neighbouring regions based on the k nearest neighbours' criterion[1], with $k = 5$.

As it is evident observing Figure 1, the real distribution in (A) appears more clustered (higher value of Moran's I) with respect to the randomised distribution

1. Consider the set $N_k(i)$ that contains the k closest units to i. For each k, the k - nearest neighbour matrix W has $w_{ij} = 1$ if $j \in N_k(i)$ and $w_{ij} = 0$ otherwise. Weights w_{ij} on the main diagonal of W are set to zero by default.

in (b) that seems more dispersed, and it is characterised by negative spatial association (negative value of Moran's *I*). However, both the different spatial patterns in Figure 1 present the same level of inequality, as measured by the Gini index *G*. This evidence confirms that the index *G* is not sensitive to spatial arrangements of the data and to the influence of neighbourhood. Therefore, it fails to understand and describe the spatial distribution of economic phenomena.

Following this narrative, it is evident how the consideration of the "space" in the inequality measures becomes essential for analysing regional disparities. In this paper, we apply some spatial modifications of the standard Gini index for evaluating regional inequality in Italy introduced by Rey and Smith (2013) and Panzera and Postiglione (2020).

Rey and Smith (2013) aim to propose a measure to combine space and inequality. They define a spatial decomposition of the Gini index, starting from the Equation [1], as:

$$G = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}\left|x_i - x_j\right|}{2N^2\mu} + \frac{\sum_{i=1}^{N}\sum_{j=1}^{N}(1-w_{ij})\left|x_i - x_j\right|}{2N^2\mu} = NG + NNG \qquad [3]$$

Where w_{ij} denotes the generic element of a spatial weight matrix expressing the proximity relationship between locations *I* and *j*. The numerator in [1] expresses the sum of all pairwise absolute differences of *x* and it is rewritten in [3] as the sum of absolute differences between pairs of neighbouring observations and absolute differences between pairs of non-neighbouring observations. The first term on the right side of the decomposition [3] is defined as the neighbouring component (*NG*), while the second term is denoted as the non-neighbour component (*NNG*).

This decomposition nests a measure of spatial autocorrelation (Rey, Smith, 2013). In fact, when the magnitude of positive spatial autocorrelation rises, the second term (*NNG* component) should increase relative to the first (*NG* component), because the association between observations in space would be in action. The result is opposite in the case of negative spatial autocorrelation.

The weight matrix can be simple binary and also row standardised. Other general forms of weights, as for example inverse distance, can be used as well, but they should be row-standardised before applying the decomposition [3]. Note that [3] is equivalent to [1] when $w_{ij} = 1 \forall i, j$ since the *NNG* component of [3] will be equal to 0.

A different approach considering the impact of spatial dependence on an inequality measure is introduced by Panzera and Postiglione (2020). The authors define a new indicator, γ, that grounds on the Gini correlation index, a not symmetric measure of association between two random variables, which is based on the covariance between one variable and its cumulative distribution function (Schechtman, Yitzhaki, 1987).

This new index incorporates both an inequality and spatial autocorrelation measure and it is calculated as the Gini correlation between the variable x (GDP per capita in our case study) observed on N spatial units and the rank of its spatially lagged variable Wx, with W representing the spatial weight matrix summarizing the neighbourhood system of regional units. The variable Wx denotes, for each region, the average GDP per capita observed in neighbouring regions.

The index γ is defined as follows (Panzera, Postiglione, 2020):

$$\gamma = \frac{Cov\left(x, R_{Wx} / N\right)}{Cov\left(x,\ R_x / N\right)} \qquad [4]$$

where R_x and R_{Wx} are the ranks of x and W_x and R_x/N and R_{Wx}/N represent the empirical estimates of the cumulative distribution functions of x and W_x, respectively. These ranks assign as 1 to the lower value of the variables and N to the higher value.

In Eq. [4], the numerator is the Gini covariance between x and W_x and can be used as a measure of spatial autocorrelation, while the denominator is a measure of variability and can be used to estimate inequality (Schechtman, Yitzhaki, 1987). In essence, γ provides the relative contribution of spatial dependence to regional inequality.

The Gini index G can be expressed as twice the covariance between the variable x and R_x/N divided by its mean μ_x as (Lerman, Yitzhaki, 1984; Schechtman, Yitzhaki, 1987):

$$G = \frac{2Cov\left(x, R_x / N\right)}{\mu_x} \qquad [5]$$

Consider now a spatial Gini index defined as:

$$G_s = \frac{2Cov\left(x, R_{Wx} / N\right)}{\mu_x} \qquad [6]$$

that ranges between $-G$ and G (Dawkins, 2004; Panzera, Postiglione, 2020).

Hence, the index in (3) can be rewritten as:

$$\gamma = G_s / G \qquad [7]$$

In other words, the index γ is a ratio between a spatial Gini index G_s and the standard Gini index G and measures the percentage impact of spatial pattern on the overall degree of inequality.

Furthermore, the following decomposition of G holds true:

$$\ddot{u} = {}_{\ddot{u}} + \qquad [8]$$

Where G_{ns} is a non-spatial Gini index that provides a measure of inequality that is not due to spatial dependence. The component G_{ns} is bounded in the following range $0 \leq G_{ns} \leq 2G$ (Panzera, Postiglione, 2020).

The index defined in [4] and [7] varies from -1 to 1. If the ranking of Wx is equal to the actual ranking of x, $G_s = G$ and $\gamma = 1$. In this case, we can observe that inequality is completely explained by spatial dependence. On the other side, as the ranking of Wx becomes more dissimilar to the actual ranking of x**,** the spatial component of inequality G_s reduces and reaches its minimum value of $-G$ when the variable Wx are ranked as opposite with respect to the original order of x.

In this case, the non-spatial component G_{ns}=2G and $\gamma = -1$. If x and Wx are uncorrelated, we have G_s=0, G=G_{ns}, and γ=0, implying inequality is completely explained by its non-spatial component G_{ns}. In this case, space does not matter.

The decompositions in [3] and in [8] identify two different typologies of spatial components. Rey and Smith (2013) define the spatial component as the absolute difference between pairs of non-neighbouring observations (see equation [3]). Conversely, Panzera and Postiglione (2020) focus on the correlation between the value that is observed for the unit under study and the ranking of the values observed for neighbouring regions (see equations [5], [6], [7] and [8]). However, both the methods allow the measurement of the influence of spatial dependence and of adjacency relationship in the analysis of regional inequality. For an analysis of the impact of different definitions of the weight matrix W on the extent of the spatial component in the Gini index see Cartone *et al*. (2022).

Statistical inference of spatial indicators *NNG* and G_s is performed by using a permutation approach following the same idea outlined by Panzera *et al*. (2022) and Rey (2004). To this end, the observed values of x are randomly reallocated to different locations, considering a large number of these permutations (ideally at least 999), and the statistics *NNG* and G_s are calculated for each of these configurations. Given the null hypothesis that each pattern is equally likely, the observed values of *NNG* and G_s are compared with the computationally based distribution obtained with the permutations and a pseudo-significance level is calculated by the position of the current value into the obtained ranked distribution.

It is important to note that this permutation approach, as highlighted by Rey and Smith (2013), consents for inference only on the spatial component of Gini index, and not on the value of the general Gini index [1].

Considering spatial dependence when analysing regional inequality is particularly important in order to guide policies at subnational or national levels. An in-depth knowledge of inequality is also required when one intends to consider the possible impacts of regional inequality on regional growth (Panzera, Postiglione, 2022).

3. Results

The empirical evidence carried on in this chapter regards country inequality in terms of GDP per capita observed on 107 Italian provinces, *i.e.*, NUTS 3 regions according to the European geographical classification. Inequality is measured over the period 2001-2021, which corresponds to the period in the aftermath of the adoption of the European currency by Italy. Data are collected using the Annual Regional Database of the European Commission (ARDECO), while spatial configurations are retrieved from Eurostat database for the official NUTS 2021 version[2].

In this chapter, we focus on some spatial decompositions of the Gini index. Some recent literature has put more emphasis on the role that spatial patterns and geographical position have on the evolution of inequality. Considering the role of spatial spillovers in the variation of the Gini index might be useful for tracking subnational inequalities (Smith, Rey, 2018). Additionally, measures of spatial inequality could be incorporated into the policy toolkit needed to target Sustainable Development Goals (SDGs) and to reduce unevenness of possibilities and development in Europe. To do so, we refer to two different alternatives suggested by Rey and Smith (2013) and Panzera and Postiglione (2020) respectively.

As a first step, we compute the level of the standard Gini index to show inequality across the Peninsula over the period under study (Figure 2 and Table 1). As it can be observed, after several years of decreasing disparities after 2001 (a minimum for the Gini index slightly above 0.13 is reached in 2006), there is a level of increasing inequality in more recent years. This is particularly evident after 2007 – the years considered as the beginning of the worldwide financial crisis. The level of regional inequality reduces again in 2019 but shows new a slight increase in 2021, the year after the Covid 19 pandemic has hit the country and the entire world.

After, we focus on the spatial distribution of the variable under study, the GDP per capita at NUTS 3 level. To show this, we report maps about the level of GDP per capita in Italian provinces for three different years (2001, 2011, and 2021). The maps are included in Figure 3.

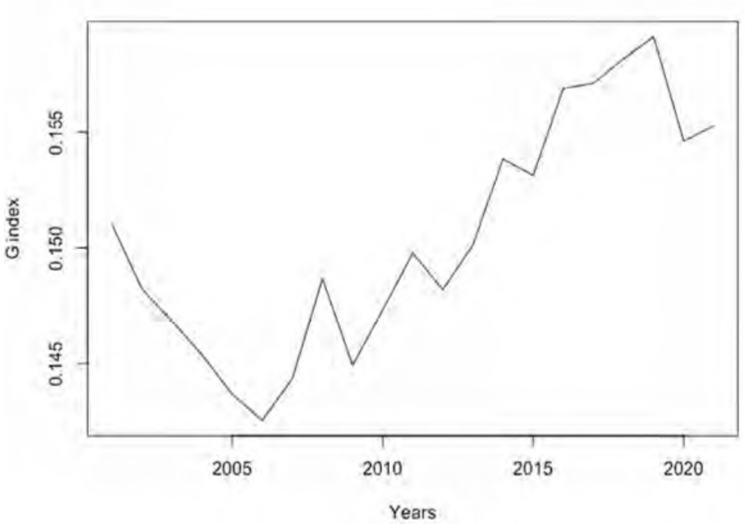
Traditionally, the north/south divide affects the regional distribution of GDP per capita across Italy. The presence of a north/south gradient has been characterizing Italy since a long time, where the northern regions are more developed, while southern regions have been struggling in terms of economic growth and job creations (Panzera, Postiglione, 2014; Bernini, Pellegrini, 2011). This is confirmed in our maps. The levels of GDP per capita are gradually higher in the north of the country, especially in the northeast, being the only exception the province of Rome. Also, there is no evidence of major shifts in the spatial patterns over the period.

We consider the potential presence of a spatial pattern due to spatial autocorrelation in our data. Precisely, to test the hypothesis of spatial dependence, we use Moran's *I* along all the years considered. The results for the test are summarized in Table 1. To calculate the level of the Moran's *I* statistics a *k*-nearest neighbours spatial weight matrix is used, considering for each province a number of $k = 5$ neighbours.

The persistent level of spatial autocorrelation evidenced by the Moran's *I* leads us not to be completely satisfied with a mere computation of the standard

2. https://knowledge4policy.ec.europa.eu/territorial/ardeco-database_en

Figure 2 – Gini index calculated on the annual GDP per capita using 107 Italian provinces between the years 2001 and 2021



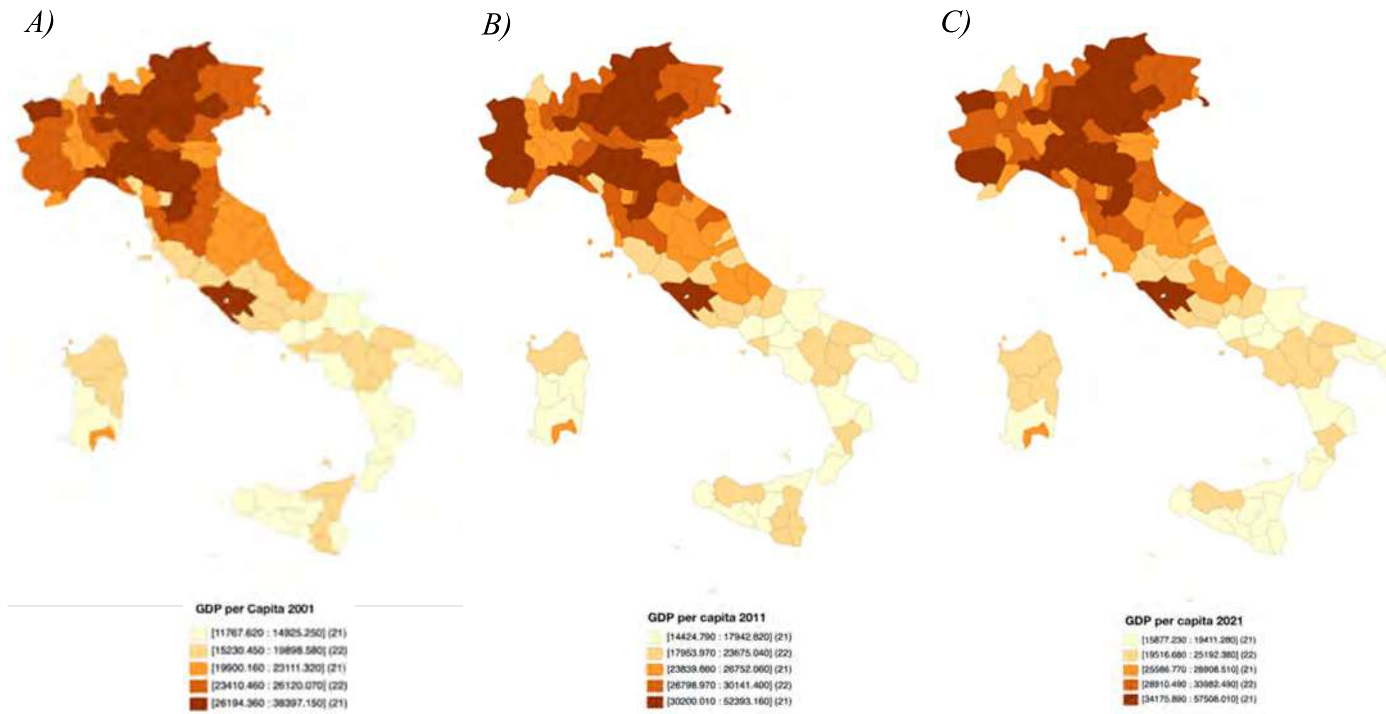
Source: Authors' elaborations

Table 1 – Results for Moran's I Statistics Calculated on GDP per Capita for 107 Province of Italy Over the Years 2001 and 2021. P-values in brackets

Year	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***
Moran's I	0.710 (0.000)	0.683 (0.000)	0.676 (0.000)	0.687 (0.000)	0.688 (0.000)	0.680 (0.000)	0.665 (0.000)
Year	***2008***	***2009***	***2010***	***2011***	***2012***	***2013***	***2014***
Moran's I	0.660 (0.000)	0.664 (0.000)	0.582 (0.000)	0.542 (0.000)	0.564 (0.000)	0.586 (0.000)	0.571 (0.000)
Year	***2015***	***2016***	***2017***	***2018***	***2019***	***2020***	***2021***
Moran's I	0.600 (0.000)	0.623 (0.000)	0.612 (0.000)	0.614 (0.000)	0.621 (0.000)	0.609 (0.000)	0.610 (0.000)

Source: Authors' elaborations

Figure 3 – GDP per Capita for 107 Italian Provinces in the Years 2001 (A), 2011 (B), and 2021 (C)



Source: Authors' elaborations on ARDECO database

Gini index. Indeed, due to the anonymity property of the Gini index, this indicator is completely not sensitive to the presence of spatial dependence. In essence, different spatial patterns across the country provide the same level of the Gini index. To overcome these drawbacks in the analysis of regional inequality in Italy, we consider spatial measures of inequality.

To obtain results for spatial inequality, we have to build a proximity structure that explains connections between regions. As summarized in the methodological section, an exogenous spatial weighting matrix W is used. In this application, we consider geographical proximity by adopting a k–nearest neighbour contiguity matrix, with the number of nearest neighbours set to five. However, as already evidenced by Cartone *et al*. (2022) at the European level, both measures tend to be quite robust in relation to the choice of the number of neighbours accounted to build the W.

Also, as in this chapter we are interested in the role that space has in the analysis of territorial inequalities, we want to evaluate the statistical significance of the two alternatives used to measure spatial inequality, *i.e.*, the NNG and G_s components. For this reason, we focus on testing the two spatial indicators. To evaluate the statistical significance of these two indicators, we use an approach based on permutations (Panzera *et al*. 2022; Rey, 2004). For all the tests reported in the analysis, we perform 999 permutations.

The results corresponding to the Rey and Smith (2013)'s spatial decomposition of the Gini index are reported in Table 2. Here, we observe how the NNG – which can be interpreted as the spatial component – accounts steadily around the 99% of the overall inequality measured by the standard Gini. Also, the N component is tested significant for all the years under analysis. Conversely, numbers corresponding to the other component (NG) are quite low. This conveys into a proportion – expressed by the ration NNG/G – which is close to one for all the years accounted.

More specifically, we observe how the ratio NNG/G remains quite constant in the years 2001 and 2007. In the years after 2007, the role of spatial inequality slightly decreases, especially in 2008 and 2009. Finally, values for this ratio in the final periods (after 2014) rise again and re-establish at levels similar to the initial years. This evidence indicates how the relevance of spatial effects gradually lowered during the initial years of the financial crisis, while it has started to resume in later years.

To broaden the picture on the role that space has in the analysis of territorial inequalities, we report the results for the spatial decomposition of the Gini index proposed by Panzera and Postiglione (2020). Results for the G_s, G_{ns}, and the ratio G_s/G are summarized in Table 3 for the years between 2001 and 2021.

From Table 3, we note how the spatial indicator G_s keeps around 0.10 across the years and it represents again a large proportion of the overall inequality calculated by the standard Gini (between 65% and 78%). Nevertheless, those

Table 2 – Non-neighbour (NNG) and Neighbour (NG) components of the Gini index calculated for GDP per capita for 107 provinces between the years 2001 and 2021. P-values for the NNG in brackets

Year	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***
NNG	0.1503	0.1476	0.1462	0.1447	0.1430	0.1419	0.1437
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
NG	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007	0.0007
NNG/G	0.9953	0.9954	0.9954	0.9954	0.9953	0.9953	0.9953
Year	***2008***	***2009***	***2010***	***2011***	***2012***	***2013***	***2014***
NNG	0.1479	0.1442	0.1466	0.1490	0.1474	0.1494	0.1531
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
NG	0.0008	0.0008	0.0008	0.0008	0.0008	0.0007	0.0007
NNG/G	0.9948	0.9946	0.9949	0.9949	0.9948	0.9951	0.9952
Year	***2015***	***2016***	***2017***	***2018***	***2019***	***2020***	***2021***
NNG	0.1524	0.1561	0.1563	0.1573	0.1583	0.1538	0.1544
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
NG	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008	0.0008
NNG/G	0.9951	0.9951	0.9951	0.9951	0.9951	0.9950	0.9950

Source: Authors' elaborations

proportions are lower if compared to the *NNG/G* ratio, a feature that allows us to better appreciate absolute yearly variations when compared to the values obtained in Table 2 for the Rey and Smith (2013)'s spatial decomposition. Spatial indices G_s are tested significant in all the years under study.

Looking more deeply at yearly variations of the role that spatial inequality G_s has on the overall inequality (*i.e.*, *G*), we observe how the relevance of spatial inequality was higher in the years between 2001 and 2003. A stronger reduction of the ratio G_s/G characterizes the years subsequent the financial crisis, with this figure levelling under the 70% in the period 2008-2012.

A minimum is reached in 2009, when Italy is progressively hit by a debt crisis involving other European countries such as Greece, Portugal, and Spain. However, the role of spatial inequality strengthens again to reach again up to more than 70% after 2013.

The trend evidenced by the G_s/G is similar to the one observed for the *NNG/G*. Hence, to better appreciate time variations in both spatial inequality indicators, yearly values for both the *NNG/G* (A) and G_s/G (B) are shown in Figure 4. Both

Table 3 – Spatial (G_s) and non-spatial (G_{ns}) components of the Gini index calculated for GDP per capita for 107 NUTS 3 EU regions between the years 2001 and 2021. P-values for the G_s in brackets

Year	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***
G_s	0.1173	0.1157	0.1137	0.1101	0.1076	0.1047	0.1069
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
G_{ns}	0.0338	0.0326	0.0331	0.0353	0.0360	0.0378	0.0374
G_s/G	0.7765	0.7802	0.7745	0.7573	0.7491	0.7345	0.7408
Year	***2008***	***2009***	***2010***	***2011***	***2012***	***2013***	***2014***
G_s	0.1013	0.0943	0.0988	0.1036	0.1013	0.1074	0.1130
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
G_{ns}	0.0473	0.0506	0.4848	0.0461	0.0469	0.0427	0.0408
G_s/G	0.6816	0.6506	0.6709	0.6920	0.6837	0.7155	0.7347
Year	***2015***	***2016***	***2017***	***2018***	***2019***	***2020***	***2021***
G_s	0.1107	0.1135	0.1143	0.1160	0.1168	0.1131	0.1141
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
G_{ns}	0.0424	0.0434	0.0428	0.4219	0.0423	0.0415	0.0412
G_s/G	0.7230	0.7236	0.7276	0.7332	0.7341	0.7318	0.7347

Source: Authors' elaborations

indicators show a clear minimum in 2009. Also, the figures show how after this year there has been again a progressive increase in the role that spatial inequality have on inequalities.

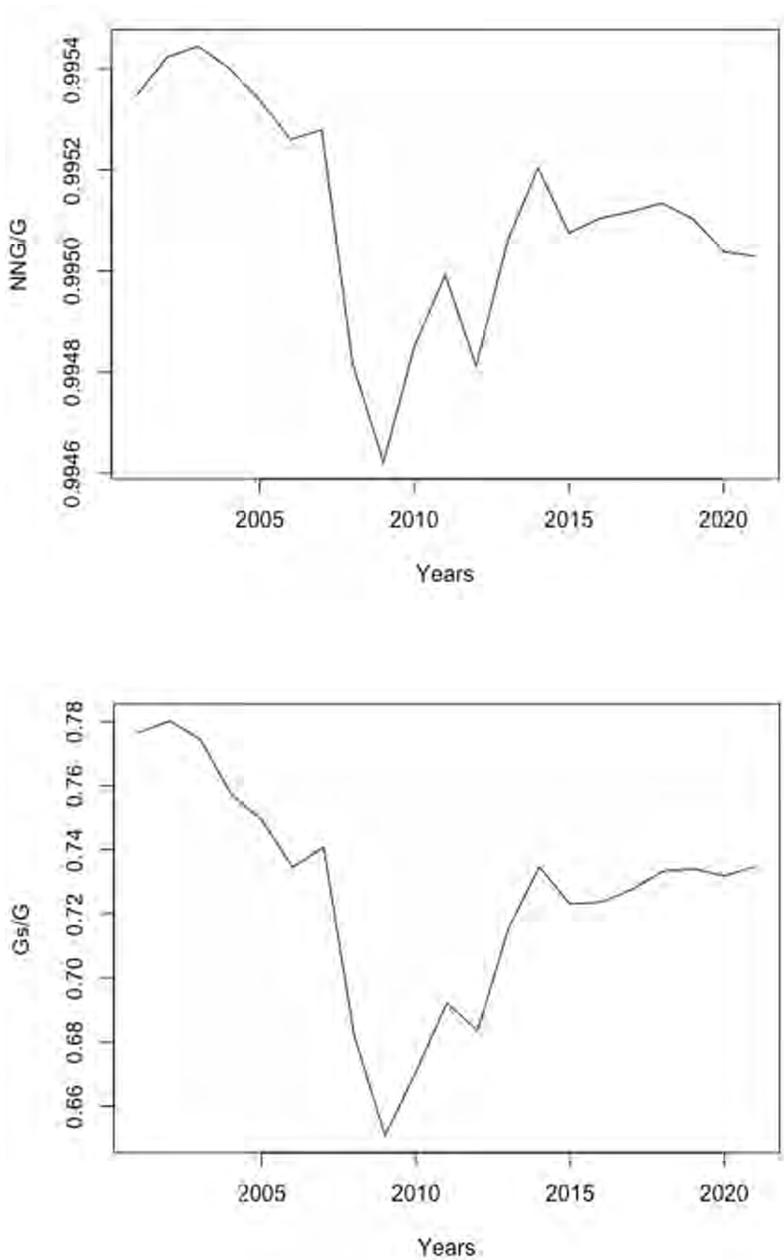
Spatial indices show some progressive reduction in parallel with the level of the overall inequality, especially in the years between 2002 and 2006. Right after 2007, while the country inequality starts to rise again, the role of spatial inequality continues to decrease, touching its minimum level in 2009. Finally, spatial inequality starts to progressively rise comparably to the overall inequality.

Therefore, the role of spatial inequality in Italy shows some duality. On the one side, spatial indices tend to perform similarly to the overall Gini index in a period of relative economic expansion, as the case of the years before 2007. On the other side, during the hardest years of the financial crisis (after 2007), while the overall inequality starts to rise again, spatial inequality continues to decrease. As it can be noted in both Tables 2 and 3, this is particularly connected to the fact that both the absolute levels of *NNG* and G_s are s or continue to lower during the financial crisis.

Figure 4 – Levels of the NNG/G (A) and G_s/G (B) Measured by Using GDP per Capita at Provincial Level over the Years between 2001 and 2021

A)

B)



Source: Authors' elaborations

These peculiarities may be linked to spatial mechanisms connected to the propagation of economic downturns (Smith, Rey, 2018; Cartone *et al.* 2022). Indeed, financial crisis hit harder more developed regions depending on their relationship with the global economy at first, so that the immediate propagation has not been linked to spatial mechanisms throughout the Peninsula. After a few years, when the effects of the crisis implied several local adjustments on the country's economy, spatial inequality turns to rise again and concurs to the more recent increase of the overall inequality.

Indicators of spatial inequality are therefore found to be valuable tool to assess the dynamic of spatial interdependencies and to add on the evidence from standard indicators as the Gini index. Also, a greater look at the role of spatial inequality can simplify the consideration of local adjustment that are linked to major economic shocks and how they can affect at different stages into national and/or regional context. This can also be linked to slow spatial adjustments in the sectorial mix through late impacts of crisis on regional businesses (Piacentino *et al.* 2017; Marin, Modica, 2021).

On the other side, specific inequality, defined as complementary to the spatial inequality, is at roots of important challenges for policy makers. This is true not only at regional level, but also at national and European level. In fact, the paradigm of cohesion grounds on a broader idea, including social, economic, and territorial dimensions. Ensuring cohesion within the regions could be pivotal to guarantee stability and avoid critical situations throughout the Union. These aspects still top as priorities for European policy makers (Urso *et al.,* 2019).

In conclusion, the joint use of tools that analyse spatial proximity in geographical concentration and specific inequality could help policy makers and inform multi-level governance. Additionally, the spatial decomposition could be adopted in spatial modelling of economic growth to account the effects of spatial inequality on economic growth. As explored by Panzera and Postiglione (2022), inequality could have different impact on growth for different groups of regions. This calls for a focus on specific inequality to capture distinctive impact of inequality on growth, as different regions may experience different consequences of inequality on development. A deeper consideration of those features to plan cohesion programs should characterize polices, as institutional, historical, and geographical factors that characterize each regional unit within a nested Union.

In this direction, we are convinced that indicators of spatial inequality will complement a careful analysis of inequality at territorial level in future studies (Arbia, Piras, 2009), since their use could support policy makers to guarantee fairer and even development in this period of recurrent downturns.

4. Concluding Remarks

In this chapter, we propose the use of spatial indices of inequality for the analysis of disparities in Italy in the years that span between 2001 and 2021. To do so, we collect available data at NUTS 3 level for the GDP per capita and consider the use of two different spatial techniques derived by standard Gini index. Following the latest methodological contributions, we apply indices introduced by Panzera and Postiglione (2020) and Rey and Smith (2013) to offer a deeper insight in the geographical features that can attain the analysis of inequality.

Generally, the results obtained by the adoption of spatial indicators strengthen the relevance that geographical features may have on the overall inequality. This highlights two aspects. First, the analysis of inequality made using geographically distributed data is perplexing when standard indices are used, mainly due to the anonymity property. Second, a more careful treatment of spatial aspects under the methodological perspective enables a more careful view on inequality, which can complement non-spatial measures.

The empirical evidence on Italy suggests new implications in the analysis of inequality. On the one hand, the relevance of spatial inequality is quite strong in the whole period considered, where all indices are tested significant using permutation tests. This corroborates the role that the geography of Italy has on determining rising inequality and the persistence of the north-south gradient. On the other side, the role of spatial inequality seems to reduce in the meanwhile of the great recessions. This is confirmed by both the statistical methodologies considered in this work.

In this regard, another aspect can be highlighted from this chapter. If someone could object that spatial indices simply track the evolution of inequality in the same fashion of standard inequality figures, we argue that considering time variations of the spatial indices of inequality can add on new information on how inequality evolve within the country. In fact, the time variations of spatial inequality do not simply resemble the evolution of the Gini index. Hence – despite the empirical evidence brought here simply focusing on Italy – it can be observed that obtaining figures of spatial indices offers different (and potentially useful) information about inequality when this exercise is performed on a sufficiently large period.

Lastly, the chapter offers another justification for focusing more on the analysis of spatial inequality. This could involve adding on the potential methodologies adopted to tackle the problem of the anonymity within several existing methods for the analysis of disparities. Indeed, new empirical applications could leverage those measures to deeply assess the impact that geographical features have on the actual distribution of resources and possibilities.

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Sommario

La dimensione spaziale della disuguaglianza economica in Italia

Le tradizionali misure di disuguaglianza non riescono a spiegare la distribuzione spaziale dei fenomeni economici. Per questo motivo, negli ultimi anni, è stata introdotta in letteratura una nuova classe di indici. In questo articolo, stimiamo le componenti spaziali della disuguaglianza economica in Italia utilizzando alcune misure spaziali di concentrazione. In particolare, ci basiamo sulle espansioni spaziali dell'indice standard di Gini, che sono state recentemente introdotte, per valutare la rilevanza che la distribuzione spaziale può avere sulla disuguaglianza dei redditi. L'obiettivo è fornire maggiori informazioni sulla dimensione spaziale della disuguaglianza e supportare i decisori politici nella valutazione delle disparità economiche.

Self-employment and Tax Evasion: A Descriptive Analysis of Italian Provinces

Amedeo Argentiero, Paolo Maranzano°,*
Gianluca Monturano§, Giulio Pedrini▪

Abstract

This chapter investigates the relationship between tax evasion and the diffusion of self-employment in the Italian provinces (NUTS-3 level). Using a dataset that combines information coming from the Italian Revenue Agency and the Italian Labour Force Survey for the period 2014-2015, we test, in particular, whether: 1) the share of self-employment in the regional labour markets is correlated with tax evasion; 2) the sectoral structure of self-employment is correlated with tax evasion; 3) occupational profiles based on skills and task families are correlated with tax evasion. A two-stage cluster analysis on the variables correlated to tax evasion is also conducted to identify homogeneous groups of provinces. The results of this study allow to detect specific sectors and occupations to which the policy maker should pay particular attention in its local tax control activities.

1. Introduction[1]

Tax evasion is a common practice in many countries, particularly in Italy, where the latest estimates report an amount of approximately € 27 billion of evaded personal income taxes in 2022 (Ministero dell'Economia e delle Finanze, 2022)

* University of International Studies of Rome, Department of International Humanities and Social Sciences, Rome, Italy, e-mail: amedeo.argentiero@unint.eu.

° University of Milano Bicocca, Department of Economics, Management and Statistics and Fondazione Eni Enrico Mattei, Milan, Italy, e-mail: paolo.maranzano@unimib.it.

§ University of Modena and Reggio Emilia, Department of Economics, Modena and University of Bari, Department of Economics, Management and Business Law, Bari, Italy, e-mail: gianluca.monturano@unimore.it.

▪ Kore University of Enna, Department of Economics and Law, Enna, Italy, e-mail: giulio.pedrini@unikore.it (corresponding author).

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very heterogeneously distributed across the country (Argentiero *et al*., 2020; 2021). Two major driving factors of such heterogeneity are represented by the sectoral and occupational structure. In particular, it is commonly acknowledged that most of the lost fiscal revenues come from the tertiary industry (Artavanis *et al*., 2016) and from self-employed workers who are not subject to withholding taxes, both in Italy (Carfora *et al*., 2018) and worldwide (e.g., Engström, Holmlund, 2009). Less is known, however, about the relationship between the occupational profiles (and their underlying tasks and skills) and tax evasion at local level. In fact, tax compliance could vary according to sectors and occupational groups (e.g. Artavanis *et al*., 2016), while a relationship between regional socio-economic structure and tax evasion has also been found in the literature (e.g. Argentiero *et al*., 2020).

This chapter aims at studying the relevance, at NUTS-3 level, of a statistical correlation between self-employment and tax evasion, as well as between tax evasion, industrial structure and occupational composition. Evidence grounds on a unique dataset that merges data on tax evasion in Italian Province released by the Italian Revenue Agency with the Italian Labour Force Survey, named "Rilevazione Continua delle Forze di Lavoro" (RCFL), that provides detailed information about workers´ characteristics and job positions, including educational attainments, occupations, and industry of the employing firm. We used the quarterly waves of the surveys that have been carried out in 2014 and 2015, for which the workers' distribution by Province is made available in the public microdata. After having showed the spatial distribution of the main variables of interest, we correlate the share of self-employment workers, as well as the sectoral and occupational structure, with the propensity to evade taxes. In particular, as far as occupations are concerned, we look at the skills and tasks that are more intensively used in the workplace to identify the occupational families that are more vulnerable to tax evasion, given the characteristics of the local context. Finally, we perform a cluster analysis to identify homogeneous groups of provinces in terms of tax evasion, occupational and sectoral structure, institutional quality, and GDP per capita.

The chapter is structured as follows. Section 2 briefly reviews the literature. Section 3 describes the dataset and the variables. Section 4 discusses the geographical distribution of the main variables. Section 5 conducts a correlation analysis. Section 6 discusses the results of the cluster analysis. Section 7 concludes.

2. Tax Evasion Across Sectors and Occupations: A Snapshot of the Literature

The propensity to avoid taxes is highly heterogenous across places, sectors, and occupations. Literature has highlighted that industrial composition, occupational conditions, tax compliance, and attitude to evasion are correlated and mutually reinforcing (Artavanis *et al*., 2016; Hashimzade *et al*., 2014). It has been shown in particular that certain industries are more prone to income tax evasion than others (e.g. Kesselman, 1989; Artavanis *et al*., 2016), and that tax evasion is deemed to be higher among young and self-employed workers (e.g. Hashimzade *et al*., 2014; Alm *et al*., 2016).

As far as industries are concerned, tertiary services, such as professional services, media, hotels, restaurants, and retail, are characterized by the highest incidence of tax evasion (Artavanis *et al*., 2016). Such sectors, in fact, are usually characterized by a higher diffusion of cash payments (Morse *et al*. 2009) and a lower probability for the tax payer to be discovered (Kleven *et al*. 2011; Pomeranz, 2015). Tax evasion is also widespread in those sectors that favour "moonlighting" practices, i.e. working simultaneously in the formal and informal economy (Slemrod, 2019). This phenomenon typically occurs among self-employed workers and in small firms where employers and employees can easily collude with respect to the amount of income reported to tax authorities (Kleven *et al*., 2016).

Moving to occupations, existing analyses refer to the generic category of self-employees or entrepreneurs who usually enjoy a higher level of discretion over reporting their income to tax authorities, showing that these workers declares income that are far lower their actual one (Slemrod, 2007). Existing empirical studies, conducted in different countries, found a substantial tax gap among self-employed workers, the hidden income ranging between 20 and 50% of the total income (Johansson, 2005; Engström, Holmlund, 2009; Kim *et al*., 2017; Kukk, Staehr, 2014; Martinez-Lopez, 2013; Kukk *et al*., 2020; Engström *et al*., 2023), with a peak of 55% in Greece (Artavanis *et al*., 2016). Within this group of workers, the share of hidden income is not even constant across income levels because it tends to be relatively constant in nominal terms and thus less than proportional to earnings, (Engström *et al*., 2023). The diffusion of tax evasion within self-employed is also stronger in specific sectors, with a consequent cumulativeness of the occupational- and industrial-driven propensity to evade (Artavanis *et al*., 2016).

This literature, however, does not disentangle between different occupational groups (typically identified by ISCO codes), a part from a rough distinction between blue collars and white collars (Lyssiotou *et al*., 2004), despite tax payers could be heterogenous with regard to the occupational group to which its job belongs to. When taken separately, in fact, each occupational group could be associated with an increase (or decrease) in the propensity to evade taxation, either for subjective or objective reasons. On the objective side, different occupations (for instance a taxi-driver, an house painter or a lawyer) may entail different probabilities to be audited and getting caught (Slemrod, 2019), which, in turn, are expected to increase/decrease individual tax compliance, like for different sectors (Alm, 2019). Moreover, some occupations typically require hard work in terms of time and effort, which in turn may influence the individual attitude to tax compliance (Buhren, Kundt, 2014; Grundmann, Lambsdorff, 2017). On the subjective side, individuals' risk-aversion, intrinsic motivation, and inclination for honesty, which are usually related to the propensity to evade taxes, may not only influence the decision of being an employee, a self-employee or an entrepreneur (Pickhardt, Prinz, 2014), but they may also affect a wider set of individuals' professional choices (e.g. being a journalist or a consultant) as different occupations underlie heterogeneous risks in terms of variance of income over time (Artavanis *et al*., 2016). Overall, therefore it is reasonable to hypothesize that tax payers behave differently according to the occupational group to which their job belongs to.

3. Data and Variables

The descriptive analysis is based on three data sources and refers to 103 Italian provinces (out of 110) observed in 2014 and 2015. This restriction was necessary due to the unavailability of the entire set of variables of interest in other periods and in the remaining provinces. The first data source comes from the Italian Revenue Agency and is referred to the yearly estimation of tax evasion implemented by the Agency. From this dataset, we draw the propensity to evade taxes for each Italian province, measured through two different ratios. The former measures this propensity as the ratio the effective tax revenues voluntarily declared by taxpayers and the potential collection of taxes, according to National Accounts data. The latter is the ratio between tax gap and the value added. The aforementioned indicators provide different but complementary pieces of information. The first propensity, i.e. the one in terms of tax compliance, highlights the attitude of taxpayers to escape their tax obligations and is the most suitable measure for analyzing whether and to what extent the recovery of tax evasion is due to an improvement in tax payer behavior. The second propensity, i.e. the one in terms of value added, is more concerned on the evolution of tax evasion, once sterilized from the effects of the business cycle.

The second data source is the Survey on Italian Professions (SIP) performed by the National Institute of Analysis of Public Policies (INAPP) to identify the constituent tasks and skills of each of the 800 job titles included in the Italian occupational classification. The last wave of SIP was held in 2013 by interviewing more than 16,000 workers who were asked to self-assess their degree of utilization (in terms of complexity) of knowledge, skills and the constituent tasks to be performed on their respective job posts with 255 variables organized on a 1-100 point scale score. These variables were then organized across 7 clusters:

Knowledge (33 questions), Skills (35 questions), Attitudes (52 questions), Values (21 questions), Working styles (16 questions), Tasks (41 questions) and Working conditions (57 questions), but we only consider Skills and Tasks for their tighter connection with the occupational profile. To detect task families we run a Principal Component Analysis, henceforth PCA, to extract latent components that explain most of the variation among the single tasks. The selected components have then been coded with the same families proposed by Autor *et al*. (2003): analytical tasks; manual tasks; interactive tasks; routine tasks; other cognitive tasks. To identify the skill families, we applied the same procedure to the skill items, and then labeled the selected components in accordance to the skill categories put in place by Gregory *et al*. (2019), Fleisher and Tsacoumis (2012), OECD (2016), and CEDEFOP (2013): cognitive skills, technical skills, horizontal skills, soft skills.

The third data source is given by the Italian Labour Force Survey, named "Rilevazione Continua delle Forze di Lavoro" (RCFL), that provides detailed information about workers′ characteristics and job positions, including educational attainments, occupations, and industry of the employing firm. We used the quarterly waves of the surveys that have been carried out in 2014 and 2015 involving more than 100,000 workers per wave. By linking each occupation (3-digit ISCO codes) to the importance of task and skill families, as previously defined, we also derived groups of occupations that require an intensive use (i.e. above the median) of different skills and tasks. After having grouped each variable by Province and computed a yearly average of their values, we calculated the share of workers by type of employment, sectors, type of occupation, i.e. associated with an intense use of the main categories of skills and tasks, for each spatial unit.

Other publicly available information included in our dataset concern the per-capita income, as made available by the National Institute of Statistics (ISTAT), and the Institutional Quality Index (IQI), specifically, developed by Nifo and Vecchione (2014). The inclusion of institutional variables in our analysis fits with another stream of literature that showed the importance of the institutional setting in driving individuals' and firms' compliance behaviour (Cummings *et al*., 2009; Andrighetto *et al*., 2016; Zhang *et al*., 2016).

Table 1 displays the descriptive statistics of the main variables of interest at Provincial level in 2014 and 2015. The average tax gap, with respect to declared taxes, amounts to approximately 43 per cent, while it accounts for 6.5 per cent with respect to the value added. The degree of dispersion is substantial for both the indicators as the coefficient of variation of these variables ranges between 27% and 41%. Moving to the occupational structure, we observe that 24 per cent of the workers are self-employed. As far as industries are concerned, the majority of the workers are employed in the service industry (53%), while manufacturing and retail account for

Table 1 – Descriptive Statistics of the Main Variables (2014-2015)

Variable (% of employed workers)	*Year*	*Obs.*	*Mean*	*Std. dev.*	*Min.*	*Max.*
Self-employed	2014	110	0.243	0.042	0.163	0.374
	2015	110	0.244	0.043	0.161	0.359
Males	2014	110	0.591	0.040	0.519	0.727
	2015	110	0.590	0.040	0.524	0.719
Professionals	2014	110	0.053	0.014	0.025	0.102
	2015	110	0.055	0.016	0.025	0.112
Entrepreneurs	2014	110	0.009	0.007	0.000	0.036
	2015	110	0.009	0.008	0.000	0.040
Cognitive skills	2014	110	0.437	0.049	0.297	0.551
	2015	110	0.438	0.049	0.307	0.562
Horizontal skills	2014	110	0.429	0.040	0.310	0.534
	2015	110	0.433	0.045	0.320	0.554
Soft skills	2014	110	0.430	0.055	0.273	0.555
	2015	110	0.431	0.052	0.318	0.557
Analytical tasks	2014	110	0.481	0.047	0.366	0.613
	2015	110	0.485	0.050	0.341	0.621
Routine tasks	2014	110	0.551	0.049	0.449	0.669
	2015	110	0.553	0.049	0.456	0.711
Interactive tasks	2014	110	0.482	0.045	0.373	0.591
	2015	110	0.477	0.044	0.345	0.582
Manufacturing	2014	110	0.198	0.089	0.063	0.448
	2015	110	0.198	0.090	0.062	0.483
Retail	2014	110	0.149	0.023	0.106	0.222
	2015	110	0.147	0.025	0.071	0.207
Construction	2014	110	0.073	0.024	0.036	0.193
	2015	110	0.070	0.019	0.032	0.150
Tertiary services	2014	110	0.528	0.079	0.361	0.745
	2015	110	0.531	0.078	0.315	0.751
GDP per capita	2014	103	24664	6701	14400	50300
	2015	103	25092	6796	14600	51300
Tax gap	2014	103	0.433	0.116	0.107	0.702
(tax evasion/tax declared)	2015	103	0.428	0.114	0.104	0.724
Tax gap	2014	103	0.066	0.027	0.029	0.262
(tax evasion/value added)	2015	103	0.062	0.019	0.026	0.145

Source: Authors' elaborations

20% and 14% of the workforce, respectively. Looking at the occupations, one can observe most of them require an intensive use of routine tasks, but also that interactive and analytical tasks are needed by 48% of these workers. Among the skills families, they report very similar shares of intensive use in the occupations of interest. Indeed, horizontal skills, soft skills and cognitive skills are intensively used by 43% of the workers. These figures do not report substantial changes between 2014 and 2015, a part from the tax gap, which shows a significant decrease in 2015, when tax evasion is divided by both declared taxes and value added.

4. Geographical Distribution of Tax Evasion and Self-employment

In the Italian provinces, the ratio of tax evasion to tax compliance ranges between a minimum of approximately 10 per cent and a maximum of more than 72 per cent and shows a substantial variability (Argentiero *et al.*, 2021). This stylized fact indicates that the structural features of regional economies can play a substantial role in driving the propensity to evade taxes of firms and individuals. When referring tax evasion to taxes declared (Table 2, second row), the highest percentage of tax evasion (56.5%) is reached in Lazio, with other 5 regions, all located in southern Italy, exceeding the 50 per cent threshold: Campania, Molise, Basilicata Calabria, Sicilia. In northern Italy, on the contrary, the tax gap is always lower than 40% except for Liguria (44.1%). In central Italy, a part from Lazio, the other regions are quite similar, reporting shares that range around 40 per cent. In terms of value added (Table 2, third row), tax gap is always below 10%, with the highest figures reported by Molise, Calabria and Campania. The distribution of this measure mainly overlaps with the one based on tax declared, except for Lazio, whose tax gap is now lower than the one of most southern regions. In the North, the ranking of the provinces is similar too, but the variability of this measure of tax gap is much lower than before.

When looking at the distribution of self-employed across the country, it is also highly heterogeneous, with peripheral and southern provinces reporting the highest share of self-employment (Figure 1). In particular, three areas with a noteworthy density of self-employees emerge: northern Puglia, Calabria, and western Sicily. In the rest of Italy, the diffusion of self-employment is lower, a part from some spots in the western boundaries of Piedmont and Liguria, and in the southern part of Tuscany, Umbria and Marche. Concerning the industrial structure, its geographical distribution displays a concentration of the manufacturing activities in Northern provinces (Figure A.1), especially in the North-East. Construction activities, on the contrary, are more evenly distributed across the country (Figure A.2). As expected, the distribution of the highest quintiles of the retail sector (Figure A.3) overlaps quite well with the distribution of self-employment, especially in southern Italy.

Table 2 – Tax Evasion Across Italian Regions (2015)

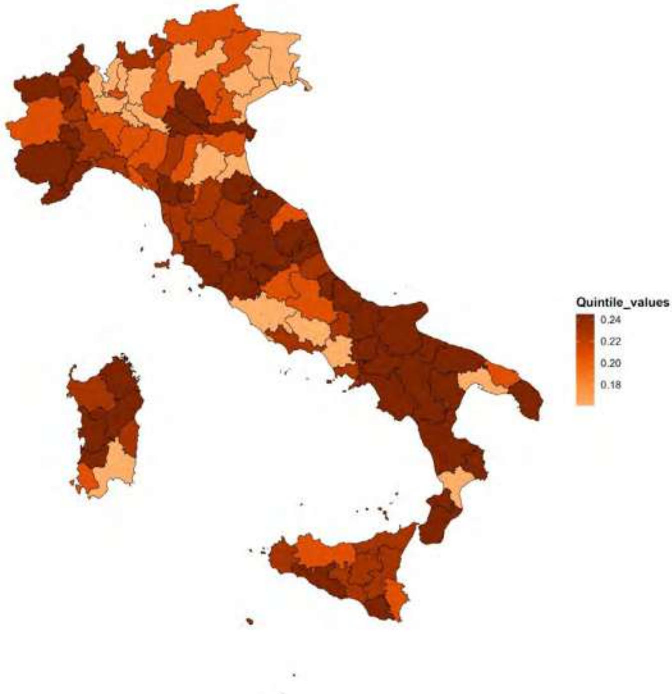
Region	*Tax Gap (On Tax Declared)*	*Tax Gap (On Value Added)*
Piedmont	0.396	0.062
Aosta Valley	0.281	0.044
Lombardy	0.341	0.045
Trentino South Tyrol	0.262	0.045
Veneto	0.321	0.047
Friuli Venezia Giulia	0.344	0.050
Liguria	0.441	0.063
Emilia-Romagna	0.364	0.057
Tuscany	0.403	0.057
Umbria	0.384	0.061
Marche	0.422	0.067
Lazio	0.565	0.074
Abruzzo	0.419	0.058
Molise	0.536	0.094
Campania	0.549	0.082
Apulia	0.490	0.073
Basilicata	0.518	0.078
Calabria	0.545	0.087
Sicily	0.552	0.081
Sardinia	0.482	0.083

Source: Authors' elaborations

Other tertiary services show instead a higher concentration in the western provinces of the Centre (Figure A.4), especially in Lazio, in the northern part of Sicily, in Sardinia, and in Trentino-South Tyrol. In this sector, all the main metropolitan areas fall in the first quintile of the distribution. This is not surprising since most business services and professionals are usually located in larger cities.

Regarding occupations, the most interesting geographical distributions are those of cognitive and horizontal skills (Figures A.5 and A.6). About the former, one can observe that they are more concentrated in the Northern provinces, in the coastal provinces of the Centre, and in the peripheral areas of the South. For what concerns horizontal skills, they are more intensively used by people working in the northern and central provinces, as well as in the main metropolitan areas. As far as tasks are concerned (Figures A.7, A.8 and A.9), a more

Figure 1 – Share of Self-employed Workers by Province (2015)



Source: Authors' elaborations

clear-cut division between the three macro-regions. Analytical tasks are more intensively used in the Northern provinces, routine tasks in the central provinces, and interactive tasks in the southern provinces. Moreover, it is worthwhile noticing that routine tasks are relatively concentrated in the two main islands: Sicily and Sardinia. Relative concentrations of analytical tasks can be also found in some provinces of Tuscany, Umbria and Marche, whereas interactive tasks are also highly required in all the provinces of Liguria.

5. Correlation Analysis

Table 3 reports the matrix showing the pairwise correlation coefficients between tax evasion, self-employment, sectors, and occupations, as previously defined. For sake of simplicity, only the variables significantly correlated with tax evasion are reported. The main evidence deals with the positive correlation between self-employment and tax evasion (Figure 2), which holds for both

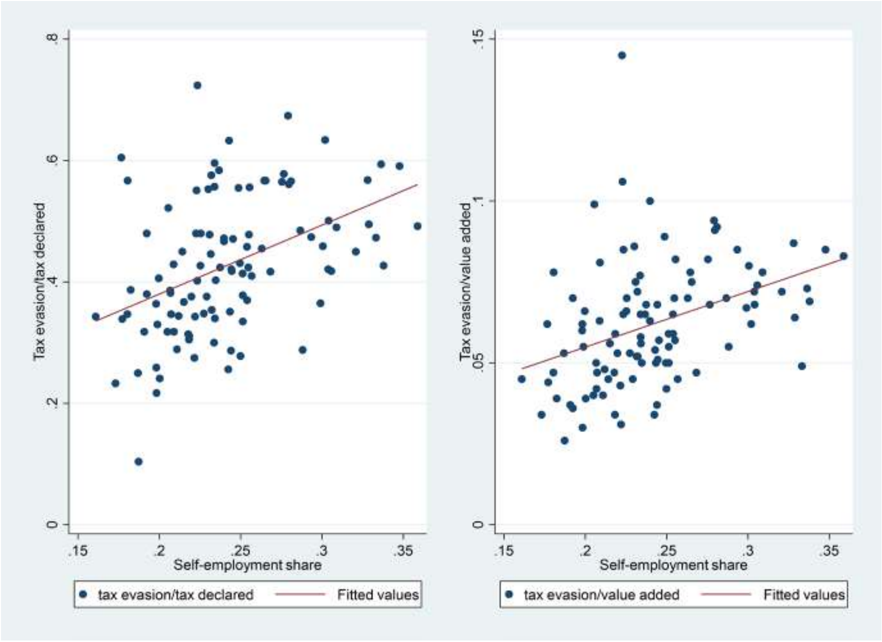
Table 3 – Correlation Matrix of the Variables Significantly Correlated to Tax Evasion (2015)

Variables	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*	*(11)*	*(12)*	*(13)*
(1) Self_empl	1.000												
(2) Tax gap	0.436*	1.000											
(on declared taxes)	(0.034)												
(3) Tax gap	0.386*	0.655*	1.000										
(on value added)	(0.206)	(0.445)											
(4) GDP per capita	-0.369*	-0.834*	-0.599*	1.000									
	(0.000)	(0.000)	(0.000)										
(5) IQI	-0.325*	-0.767*	-0.595*	0.818*	1.000								
	(0.017)	(0.031)	(0.066)	(1654)									
(6) Constructions	0.310*	0.175	0.043	-0.171	-0.108	1.000							
	(0.211)	(0.589)	(0.107)	(35503)	(1.202)								
(7) Retail	0.374*	0.353*	0.273*	-0.400*	-0.465*	0.120	1.000						
	(0.157)	(0.451)	(0.078)	(26551)	(0.848)	(0.072)							
(8) Manufacturing	-0.271*	-0.435*	-0.449*	0.516*	0.635*	-0.118	-0.303*	1.000					
	(0.044)	(0.116)	(0.020)	(6633)	(0.194)	(0.012)	-(0.025)						
(9) Interactive tasks	0.311*	0.546*	0.407*	-0.640*	-0.692*	0.064	0.441*	-0.662*	1.000				
	(0.088)	(0.223)	(0.041)	(12238)	(0.369)	(0.040)	(0.048)	(0.146)					
(10) Routine tasks	0.592*	0.474*	0.341*	-0.398*	-0.410*	0.233*	0.422*	-0.465	0.416*	1.000			
	(0.068)	(0.206)	(0.037)	(12861)	(0.429)	(0.035)	(0.043)	(0.155)	(0.079)				
(11) Analytical tasks	-0.186	-0.390*	-0.151	0.324*	0.154	-0.168	-0.111	-0.095	-0.109	-0.338*	1.000		
	(0.082)	(0.222)	(0.040)	(13367)	(0.467)	(0.356)	(0.047)	(0.174)	(0.086)	(0.090)			
(12) Horizontal skills	0.205*	-0.029	0.007	0.066	0.000	0.032	0.159	-0.010	0.167	0.120	0.399*	1.000	
	(0.091)	(0.272)	(0.045)	(16127)	(0.529)	(0.401)	(0.052)	(0.194)	(0.095)	(0.106)	(0.098)		
(13) Cognitive skills	-0.180	-0.369*	-0.316*	0.407*	0.365*	-0.240*	-0.194*	0.433*	-0.244*	-0.314*	0.455*	0.568*	1.000
	(0.083)	(0.222)	(0.038)	(12997)	(0.436)	(0.352)	(0.047)	(0.158)	(0.083)	(0.091)	(0.086)	(0.071)	
(14) Professionals	0.225*	-0.004	0.078	-0.012	-0.111	-0.062	0.032	-0.166	0.102	-0.040	0.450*	0.351*	0.335*
	(0.250)	(0.004)	(0.118)	(41288)	(1.396)	(0.111)	(0.146)	(0.530)	(0.263)	(0.295)	(0.264)	(0.249)	(0.277)

Note: * shows significance at p<.05. Standard error of the corresponding linear regression in parentheses.

Source: Authors' elaborations

Figure 2 – Correlation Between Tax Evasion and Self-employment Share (2015)



Source: Authors' elaborations

measures of tax evasion. This result is in line with the evidence found by the reviewed literature that addressed this topic.

Looking at the sectoral structure, the highest significant and positive coefficient is the one attached to the weight of the retail sector. The construction sector is also positively correlated with tax evasion but to a smaller extent. A potential reason for the higher coefficient attached to retail is that transactions in this sector are often made in cash, making difficult for tax audits to discover the hidden income. For the construction sector, the positive correlation with tax evasion could be instead caused by the higher diffusion of moonlighting in this industry, with the consequence that it is more probable that employees are more often paid in "envelope wages" (Putnins, Sauka, 2015). On the contrary, the correlation is negative for manufacturing and non-significant for the other tertiary sectors (i.e. excluding retail). This latter result, however, could be misleading due to the absence of a more fine-grained disaggregation in the dataset, which does not autonomously consider specific industries that are more likely to be associated with tax evasion, such as hotel and restaurants. Interestingly, the share of professionals is only positively correlated with one measure of tax evasion (tax evasion/tax declared), and with a lower intensity than the retail and the constructions sectors. This suggests that the role of professionals in explaining the heterogeneity of tax evasion across local systems may be less important than in other countries, such as Greece.

As far as tasks are concerned, two task families are positively correlated with tax evasion: routine and interactive tasks. Routine tasks are easily replicable by applying standardized rules, and they are usually intended to encompass those situations requiring setting of limits, tolerances or standards, i.e. routine cognitive tasks, or moving fingers and manipulating small objects, i.e. routine manual tasks (Autor *et al.*, 2003). Following our analysis of the task items, the occupations that mostly demand these types of tasks are typically low-skilled and include, for instance, the following job titles: "riggers and cable splicers", "power-production plants, boilers, incinerators, water-treatment and related plants operators", and "machinery mechanics and repairers". Interactive tasks, conversely, are typically activities that "create and provide value through complex interpersonal communication such as negotiation, management, and consulting" (Ikenaga, Kambayashi, 2016). According to our proxies, three illustrative occupations with an intensive use of such tasks are: "artisans of textile, wood, leather and hide products, engravers, papier-mâché makers", "painters and sculptors, designers, restorers of cultural heritage, actors, artists, acrobats", and "hairstylists, beauticians, make-up artists, masseurs".

Looking at the skill families, horizontal skills are positively related to tax evasion when the latter is divided by the amount of declared taxes. These skills basically include those competences that are sophisticated relational and socio-emotional (OECD, 2018; Iversen, Soskice, 2019), and are not tied with specific fields of study. They mainly include those organizational abilities that allow the individual to correctly assess and develop information. According to our classification, three exemplary jobs reporting an intensive use of such skills are "small entrepreneurs", "retailers", and "hotel keepers".

6. Cluster Analysis

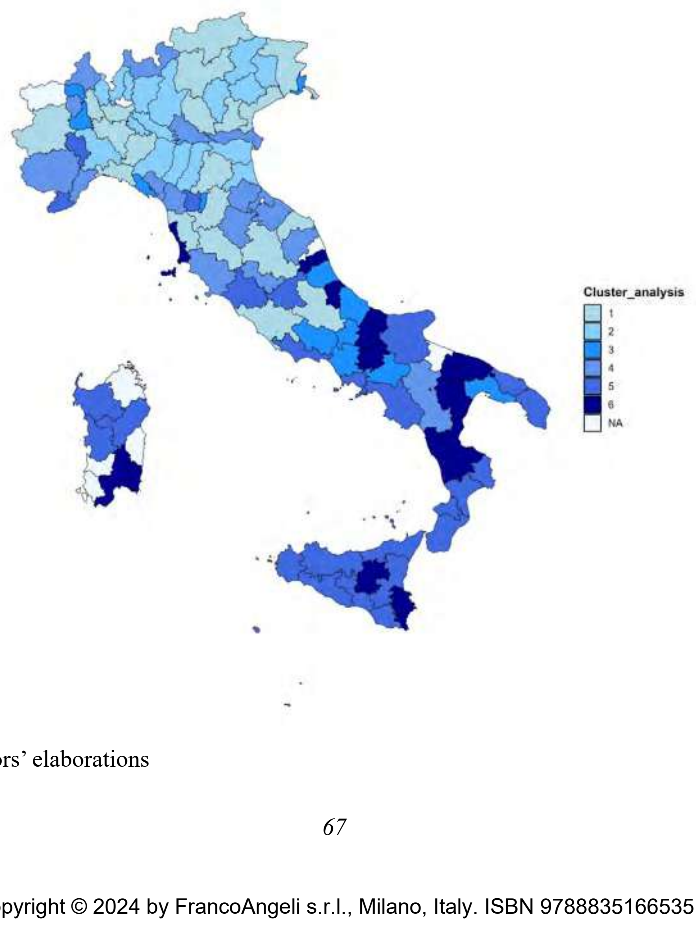
To classify Italian provinces according to a set of variables that include both tax evasion and the territorial features identified through the correlation analysis, we use a two-step cluster analysis. In the first step, we run a PCA on all these variables. Then, we select those components having an eigenvalue higher than one and explaining at least 75% of the variance. Following this criterion, we kept the first five components, as their cumulative explained variance is approximately 76%[2]. The vectors associated with each selected component are thus used

2. Results of the PCA are available upon request.

as variables of a non-hierarchical cluster analysis (Ward's method) in which the number of clusters is determined through a stopping rule based on pseudo-T-squared values (Duda *et al*., 2000). Such analysis leads to the identification of six groups of provinces, whose geographical distribution is represented in Figure 3 (and reported in Table A.1), and whose main features are displayed in Table 4.

Looking at the first two clusters (Clusters 1 and 2), one can primarily notice that they both report lower shares of both tax gap and self-employees than the national average. The main difference between them is that the first one includes the largest urban areas of the North and the Centre, where the share of tertiary activities is relatively large (58.2%), whereas the second one gathers smaller cities located in the northern part of the country and characterized by a vigorous manufacturing specialization. The last two clusters (Clusters 5 and 6), on the contrary, are both characterized by large tax gaps and self-employment shares, their main difference

Figure 3 – Geographical Distribution of the Six Clusters



Source: Authors' elaborations

Table 4 – Clusters' Main Features

	Cluster 1	*Cluster 2*	*Cluster 3*	*Cluster 4*	*Cluster 5*	*Cluster 6*
	Mean	*Mean*	*Mean*	*Mean*	*Mean*	*Mean*
Self-employment	0.219	0.205	0.214	0.274	0.266	0.267
Tax gap (on declared taxes)	0.307	0.354	0.478	0.428	0.541	0.480
Tax gap (on value added)	0.047	0.048	0.066	0.060	0.076	0.082
GDP per capita	32,286	30,047	22,600	2,6035	18,188	20,064
IQI	0.797	0.801	0.557	0.703	0.337	0.455
Tertiary services	0.582	0.448	0.516	0.502	0.555	0.580
Constructions	0.061	0.066	0.070	0.083	0.073	0.062
Retail	0.132	0.135	0.141	0.146	0.171	0.147
Manufacturing	0.194	0.319	0.231	0.225	0.110	0.139
Interactive tasks	0.454	0.444	0.461	0.459	0.522	0.513
Routine tasks	0.532	0.511	0.518	0.555	0.604	0.543
Analytical tasks	0.524	0.494	0.438	0.482	0.461	0.524
Horizontal skills	0.431	0.463	0.370	0.438	0.437	0.463
Cognitive skills	0.457	0.487	0.395	0.436	0.405	0.460
Professionals	0.061	0.048	0.041	0.055	0.052	0.077

Source: Authors' elaborations

lying on the stronger presence of the retail sector of the fifth cluster, along with a lower diffusion of analytical tasks and cognitive skills, as well as a poorer level of institutional quality. These clusters include all the southern provinces, except for Avellino, Caserta and Taranto, and Potenza, with the adding of some provinces of the North and the Centre, namely Livorno, Pescara, Ascoli Piceno, Rieti, Pistoia, Latina, Imperia, Viterbo, and Asti. Interestingly, Clusters 3 and 4 identify those small provinces characterized by a lower correlation between self-employment and tax evasion. Cluster 3 includes 11 provinces heterogeneously distributed across the country that report a relatively high share of tax evasion, despite the relatively low share of self-employed workers. The level of tax evasion in these provinces, therefore, seems to be unreasonably high compared to the rest of the country. Cluster 4 includes 17 provinces and combines, instead, a noticeable share of self-employed worker and a substantial weight of the retail industry with a level of tax evasion (and GDP) that does not exceed the national average. This indicates that in this cluster the level of tax evasion is lower than the one envisaged by its occupational and sectoral structure. Most of these virtuous provinces are small-sized and located in the North and in the Centre, except for Potenza. It is also worth noticing that their institutional quality is remarkably high, being just slightly lower than in the first two clusters.

7. Conclusive Remarks

This chapter identifies those sectors and occupational groups correlated with a higher probability of evading taxes in different local contexts. Once established that the diffusion of self-employment is positively correlated with tax evasion in the Italian provinces, as suggested by the literature, the correlation analysis provides a twofold result. First, it highlights the potential role of the retail industry, and to a lower extent of the construction industry, in nurturing tax evasion. Second, it shows that those provinces characterized by an intensive use of horizontal skills, routine tasks, and interactive tasks are associated with higher levels of tax evasion.

When delving into these tasks and skills, it is possible to link them to the occupational-related objective and subjective reasons of tax evasion suggested by the reviewed literature. In the case of horizontal skills, the higher propensity to evade may arise from both subjective and objective reasons. Indeed, workers in the corresponding occupations are typically small entrepreneurs, theoretically conceivable as risk-neutrals or risk-lovers, who need to assess the costs and revenue of their activities on a daily basis, and therefore could be more capable to compare tax evasion and tax compliance in terms of expected utility. Routine-intensive occupations could be associated with conditions of hard work in terms of time and effort, which in turn may curb the worker's willingness to be tax compliant. Highly interactive occupations, are characterized by idiosyncratic relations between the self-employed worker and her customers, which limits the capabilities of an external agent (such as the Internal Revenue Agency) to identify tax avoiders through reliable predictions. In particular, it could be difficult for the tax auditors to distinguish those workers that hide part of their income through presumed income initiatives. These insights represent our main contribution to the literature. Previous research, indeed, only analysed the relationship between self-employment and tax evasion without digging into specific occupational groups. By looking at different occupations and isolating the underlying skills and tasks, our paper offers original insights into self-employees attitudes towards tax evasion relying on the assumption that such attitude could change according to the type of tasks and skills mostly used in the job post.

Our correlation analysis, obviously, does not allow us to interpret this relationship as causal. It does not take into account any potential confounding factor either observable or unobservable. Moreover, at NUTS-3 level, i.e. our unit of observation, the share of self-employees can be influenced by sources of spatial heterogeneity that can also explain the individual attitudes towards taxation. This limitation couples with the short time span of the analysis, which is caused by the unavailability of the information about the working province for more than two years of observations (2014 and 2015). Future research could therefore access dataset that include such observation for a longer period and try to get a causal interpretation of the results through appropriate econometric techniques. Finally, our analysis cannot be repeated at worker level to provide a more robust empirical microfoundation of the results. Such limitation stems from the impossibility for the Italian Revenue Agency to release individual data on tax evasion for privacy protection.

The cluster analysis then offers some useful insight to identify a set of local features that could be viewed as drivers of tax evasion or tax compliance, and thus that should be taken into account in the design of place-based tax policies and audits. First of all, it identifies two groups of provinces reliant on self-employment and on sectors and occupations that are more vulnerable to tax evasion, such as retail and constructions, on the one hand, and interactive and routine occupations, on the other hand. These provinces are mainly situated in southern Italy, but they also include a bundle of small provinces located in north-western and central Italy, in particular in Lazio. In these areas, the enhancement of institutional quality, along with the implementation of educational and training program aimed at developing cognitive skills, could be viewed as initiatives potentially capable to reduce tax evasion tendencies at local level.

Finally, the results of the cluster analysis allow us to isolate a group of small provinces, mainly located in the Centre (excluding Lazio) with relatively low tax evasion rates, despite their occupational and sectoral structure would suggest the opposite. A thorough examination of the geographical, demographic and socio-economic characteristics of these clusters could be a preliminary valuable step to create an environment conducive to compliance in the other provinces and to help to reduce the overall tax evasion at country level. On the contrary, the other two "virtuous" clusters, mainly constituted by large urban areas of northern and central Italy and manufacturing specialized provinces of the North-East, do not seem to represent a useful benchmark for the rest of the country, despite their low levels of tax evasion, due to their very dissimilar industrial and occupational structure from the rest of the country.

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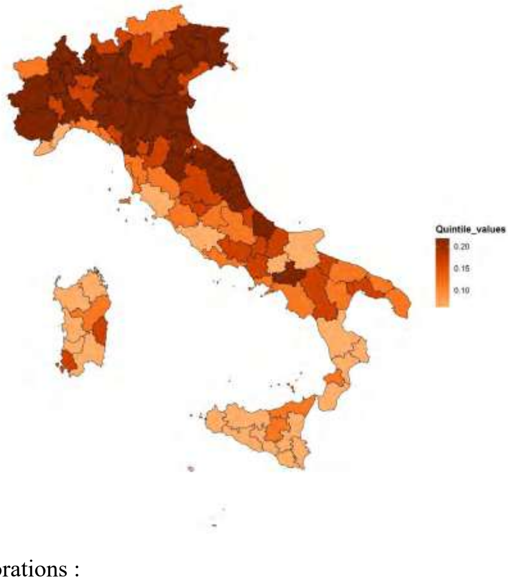
Sommario

Lavoro autonomo ed evasione fiscale: un'analisi descrittiva delle province italiane

Questo capitolo analizza la relazione tra evasione fiscale e la quota di lavoro autonomo nelle province italiane (NUTS-3). Utilizzando dati provenienti dall'Agenzia delle Entrate e dall'Indagine sulle Forze di Lavoro italiane per il periodo 2014-2015, l'analisi empirica riguarda in particolare: 1) la correlazione tra quota di lavoro autonomo nei mercati del lavoro regionali ed evasione fiscale; 2) la correlazione tra struttura settoriale del lavoro autonomo ed evasione fiscale; 3) la correlazione tra i profili occupazionali, basati sulle competenze e sulle famiglie di mansioni, e l'evasione fiscale. Un'analisi cluster a due stadi individua inoltre sei gruppi di sistemi locali tra loro omogenei rispetto alle variabili correlate al tasso di evasione. I risultati dello studio consentono di determinare specifici settori e occupazioni cui i policy maker dovrebbero prestare particolare attenzione nelle loro attività di controllo tributario a livello locale.

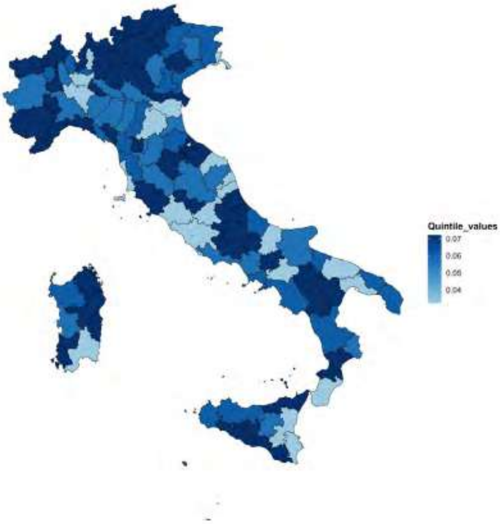
Appendix

Figure A.1 – Share of Workers in the Manufacturing Sector by Province (2015)



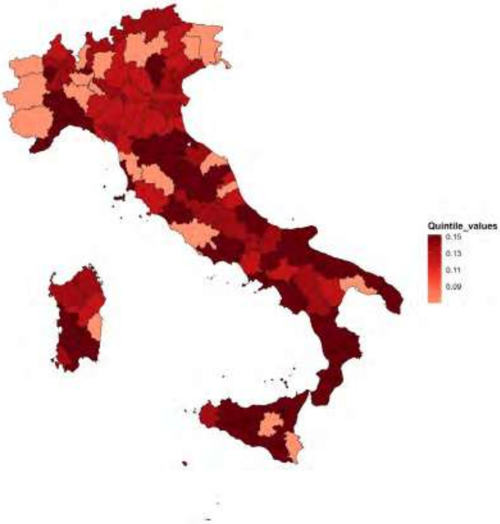
Source: Authors' elaborations :

Figure A.2 – Share of Workers in the Construction Sector by Province (2015)



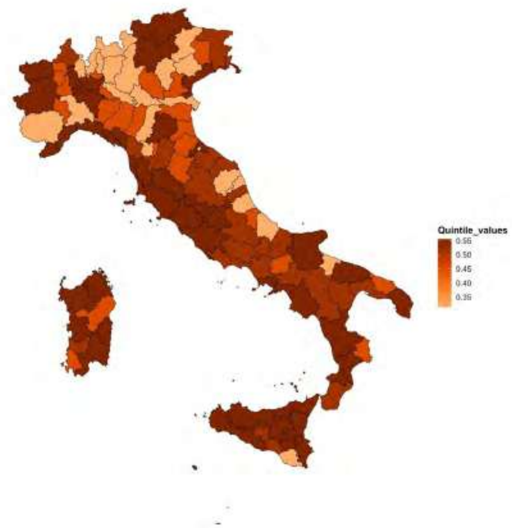
Source: Authors' elaborations

Figure A.3– Share of workers in the retail sector by Province (2015)



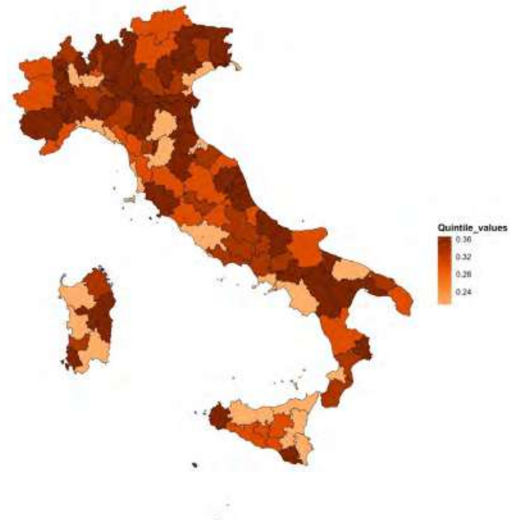
Source: Authors' elaborations

Figure A.4 – Share of Workers in the Tertiary Sector (Excluding Retail) by Province (2015)



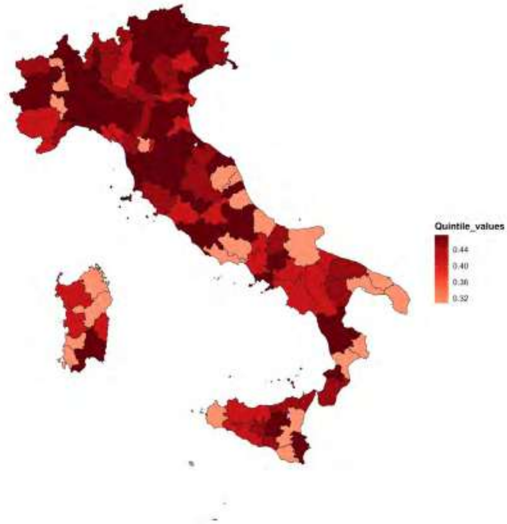
Source: Authors' elaborations

Figure A.5 – Share of Workers in Occupations Characterized by an Intensive Use of Cognitive Skills by Province (2015)



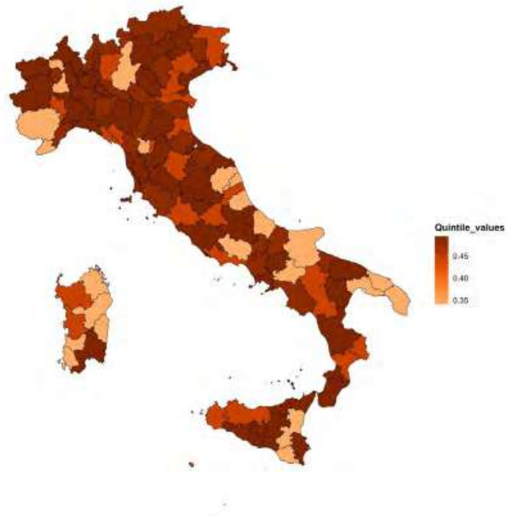
Source: Authors' elaborations

Figure A.6 – Share of Workers in Occupations Characterized by an Intensive Use of Horizontal Skills by Province (2015)



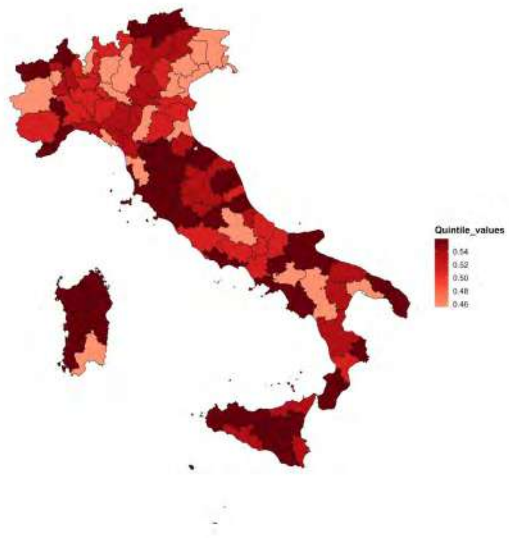
Source: Authors’ elaborations

Figure A.7 – Share of Workers in Occupations Characterized by an Intensive Use of Analytical Tasks by Province (2015)



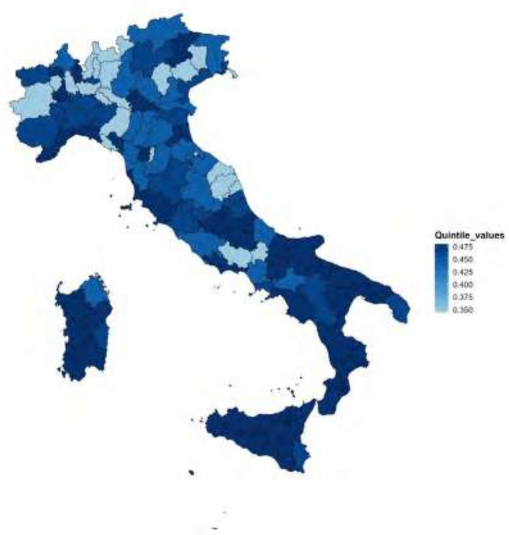
Source: Authors’ elaborations

Figure A.8 – Share of Workers in Occupations Characterized by an Intensive Use of Routine Tasks by Province (2015)



Source: Authors' elaborations

Figure A.9 – Share of Workers in Occupations Characterized by an Intensive Use of Interactive Tasks by Province (2015)



Source: Authors' elaborations

Table A.1 – Clusters Composition

Cluster1	*Cluster 2*	*Cluster 3*	*Cluster 4*	*Cluster 5*	*Cluster 6*
Ancona	Alessandria	Avellino	Arezzo	Agrigento	Ascoli Piceno
Bologna	Belluno	Caserta	Biella	Asti	Bari
Bolzano	Bergamo	Chieti	Cuneo	Brindisi	Benevento
Firenze	Brescia	Frosinone	Forlì-Cesena	Catania	Cagliari
Genova	Como	Gorizia	Grosseto	Catanzaro	Caltanissetta
L'Aquila	Cremona	Isernia	Lucca	Crotone	Campobasso
Milano	Ferrara	La Spezia	Macerata	Foggia	Cosenza
Novara	Lecco	Prato	Mantova	Imperia	Enna
Padova	Lodi	Taranto	Massa-Carrara	Latina	Livorno
Pavia	Modena	Teramo	Pesaro e Urbi-	Lecce	Pescara
Perugia	Parma	Vercelli	no Potenza	Matera	Siracusa
Piacenza	Pordenone		Rimini	Messina	
Pisa	Ravenna		Rovigo	Napoli	
Roma	Reggio Emilia		Savona	Nuoro	
Siena	Treviso		Sondrio	Oristano	
Trento	Varese		Terni	Palermo	
Trieste	Vicenza		Verbanio-Cu-	Pistoia	
Udine			sio-Ossola	Ragusa	
Venezia				Reggio	
Verona				Calabria	
				Rieti	
				Salerno	
				Sassari	
				Trapani	
				Vibo Valentia	
				Viterbo	
20	17	11	17	25	11

Source: Authors' elaborations

Occupational Safety and Health, Society and Research: A Bibliometric Exploration of National Cases

*Ugo Finardi**

Abstract

Aim of the present work is the evaluation of the influence of factors, external to research, on the scientific production in a specific field, that of Occupational Safety and Health. To this end the work performs the bibliometric analysis of a database of scientific publications, in order to highlight specific cases relative to research areas particularly represented at national level in different Countries. Three cases are highlighted and analyzed, showing how not-research bodies can somehow orient scientific publication in the field at national level. Each case study presents specific features, that are interpreted.

1. Introduction

The study of the relationship between scientific research and society is a relevant research topic, particularly important for those socially relevant fields which, due to their nature, might be more influenced by issues deriving from the society. Among these ones an important place is that occupied by the research field related to Occupational Safety and Health (OSH from now on). This research area is extremely important due to the social relevance of health and safety of workers.

Thus, OSH seem an ideal subject when one tries to perform a study dealing with the analysis of the effects on research deriving from society: entities, bodies or organizations, or specific issues external to research and in some way orienting research efforts in terms of topics or research questions. More in specific, this work tries to explore the following research question: "Is it possible to highlight and understand the presence and nature of effects, generated within bodies or organizations, or by issues, external to research activities, which in some way orient and direct research in terms of scientific production?". In order to respond to this question, the present work exploits a bibliometric analysis of OSH scientific literature,

* CNR-IRCrES, National Research Council of Italy, Research Institute on Sustainable Economic Growth, Torino, Italy, e-mail: ugo.finardi@ircres.cnr.it.

trying to outline specific cases in which these effects are particularly evident. Studying the features of one of the main research outputs, publications, is a viable method to understand the phenomena that are at play in this specific case. More in detail, in order to respond to the research question this work performs the analysis of some case studies, outlined through a bibliometric methodology.

The highlighted case studies show that the presence, in the studied Countries, of public or private bodies (not strictly devoted to research activities) seem to have an influence in fostering research towards specific subfields. They do so mainly through the publication of research journals that publish scientific works written by both researchers and practitioners.

This work is organized as follows. Section 2 presents a theoretical framework, describing the nature of OSH and of bibliometric, and a literature overview of works dealing with the relations existing between society and scientific research. Section 3 presents the dataset and the methodology. Section 4 shows some general results, while section 5 presents the specific results related to the case studies outlined through the bibliometric methodology described in section 3. Eventually, section 6 presents the results and the conclusions.

2. Theoretical Framework and Literature Overview

This section presents a theoretical introduction to the main topics tackled by the present research effort. A first subsection performs a synthetic description of the nature of bibliometrics, in order to frame the methodology of the paper. A second subsection deals with an assessment of the social relevance of Occupational Safety and Health. Finally, a third subsection resumes the main literature dealing with the relationship between societal issues and scientific research.

2.1. The Nature of Bibliometrics

From the methodological point of view, in order to respond to the main above-described research question, this work exploits a bibliometric analysis of OSH scientific literature. Bibliometrics is the field of research that exploits statistical analysis of data intrinsically relative to scientific publications in order to measure scientific activities through one of its main outputs, scientific publications (Garfield, 1955; de Solla Price, 1976; De Bellis, 2014).

Bibliometric studies may be rather varied in their target. In fact, they can be based on data related to many different features of scientific literature: e.g., authors, their countries and affiliations, the content and topic of scientific works. Another relevant set of features is that related to the use of a research work by part of scientific community. This is generally measured through citations. Thus, while received citations measure how much a work is used by other researchers in the time following its publication, given citations measure the nature of previous knowledge used by the authors of the work in object. Finally, a large fraction of bibliometric studies is conducted through the analysis of the links existing between research works. These links can be measured through the combined use of the above cited determinants through measures such as co-authorships or co-citations.

In order to obtain data for bibliometric analyses several specific databases are available. The most relevant ones are Google Scholar® (a free access database, owned by Google, Inc.®), Scopus® (a pay-per-use database, owned by Elsevier®) and the Web of Science® (also a pay-per-use database, owned by Clarivate Plc®).

Thus, a bibliometric study is able, under a general point of view, to offer a picture of the status quo of scientific research performed in research institutions or firms, Countries, research fields (whatever the meaning of the term), and to measure the evolution of such magnitudes through the analysis of data relative to different timings.

2.2. The Social Relevance of OSH

Occupational Safety and Health is, according to the ILO – International Labour Office "identified as the discipline dealing with the prevention of work-related injuries and diseases as well as the protection and promotion of the health of workers"[1]. According to the same document two further relevant points must be highlighted. The first one is its aim, which is the improvement of the environment where work is undertaken, as well as its conditions. The second one, and possibly the most relevant in the context of this work, is the fact that the contribution to safety, health, hygiene of the working environment comes from many different professions, such as MDs and nurses, as well as engineers or other technical specializations.

Research on OSH has a rather long historical path. For instance, the effects of the US OSH Act were under the spotlight since the 1970s. Viscusi (1979) showed the effect of penalties on firms' investments, and the fact that enforcement policies had – at that time – no direct impact on workplace hazards.

A more recent and comprehensive work is the book of Alli (2008), published by the International Labour Organization. In this book OSH is defined as "the science of the anticipation, recognition, evaluation and control of hazards arising in or from the workplace that could impair the health and well-being of workers" (p. vii).

Summing up, this short description shows in few words the social relevance of OSH, and thus of the scientific research that deals with the many different topics it encompasses.

1. Technical and ethical guidelines for workers' health surveillance, ILO-International, 1998. See: https://www.ilo.org/wcmsp5/groups/public/@ed_protect/@protrav/@safework/documents/normativeinstrument/wcms_177384.pdf.

2.3. Literature Overview

This section explores a set of publications dealing with the topic of the relationship existing between social issues, by one side, and research activities and their outcomes, by the other side. It must be noted, in principle, that the specific topic of how and how much research is conditioned and shaped by external issues is not so widely studied to the best of my knowledge. The largest part of this literature body studies the effects of science- and research-related policies on scientific production.

The analysis of data relative to two large research institutes, performed by Bonaccorsi and Daraio (2005) shows that there is no support for the hypothesis of size effects, as well as no strong support for effects of agglomeration. Hence, results show no strong support for policies aimed at creating agglomeration and "critical mass".

A slightly different case is studied in an empirical work on Peruvian universities by Millones-Gómez *et al*. (2021). More in specific, the work studies the effects on scientific production of research policies. The analysis indicates that, while research policies do not influence scientific production, other determinants – such as the type of management – had an influence on it.

Other results on funding effects have been devised from the analysis of UK's Performance-Based Funding System. The analysis of the Research Excellence Framework (REF) performed by Banal-Estañol *et al*. (2023) shows a significant and positive impact on produced research, both on the quality and on the quantity sides. Nevertheless, no effect is shown in the measures per author. This suggests that productivity has not been influenced. On the other side, some literature explores the effects on society of scientific research. More in specific, a certain number of articles deals with the topics of "responsible research and innovation" (RRI). A comprehensive evaluation of RRI is performed by Wiarda *et al*. (2021) who substantially resume past literature and try to highlight the knowledge accumulation in the field. The result of the analysis shows the convergence between the fields of RRI and of Responsible Innovation. Other works deal for instance with the possible instruments to be used in order to raise awareness of scientists towards RRI practices (Lukovics *et al*., 2019) or with the relations between digital technologies and entrepreneurs' awareness of RRI practices (Fellnhofer, 2022).

3. Data and Methodology

From the experimental point of view, the present work is based on a dataset extracted from the Web of Science® online database in April – July 2023. The database was obtained in different steps through the following methodology:

1. The first step has been searching in "Topic" (Title, abstract, keywords) for the exact phrase "Occupational Safety and Health" (TS = "occupational safety and health").
2. Subsequently, as it was noticed that many works refer to "Occupational Safety and Health Agency" or "OSHA", a refined query was performed: TS = (("occupational safety and health") NOT ((OSHA) OR ("occupational safety and health agency")))
3. Then, a subsequent scan of the scientific literature did show that many scientific works entail the use of the term "Occupational Health and Safety" rather than "Occupational Safety and Health", so a further query was performed (TS = "occupational health and safety").
4. The final dataset thus resulted from the merging of the two sets obtained with the queries at point 2 and at point 3, followed by the elimination of duplicates.

This dataset contains a total of 9,984 scientific works (journal articles, book chapters, congress papers etc.). The bibliometric analysis performed in the present work is based on this dataset.

A further refinement was needed in order to perform country-specific analyses. To this end, the "refine" instrument of Web of Science was exploited flagging specific countries after performing the main queries and then downloading and subsequently merging country-specific datasets.

A first important point to note about this database is its dimension. The total number of scientific works that is encompasses is not very large. While almost 10 thousand works might seem a relevant number at a first sight, we must note that this dataset encompasses the whole world's scientific production across more than fifty years. This means that, if we compare these figures with those relative to other research fields, numbers are low. Moreover, as the following of the paper will show, disaggregating the database according to different countries and topics makes in most cases difficult to perform a meaningful analysis, due to a too low number of data points.

The first methodological step performed in the present paper is an analysis of the obtained database, performed exploiting some classic, bibliometric instruments. These substantially entail counting specific features of the scientific works encompassed by the database. In specific, counting has been performed on Web of Science Subject Categories of the scientific works. Subject Categories (SC from now on) are a specific system of classification of the Web of Science. Each one of the 254 SCs encompasses journals according to their aim and scope, and to their content. Each SC has a specific descriptive title (e.g., "*Chemistry, Physical*", "*Management*" or "*History & Philosophy* of *Science*"). Journals may belong to more than one SC, according to their level of inter/trans disciplinarity. The first subject category assigned to a journal is the one better describing its content, aim and scope. SC are further grouped into 21 Groups (going from "*Agricultural sciences*" to "*Visual & Performing Arts*") and belong either to Science Citation Index (STEM sciences) or Social Science Citation Index (SSH sciences).

As the nature of the journals encompassed in a SC is rather specific, SC are often used in bibliometric analyses as describing the scientific field of encompassed journals (Abramo *et al.*, 2022; Finardi, Lamberti, 2021). This feature has been exploited in the present paper in order to investigate if and when research in OSH is performed within specific scientific fields in different Countries. An alternative, and possibly more fine-grained method of analysis could be counting articles' keywords. Nevertheless, in the present case keywords are too many, and each one of them counts relatively few occurrences. This makes impossible to use them for a specific analysis of research fields.

From the practical point of view the methodology of analysis entails first of all counting the occurrences of the different subject categories at country level. More in specific, what has been considered is the prevalence – in terms of percent fraction – of a SC at national level, and the prevalence of a country in a SC at world level.

In other words, the first part of the main analysis of this work has been understanding whether one (or more) specific research fields (represented by a SC) are more present than other ones – at country level – in the OSH-related literature, as well as the evolution across time of the SC. To this end the database has been split into six time periods: prior to 1999, 2000-2004, 2005-2009, 2010-2014, 2015-2019, 2020-2023. This has been done in order to follow the time evolution of the dataset, and at the same time smoothing data fluctuation and building a manageable dataset.

Summing up, the first step of the analysis entailed calculating:

- the fraction of the different SCs at national level over the total scientific production of the country.
- the fraction of a country's production in a specific SC over the world scientific production in the SC.

Both analyses have been performed on the complete database and on the six time periods.

This method allows to highlight specific cases of SC (research fields) that are particularly pursued at national level in the research in OSH. Once highlighted some cases, they were considered and analysed more specifically, trying to understand the reasons of the prevalence of the SC at national level, that is, why a country's research in OSH is performed prominently in this specific field.

In this way, the prevalence of a SC (research field) over the other ones in a county, as well as the specific features of the scientific production encompassed in the SC, helps to identify the effects of country-specific social issues on the modalities research in OSH is performed. Besides prevalence also absolute values have been considered, as SCs presenting only a substantial number of occurrences at national level have been taken in account.

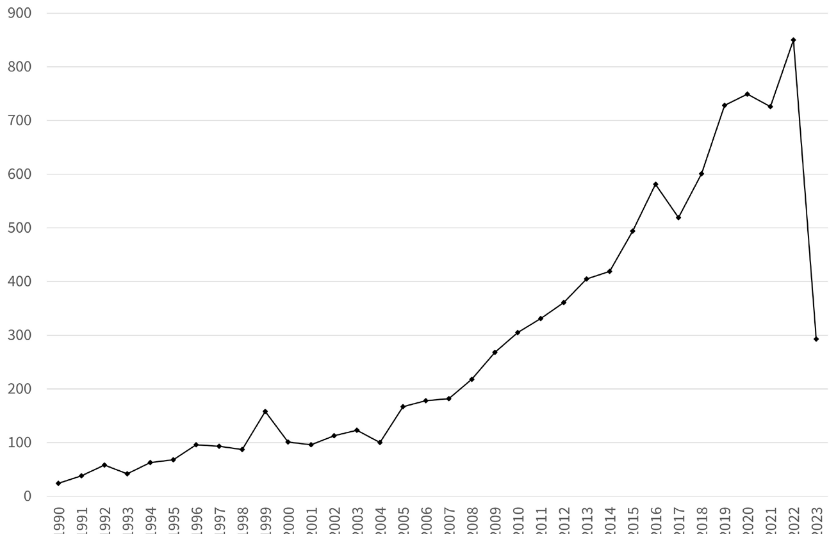
4. General Results

This section presents some general results of the analysis of the complete database, as well as of the different time periods. Such results are introductive to the more specific analysis performed in the following section.

Figure 1 and table 1 present the figures relative to the evolution of the total scientific production in OSH per year from 1990 onwards. It is easily seen that the scientific production in the field grows steadily across time, with a slight change of pace at the mid of the years 2000s.

Given this constant growth, it would be interesting to understand whether the scientific production in this specific field outperforms the total scientific production at world level in all fields or if, on the contrary, it grows less steadily or more slowly. Figure 2 presents the comparison of the two trends. The dotted line (left hand side scale) shows the total number of publications per year in the Web of Science database, whereas the continuous line (right hand side scale) shows the

Figure 1 – Evolution of the Total OSH Scientific Production Across Time



Source: author's elaborations of data extracted from Web of Science®

Table 1 – Evolution of the Total OSH Scientific Production Across Time

Year	*Publications*	*Year*	*Publications*
1990	24	2007	182
1991	38	2008	218
1992	58	2009	268
1993	42	2010	305
1994	63	2011	331
1995	68	2012	361
1996	96	2013	405
1997	93	2014	419
1998	87	2015	494
1999	158	2016	581
2000	101	2017	519
2001	96	2018	601
2002	113	2019	728
2003	123	2020	749
2004	100	2021	726
2005	167	2022	850
2006	178	2023	293

Source: author's elaborations of data extracted from Web of Science®

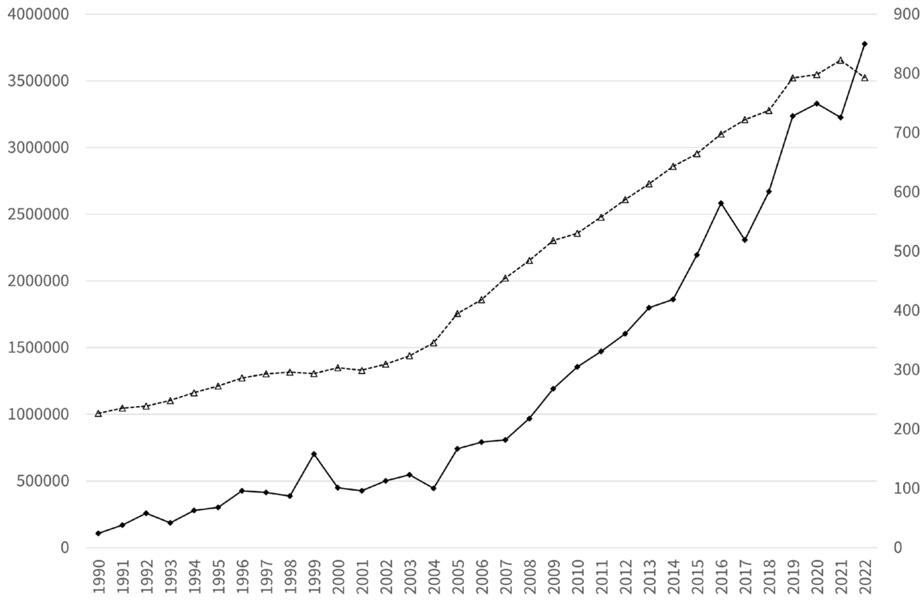
total number of OSH publications. The figure shows that in both cases a change of pace is present at mid-2000s, but that OSH production grows slightly faster than the total. This fact tells us that the research interest of scientists towards OSH could have grown in the last decades.

An important point to consider is the prevalence in the database of specific elements of the main units of analysis: Countries and SCs.

Data show a prevalence of OSH scientific production in works published in the US (2938 publications, 29.4 % of the total) and in the WoS SC "*Public, Environmental & Occupational Health*" (3,015 publications, 30,2 % of the total).

Nevertheless, besides these two main sets of scientific works, the rest of the dataset encompasses a large number of Countries and SCs presenting a lower number of publications each. Thus, in order to highlight case studies, it was chosen to consider only the most represented Countries and SCs in order to obtain operability and to analyse only meaningful data, as it would have been nonsensical to study countries which published very few scientific works. In specific the considered Countries and SCs are:

Figure 2 – Evolution of the Total OSH Scientific Production Compared with the Total WoS Database



Source: author's elaborations of data extracted from Web of Science®

- Subject Categories with more than 50 publications (about 0,5 % of the total). These SC represent 8,119 publications (81.3 % of the total).
- Countries with more than 200 publications (about 2 % of the total). These Countries represent 7,357 publications (73.7 % of the total).

After the selection specific queries have been performed on WoS for each considered country. Summing up, the analysis was performed on:

- 30 subject categories.
- 11 Countries.

The crossing of the two sets renders a total of 5,893 publications (59.0 % of the total database). It is important to note that specific queries have been performed for each country in the dataset. Tables 2 and 3 show respectively the numbers of scientific works for each country and subject category.

Another relevant point to consider for a general analysis of the database is that on international collaboration. The instrument used in order to perform this analysis has been the VOSViewer software for bibliometric analysis (van Eck, Waltman, 2010). The results of the analysis are rendered graphically in figure 3. Nodes represent countries, while edges are collaboration in terms of scientific

Table 2 – Scientific Works for the Most Represented Countries

Country	*Occurrences*
USA	2938
Australia	757
Canada	752
Germany	581
England	415
PRC	376
Italy	364
Turkey	322
South Korea	322
Spain	274
Malaysia	239

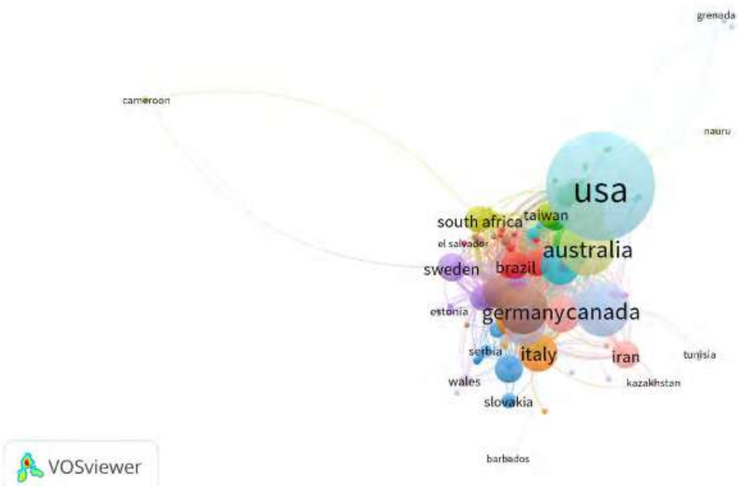
Source: author's elaborations of data extracted from Web of Science®

Table 3 – Scientific Works for the 15 Most Represented Subject Categories

Subject Category	*Occurrences*
Public, Environmental & Occupational Health	3015
Environmental Sciences	932
Engineering, Industrial	690
Ergonomics	362
Engineering, Environmental	218
Industrial Relations & Labor	211
Nursing	206
Engineering, Multidisciplinary	201
Management	186
Business	185
Medicine, General & Internal	152
Construction & Building Technology	151
Health Care Sciences & Services	149
Green & Sustainable Science & Technology	136
Education & Educational Research	125

Source: author's elaborations of data extracted from Web of Science®

Figure 3 – Pattern of International Collaboration in OSH



Source: data extracted from Web of Science® and elaborated by the author with the use of VOSViewer software

works coauthored between authors of two countries. The figure shows that the pattern of collaborations is rather wide and intertwined, but the numbers are low.

Finally, the last analysis performed on the dataset is relative to the evolution of the number of scientific works for the most represented countries. The results are presented in figure 4. Figures are the average for each 5-year period for each country. Results show a generalized growth across time for all countries but the US. Nevertheless, the patterns of growth are different across countries.

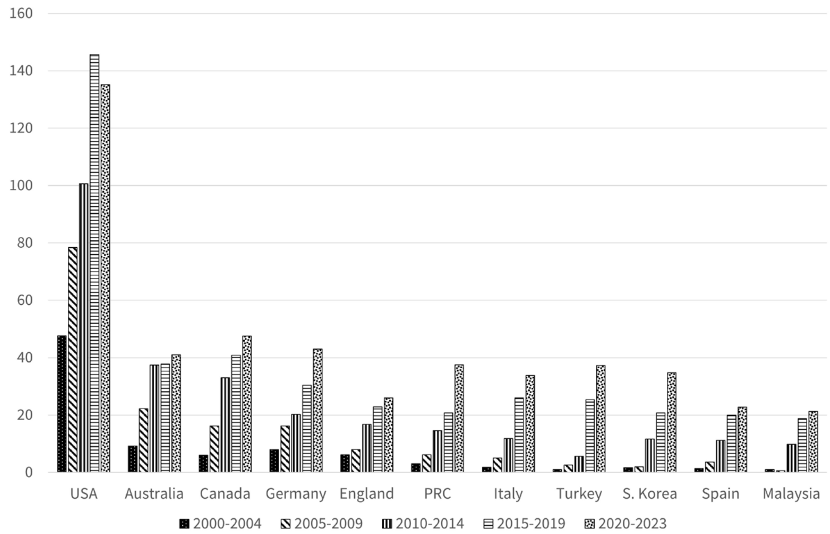
5. Case Study Analysis

This section presents the core analysis of the paper. Three case studies have been selected exploiting the methodology described in section 3. Then, once identified the cases of SCs with a relevant prevalence at country level, each of them has been studied in depth, mainly exploiting a further bibliometric analysis. In this way it has been possible to identify factors external to research and to find evidence of the causes of this high fraction of scientific works in a specific field.

5.1. "Nursing" in USA

The subject category "*Nursing*" counts in the US 150 of the total 206 works published worldwide in this SC. This accounts for about 72.8 % of the total global production. Moreover, the largest part of the publications (99, two thirds of the total) was published in the time period 2015-2019. Thus, one might ask

Figure 4 – Evolution of the Production of the Most Represented Countries



Source: author's elaborations of data extracted from Web of Science®

the reasons of the high prevalence of scientific production in this SC in a specific country, and which factors drive the interest of US researchers towards it.

The first step in the analysis of this case study has been looking at the sources (in terms of journals and/or books publishing the scientific works). This simple analysis renders the results presented in table 4.

Results shows that the largest part of the US "Nursing" articles (118 on 150, 79 % of the total) were published on the journal "*Workplace Health & Safety*" (Sage Pub.)[2]. "*Workplace Health & Safety*", a scientific peer-reviewed journal, is the official publication of the American Association of Occupational Health Nursing, Inc. (AAOHN), the professional association of licensed nurses engaged in the practice of occupation and environmental health nursing[3].

A further step in the analysis, going deeper in the specific dataset of US "*Nursing*" production, has been a keywords analysis. Results are presented in table 5. This analysis shows that the most targeted keywords in the US scientific production in "Nursing" are aligned with the institutional aims of AAOHN. Thus, it is feasible that the strong presence of the Association's journal influences research in the field.

Finally, a further analysis has been conducted on the affiliations of the articles' authors. Table 6 shows the breakdown of the most present affiliations. Data show that a large number of articles (about 35%) is authored or co-authored

2. https://journals.sagepub.com/description/WHS, link visited February 2024.
3. https://www.aaohn.org/About/About-AAOHN, link visited February 2024.

Table 4 – Journals Publishing "Nursing" Articles in the US

Source	*Total*	*2015-2019*
Workplace Health & Safety	118	90
Orthopaedic Nursing	7	0
Journal of Infusion Nursing	4	3
International Journal of Nursing Studies	3	1
Sage Open Nursing	3	3

Source: author's elaborations of data extracted from Web of Science®

Table 5 – Keywords Analysis for the US "Nursing" Scientific Production

Keywords	*Total*	*2015-2019*
Occupational health and safety programs	80	73
Health coaching/education/literacy/promotion	69	66
Disease prevention	31	29
Occupational hazard(s)	29	25
Workforce	23	21
Occupational health and safety team	20	20
Occupational injuries	18	17
Best practices	13	13
Government regulation	13	13
Program planning and evaluation	13	13
Mental health	13	11
Chronic diseases/illnesses	12	10
Global occupational health	11	10
Safety	11	11

Source: author's elaborations of data extracted from Web of Science®

by researchers working in three state Universities: Alabama, North Carolina and Florida. It is interesting to note that the three Universities host three of the NIOSH (National Institute for Occupational Safety and Health)-financed "Education and Research Centres"[4]. Thus, it is possible that the presence of a federal body devoted to OSH and financing specific education and research activities orients in some way the geographical distribution of research activities towards specific regions (US state university system in this case).

4. See https://www.cdc.gov/niosh/oep/ercportfolio.html, link visited February 2024.

Table 6 – Affiliation Analysis for the US "Nursing" scientific production

US State/Affiliation	*2015-2019*
Alabama	*40*
University of Alabama System	
University of Alabama Birmingham	
University of Alabama Huntsville	
North Carolina	*28*
University of North Carolina	
University of North Carolina Chapel Hill	
University of North Carolina School of Medicine	
Florida	*24*
State University System of Florida	
University of South Florida	
University of Central Florida	
University of Florida	
Total: 92 out of 264 (35 %)	

Source: author's elaborations of data extracted from Web of Science®

Summing up, this case study tells us that, feasibly, the presence in the US of a National Professional Association of professionals (Nurses), AAOHN, engaged in the specific field of occupational and environmental nursing and engaged in specific research activities has an effect in incrementing OSH research in "Nursing" at Country level. The fact that AAOHN publishes an official journal which is listed in WoS is the factual instrument that might allow this influence. A further influence could be due to the presence of NIOSH, that might foster research activities at regional (state) level.

5.2. "Engineering, Environmental" in Germany

A second, relevant case is based in Europe, more in specific in Germany. This country presents a high prevalence of the SC "Engineering, Environmental" in terms of OSH scientific production. In fact, more than 56% of the publications in this SC for OSH/OHS at world level has been authored/coauthored by German authors. Moreover, "Engineering, Environmental" represents more than 21 % of the Country's scientific production in the field. Finally, it must be noted that scientific production (in fraction) in Germany in this SC in OSH remains constant across time. One might again ask the reasons of such prevalence of this SC, trying to understand what drives the scientific production in OSH towards this specific field.

The bibliometric analysis of this specific dataset highlighted the following features. First, a large part of the scientific works in this SC (113 out of 124 works) have been published in the journal "Gefahrstoffe Reinhaltung der Luft" (Hazardous Substances – Keeping the Air Clean). This journal is published by the Institute for Occupational Safety and Health of the German Social Accident Insurance (*Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung*)[5].

A keyword analysis is not possible in this case, as Web of Science does not list the keywords for this journal. Nevertheless, the analysis of the authors' affiliations renders the following results:

- In the 124 scientific works encompassed in this SC for Germany, a total of 224 affiliations is present. This means that, in average, each article is authored by authors working on a little less than two bodies (average is 1.8 affiliations per work).
- Out of those affiliations, 55 (24.5 %) are relative to the "Institute for Occupational Safety and Health of the German Social Accident Insurance" – IFA: this is the public body that publishes "Gefahrstoffe Reinhaltung der Luft".
- 45 (20,1 %) of the affiliations are instead relative to the "*Berufsgenossenschaft*". These are professional associations, in charge of the Statutory Accident Insurance for the German private sector firms and their workers[6].
- 18 (8.0 %) of the affiliations are relative to the "*Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, BAuA*", the Federal Institute of Occupational Safety and Health[7]. More in specific, this institution is a German federal agency (controlled by the Ministry of Labour and Social Affairs) working at the intersection between practice, policymaking and research.
- Finally, also academics are represented in this specific SC in OSH in Germany, though their presence is largely a minority. In fact, only 20 affiliations (8,9 %) are relative to Universities/University institutes, either in Germany (14 affiliations) or abroad (6 affiliations).

These results show the presence of external effects, mainly deriving from organizations dealing with OSH, on the scientific production in the "Engineering, Environmental" SC in Germany in OSH. In specific the main topics highlighted by results are:

- Research in OSH in Germany, in the specific field of Environmental engineering (the most relevant at country level) is mainly originated outside academia, as witnessed by scientific production.

5. See https://www.dguv.de/ifa/index-2.jsp, link visited February 2024).
6. See https://www.dguv.de/en/bg-uk-lv/index.jsp and https://www.dguv.de/en/bg-uk-lv/bgen/index.jsp, links visited February 2024.
7. https://www.baua.de/EN/Home/Home_node.html, link visited February 2024.

- In detail, most part of scientific production is originated by institutions that take care of the aspects of OSH under the professional or practical point of view, or perform research strictly connected to, and shaped by, policies and practices.
- The presence of a WoS journal published by a national body dealing with OSH could incentivize research in this specific field by practitioners-researchers aiming at publishing.
- The limits of the database do not allow at this stage to infer more deeply on the specific topics of the research.

This case study shows, again, the presence of effects external to research on scientific production. In specific, it could be possible that the scientific production is oriented towards a specific field through the presence of public bodies (in charge of OSH policies) that foster research towards fields of their interest. In doing so, they exploit both the publication of specific research journals and the interest of personnel aiming at publishing research works. Conversely, results also show that, in a practice-oriented, socially relevant research field, connections between practice and research are very strict.

5.3. "Public, Environmental & Occupational Health" in South Korea

The WoS SC "Public, Environmental & Occupational Health" is the most relevant at world level in terms of number of publications and of fraction of the total OSH production. Nevertheless, the specific case of South Korea must be highlighted. In fact, this SC is particularly represented in South Korean OSH scientific production. 211 OSH South Korean works over 322 (65,5 % of the total national production) are in this SC; moreover, numbers grow constantly across time. Also in this case these numbers stimulate researcher's curiosity to understand why they are so high. The analysis of South Korean scientific production in this specific SC shows the following features:

- This case shows again that most part of the scientific production comes from a specific journal, "Safety and health at work" (Elsevier), with more than 75% of the total publications in the SC (160 over 211).
- The number of authors is very high, thus making the number of publications per author low. The total number in fact is of 529 national and international authors.
- The number of author keywords is also high. Publications present a total of 693 single keywords; most of them (556) are present only once. The most targeted is "Occupational exposure" (11 times) followed by "Exposure" (9 times).

Also in this case, this high prevalence in a specific sector looks like being influenced by the presence of a public body and of a journal. In fact, a quick search tells that the journal "Safety and Health at Work" (which strongly shapes

Table 7 – Occurrences of Affiliations in "Public, Environmental & Occupational Health" in South Korea

Affiliation/author	*Total*	*Safety and Health .at Work*
Yonsei U./Y.U. Health System	68	56
Seoul National University (SNU)	42	25
Catholic University of Korea	28	22
Pusan National University	21	16
Gachon University	18	17
Catholic University of Daegu	17	14
Jeju National University	15	15
Korea National Open University	15	13
Korea University	15	7

Source: author's elaborations of data extracted from Web of Science®

the SC with its presence) is the official peer-reviewed journal of the "Occupational Safety and Health Research Institute" of the "Korea Occupational Safety and Health Agency"[8]. This institute has a double role. By one side it performs research on safety and health policies, while by the other one it offers professional services (such as epidemiological investigation on occupational diseases).

A relevant finding in this case is the composition of the set of authors, as in this case research is mainly led by academics. In fact, counting the number of authors according to their affiliations gives the results presented in table 7. It is easily seen that the most represented affiliations are those of several South Korean universities.

The analysis of this case study shows again that the presence of a public body, specialized in OSH but non totally involved in research, might have some influence on research activities through the publication of a journal. Also in this case the journal is published by a leading scientific publishing company. This fact is probably one of the causes of the fact that most part of the authors work in academia.

6. Discussion and Conclusions

This work tries to respond to a specific research question, aiming at understanding whether it is possible to devise the presence of effects, deriving from non-research-specialized entities, on research activities in a practice-oriented field such as OSH. In specific the research is applied to a specific field of high social relevance, Occupational Safety and Health. This is due both to the need to find a

8. https://oshri.kosha.or.kr, link visited February 2024.

suitable case study, and to the will to explore more in deep the features of OSH. In order to respond to this research question, this work exploits a bibliometric methodology, performing an analysis of scientific literature. The analysis is based on a database of scientific works obtained from the Web of Science®. After a general appraisal of the database, the adopted methodology allowed to select three specific case studies to be analysed more in depth. The cases are those of specific research fields (WoS subject categories) particularly relevant at country level from the point of view of their numeric incidence in terms of scientific works.

The joint analysis of the case studies represents the core of the paper. The three cases are set in three different continents (North America, Europe and Asia) showing by one side the global relevance of OSH, and by the other side the fact that non-research factors can shape scientific production in very different contexts. The cases show some strong similarities. In all three cases the high prevalence at national level of a specific SC is influenced, in the first instance, by the presence of a WoS research journal. All three journals, in turn, are the official journals of private or public bodies directly involved in OSH policies. This fact shows that also non-research-specific bodies (that is, bodies that are not Universities or Public Research Institutions) can in some way orient research in a field, for instance fostering publications of journals related to specific field subjects.

The three case studies are set at distance between them and are relative to countries situated in different continents. Thus, cases do not show in principle a spatial effect due to location. Nevertheless, at local level, some regional effects are present. In the US case study, research activities in the specific SC present a geographic bias towards some states, driven by the research and publication activities of State University systems, and, in turn, possibly due to the presence of NIOSH-financed research centres. The German case, instead, allows less deepening from the point of view of regional location of research activities. Though both the "Berufsgenossenschaften" and the "BAuA" have several different geographical locations, it is more difficult to infer some regional effect on German scientific production in the specific SC. For what about the South Korean case, most part of the most prolific Universities are located in Seoul or in the surrounding area. Nevertheless, again it is difficult to infer some local effect from this concentration.

What is more interesting is the fact that external effects on research are fostered by the policies of bodies of different nature. The case of "Nursing" in the US originates from an association of professionals, AAOHN, an Incorporated (and feasibly non-for-profit) private body. South Korean OSHRI (Occupational Safety and Health Research Institute), instead, is part of the South Korea Occupational Safety and Health Agency (KOSHA) and is partly a specialized research institutions and partly a service provider for professional epidemiology. Anyway, being part of KOSHA, it is probably strongly involved in policy making. It is important to note that in South Korea policies related to Occupational Safety and Health developed relatively early: in fact, according to ILO website, the Occupational Safety and Health Act, No. 4420 was adopted January 13th, 1990, and has been continuously amended since. The German case, finally, shows that the involvement of academia in the most relevant country's SC is only marginal. Publications, instead, are almost solely authored by practice-oriented bodies.

Summing up, it is possible to say that some social, non-research-specific issues shape in some way research in OSH in different Countries. In particular, the findings of the three presented case studies tell us that research in this field is not necessarily led by academics, that a consistent body of literature might derive from professionals/practitioners, and that public bodies that are not research institution can foster research, in particular in such a practical oriented field. Research topics might derive not only from curiosity but also from issues stemming out of the direct engagement of practitioners and "policy orienting" bodies. Geographical and regional issues might be present but do not seem to be determinant.

It is also important to note that the specific case of OSH is a rather niche field, meaning that scientific production is not-so-abundant, making rather difficult a fine-grained bibliometric analysis.

A further deepening could be trying to find a specific connection between research activities and country-specific work safety problems. Under this point of view, it might prove relevant the joint use of databases related to accidents at national level, in order to understand if and how research is shaped by the specific occupational health and safety conditions of the nation.

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Sommario

Sicurezza e salute sul lavoro, società e ricerca: una esplorazione bibliometrica di casi nazionali

Il presente lavoro mira a valutare le influenze derivanti da fattori esterni alla ricerca, sulla produzione scientifica in un campo specifico, quello della Salute e sicurezza sul lavoro. Viene quindi effettuata una analisi bibliometrica di un database di pubblicazioni scientifiche per evidenziare casi specifici relativi ad aree scientifiche particolarmente rappresentate a livello nazionale in diversi Paesi. Vengono evidenziati e analizzati tre casi, che mostrano come enti che non svolgono attività strettamente di ricerca possano in qualche modo orientare la pubblicazione scientifica a livello nazionale. Ogni caso di studio presenta caratteristiche peculiari, che vengono interpretate.

Polycentric Urban Regions in Italy. A Novel Assessment

Davide Lunardon, Carlo Caporali**

Abstract

Despite the existence of a shared definition of Polycentric Urban Regions (PURs), the practical implementation of this concept remains somewhat unclear. We present an application of the PURban software to perform a mapping of PURs in Italy, a country renowned for its intricate multi-level urban system and diverse urban agglomerations. We then evaluate whether the identification of PURs through PURban, which is based on a morphological perspective, corresponds to the presence of functional interconnection by leveraging commuting flow data. We identify three PURs that presents also functional characteristics, and we classify them according to a recent taxonomy of polycentricity.

1. Introduction[1]

The ongoing debate regarding the definition of a city, of a city in relationship with other cities, and the constituent elements of the (inter and intra) urbanization process has a deep-rooted history within the social sciences. From this perspective, polycentricity can be considered a key issue. Its analysis and deep understanding might provide useful and policy-relevant information both for national and local policymakers (Brezzi, Veneri, 2015).

To enrich both the theoretical and technical discourse, with particular reference to the case of Italy, with this paper we undertake an exploration of the complexities associated with the identification of Polycentric Urban Regions

* Gran Sasso Science Institute, L'Aquila, Italy, e-mail: davide.lunardon@gssi.it, carlo.caporali@gssi.it (corresponding author).

1. This research stems from the desire to delve deeper into the topics presented during the *Lectio Magistralis* titled *"Polycentric Urban Regions: Theoretical Underpinnings, Analytical Challenges*, *Ambiguous Impacts*" delivered by Professor Ben Derudder. The lecture marked the opening of the proceedings of the XLIV Italian Regional Science Conference AISRe, held in Naples from the 6th to the 8th of 2023. Special appreciation is extended to the conference organizers and the editors of the conference volume, Professors Marco Modica and Davide Piacentino, as well as the anonymous reviewer for the valuable insights.

(hereafter PURs) by the adoption of the recently developed open-source software PURban (Caset *et al.*, 2022), that proposes a potentially common framework for their identification. However, this tool defines PUR only from a morphological point of view. In this respect, we aim at testing if the resulting classification also denotes functional characteristics by analyzing commuting flows leveraging data from the bt.Flussi database developed by the Italian Institute of Statistics (ISTAT). According to our findings, out of the nine PURs initially identified by PURban, only three could be substantiated from a functional standpoint. As a final step, we classify these three PURs based on the taxonomy recently proposed by Brezzi and Veneri (2015).

The aim of our contribution is twofold. On the one hand, we aim at testing a newly developed tool while underlying the necessity of complementing the analysis with other sources of data. On the other hand, we aim at contributing to renew the interest within the realm of regional science for polycentricity in Italy.[2]

The paper is organized as follows. Beginning with a succinct overview of the concept of polycentricity in the second part of Section 1, Section 2 provides a comprehensive elucidation of PURban, highlighting the reasoning behind its application to the Italian context. Section 3 is dedicated to the assessment of the functional attributes of the identified PURs, offering a meticulous analysis of our findings. Finally, in Section 4, we encapsulate the key outcomes, culminating in a conclusive discussion and a detailed outline of potential future steps in this research endeavor.

1.1. Polycentricity and Polycentric Urban Regions

Polycentrism, a concept denoting the presence of multiple centers within a specific geographical area, has been acknowledged as a predominant characteristic in advanced economies (Kloosterman, Musterd, 2001). The concept of polycentricity has historical roots that, with various iterations, can be traced back to the early twentieth-century literature that delved into the conceptualization of urban spatial structure, notably within the works of urban sociologists associated with the Chicago School (Kitchin, Thrift, 2009). However, at least in the European context, only at the end of the past century has polycentricity ceased to be a mere theoretical interpretation of spatial organization (Veneri, Burgalassi, 2012) to become, with particular reference to metropolitan regions, a pivotal issue in policymaking (Davoudi, 2003). Despite its widespread adoption, the concept lacks a clear definition, a robust universal theoretical framework, and rigorous

2. Italy has a rich tradition of research exploring the concept of polycentricity, both directly and indirectly. Notable areas of study include research on industrial districts (Becattini, 2002, 2017), the so-called Third Italy (Bagnasco, 1977), the network of cities (Camagni, Capello, 2004) and the city-region paradigm (Scott, 2001; Perulli, 2012).

generalizable empirical analysis (Kitchin, Thrift, 2009; Brezzi, Veneri, 2015). In this regard, polycentricity may carry divergent meanings for different categories of analysts (Natalia, Heinrichs, 2020) and its interpretation varies across different spatial scales (Davoudi, 2003; Veneri, Burgalassi, 2012).

Within the wider debate on polycentricity, the idea of PUR (Dieleman, Faludi, 1998; Kloosterman, Musterd, 2001; Parr, 2004) has appeared to carry a more applied nature. The origin of this concept, in opposition to the one related to the monocentric urban system showing a sharp divide between core and suburban hinterland (Kloosterman, Musterd, 2001: 623), can be traced back to the conceptualization of the *urban field* (Friedmann, Miller, 1965; Pred, 1984). Also in this case, however, despite the existence of a shared definition of PUR as regions containing numerous closely located sub-centers that exhibit balanced urban development (Caset *et al*., 2022), the practical implementation of this concept for analytical purposes remains somewhat unclear.

Several efforts have been made to delineate and comprehend PURs' urban and economic essence, to utilize it as a territorial concept for informing policies. One significant challenge associated with applying the PUR concept revolves around its external validity, particularly regarding its generalizability, reproducibility, and replicability (Caset *et al*., 2022). This is mainly due to its inherent place-based nature. Moreover, such scarcity can also be attributed to the continued existence of what seem to be two analytically separate approaches in comprehending and quantifying polycentricity: a *morphological* approach centered on nodal features and a *functional* approach concentrated on the interactions among centers.

As clearly highlighted by Veneri and Burgalassi (2012), the key disparity lies in the interpretation of the term 'centre'. Morphologically, an urban centre might be straightforwardly characterized as a concentration of employment and residents. Conversely, from a functional standpoint, an urban centre is a place that exerts influence over the surrounding territory[3]. In this line, Burger and Meijers (2012) present a general theoretical framework that links both approaches and discusses the way both can be measured and compared coherently. Addressing the case of the Netherlands, they demonstrated that most regions tend to be more morphologically polycentric than functionally polycentric. The difference seems to be explained by the size, external connectivity, and degree of self-sufficiency of a region's principal center. Arguably, understanding the hierarchical identity of the polycentric dynamics underpinning PURs is one of the key issues.

There is a notable demand for empirical research to ascertain the costs and benefits linked with polycentric urban systems. The assessment of polycentricism is one of the available approaches to understanding the process of urban expansion

3. It is interesting noticing that the concept of *centre* is very similar to the one of *central place*, as theorized by Getis and Getis (1966).

and its structural changes (Natalia, Heinrichs, 2020). In many regions, several cities and towns are increasingly linking up while showing different trajectories in spatial organization and connections among urban areas (Brezzi, Veneri, 2015). The assessment is important to provide knowledge as a basis for future planning and policy. According to the guidelines provided by the "European Spatial Development Perspective," polycentric development should be understood as a key prerequisite for sustainable and balanced development (CSD, 1999 in Veneri, Burgalassi, 2012).[4] In this sense, there has been a growing realization that polycentricity can also be closely tied, through enhanced efficiency, to a more sustainable form of urban and inter-urban development. Understanding the dynamics underpinning the needs of people to commute within and across urban centers is indeed crucial. By facilitating seamless movement between leisure, work, and residential areas, polycentric structures inherently promote modal shifts towards more sustainable forms of transportation and thus enhancing the green transition (Liu *et al*., 2012; van Zeben, 2020).

2. Online Software: PURban

As a first step to identify the potential PURs, we draw on the recently developed open-source tool called PURban (Caset *et al*., 2022)[5]. Thanks to an algorithmic approach, the software allows the user to identify on the map the urban systems showing the characteristics considered compatible with a PUR. PURban represents the first tool able to facilitate a flexible, comparative, and reproducible assessment of the spatial conditions of polycentric urban development (Caset *et al*., 2022: 584).

With few exceptions (Caset *et al*., 2023), it seems still pretty new to the literature addressing polycentrism. This tool might represent a credible and straightforward alternative with respect to other methodologies relying on the usage of software such as QGIS (Brezzi, Veneri, 2015), statistical methods for network analysis (Limtanakool *et al*., 2007), or pre-post comparison (Wang *et al*., 2020).

According to the foundational work of Caset *et al*. (2022), the main parameters on which PURban is based represent the operationalized version of the theoretical background developed by Parr (2004). These parameters are: i) Geographical scale; ii) Minimum number of centers (N); iii) Critical mass; iv) Balanced size distribution. The first parameter enables the specification of the maximum distance between centers, measured in travel time (expressed in kilometers or travel

4. It is worth noticing how, from that moment, the idea of polycentricity has been assuming an increasingly relevant role as a guiding principle of the European territorial agenda and the so-called cohesion policies (Barca, 2009), and consequently for urban planners, applied economists, and policymakers.
5. Accessible here: https://purban.be/.

time). The second parameter establishes the minimum number of urban centers required to identify a PUR. The third parameter incorporates a fundamental socio-economic variable used to define the size of a PUR, such as population or GDP. Lastly, the fourth and final parameter assesses the degree of polycentricity, determining whether there is a balanced size distribution among different urban centers within each PUR[6].

PURban utilizes data freely accessible from the Global Human Settlement Layer Urban Centre Database (GHS-UCDB). This database serves as the primary source for deriving the key analytical spatial unit known as the "Urban Centre" (hereafter UC). The identification of a UC relies on the "degree of urbanization" method as elucidated by Dijkstra and Poelman (2014). To classify as a UC, there must be a contiguous population area of at least 50,000 inhabitants, with more than 50% residing in high-density cells featuring a population density exceeding 1500 inhabitants per square kilometer.

2.1. Application of PURban to the Italian Case

Arguably, the understudied case of Italy represents a relevant case study mainly due to its specificities. Italy is a country renowned for its intricate multi-level urban system and diverse urban agglomerations, generating a complex galaxy of medium-level cities that are closely intertwined with an economic fabric dominated by small and medium-sized enterprises (Camagni, Salone, 1993; Veneri, Burgalassi, 2012). To the best of our knowledge, besides a few recent exceptions focusing specifically on the cases of suburban networks and suburban growth patterns within and around Milan and Naples (see, respectively, De Vidovich, Scolari, 2022; Salvati *et al.*, 2018), empirical evidence of PURs in Italy is lacking.

In the process of identifying Italian PURs, we initiate by utilizing the identical geographical scale and balanced size distribution parameters as employed in Caset *et al.* (2022). Specifically, we set the maximum distance between urban centers to 45 minutes of travel time by car, and the Herfindahl index (HI hereafter) with a cut-off value of 0.44.[7] Differently from the approach taken by Caset *et al.* (2022), we choose to set 3 as the minimum number of centers and 100,000 population as a minimum critical mass. These decisions are motivated by our aim to account for the unique characteristics of the Italian urban landscape, which is predominantly composed of small and medium-sized cities[8].

6. By default, PURban provides four types of indicators: primary city index, Herfindahl index, rank-size rule, and standard deviation.
7. The value serves as the reference threshold for capturing morphological polycentricity, in accordance with (Meijers *et al.*, 2018).
8. According to ISTAT, only 44 municipalities out of almost 8,000 account for more than 100,000 inhabitants. Given this information, we believe that using this population threshold is appropriate

Having set PURban with the above-mentioned new list of parameters[9], we obtain an initial list of 28 PURs, summarized in Table A1. Upon meticulous examination of this list, we observe that PURban yields numerous instances of overlapping PURs characterized by substantial similarities. The variation lies in the selection of the center considered as the focal point from which the PUR originates.

Before proceeding, it is worth highlighting that PURban automatically identifies the center – or origin – of a PUR. While this feature eliminates the need for users to pre-set a center, it introduces a potential for confusion requiring a discretionary choice by the user post-analysis. As an example, let's consider the Veneto region where PURban identifies four distinct PURs sharing the same UCs, but centered respectively in Padova, Vicenza, Treviso, and Mestre. In these instances, we opted to choose the PUR configuration with the highest critical mass, which in this case is centered on Padova. The nine PURs identified through this selection process are presented in Table 1.

The most populous are Central Apulia and Grande Firenze, each with a population exceeding 700,000 inhabitants. In contrast, the least populous are Romagna and Lombardy-Piedmont, with approximately 280,000 and 200,000 inhabitants, respectively. Column 4 displays the coefficients of the polycentrism indicator used in this analysis. As calculated in Caset *et al*. (2022), a value closer to 1 indicates a higher degree of polycentricity in the urban system. Seaside Tuscany, centered in Viareggio, stands out with the highest HI reaching 0.77. Central Apulia, centered in Andria, and Central Veneto, centered in Padova, exhibit significant degrees of polycentricity with values of 0.75 and 0.70, respectively. On the contrary, Central Emilia and Great Florence, both with an HI of 0.53, represent the areas with a lower measure of polycentricity. In Table 2, we provide detailed information about the various components of each PUR by highlighting in bold, in column (2), the UC identified as the center of the PUR by the PURban tool. Interestingly, PURban identifies centers that are not necessarily the largest urban areas but often designates cities that might typically be considered secondary.

3. Assessing Functionality Among Italian PURs

As detailed in the previous section, the output provided by PURban is solely based on morphological factors. However, as detailed by the literature, morphological polycentricity does not always align with functional polycentricity. While the former refers to a visible balance in the distribution of centers, the latter implies balanced development as visible in territorial integration processes (Caset *et al*., 2022). The main straightforward intuition behind the need

for capturing significant urban agglomerations or systems in the Italian context.

9. We use 2015 data, which is the most recent year available in PURban.

Table 1 – Italian PURs

(1) PUR	(2) PUR centre(s)	(3) Pop. 2015	(4) HI[2]
More than 500.000 inhabitants			
Central Apulia	Andria-*Trani-Bisceglie*[3]	712269	0,75
Greater Florence	Firenze-*Prato-Pistoia*[3]	708029	0,53
Central Emilia	Modena	669766	0,53
Central Veneto	Padova	623167	0,70
Western Lombardy	Varese	594892	0,68
Between 300.000 and 500.000 inhabitants			
Seaside Tuscany	Viareggio	473849	0,77
Southern Campania	Battipaglia	350740	0,68
Less than 300.000 inhabitants			
Romagna	Forlì	279069	0,66
Lombardy – Piedmont	Vigevano	199730	0,65

Notes: (1) These are the centre of each PUR identify by PURban software. (2) Herfindahl index. (3) In case of multiple PUR centre with equal Herfindal index (balance size indicator), as identified by PURurban, the bigger centre in term of population is considered as the PUR centre. In this case, Firenze for "Grande Firenze" and Andria for "Puglia Centrale".

Source: Authors' elaborations based on PURban

to deepen the analysis of the potential existence of 'more-than-morphological' interconnection in the polycentric urban regions is often associated with the notion of synergy. The assumption is that the individual cities in these collections of distinct but proximally located cities relate to each other in a synergetic way, making the whole network of cities more than the sum of its parts (Meijers, 2005). Given the role of space and the urban economic structure, it appears difficult to spot within the literature a global agreement on the dynamics underpinning the process of urban interdependence or polycentrism[10].

Leveraging insights from pertinent literature, particularly sources like Limtanakool *et al*. (2007), Green (2007), Brezzi and Veneri (2015), and Zhang *et al*. (2020), we center our attention on *commuting flows* as a plausible proxy for understanding the functional interconnections within PURs. To optimize our data accessibility efforts and establish a benchmark for comparing PURban findings, we adopt local labor market areas (hereafter referred to as LLM) as our new key analytical unit.

10. For instance, according to Meijers (2005) who analyzed the case of the Randstad region (Netherlands), the results of considering the synergy mechanism of co-operation and complementarity among urban centers are mixed.

Table 2 – Italian PURs: Composition

(1) PUR	(2) Urban centre	(3) Pop. 2015	(4) Size in km²	(5) Den. per km²
Southern Campania	Salerno	167664	55	3048
	Avellino	63796	17	3753
	Battipaglia	59949	16	3747
	San Giuseppe V.	59331	19	3123
Central Emilia	Bologna	421342	96	4389
	Modena	142871	31	4609
	Reggio Emilia	105553	24	4398
Greater Florence[1]	Florence	421019	91	4627
	Prato	235551	71	3318
	Pistoia	51459	17	3027
Western Lombardy[2]	Busto Arsizio	284567	99	2874
	Gallarate	129787	53	2449
	Como	94749	41	2311
	Varese	85789	33	2600
Lombardy – Piedmont	Novara	87563	20	4378
	Pavia	59301	20	2965
	Vigevano	52867	12	4406
Central Apulia[1]	Bari	310239	80	3878
	Andria	96742	12	8062
	Barletta	90810	14	6486
	Molfetta	56528	9	6281
	Trani	54002	11	4909
	Bisceglie	53171	10	5317
	Cerignola	50778	8	6347
Romagna	Rimini	116867	38	3075
	Ravenna	81564	22	3707
	Forlì	80638	25	3226
Seaside Tuscany	Livorno	148916	44	3384
	Massa	119351	64	1865
	La Spezia	85011	25	3400
	Pisa	62940	19	3313
	Viareggio	57631	28	2058
Central Veneto	Mestre/Venezia[3]	231530	100	2315
	Padua	217448	81	2685
	Vicenza	94715	29	3266
	Treviso	79474	30	2649

Notes: (1) In case of multiple urban centres with equal Herfindal index (balance size indicator), as identified by PURurban, the bigger urban centre in term of population is considered as the PUR centre. In this case, we select Firenze for "Grande Firenze" and Andria for "Puglia Centrale". (2) According to PURban tool, Varese is connected also to Lugano (CH). This center has been removed since the city belongs to a different country, Switzerland. (3) We include also Venezia as part of the urban center. Originally PURBAN separates Mestre and Venezia.

Source: Authors' elaborations based on PURban.

Table 3 – Comparison of the Degrees of Polycentricity

PURs	*UC*	*LLM*
Seaside Tuscany	0,77	0,81
Central Apulia	0,75	0,58
Central Veneto	0,70	0,71
Southern Campania	0,68	0,67
Lombardy – Piedmont	0,68	0,66
Romagna	0,66	0,67
Western Lombardy	0,65	0,65
Central Emilia	0,53	0,57
Greater Florence	0,53	0,53

Notes: The table compare PUR's Herfindahl index using UC and LLM as analytical units.
Source: Authors' elaborations based on PURban

LLM represent indeed geostatistical units that partition the Italian territory into sub-regional entities. These entities consist of multiple municipalities tightly integrated through daily commuting work and study flows, thus offering a more nuanced understanding of the functional integration of local territories (Istat, 2015).[11]

In opting for LLM as the novel analytical unit to assess PURs from a functional standpoint, we deviate from the methodology applied by PURban, which uses UC. While these can be viewed as measures of population concentration, LLM encapsulates metrics of local territorial integration. In our perspective, LLM stands out as the most suitable analytical unit for comprehensively addressing functionality in the context of PUR analysis.

To proceed with the functional analysis, we substitute the UC with LLM. The initial step involves determining if there is a corresponding LLM for each UC (see Table A2). Subsequently, we evaluate whether the PURs formed through LLM maintain a sufficient degree of polycentricity, using a cutoff value of 0.44 for the HI, consistent with Caset *et al*. (2022).

Table 3 reveals that, despite the change in the analytical unit, the polycentricity values remain mostly consistent.[12] Figure 1 depicts a map illustrating the

11. While these units have been utilized empirically in various works (Daniele, 2021; Ascani *et al*., 2021; Dottori, 2021), there has been an ongoing debate about their potential as not just statistical units but also as institutional political units, although this perspective has gained limited traction so far (Calafati, 2007; Calafati, Mazzoni, 2009; Calafati, 2009).

12. There is only one exception concerning the Central Apulia, which experiences a notable decrease in polycentricity. This shift is attributed to the change in the analytical unit, which leads to a decrease in the number of centers, from 7 centers to 4.

Figure 1 – Italian PURs

Note: The Figure depicts a map illustrating the distribution of various PURs in Italy when considering LLM. Additionally, the UCs previously used by PURban are retained on the map for reference, providing a visual representation of the interconnected urban centers within the identified polycentric regions.

Source: Authors' elaboration using QGIS

distribution of various PURs in Italy, while Table 4 presents the new data on the newly aggregated PUR using LLM. As it is visible from the table, Central Veneto is now the largest PUR in term of population, with more than 1.8 million inhabitants, followed by Western Lombardy and Central Emilia both with more than 1.4 million inhabitants. Romagna and Lombardy-Piedmont remain the two last PURs in terms of population both with around 550.000 inhabitants.

3.1. Analysis of the Commuting Flows

As anticipated, we aim to provide evidence on the functionality of PURs identified by PURban, utilizing data on inter-LLMs commuting flows from

Table 4 – PURs Identified Through LLM

PURs	*Pop 2011*	*Km²*	*Density*
Central Veneto	1832649	3291	557
Western Lombardy	1514033	1710	885
Central Emilia	1436678	3788	379
Central Apulia	1259267	3354	375
Greater Florence	1089891	1982	550
Seaside Tuscany	857579	2129	403
Southern Campania	709240	1505	471
Romagna	557106	1804	309
Lombardy – Piedmont	550273	1970	279

Notes: The table provides a summary of the data on newly aggregated PURs using LLM as an analytical unit.

Source: Authors' elaboration based on PURban data

the BT-Flussi database[13]. The analysis is conducted by considering the center of each PUR as the focal point from where to observe the flows. We begin by examining the flows in absolute terms.

Table 5 shows that the central LLM of Florence, Padua, Modena, and Forlì exhibit an overall positive flow balance, i.e., inflows overcome outflows. On the contrary, the systems of Vigevano, Barletta, Viareggio, Varese, and Battipaglia present negative flow balances. Notably, Florence stands out as a significant centralizing force, with a positive balance of more than 50,000 people commuting into the system every day. Conversely, Vigevano represents the system with the highest differential in terms of outflows, with a negative balance of more than 13,000 people.

To gain a better understanding of the significance of these flow patterns, we weigh these flows by considering the population residing in the center of the PUR (Table 6). In relative terms, the LLM of Modena, Florence, and Battipaglia emerge as highly mobile. On the other hand, the LLM of Barletta shows remarkably low percentage of outflows and inflows. For this reason, we therefore argue that Central Apulia as a PUR cannot be sustained from a functional perspective, thus removing it from the rest of the analysis.

Pivotal for the detection of functional integration are the results showed in Table 7, which presents the share of the total flows originating from the other centers within the same PUR. To identify which PURs are the most functionally

13. We use 2011 data which is the last year available in Bt-Flussi.

Table 5 – In-Out Flows

PUR centre	*In-Flows*	*Out-Flows*	*Δ Flows*
Firenze	75222	21871	53351
Padova	64485	43724	20761
Modena	41565	24232	17333
Forlì	12809	10617	2192
Battipaglia	8775	10794	-2019
Varese	31176	33916	-2740
Viareggio	7054	10736	-3682
Barletta	8272	13541	-5269
Vigevano	11469	24660	-13191

Source: Authors' elaboration based on Bt-Flussi data

Table 6 – Flows in Relative Terms

PUR	*PUR centre*	*In-Flows*	*Out-Flows*
Central Emilia	Modena	15,1	8,8
Greater Florence	Firenze	11,0	3,2
Southern Campania	Battipaglia	10,2	12,6
Central Veneto	Padova	9,7	6,6
Western Lombardy	Varese	8,8	9,6
Romagna	Forlì	7,6	6,3
Lombardy – Piedmont	Vigevano	7,2	15,5
Seaside Tuscany	Viareggio	6,1	9,2
Central Apulia	Barletta	2,8	4,6

Notes: The Table sheds light on the dynamics partially depicted in Table 5. The flows here reported have been weighed accounting for the population residing in the focal node of the PUR.

Source: Authors' elaboration based on Bt-Flussi data

integrated, we consider those which shares are equal to or higher than the median and mean values for both inflows and outflows[14]. Out of the eight PURs, only four seem to meet the requirements: Western Lombardy, Central Veneto, Southern Campania, and Greater Florence.

14. The mean value is 36.5 for inflows, while 40 % for outflows. Both median values are in between Greater Florence and Seaside Tuscany.

Table 7 – PUR Integration, Flows Analysis

PUR	PUR centre	Flows within PUR	
		In	*Out*
Western Lombardy	Varese	67,2	51,6
Central Veneto	Padova	41,3	54,1
Southern Campania	Battipaglia	40,7	61,9
Greater Florence	Firenze	39,8	46,4
Seaside Tuscany	Viareggio	36,9	39,5
Romagna	Forlì	28,1	20,0
Central Emilia	Modena	21,3	35,9
Lombardy – Piedmont	Vigevano	17,3	11,2

Notes: The Table presents the PUR in the first column, and the center of the PUR in the second one. The third and fourth columns display re- spectively the percentage of the total inflow and outflows coming from or going to the other centers of the same PUR.

Source: Authors' elaboration based on Bt-Flussi data

In Tables A3 to A6 we deepen the analysis of each PUR. Table A3 elucidates that the strongest connection within Western Lombardy PUR is between Varese and Busto Arsizio. At the same time, the relationship Varese-Como is quite established too[15].

Table A4 displays the flows of the Central Veneto revealing the presence of a strong link, in particular between the LLMs of Padova and Venice, followed by Padova-Vicenza and Padova-Treviso.

Table A5 illustrates the distribution of flows within the Southern Campania PUR with its center in Battipaglia. The connections between Battipaglia and Avellino/San Giuseppe Vesuviano are practically non-existent, and thus, we would not consider it as a functional PUR anymore. We observe a high level of integration between Salerno and Battipaglia, suggesting a different territorial configuration which analysis goes beyond the scope of this paper[16].

Finally, Table A6 elucidates the flow of the Greater Florence PUR, showing a particularly strong connection between central Florence and the nearby Prato, but also a consistent relation Florence-Pistoia. To summarize, we then identify three PURs: Western Lombardy, Central Veneto, and Greater Florence.

15. For further reading on the area refers to Gavinelli and Morazzoni (2012) and De Vidovich and Scolari (2022).

16. Regarding the case of Battipaglia, the reader can refer to the analysis provided by Matarazzo *et al*. (2022).

3.2. Classifying the PURs

As already mentioned in Section 1.1, the multi-scalar nature of polycentric regions and urban areas represents one of the main challenges connected to the implementation of applied research. Functionality and morphology are indeed tightly connected with the territorial level to which these concepts themselves are analyzed (Brezzi, Veneri, 2015). Drawing on the Espon classification (ESPON 3.1, 2003), Brezzi and Veneri (2015) propose to consider three perspectives through which to assess polycentricity from the spatial scale perspective: the *metropolitan*, the *regional*, and the *national*.

Adopting the metropolitan scale implies considering the spatial organization within the metropolitan space, which is characterized by one single—or multiple overlapping—labour market areas. On the other hand, the national perspective looks at the spatial structure of the entire national urban system or, in the case of the European space, the supra-national urban system. Finally, the regional perspective refers to networks of two or more functional urban areas that are connected through functional relationships and lie in the same larger administrative region.

Following this taxonomy, the PUR of Greater Florence seems to show the characteristics of a metropolitan system due to its prevalent monocentric nature (see Tables 5 and 6). On the other hand, Central Veneto and Western Lombardy, seem to be coherent with a regional (or inter-metropolitan) scale, showing more polycentric and balanced structure. The case of Western Lombardy is particularly relevant. Notwithstanding the proximity to a large metropolis such as Milan able to exert an impressive gravitational force, this PUR seems to maintain high level of functional independence.

4. Conclusive Remarks

Evaluating polycentrism, along with its multifaceted origins and implications, poses a formidable challenge for scholars, especially those within the field of regional science. The complexity of this task is heightened when examining urban systems at levels beyond the well-studied large urban areas or urban regions, which constitute the primary focus of much of the existing literature, both in theoretical and applied contexts. Polycentric Urban Regions serve as a theoretical construct and, simultaneously, an analytical instrument capable of capturing intricate network dynamics.

Through this contribution, we unravel the intricacies of the Italian urban landscape, seeking to tailor existing knowledge to its more modest scale and increased granularity. Adopting the analytical capabilities offered by the recently developed software, PURban (Caset *et al*., 2022), we embark on a mapping endeavor of Polycentric Urban Regions in Italy, primarily focusing on their morphological aspects. Subsequently, we undertake a preliminary effort to assess whether the morphological characteristics align with functional interconnections. In doing so, we draw on daily commuting flow data made available by ISTAT through the bt.Flussi database.

This analysis yields two primary contributions. Firstly, we implement the further steps outlined by Caset *et al*. (2022) by demonstrating the applicability of PURban in diverse contexts and the importance of complementing its use with other tools or data sources. Our study showcases how PURban can be successfully employed to analyze polycentric urban regions in various settings, providing a credible and adaptable tool for researchers and urban planners. Secondly, our research offers a comprehensive assessment of urban polycentricity in Italy. This endeavor is pioneering, as it involves fitting the taxonomy of Polycentric Urban Regions proposed by Brezzi and Veneri (2015) to classify Italian PURs. By adopting this taxonomy, we contribute to the global discourse on polycentric urban development by providing a preliminary systematic framework for understanding and categorizing the polycentric nature of urban regions in Italy.

As a conclusive remark, we think that further research endeavor should be devoted to deepening the potential of PUR as a territorial category in the larger framework green transition (Homsy, Warner, 2015; Smith, 2020; Chen *et al*., 2021). By leveraging the tools and methodologies outlined in this paper to map urban development and analyze mobility patterns, policymakers could indeed formulate data-driven strategies to improve public transportation networks and alleviate urban congestion – a significant barrier to the green transition. While this endeavor necessitates a substantial amount of disaggregated data, we contend that the integration of urban polycentricity and the green transition is not only feasible but imperative for fostering sustainable and resilient urban futures.

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Sommario

Regioni urbane policentriche in Italia. Una nuova valutazione

Nonostante l'esistenza di una definizione condivisa di Regioni Urbane Policentriche (PURs), l'implementazione pratica di questo concetto rimane poco chiara. In questo contributo presentiamo un'applicazione del software PURban per eseguire una mappatura delle PUR in Italia, un paese conosciuto per il suo intricato sistema urbano a più livelli e le differenti forme di agglomerazioni urbane. Valutiamo inoltre se l'identificazione delle PUR attraverso PURban, basata su una prospettiva morfologica, corrisponda alla presenza di interconnessione funzionale utilizzando i dati sui flussi pendolari. In conclusione, identifichiamo tre PUR che presentano anche caratteristiche di integrazione funzionale, e le classifichiamo applicando una recente tassonomia della policentricità.

Appendix

Table A1 – Original Italian PURs

PUR centre	*Centers*	*Critical mass*	*Herfindahl Index*
Barletta	6	402030	0,820
Cerignola	6	476773	0,810
Viareggio	5	473849	0,773
Bisceglie	7	712269	0,753
Trani	7	712269	0,753
Andria	7	712269	0,753
Varese	5	670854	0,734
Massa	4	324933	0,728
Molfetta	6	661491	0,719
Pisa	4	388838	0,711
Padua	4	547866	0,710
Bari	6	637617	0,707
Mestre	4	528453	0,700
Battipaglia	4	350740	0,681
Reggio nell'Emilia	3	384893	0,661
Forlì	3	279069	0,656
Vigevano	3	199730	0,650
Rimini	3	261232	0,645
La Spezia	3	261993	0,639
Vicenza	3	512886	0,633
Treviso	3	453151	0,620
Livorno	3	269487	0,594
Foggia	3	235450	0,591
Modena	3	669766	0,534
Florence	3	708029	0,530
Prato	3	708029	0,530
Pistoia	3	708029	0,530
Bologna	3	654064	0,518

Source: Author elaborations from PURban software

Table A2 – LLM-UC correspondence

PUR	*Local Labour Market Areas*	*Urban Centres*
Basso Napoletano	Avellino	
	Battipaglia	
	Salerno	
	San Giuseppe V.	
Emilia Centrale	Reggio Emili	
	Bologna	
	Modena	
Grande Firenze	**Firenze**	
	Pistoia	
	Prato	
Lombardia Ovest	Busto Arsizio[1]	Busto Arsizio, Gallarate
	Como	
	Varese	
Piemonte-Lombardia	Novara	
	Pavia	
	Vigevano	
Puglia Centrale	Bari – **Barletta**[1]	**Andria**, Trani, Barletta
	Cerignola – Molfetta[1]	Molfetta, Bisceglie
Romagna	**Forlì**	
	Ravenna	
	Rimini	
Toscana Mare	Carrara[2]	Massa
	La Spezia	
	Livorno – Massa[2]	Massa
	Pisa	
	Viareggio	
Veneto Centrale	**Padova**	
	Treviso	
	Venezia	
	Vicenza	

Notes: The LLS in bold are those considered as the centre of PUR. When not specify, for the same UC correspond a LLM. (1) These cases denote that within a LLM, there are multiple UCs proving that among these centres, there are very high degree of functional integration. (2) This case is opposite to 1 in fact the UC of Massa belongs to both LLM of Massa and Carrara.

Source: Authors' elaborations on ISTAT and PURban data.

Table A3 – Western Lombardy

	Busto Arsizio		*Como*	
	In	*Out*	*In*	*Out*
Varese	51,7	40,2	15,5	11,4

Table A4 – Central Veneto

	Venezia		*Vicenza*		*Treviso*	
	In	*Out*	*In*	*Out*	*In*	*Out*
Padova	30,9	40,7	7,1	11,1	3,3	2,3

Table A5 – Southern Campania

	Salerno		*Avellino*		*S. Giuseppe*	
	In	*Out*	*In*	*Out*	*In*	*Out*
Battipaglia	39,4	60,9	0,7	1,0	0,6	0,0

Table A6 – Greater Florence

	Prato		*Pistoia*	
	In	*Out*	*In*	*Out*
Firenze	32,7	42,5	7,1	3,9

Regional Gendered Sectoral Segregation in the EU. Is Regional Specialization a Gender Segregation Trap?

*Barbara Martini**

Abstract

This paper explores the interplay among gender segregation, regional specialization, and economic growth. Examining data from 242 EU regions (2008-2021), we reveal that Scandinavia exhibits the highest gender dissimilarity, while Eastern regions demonstrate greater gender equality. This disparity is rooted in social, cultural, and welfare factors. The study introduces a novel perspective by examining the influence of regional specialization on gender dissimilarity, an aspect overlooked in existing literature. Additionally, our findings suggest that gender segregation can impede regional growth, emphasizing the interconnected dynamics of regional specialization, gender segregation, and economic development.

1. Introduction

Following the definition provided by the World Health Organization, gender is used to describe the characteristics of women and men that are socially constructed. At the same time, sex refers to those that are biologically determined. For example, people are born female or male but learn to be girls and boys who grow into women and men. This learnt behavior makes up gender identity and determines gender roles. Despite the increasing interest of gender in economic literature, the topic is still neglected in regional science and contributions are limited (Hirschler, 2010; Pavlyuk, 2011; Noback *et al*., 2013; Lamarche *et al*., 2003; Martini, 2022; Martini, Platania, 2022).

The relationship between regional specialization and regional growth has been investigated in several studies (Traistaru *et al*., 2003; Ezcurra *et al*., 2006; Kemeny, Storper, 2014; Levenson, Prato, 2022) but none of them have taken gender into account. However, using the Eurostat data set at the NACE_2 level for the European regions for the period 2008-2021, the data highlight a gender segregation

* University of Rome Tor Vergata, Department of Enterprise Engineering, Rome, Italy, e-mail: barbara.martini@uniroma2.it.

between industries. Occupational segregation occurs when a demographic group is over-represented or under-represented in a certain job category. Gender segregation is a universal phenomenon. Women dominated the services sector in all regions of the world, except South Asia, and men dominated the industry sector in all regions. Furthermore, within the service sector, at a global level, women are concentrated in wholesale and retail trade, health and social work, and education (World Economic Forum, 2023) Gender segregation is not a problem per se if women choose to work in some industries and if they have the same wage and the same job security. Unfortunately, it is not so. Females are horizontally segregated in less paid and less resilient jobs and are vertically segregated due to the glass ceiling. Furthermore, gender segregation and gender inequality are a barrier to economic development. Exogenous barriers to women's participation in the labour market or access to a certain occupation reduce aggregate productivity and output per capita – talent misallocation – (Cuberes, Teignier, 2014, 2016, Hsieh *et al.*, 2019). Gender segregation is generated by a wide range of processes. These processes find their roots in interrelated historical, educational, cultural, and sociological components. Moreover, this unequal distribution of women and men within and between industries means that an increase in women in the labour market will not be equally distributed between industries. As a result, women have a greater probability of falling in some industries than others. Employment segregation has significant consequences for overall economic growth, household welfare, firm performance, and intergenerational social mobility. Efforts to reduce employment segregation can create a virtuous cycle in which increased female participation in high-return occupations creates more extensive networks of women and changes social norms (Das, Kotikula, 2019).

The aim of the paper is twofold. First, we investigate the relationship between regional specialization and gender segregation. Regional specialization expresses the regional perspective and depicts the distribution of sectoral shares and its overall economy, usually compared to the rest of the country. A region is considered highly specialized if a small number of industries have a large-combined share in the economy of that region (Goshin *et al.*, 2009). If women work mainly in the service sector and a region is specialized in industry, do women in that region have the same chance to be employed as a male? Is regional specialization an obstacle for the females' employment? The second aim of the article is to investigate the relationship between gender segregation, regional specialization, and regional economic growth. It is well known that regional specialization can have an impact on regional growth. Our contribution adds a new variable to the analysis, and this represents a novelty in literature. The relationship between gender segregation and growth suffers from reverse causality. On the one hand, gender segregation can lead to low economic growth, but, on the other hand, high economic growth leads to a reduction in gender segregation. Our results put several significant results forward. First, there is a relationship between gender segregation and regional specialization. The higher the regional specialization in sectors in which the female share is low, the higher the gender segregation. Second, the relationship between gender segregation and regional growth is investigated. Our results highlight that there is evidence that decreasing gender inequality has a positive impact on regional growth. Nevertheless, the Scandinavian puzzle remains unsolved.

2. Gender, Segregation, and Growth in the Economic Literature

The literature explains gender segregation through three different approaches: human capital, institutional approach, and cultural approach. According to neoclassical theory, workers and employers are rational and the labour market works efficiently. Furthermore, theories of economic growth and development have consistently neglected to include gender as a variable. According to the human capital model, individuals choose occupation consistent with their life-cycle labour force participation. Starting from Becker (1962), individuals will invest in education in anticipation of a wide range of benefits, and workers will search for the best-paid job considering their own personal endowments (education-experience) and their own constraints (caregiving, children, leisure time). Polachek (1979) allies with neoclassical economics in recognizing the importance of human capital and individual choice, but it also highlights the limitation of neoclassical assumptions by emphasizing the roles of nonmonetary factors, discrimination, and social network in explaining occupational segregation. The role of education, gender differences in the field of studies, and the choices made by women in terms of flexibility of time to have a work-life balance have conciliated the human capital theory and gender segregation (Goldwin, 1991). Nevertheless, during that time, especially in Europe, women's skills increased, and the fertility rate decreased; however, segregation between the sexes persists. Furthermore, Albelda (1986) proved that during the period 1958-1981, the segregation between with and black decreased in the US while the segregation by gender remained unchanged. The second approach is the institutional approach. According to the literature, attention is paid to laws designed to promote and protect women. Furthermore, institutions such as the worker union and welfare state play an important role in determining labour demand and career pattern (Farnadale *et al.*, 2023; Li, Farrel, 2021; North, 1990). Moreover, the labour market is segmented, and it is difficult for workers to move between segments. A third strand of literature is focused on discrimination based on cultural context. Cultural theories, starting from the contribution of England (1982), emphasize the role of non-rational factors such as 'employment taste', cultural norms, and social values. According to this approach, two types of segregation can affect women's career choices: vertical and horizontal segregation (Correl, 2001). Horizontal segregation occurs when certain jobs are stereotyped as masculine or feminine. Vertical segregation, on the contrary, occurs due to cultural norms that define authority as a masculine quality. Consequently, vertical segregation generates under representation of women in high-status occupations such as manager and over representation in low-status occupations such as clerical jobs. Horizontal segregation creates under-representation of women in manufacturing and craft jobs and an over-representation in service sector jobs (Inglehart, Norris, 2003). Despite all those studies, statistical evidence highlights that high levels of female labour force participation are usually combined with higher level of gender segregation, especially in the Scandinavian countries (Charles, Grusky, 2004), and the Scandinavian paradox is still unsolved.

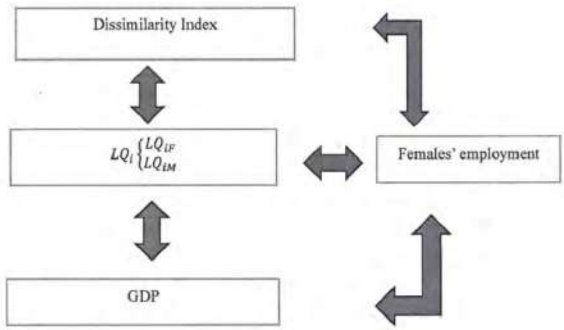
The relationship between gender inequality and growth has been studied in the literature, focussing primarily on education. This is because in growth models, education is one of the most studied determinants. Growing models take labour as given and determined exogenously. The first study that took gender into account in this field was the Barro-Lee (1994) model. Based on a panel data set for 1965-1975, 1975-1985 and 138 countries, they explored the determinant of GDP growth. Secondary education attainment for women and men was included as separate independent variables. The coefficient of female education was found to be negative, while the coefficient of male education was positive. Based on the results of the Barro-Lee model, Barro-Sala-i-Martin (1995) included separate education variables: higher and secondary education for females and males. Their findings enhance the Barro-Lee results. The relationship between women's education and economic growth was negative. Perotti (1996) confirmed the Barro Lee and Barro-Sala-i-Marten results. Subsequent studies (Forbes, 2000; Klasen, 1999; 2002; Knowles *et al.*, 2002; Lorgelly, Oven, 1999) highlight the presence of multicollinearity in the Barro Lee study, and the results were biased due to the presence of it. Subsequent studies (Dollar, Gatti, 1999; Klasen, Lamanna, 2009; Esteve-Volart 2000; 2004; Baliamoune-Lutz, Mcgillivray, 2007; 2009; Brummet, 2008) found that gender inequality in education reduces economic growth. Eliminating exogenous barriers to women's participation in the labour market increases aggregate productivity and per capita output (Cuberes, Teignier, 2016; Hsieh *et al.*, 2019).

Outside the relationship between growth, education and gender, literature focused the attention on economic growth and the impact the trade can have on women's employment and gender segregation. Arora *et al.* (2023) studied the phenomenon for Latin America, and the results highlight that an increase in import in manufacturing is positively related with a women's decline in women's relatively good job shares. Those results are in line with the ones obtained by Tejani and Milberg (2016). The authors found that women tend to lose jobs in manufacturing as industries upgrade. Moreover, Arora *et al*. (2023) found that the main contributor to increases in women's share of good jobs is social policy. Finally, another strand of literature focused the attention on the relation between democratic representation of women and growth. The results highlight that higher democratic representation of women stimulates economic growth (Cabeza-Garcia *et al*., 2018; Jayasuriya, Burke, 2013).

3. Data and Descriptive Statistics

Females and males do not work in the same industries. Using a NACE_2 rev classification, industries will be grouped as shown in Table A1 in the Appendix. According to this group, the share of women and men in different sectors by region is shown in Figure A1 (a-e) in the Appendix. Females are more concentrated in services than industries and construction. Furthermore, among services, the highest share of women is in public administration and defense, compulsory social security (*O*), education (*P*), human health and social work activities (*Q*). This unbalance distribution of females and males between sectors is captured by a Dissimilarity index, and it can affect the regional specialization, captured by the Location Quotient. Furthermore, the *LQ* will have an impact on the employment of women and the GDP. Figure 1 summarizes all the casual links.

Figure 1 – Relationship between ID index, LQ and GDP



To capture the dissimilarity between industries, the literature uses the Dissimilarity Index (*ID*) proposed by Ducan and Ducan (1955). The index measures whether there is a larger than expected presence of one gender over another in each sector by identifying the percentage of employed women (or men) who would have to change occupations for the occupational distribution of men and women to be equal. A Duncan Segregation Index value of 0 occurs when the share of women in every occupation is the same as the women's share of employment. In other words, 0 indicates *perfect* gender integration within the workforce, while a value of 1 indicates complete gender segregation within the workforce.

$$ID = \frac{1}{2}\sum_{i=1}^{N}\left|\frac{m_i}{M} - \frac{f_i}{F}\right| \qquad [1]$$

where m_i is the male population of the i-th sector, M is the total male population of the country or the labour force of interest, f_i is the female population of the i-th occupation, and F is the total female population of the country or the labour force of interest. The ID index for EU regions is depicted in Figure A2 in the Appendix. The highest value of ID is in the Nordic countries, while the most equal ones are in the eastern countries. This result is well known in the literature as the Scandinavian paradox (Anker, 1988; Hansen, 1997; Ellingsæter, 2013; Bhagat, 2021). Regional specialization is captured by the Location Quotient (LQ).

$$LQ_i = \frac{e_{ij} / E_j}{E_i / E} \qquad [2]$$

where e_{ij} is the employment in sector i in region j, E_j is the total employment in region j, E_i is the total employment in sector i at the EU level, and E is the total employment in EU. LQ provides information on regional specialization with respect to the EU. LQ=1 means that the regional specialization is equal to the EU specialization. LQ>1 means that the region is more specialized than the EU. The Location Quotient does not consider gender. A region can be more specialized than the EU in each industry due to the high number of employees, but those employees can belong all to the same gender. LQ will be split into two different components, the first one taking into consideration the employment of females and the second one considering the employment of males:

$$LQ_{ij} = \frac{\left(\frac{e_{Fij}}{E_j} + \frac{e_{Mij}}{E_j}\right)}{\frac{E_i}{E}} = \underbrace{\frac{\frac{e_{Fij}}{E_j}}{\frac{E_i}{E}}}_{LQ_{Fij}} + \underbrace{\frac{\frac{e_{Mij}}{E_j}}{\frac{E_i}{E}}}_{LQ_{Mij}} \qquad [3]$$

to consider regional specialization and gender in the same index. e_{Fij} is the female employment in sector i in region j, E_i is the EU employment in sector i, E_j is the regional employment and E is the EU employment. The sum of LQ_{Fij} and LQ_{Mij} is equal to the regional LQ. This decomposition allows us to consider regional specialization and regional specialization by gender. When regional specialization increases, it means that the employment in an industry rose up with respect to the EU employment. However, the LQ does not highlight whether this increase is due to increased females increase, or males. This difference is important especially in situations in which women have less opportunity to find a job, for example. The *LQ* by gender and region is shown in Figure A3 (a-e) in the Appendix.

Regional specialization can have an impact on female employment. Let us consider a region specialized in a sector in which the male share is high. If the employment will increase in the region, then the probability that the new employees will be male is high. Consequently, women will be penalized. Figures A4 (a-e) in the Appendix show the relationship between regional specialization and the employment of women. The relationship is negative when regions are specialized in the low-skilled sector, while positive when regions are specialized in the *OQ* sector. Furthermore, when regions are not specialized in industry and high-skilled labour sectors (LQ<1) the relationship between specialization and female employment is positive, that is, the closer 1 is the *LQ*, the higher is the employment of women.

So far, we have investigated the relationship between regional specialization, split between women and men, and female employment, and our descriptive results highlight a positive/negative or null relationship depending on the sector and on the regional specialization. Another step is represented by investigating the relationship between regional specialization, by gender, and dissimilarity index. Our hypothesis is that dissimilarity depends on specialization because specialization is the result of regional traditions, cultural values, human capital specialization, and so on. However, the phenomenon can be affected by reverse causality. The relationship between dissimilarity index and location characteristic is depicted in Figure A5 (a-e) in the Appendix. The relationship between *LQ* and the dissimilarity index is negative and significant between *LQlowK* for male (R^2=0.28) and *ID* and is significant and positive between *LQOQ* for women and *ID* (R^2=0.38). In the other case the R^2 is less than 0.12. Increasing regional specialization can have an impact on dissimilarity, that is, the segregation of women will increase.

The last step of the analysis consists of exploring the relationship between dissimilarity and GDP. Figure A6 in the Appendix depicted the regional GDP. Figure A7 in the Appendix shows the relationship between the dissimilarity index and GDP. The figure highlights that there are 4 clusters. The first one, the lower right, is characterized by a high GDP and low dissimilarity. The second cluster, on the right, describes regions characterized by high GDP and low dissimilarity. Regions falling in quadrant down the left experience a low GDP associated with a low dissimilarity index. The quadrant on the left describes the worst situation. Regions falling in this quadrant have a high dissimilarity index and low GDP. Finally, Figure A8 in the Appendix maps the regions by cluster.

4. Methodology and Results

Our aim is to investigate the relationship between the dissimilarity index, GDP, and regional specialization. Our strategy will be using a multinomial probit model (MNP). The MNP is used with discrete dependent variables that take on more than two outcomes that do not have a natural ordering. Moreover, the MNP model does not assume IIA. Without going through the details of the model, we are interested in the marginal effects – an increase of a regressor on the probability of selecting alternative *j*–. The marginal effects can be interpreted as follows: each unit increase in the independent variable increases/decreases the probability of selecting alternative *j* by the marginal effect expressed as a percent. In accordance with the previous paragraph our dependent variable will be obtained as follows:

Figure 1 – Relationship between ID Index and GDP

ID Index	(HL) 1	(HH) 3
	(LL) 2	(LH) 4
	GDP	

Source: Author elaborations

As described in the previous paragraph, the quadrant marked as 4 – low right – is characterized by high GDP and low dissimilarity. This is the most desirable situation because regions falling in this quadrant experience high growth with low dissimilarity. The quadrant marked 1 on the left-hand side describes the worst situation. Regions that fall into this situation have a high dissimilarity index and low GDP. The quadrant up right marked as 3 – describes regions characterized by high GDP and high dissimilarity. Regions falling in the quadrant down left marked as 2 – experience a low GDP associated with a low dissimilarity index. The combination shown in Figure 1 represents the dependent variable in our model. Our aim is to investigate the probability of experiencing high GDP and low *ID* (or a combination of them) using regional specialization, employment, and inactivity rate as dependent variable. Our equation will be as follows.

$$
\begin{aligned}
Variable = {} & LQIND_F + LQIND_M + LQCOST_F + LQCOST_M + LQLowK_F + LQLowK_M \\
& + LQHighK_F + LQHighK_M + LQOQ_F + EMP_F + EMP_M + INA_F + INA_M
\end{aligned}
$$

Where variable is the dependent variable previously described, *LQ* represents the location quotient in the different sectors divided by females and males. *LQ* is obtained as the regional average in the period 2008-2021. EMP represents the employment rate, and INA the inactivity rate obtained as the regional average in the period 2008-2021. The results for the marginal effects are shown in Table

1 in Appendix B. In Table 1, we briefly present only the sign of the significant variables:

Table 1 – Marginal Effects

$LQIND_F$		$LQIND_M$	
2._predict	Positive	2._predict	Negative
3._predict	Negative	3._predict	Positive
4._predict	Positive	4._predict	Negative
$LQCOST_M$		$LQCOST_F$	
3._predict	Positive	4._predict	Positive
4._predict	Negative		
$LQlowK_M$		$LQhighK_M$	
1._predict	Negative	1._predict	Negative
2._predict	Positive	3._predict	Positive
$LQOQ_F$		$EMPL_F$	
2._predict	Negative	1._predict	Negative
		3._predict	Positive
INA_F			
1._predict	Negative		

Source: Author's elaborations

*_ predict represents the probability that the dependent variable will assume values 1 to 4 when the dependent variable increases. If a region increases industry specialization and increases female employment ($LQIND_F$ increases) the probability that the region will have a low GDP and low dissimilarity (variable=2) or a low dissimilarity and a high GDP (variable=4) is positive and significant. On the contrary, it decreases the probability of being a region characterized by high dissimilarity and high GDP (variable=3). Increasing women's employment in industry has a positive effect on GDP and differences. When regional specialization in industry increases but increases the males' employment rather than the female's employment, the results are flipped. Considering the construction sector, the results highlight that increasing the employment of men will increase GDP and dissimilarity (variable=3) and will decrease the probability of being a region with high GDP and low dissimilarity (variable=4). On the contrary, increasing the employment of women will increase the probability of being a region with high GDP and low dissimilarity (variable=4). Increasing the specialization in the low-skilled sector has no impact when the female employment increases. This sector is characterized by an equal share of women and men. Furthermore, increasing the specialization in this sector by increasing male employment will decrease the probability of being a region with high dissimilarity and low GDP (variable = 1), but will increase the probability of being a region with low dissimilarity and low GDP (variable=2). This result is obviously related to the fact that this sector is gender equal (50%) i.e., females and males are equally distributed. Regional specialization in high-skills sectors increases the probability of being a region with a high GDP but also with a high dissimilarity (variable=3) when male employment increases. At the same time, it decreases the probability of being a region with high dissimilarity and low GDP (variable=1). Finally, increasing the employment of women in the *OQ* sector will decrease the probability of being a region with low GDP and low diversity (variable=2). An increase in female employment will increase the probability to be a region with high dissimilarity and low GDP (variable=1) and increase the probability to be a region with high dissimilarity but high GDP (variable=3). The results for different levels of inactivity and unemployment are depicted in Appendix 2. The results highlight that regional specialization matters. When a region is more specialized in industry or construction sector and the male share in that region is higher than the male share in the EU, the region has a positive probability of being characterized by high diversity and high/low GDP. When a region is more specialized in industry or construction sector and the share of women in that region is higher than the share of women in the EU, that region has a higher probability of being characterized by low diversity and high GDP.

5. Conclusions

The paper is among the first to study the relationship between regional specialization, dissimilarity, and regional economic growth. Based on empirical evidence that women and men are not employed in the same industries, gender segregation is captured by the dissimilarity index. The higher the index value, the higher is the gender segregation. Our results highlight that gender segregation differ from region to region, but there are some common characteristics among regions in the same macro-area. For example, eastern countries have low diversity and low GDP, as Baltic countries have, while Scandinavian countries have high diversity and high GDP. Family-friendly policies developed by Scandinavian countries may not overcome domestic division of labour. In accordance with the UNICEF definition Family Friendly Policies are defined as those policies that help to balance and benefit both work and family life that typically provide three types of essential resources needed by parents and caregivers of young children: time, finances, and services. Family-friendly policies can help to reduce stress and promote wellbeing, which in turn leads to better work performance. Balancing the dual demands of paid work and raising children is a common challenge of contemporary parenthood. The fundamental point, which requires a cultural shift, is represented by the transition from the concept of motherhood to the concept of parenthood. In country in which family friendly policies are applied, many women decide to have a part-time job in the public sector. Baltic countries, in contrast, are more egalitarian but more conservative and less developed than Scandinavian countries. In the Baltic countries the number of women managers is higher in the Baltic countries than in the Nordic ones. The difference is even greater in the private sector. Eastern European countries have the same behavior as the Baltic ones. These regions are a mix between a socialist legacy and capitalism. Central European regions have high GDP but can be associated with a high or low *ID* index. In conclusion, each region has its own endowments, social capital, specialization, but the *ID* index will depend also on the welfare state, like in the Scandinavian countries, and from the past legacy.

The relationship between dissimilarity and regional specialization is not univocal and depends on the sector. Consequently, regional specialization is not gender neutral. Furthermore, in regions more specialized in industry and construction, women have fewer chances to find a job because they have a lower probability of falling in these sectors. By increasing female employment in these sectors, regions will decrease the *ID* index and will have a higher probability of having a high GDP. The most desirable situation is characterized by low dissimilarity and high GDP. This situation has the highest probability when the region increases its specialization in industry or construction sector and more women are hired in those industries.

In conclusion, regional specialization, female employment, gender segregation, and regional economic growth are interrelated and intertwined through complex relationships. They are the results of cultural, welfare, economic, and social dimensions. Our hypothesis is that the combination between *ID* and GDP can be explained, in probabilistic terms, by regional specialization. The latter is considered by gender. Furthermore, the employment of women will depend on regional specialization.

Employment segregation has significant consequences for overall economic growth, household welfare, firm performance, and intergenerational social mobility. Efforts to reduce employment segregation can create a virtuous cycle in which increased female participation in high-return occupations creates more extensive networks of women and changes social norms (Das, Kotikula 2018).

From the policy point of view, twisting regional specialization is not an easy task and sometimes it is not desirable. Regional specialization is the result of history, culture, human capital, skills, and capabilities. Furthermore, redistributing employees between sectors is not easy. Consequently, switching from one situation to another, most favorable, is not simple. However, this does not mean that it is not possible to try to achieve some changes by taking advantage of social and cultural dimensions. Regional specialization, as previously highlighted, is the consequence of natural endowments, cultural beliefs, human capital education, skills, and capabilities. Eliminating exogenous barriers to women's participation in the labour market can help increase female participation in sectors where they are more segregated, such as industry and construction. Female participation in the industry sector is high in easter countries, and this result finds its roots in history. Consequently, a different way to growth and to be inclusive from a gender point of view is possible and combining growth and gender equality is not only desirable, but also possible using education and social dimensions. This paper represents one of the first contributions to regional science. It would be desirable to do more research in the field to improve the results and highlight new and more effective policies.

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Sommario

Segregazione di genere nelle regioni europee. La specializzazione produttiva è una trappola per la segregazione di genere?

Obiettivo del lavoro è quello di studiare la relazione tra segregazione di genere, specializzazione produttiva e crescita regionale. Partendo dalla evidenza empirica, ottenuta utilizzando i dati Eurostat regionali per il periodo 2008-2021, emerge che gli uomini e le donne sono occupati in settori diversi. La diversa distribuzione, che trova le sue origini in motivazioni di tipo economico, culturale, sociale e dipende anche dai regimi di welfare presenti nei diversi paesi, è catturata dall'indice di dissimilarità. Le regioni europee in cui si riscontra un maggior livello di segregazione sono le regioni scandinave mentre quelle in cui il livello di segregazione è più basso sono le regioni dell'Europa dell'Est. La relazione tra specializzazione produttiva regionale e indice di dissimilarità non è ancora stata esplorata in letteratura. La segregazione di genere può avere impatti anche sulla crescita economica regionale. I risultati evidenziano una relazione tra segregazione di genere e specializzazione regionale. Inoltre, la specializzazione regionale e la segregazione di genere hanno un impatto sulla crescita

Appendix A

Table A1 – Industries Groups NACE_2 rev classification

Industry	Mining and quarrying (B); manufacturing (C); electricity, gas, steam and air conditioning supply (D) water supply; sewerage, waste management and remediation activities (E)
Construction	Construction (F)
G-I-R-U	Wholesale and retail trade, repair of motor vehicles and motorcycles (G); transportation and storage (H); accommodation and food service activities (I); Arts, entertainment and recreation (R); other service activities (S)
J-N	Information and communication (J); financial and insurance activities (K); section l — real estate activities (L); Professional, scientific and technical activities (M); administrative and support service activities (N)
O-Q	Public administration and defense , Compulsory social security (O); education (P) ; human health and social work activities (Q)

Source: Author's elaborations

Figure A1.a – Share of Employes by Gender (average 2008-2021); Industry

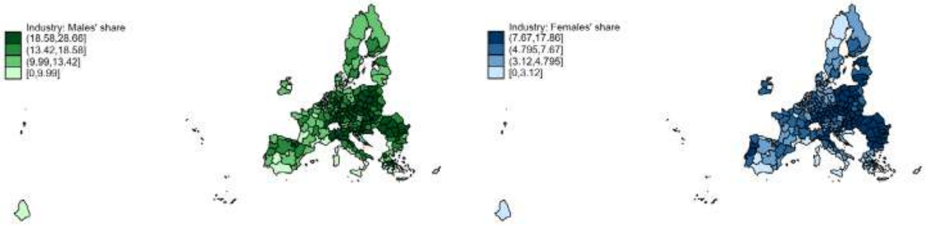


Figure A1.b – Share of Employes by Gender (average 2008-2021); Construction

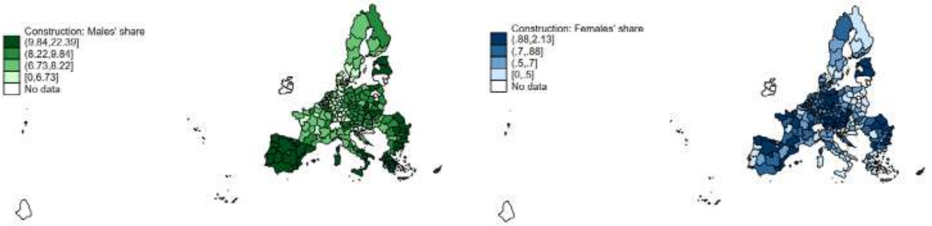


Figure A1.c – Share of Employes by Gender (average 2008-2021); Low skilled sector (G-I; R-U)

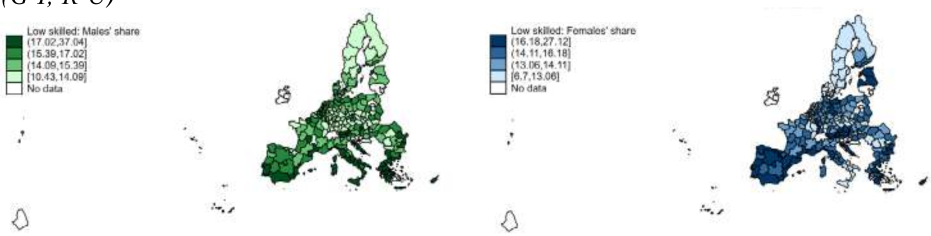


Figure A1.d – Share of Employes by Gender (average 2008-2021) High skilled sector (J-N)

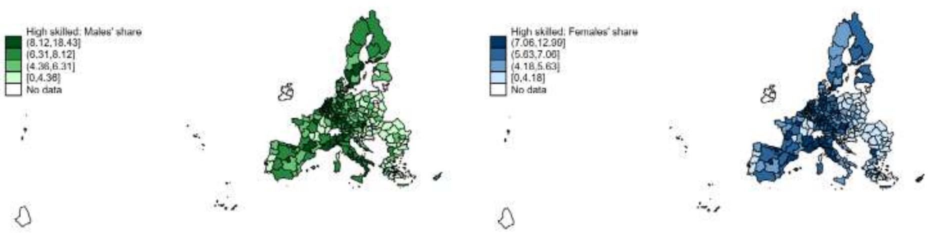
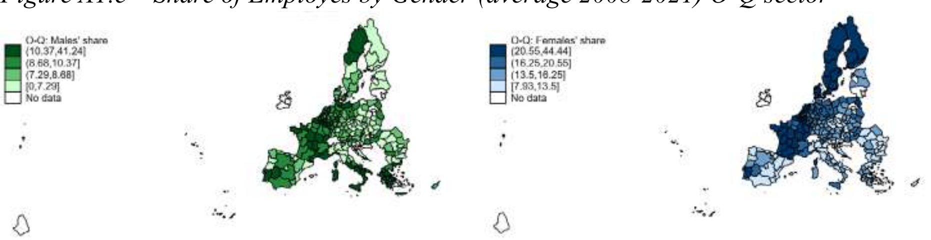
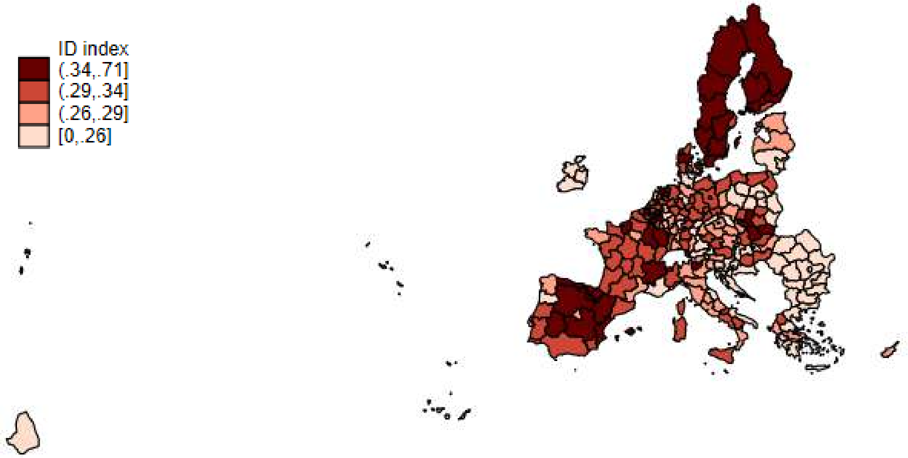


Figure A1.e – Share of Employes by Gender (average 2008-2021) O-Q sector



Source: Author's elaborations

Figure A2 – ID Index (average 2008-2021)



Source: Author's elaborations

Figure A3.a – Location Quotient: Industry; Average 2008-2021

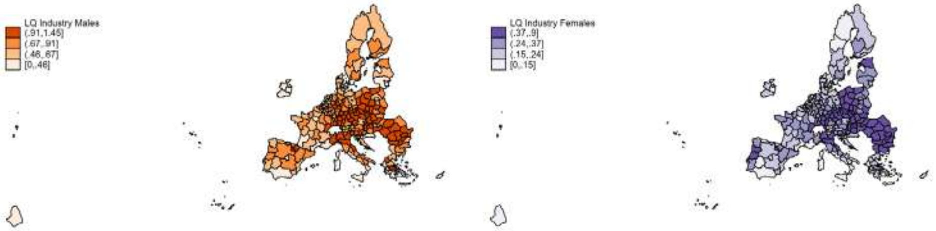


Figure A3.b – Location Quotient: Construction; Average 2008-2021

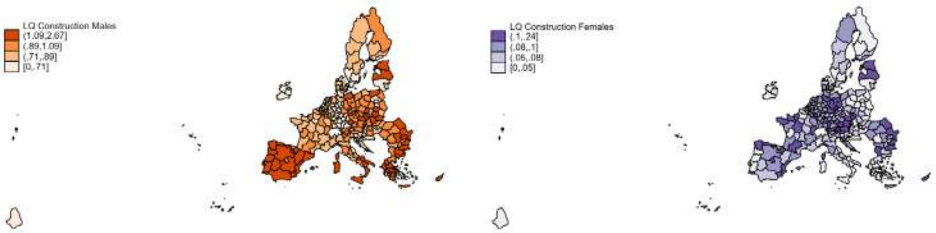


Figure A3.c – Location Quotient: Low skilled sector (G-I; R-U); Average 2008-2021

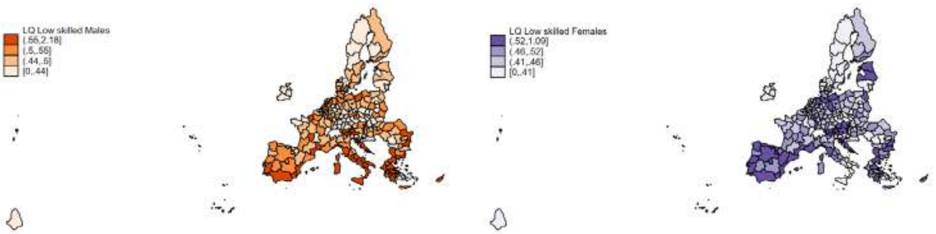


Figure A3.d – Location Quotient: High skilled sector (J-N); Average 2008-2021

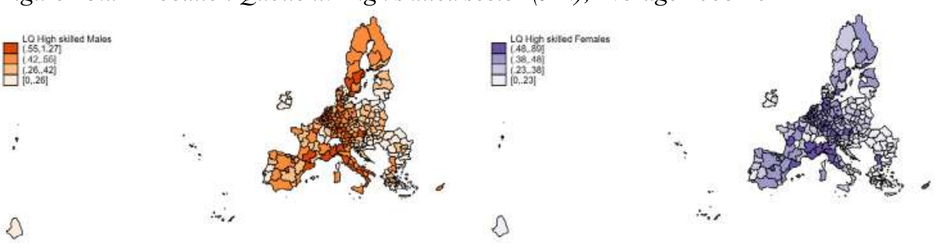
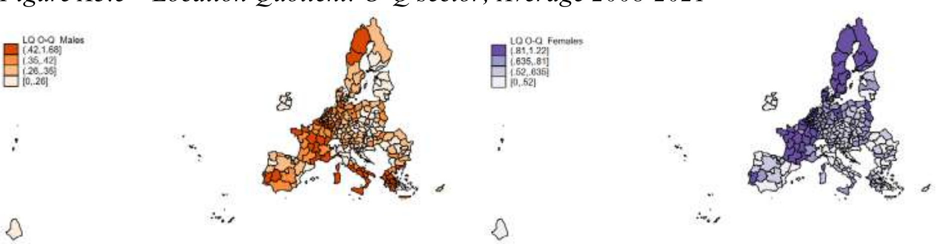


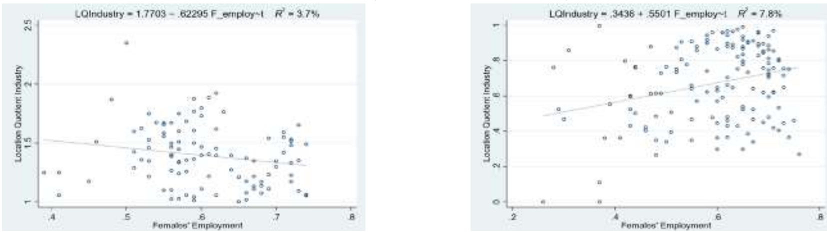
Figure A3.e – Location Quotient: O-Q sector; Average 2008-2021



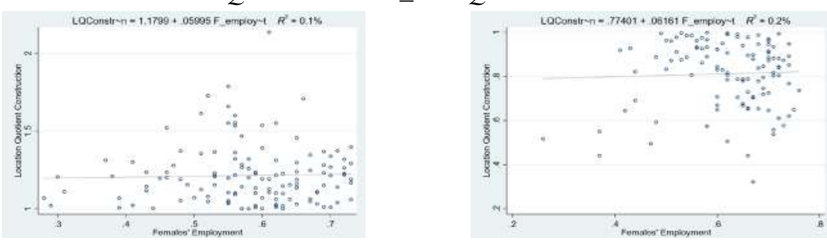
Source: Author's elaborations

Figure A4 – Relationship between Location Quotient and Females employment, 2008-2021 average

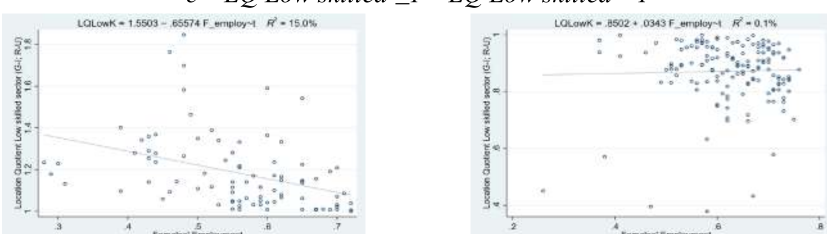
a – LQ Industry ≥1 – LQ Industry <1



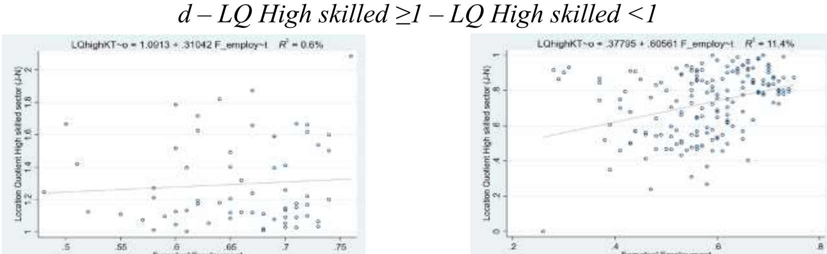
b – LQ Construction ≥1 – LQ Construction<1



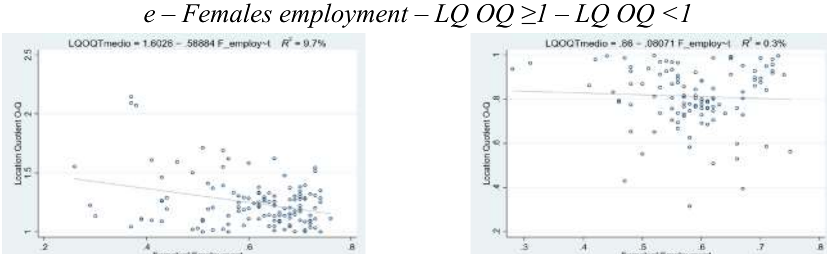
c – LQ Low skilled ≥1 – LQ Low skilled <1



d – LQ High skilled ≥1 – LQ High skilled <1



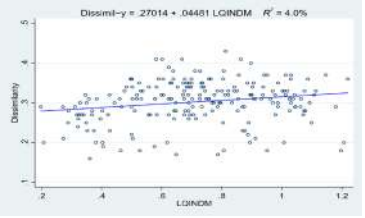
e – Females employment – LQ OQ ≥1 – LQ OQ <1

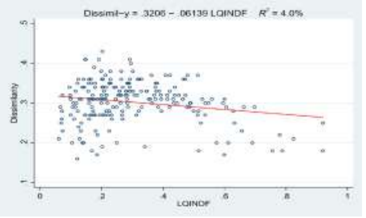


Source: Eurostat

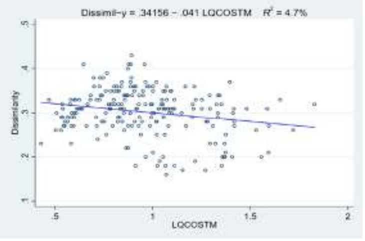
Figure A5 – Relationship between Dissimilarity and Location Quotient-O-Q 2008-2021 average

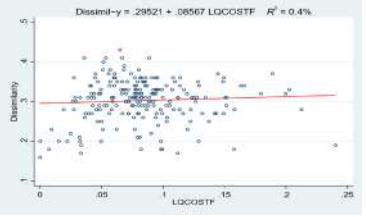
a – LQ Industry Male – LQ Industry Female



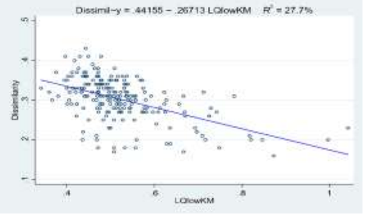


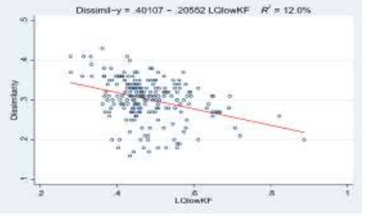
b – LQ Construction Male – LQ Construction Female



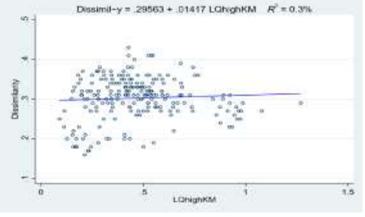


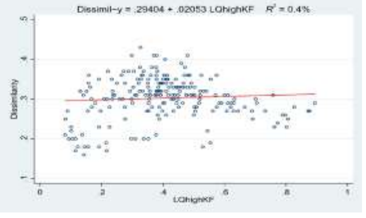
c – LQ Low skills Male – LQ Low skills Female



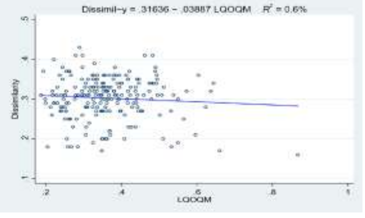


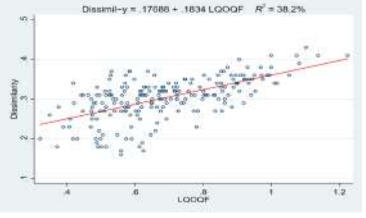
d – LQ High skilled Male – LQ High skilled Female





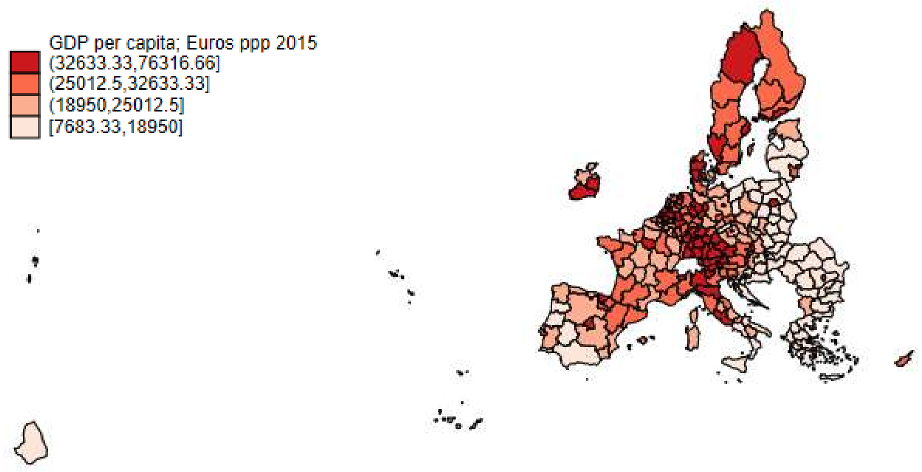
e – LQ O-Q Male – LQ O-Q Female





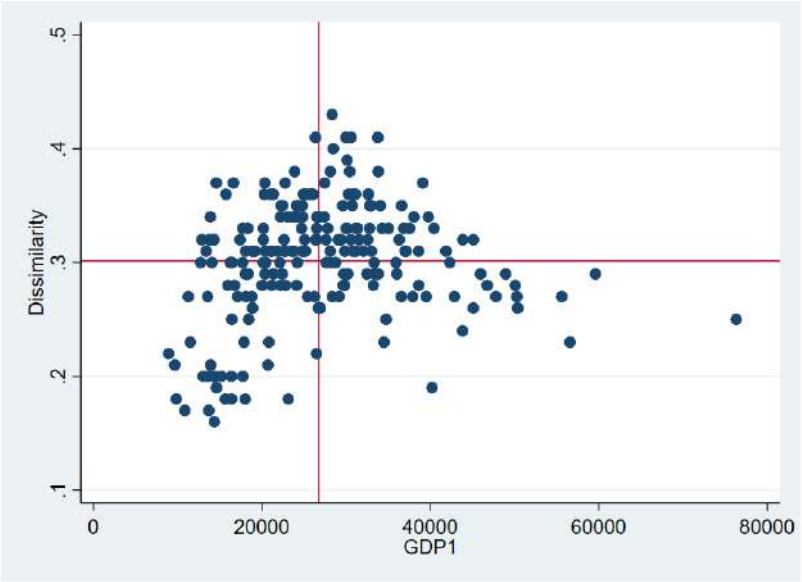
Source: Eurostat

Figure A6 – Regional GDP per capita – 2008-2021 average



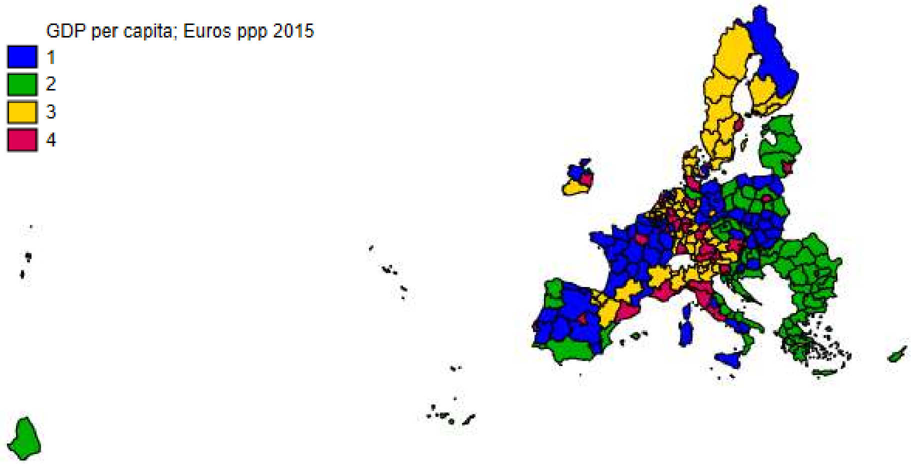
Source: Eurostat

Figure A7 – Relationship between Dissimilarity Index and GDP – 2008-2021 average



Source: Eurostat

Figure A8 – Dissimilarity Index and GDP – 2008-2021 average



Source: Eurostat

Appendix B

Table B1 – Marginal Effects

	LQINDF
1._predict	-0.0991
	(-0.29)
2._predict	0.924***
	(4.30)
3._predict	-1.718**
	(-3.01)
4._predict	0.894**
	(2.67)

	LQINDM
1._predict	-0.344
	(-1.76)
2._predict	-0.584***
	(-3.97)
3._predict	1.812***
	(6.03)
4._predict	-0.884***
	(-4.20)

	LQCOSTM
1._predict	0.167
	(1.75)
2._predict	-0.0958
	(-0.99)
3._predict	0.533***
	(3.75)
4._predict	-0.605***
	(-5.60)

	LQCOSTF
1._predict	-0.0734
	(-0.11)
2._predict	-0.376
	(-0.63)
3._predict	-0.624
	(-1.05)
4._predict	1.074**
	(2.80)

	LQlowKM
1._predict	-1.072*
	(-2.38)
2._predict	0.967*
	(2.38)
3._predict	0.749
	(1.36)
4._predict	-0.645
	(-1.51)

	LQlowKF
1._predict	-0.524
	(-1.20)
2._predict	-0.0336
	(-0.10)
3._predict	-0.171
	(-0.24)
4._predict	0.729
	(1.63)

	LQhighKF
1._predict	0.704
	(1.67)
2._predict	-0.155
	(-0.45)
3._predict	-0.755
	(-1.57)
4._predict	0.206
	(0.74)

	LQhighKM
1._predict	-0.778*
	(-2.21)
2._predict	-0.562
	(-1.72)
3._predict	1.281***
	(3.41)
4._predict	0.0591
	(0.25)

	LQOQF
1._predict	0.609
	(1.84)
2._predict	-0.553**
	(-3.23)
3._predict	0.281
	(0.44)
4._predict	-0.338
	(-1.11)

	EMPLF
1._predict	-4.635**
	(-3.16)
2._predict	-0.181
	(-0.12)
3._predict	4.954**
	(3.26)
4._predict	-0.138
	(-0.09)

	EMPLM
1._predict	1.208
	(0.94)
2._predict	0.795
	(0.62)
3._predict	-0.844
	(-0.65)
4._predict	-1.159
	(-1.02)

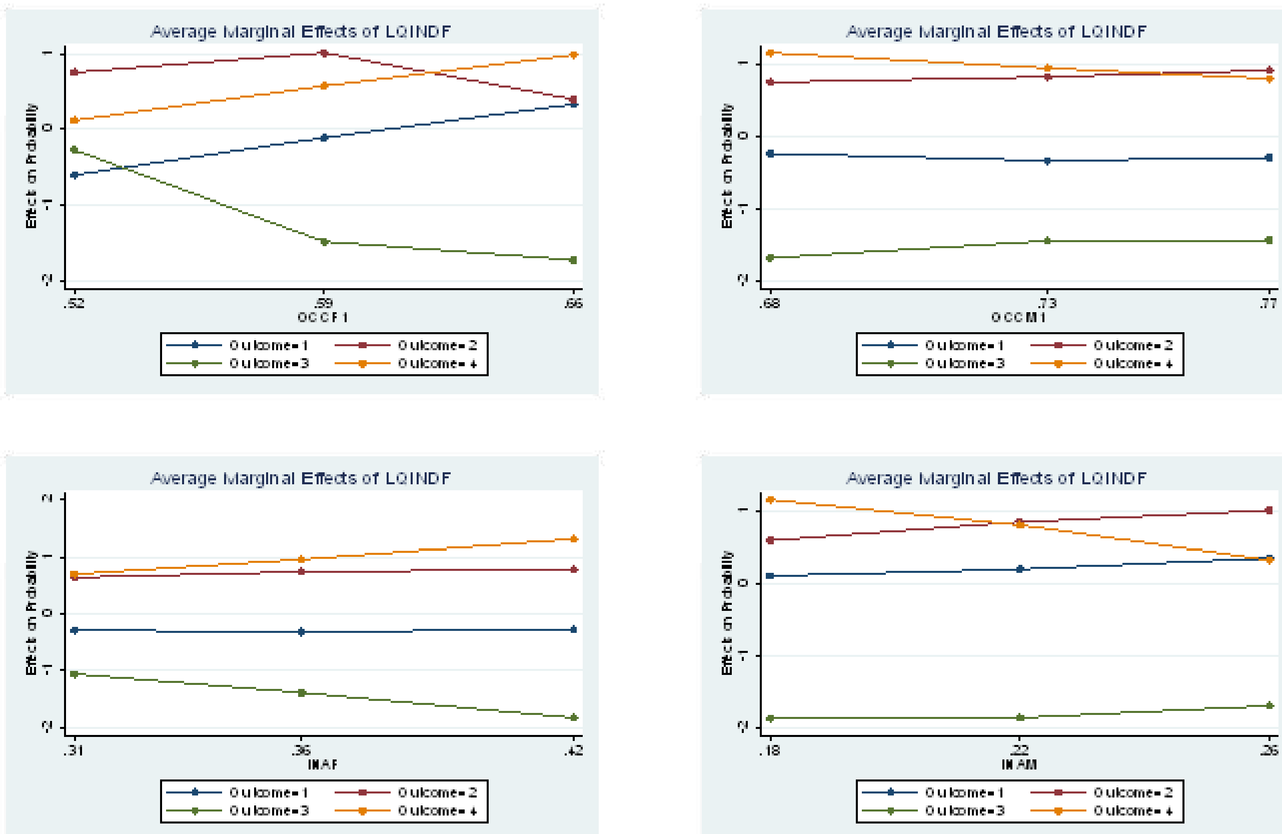
	INAM
1._predict	2.074
	(1.38)
2._predict	0.406
	(0.27)
3._predict	0.0433
	(0.03)
4._predict	-2.523
	(-1.96)

	INAF
1._predict	-4.032*
	(-2.51)
2._predict	0.318
	(0.20)
3._predict	2.175
	(1.22)
4._predict	1.539
	(0.99)
N	226

Note: t statistics in parentheses
* $p < 0.05$,
** $p < 0.01$,
*** $p < 0.001$

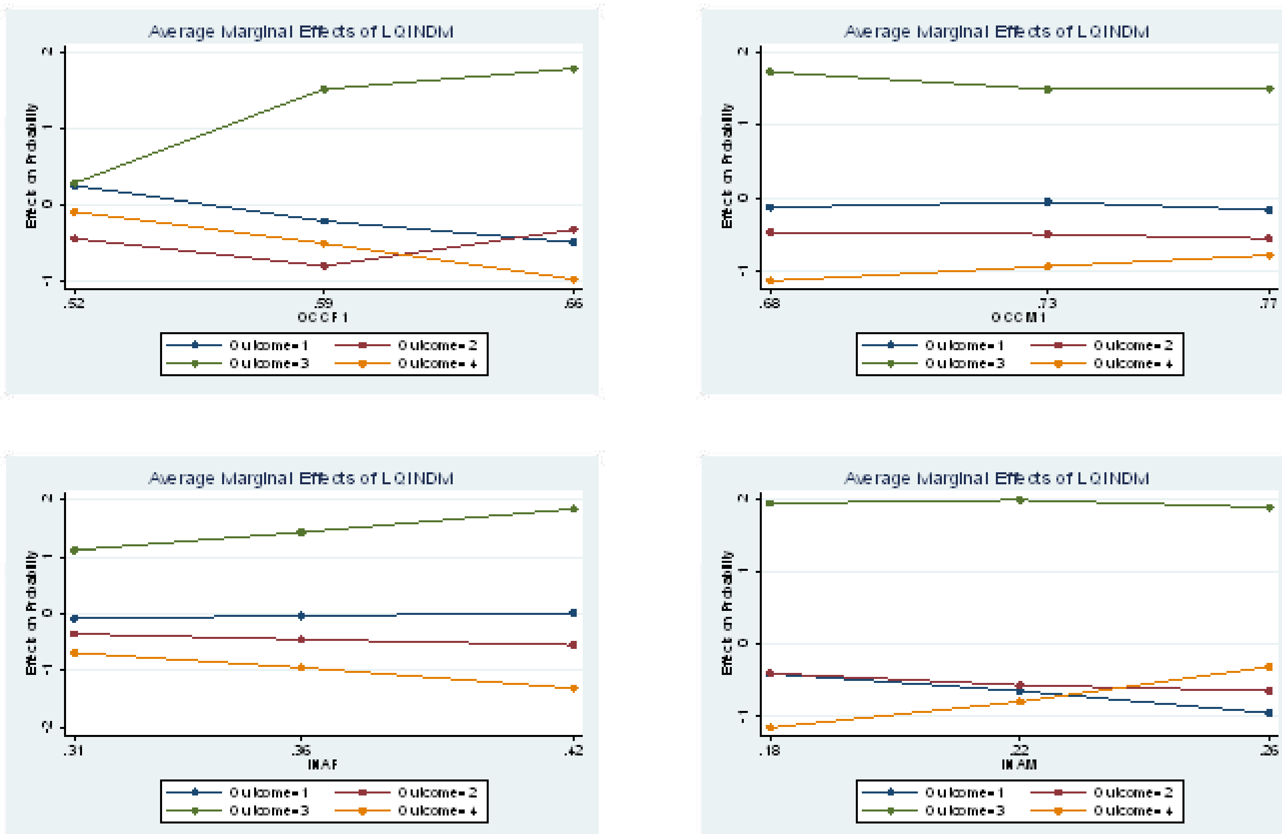
Source: Author's elaborations

Figure B1 – Marginal effects – LQINDF



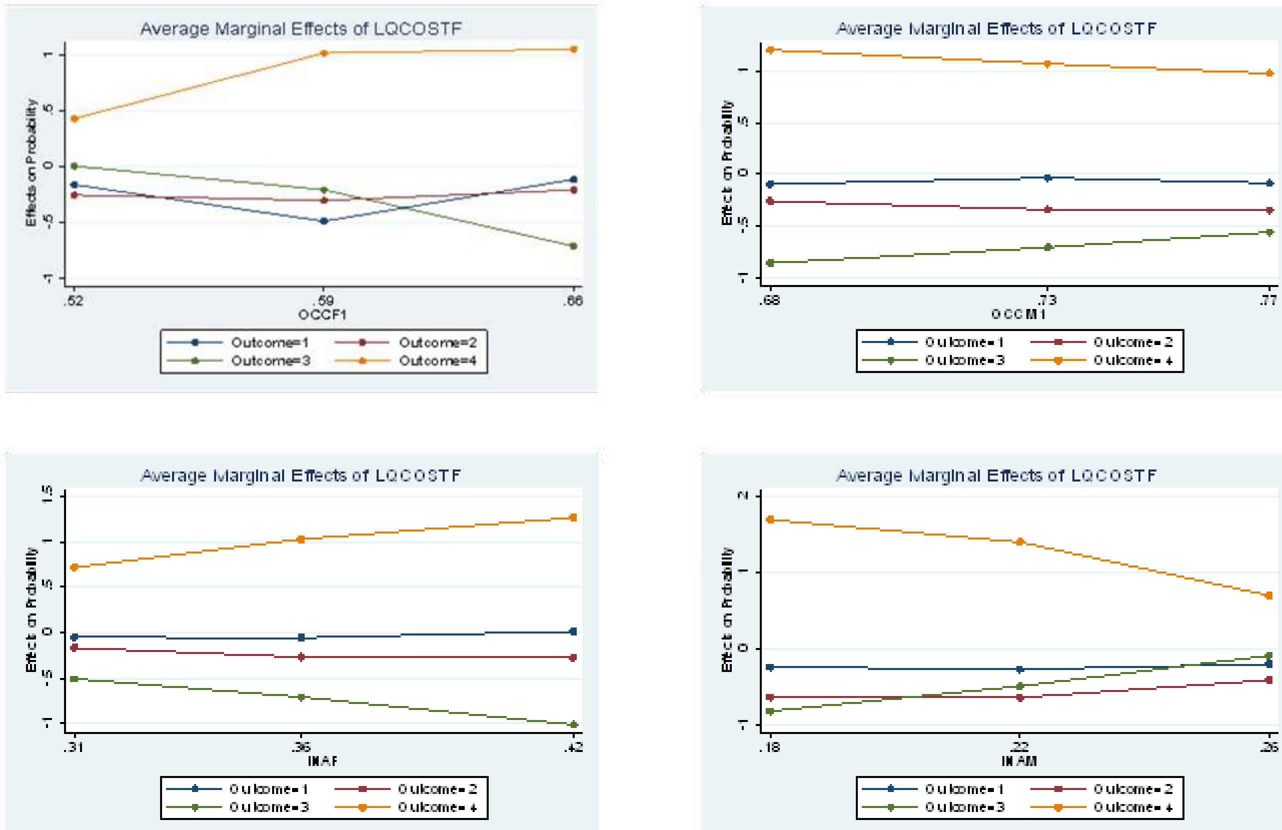
Source: Author's elaborations

Figure B2 – Marginal effects – LQINDM



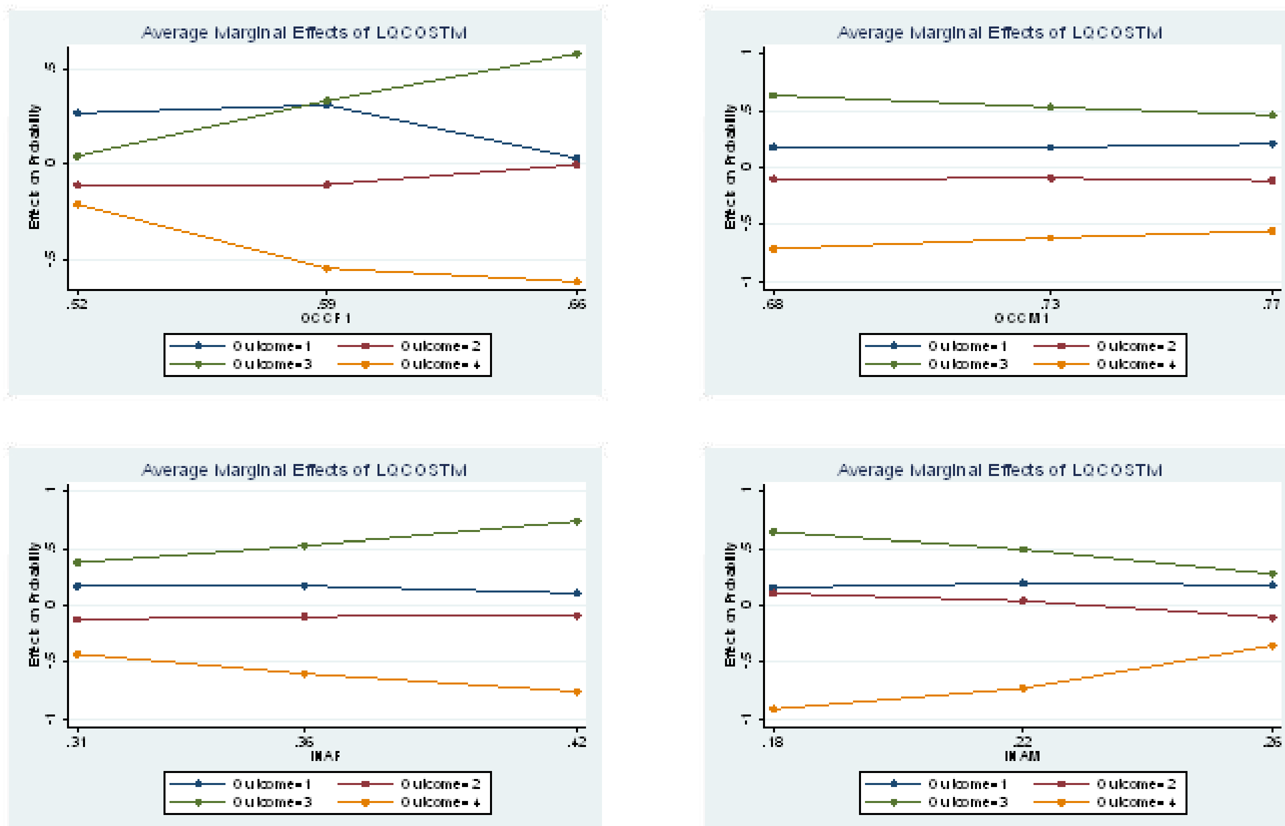
Source: Author's elaborations

Figure B3 – Marginal effects – LQCOSTF



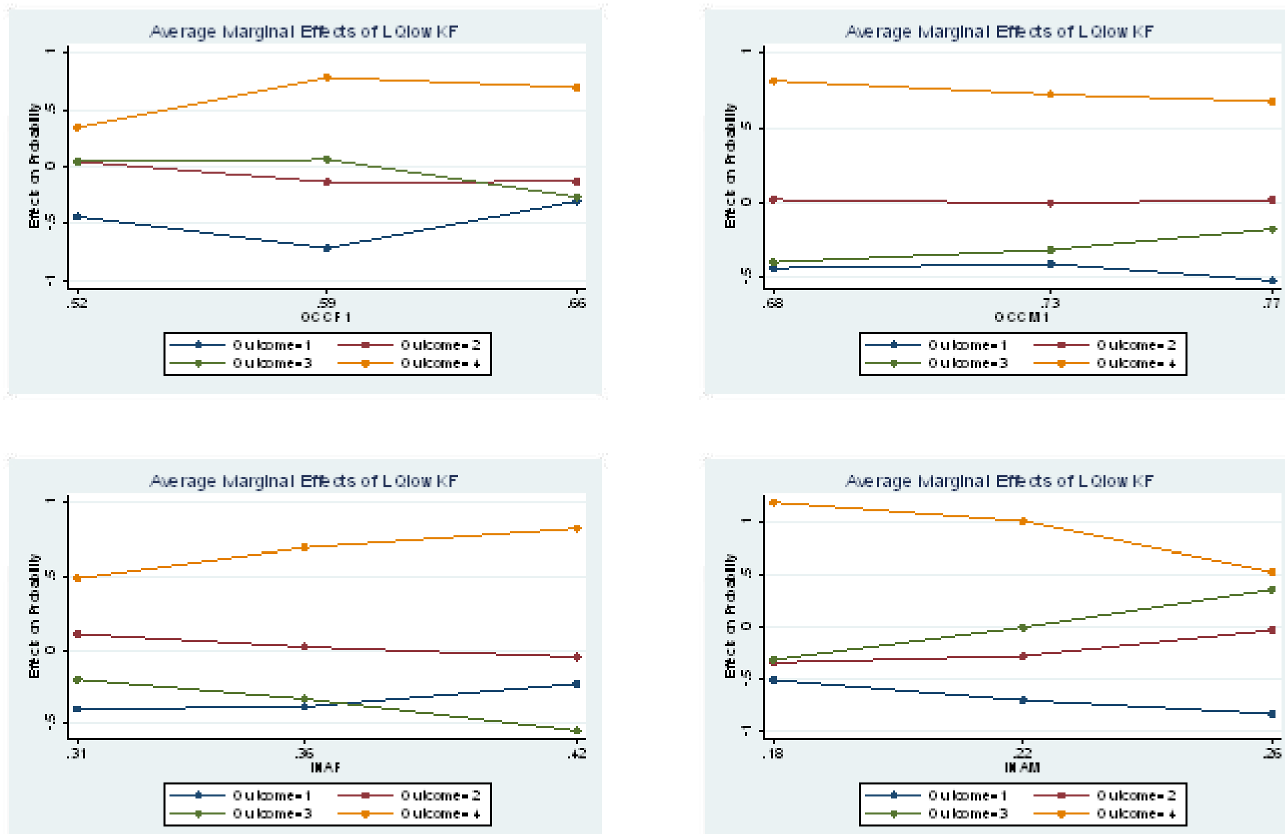
Source: Author’s elaborations

Figure B4 – Marginal effects – LQCOSTM



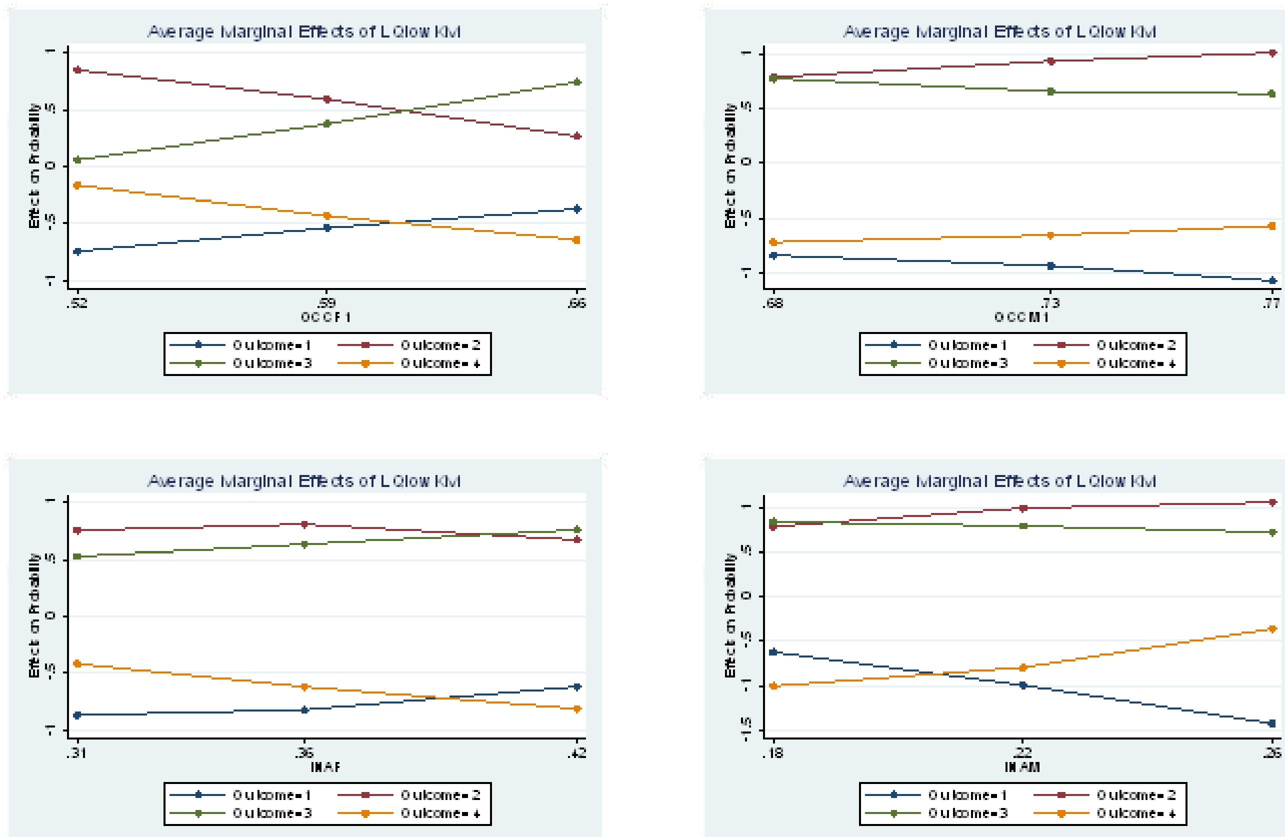
Source: Author's elaborations

Figure B5 – Marginal effects – LQLowKF



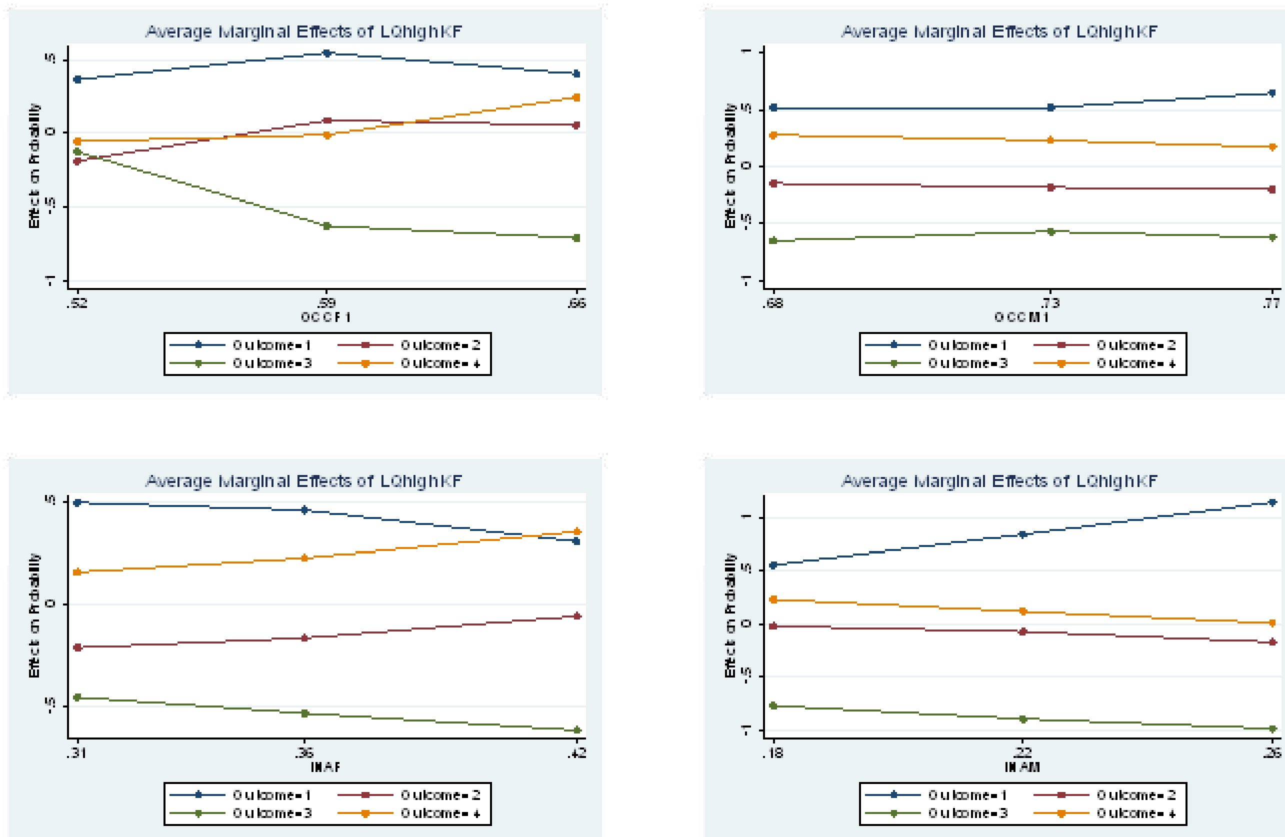
Source: Author's elaborations

Figure B6 – Marginal effects – LQLowKM



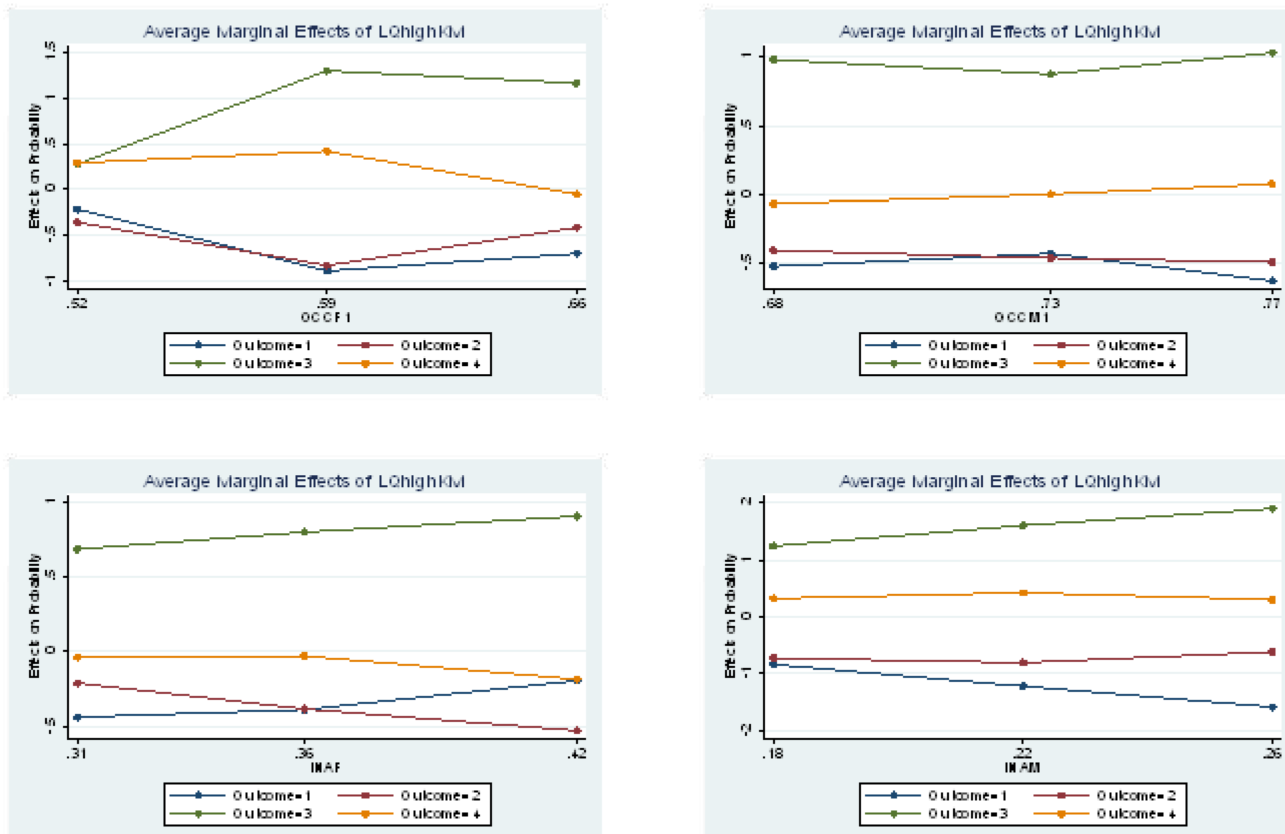
Source: Author’s elaborations

Figure B7 – Marginal effects – LQHighKF



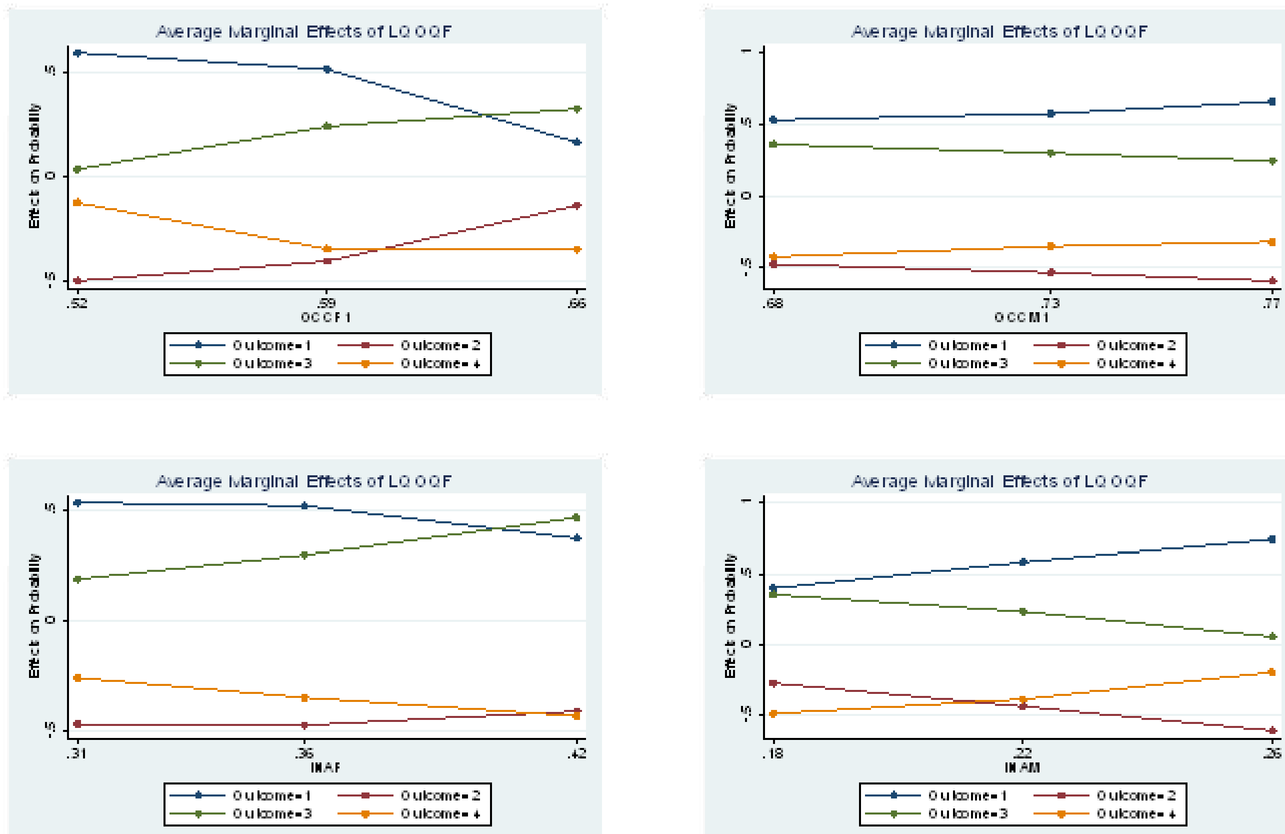
Source: Author's elaborations

Figure B8 – Marginal effects – LQHighKM



Source: Author's elaborations

Figure B9 – Marginal effects – LQOQF



Source: Author's elaborations

Table B2 – Marginal Effects

	Empl F		*Empl M*		*Ina F*		*Ina M*		*Empl F*		*Empl M*		*Ina F*		*Ina M*	
				LQindF								*LQindM*				
L	2	pos	4	pos	4	pos	4	pos	3	pos	3	pos	3	pos	3	pos
	4	pos	2	pos	2	pos	2	pos	1	pos	1	neg	1	neg/pos	2	neg
	3	neg	1	neg	1	neg	1	pos	4	neg	2	neg	2	neg/pos	1	neg
	1	neg	3	neg	3	neg	3	neg	2	neg	4	neg	4	neg/pos	4	neg
M	2	pos	4	pos	4	pos	4	pos	3	pos	3	pos	3	pos	3	pos
	4	pos	2	pos	2	pos	2	pos	1	neg	1	neg	1	neg/pos	2	neg
	1	neg	1	neg	1	neg	1	pos	4	neg	2	neg	2	neg/pos	1	neg
	3	neg	3	neg	3	neg	3	neg	2	neg	4	neg	4	neg/pos	4	neg
H	4	pos	2	pos	4	pos	2	pos	3	pos	3	pos	3	pos	3	pos
	1	pos	4	pos	2	pos	4	pos	2	neg	1	neg	1	neg/pos	4	neg
	2	pos	1	neg	1	neg	1	pos	1	neg	2	neg	2	neg/pos	2	neg
	3	neg	3	neg	3	neg	3	neg	4	neg	4	neg	4	neg/pos	1	neg
				LQCostF								*LQCostM*				
L	4	pos	4	pos	4	pos	4	pos	1	pos	3	pos	3	pos	3	pos
	3	pos/neg	1	neg	1	neg	1	neg	3	pos	1	pos	1	pos	1	pos
	1	neg	2	neg	2	neg	2	neg	2	neg	2	neg	2	neg	2	neg
	2	neg	3	neg	3	neg	3	neg	4	neg	4	neg	4	neg	4	neg
M	4	pos	4	pos	4	pos	4	pos	3	pos	3	pos	3	pos	3	pos
	3	neg	1	neg	1	neg	1	neg	1	pos	1	pos	1	pos	1	pos
	2	neg	2	neg	2	neg	3	neg	2	neg	2	neg	2	neg	2	neg
	1	neg	3	neg	3	neg	2	neg	4	neg	4	neg	4	neg	4	neg
H	4	pos	4	pos	4	pos	4	pos	3	pos	3	pos	3	pos	3	pos
	1	neg	1	neg	1	neg	3	neg	1	pos	1	pos	1	pos	1	pos
	2	neg	2	neg	2	neg	1	neg	2	neg	2	neg	2	neg	2	neg
	3	neg	3	neg	3	neg	2	neg	4	neg	4	neg	4	neg	4	neg
				LQlowKF								*LQlowKM*				
L	4	pos	4	pos	4	pos	4	pos	2	pos	2	pos	2	pos	3	pos
	3	pos	2	pos/neg	2	pos	3	neg	3	pos	3	pos	3	pos	2	pos
	2	pos	3	neg	3	neg	2	neg	4	neg	4	neg	4	neg	1	neg
	1	neg	1	neg	1	neg	1	neg	1	neg	1	neg	1	neg	4	neg
M	4	pos	4	pos	4	pos	4	pos	2	pos	2	pos	2	pos	2	pos
	3	pos	2	pos/neg	2	pos	3	neg	3	pos	3	pos	3	pos	3	pos
	2	neg	3	neg	3	neg	2	neg	4	neg	4	neg	4	neg	4	neg
	1	neg	1	neg	1	neg	1	neg	1	neg	1	neg	1	neg	1	neg
H	4	pos	4	pos	4	pos	4	pos	3	pos	2	pos	3	pos	2	pos
	3	neg	2	pos/neg	2	pos	3	pos	2	pos	3	pos	2	pos	3	pos
	2	neg	3	neg	1	neg	2	neg	1	neg	4	neg	1	neg	4	neg
	1	neg	1	neg	3	neg	1	neg	4	neg	1	neg	4	neg	1	neg

(Continued...)

(...continued)

	Empl F		Empl M		Ina F		Ina M		Empl F		Empl M		Ina F		Ina M	
				LQHighKF								*LQHighKM*				
L	1	pos	1	pos	1	pos	1	pos	3	pos	3	pos	3	pos	3	pos
	4	neg	4	pos	4	pos	4	pos	4	pos	4	neg	4	neg	4	pos
	3	neg	2	neg	2	neg	2	pos/neg	1	neg	2	neg	2	neg	2	neg
	2	neg	3	neg	3	neg	3	neg	2	neg	1	neg	1	neg	1	neg
M	1	pos	1	pos	1	pos	1	pos	3	pos	3	pos	3	pos	3	pos
	2	pos	4	pos	4	pos	4	pos	4	pos	4	pos	4	neg	4	pos
	4	pos/neg	2	neg	2	neg	2	neg	2	neg	1	neg	2	neg	2	neg
	3	neg	3	neg	3	neg	3	neg	1	neg	2	neg	1	neg	1	neg
H	1	pos	1	pos	4	pos	1	pos	3	pos	3	pos	3	pos	3	pos
	4	pos	4	pos	1	pos	4	pos	4	neg	4	pos	4	neg	4	pos
	2	pos	2	neg	2	neg	2	neg	2	neg	2	neg	1	neg	2	neg
	3	neg	3	neg	3	neg	3	neg	1	neg	1	neg	2	neg	1	neg
				LQOQF												
L	1	pos	1	pos	1	pos	1	pos								
	3	pos	3	pos	3	pos	3	pos								
	4	neg	4	neg	4	neg	2	neg								
	2	neg	2	neg	2	neg	4	neg								
M	1	pos	1	pos	1	pos	1	pos								
	3	pos	3	pos	3	pos	3	pos								
	4	neg	4	neg	4	neg	4	neg								
	2	neg	2	neg	2	neg	2	neg								
H	3	pos	1	pos	3	pos	1	pos								
	1	pos	3	pos	1	pos	3	pos								
	2	neg	4	neg	2	neg	4	neg								
	4	neg	2	neg	4	neg	2	neg								

Source: Author’s elaborations

Shattered Ground: How the 2016 Central Italy Earthquake Reshaped Business and Jobs

Diego D'Adda, Davide Di Marcoberardino°,*
Donato Iacobucci, Francesco Perugini**

Abstract

This study examines the economic consequences of the 2016 earthquake in the Abruzzo, Marche, and Umbria regions (AMU). By analyzing comprehensive municipality-level data from 2010 to 2019, our research evaluates the effects of the earthquake on local businesses and employment levels. To accomplish this, we compare the municipalities directly impacted by the disaster with those unaffected. Employing a difference-in-difference estimation method, our analysis reveals a significant initial decline in per-capita local businesses and employees in the affected municipalities, followed by a subsequent recovery in the years that followed.

1. Introduction

Extensive research has been conducted to explore the impact of earthquakes and other natural disasters on local labor market outcomes (Basile *et al.*, 2024). However, these studies have seldom combined an analysis of the effects on the local industrial structure. It is important to note that the effects of natural disasters exhibit significant heterogeneity, both across different countries and within a single country. This heterogeneity arises due to various factors, including the type and intensity of the disaster, as well as the level of economic development and institutional quality of the affected region. Notably, earthquakes differ from other economic shocks in several ways. For instance, earthquakes are more selective, meaning that some areas may remain undamaged. Additionally, earthquakes are concentrated in time and their effects are closely tied to characteristics such as magnitude and the unique

* Università Politecnica delle Marche – Dipartimento di Ingegneria dell'Informazione, Ancona, Italy, e-mail: d.dadda@univpm.it (corresponding author), d.iacobucci@univpm.it, f.perugini@univpm.it.
° Università Politecnica delle Marche – Dipartimento di Scienze Economiche e Sociali, Ancona, Italy, e-mail: d.dimarcoberardino@pm.univpm.it.

features of the impacted local areas. Consequently, earthquakes not only disrupt networks and destroy infrastructure but also have the potential to generate new opportunities for existing firms, new ventures, and employment (Boudreaux *et al*., 2023).In this paper, we look at the effects on industrial structure and employment induced by an unforeseeable natural disaster: the earthquake that hit the Central Italian regions, i.e., the Abruzzo, Marche, and Umbria (henceforth AMU) regions in 2016. We look at how the earthquake may impact on existing level of enterprise and occupation in this specific area. This paper adds to the existing literature in several ways. First, while there are several attempts to try to seize the impact of an earthquake on economic activity, or economic growth (see e.g., Barone, Mocetti, 2014; Porcelli, Trezzi, 2019) as to our knowledge there are no studies looking at the impact on both local unit and occupational level. One exemption is Basile *et al*. (2024), which however analyses the impact on employment rate in the aftermath of three earthquake episodes that occurred in Italy over the last two decades using data at a higher spatial unit of analysis than municipalities.

As a result, the second contribution of the paper is the use of very fine-grained level of data for analyzing the seismic event, i.e., data are at the municipality-level.[1] As argued by Porcelli and Trezzi (2019), seismic events are large idiosyncratic shocks at the local level, but tend to be negligible in aggregated terms, especially in advanced economies. Thus, employing national data tends to bias downwardly the estimates of their impact on economic activity. Second, seismic events are rare, and counterfactuals are often entirely absent. Moving the analysis at the municipality level allow us to overcome both shortcomings, allowing to precisely seize the local effect and use other unaffected municipalities as a reliable counterfactual. Moreover, the municipality level is an appropriate unit of analysis when studying entrepreneurship. Indeed, the literature on entrepreneurship argue that most of the factors that affect small businesses, such as regulations, institutions and norms, infrastructure, city amenities, access to finance, demand, etc., vary largely between local territories (Audretsch *et al*., 2021; Bruns *et al*., 2017; Fritsch, 2013; Ratten, 2020; Spigel, Harrison, 2018). This is specifically the case when focusing on the rural internal areas like those hit by the earthquake in the AMU regions in 2016.

The aim of this paper is to assess the impact of the 2016 earthquake in the AMU regions on employment level and on the level of existing firms, the latter measured by the number of local units. Besides assessing the impact of the shock, we aim to understand the plausible causes behind this effect. Contrasting hypothesis are at play in this case. On one hand, we would expect a reduction in terms of firms' activity and more plausible of employment level following an earthquake, due to several reasons. For example, displacement of regular activities like business services (e.g., by governmental organization), damages

1. Municipality (Comuni) level correspond to the European LAU (Local Administrative Units) level.

to production facilities and infrastructures, relocation of people due to house structural damages[2]. All these factors are likely to negatively affect both existent and nascent entrepreneurial activities. On the other hand, some "positive" consequences may also occur, potentially inducing higher entrepreneurial rates. For example, supporting/incentives schemes are likely to be set right after the natural disaster to boost local recovery. Moreover, an earthquake may induce positive demand shocks, for example related to the reconstruction and the reparation of damaged buildings and infrastructures. In addition, self-employment may also be a response to job loss by those people employed in ceased activities.

To analyze these dynamics, we use data on the number of Local Units (LU) and Employees (Emp) in the municipality, controlling for its population. The source of the data is the Statistical register of active enterprises (ASIA – Enterprises) and the Statistical register of enterprises' occupation (ASIA – Employment). These datasets are provided by ISTAT, the Italian National Institute of Statistics. Using difference in difference estimation method, we find that in the municipalities in the affected area the per-capita level of local units and employment falls in the year right after the earthquake, but then increased in the subsequent years the seismic event.

The paper is structured as follows. Section 2 review the literature; section 3 presents the data and the methodology used; section 3 provides the descriptive statistics and presents the results; section 4 summarizes the conclusions.

2. Literature Review

The body of literature delving into the impact of earthquakes and natural hazards on the labor market is extensive. As for the literature on earthquakes, researchers have widely examined the impact of major earthquakes on local labor markets. Basile *et al.* (2024) focused on Italy, employing Local Labour Market Areas (LLMAs) to understand the impacts on the 2009 earthquake in L'Aquila, the earthquake that occurred in 2012 in Emilia-Romagna, and the earthquake in 2016 in Central Italy. Remarkably, the earthquake in 2009 exhibited a substantial and persistent negative impact on the employment rate, whereas no discernible effects were observed for the other two seismic events. Further exploring the aftermath of the 2009 earthquake, Di Pietro and Mora (2015) found a reduction in the likelihood of employment for a period of nine months after the event.

There are also some empirical works at international level. For instance, Ohtake *et al.* (2012) studying the Great Hanshin-Awaji earthquake (1995) in Japan, identified a decline in job placements for part-time workers and a deceleration in the

2. Please note that also positive effects may be induced in the area where people are relocated. In other words, the treatment may generate external effects especially in those municipalities that have been destinations for the displaced individuals after the earthquake.

growth of job placements for full-time workers. Delving into the topic in the Chilean context, Jiménez Martínez *et al*. (2020), demonstrated that regions most severely impacted by earthquakes are likely to experience more adverse effects on employment. If not promptly addressed, these effects can persist in the months following the seismic event. In contrast, Kirchberger (2017) discovered that individuals residing in regions of Indonesia affected by earthquakes exhibit remarkable resilience in labour market outcomes, despite the magnitude of such substantial shocks. In a comprehensive examination of labor market effects across Ecuador, Chile, and Italy, Mendoza *et al*. (2020) observed an increase only in worked hours for females in Italy, for both males and females in Ecuador, while no significant effects are found in Chile. These noteworthy differences can be attributed to the institutional context, economic trends, and governmental responses to the events. Additionally, also gender has a crucial role in the aftermath of such events, a conclusion consistent with the findings of Di Pietro and Mora (2015).

Researchers have also investigated the impact of other natural hazards on the labour market. However, most of the studies do not focus on the Italian case. For instance, Coffman and Noy (2012) studying a hurricane impacting a Hawaiian island, observed a substantial and prolonged increase in unemployment that persisted for several months following the event. Supporting this, Belasen and Polachek (2009) observed that hurricanes lead to a reduction in employment within the affected counties, accompanied by an increase in labor supply in neighbouring counties. In a related vein, Deryugina *et al*. (2018) discovered a short-term negative impact on employment following a disaster, with wealthier countries exhibiting greater resilience in the long term. In addition, Bondonio and Greenbaum (2018) identified a detrimental effect on employment persisting even one year after the occurrence of the event. Moreover, Roth Tran (2020) and Skidmore and Toya (2002) both identified an increase in employment after a disaster. Leiter *et al*. (2009) specifically found a significant increase in employment growth in the aftermath of a major flood. On a related note, Porcelli and Trezzi (2019) observed a comparatively weak and transitory impact on employment, which was reabsorbed within a span of two years, in Italy and USA respectively. Di Pietro and Mora (2015) and Rodriguez-Oreggia *et al*. (2013) highlight that highly educated individuals tend to experience more pronounced adverse effects in the labor market compared to their less educated counterparts. In contrast, Budina *et al*. (2023) assert an opposing perspective, suggesting that the detrimental impacts on the labor market following disasters are more prevalent among individuals with lower levels of education.

Focusing on firms activity, Boudreaux *et al*. (2019) and Brück *et al*. (2011) underscored a noteworthy correlation between the incidence of natural disasters and a subsequent decline in start-up endeavors. These findings posit that natural disasters serve as discouraging factors for firms' activity in the aftermath. Moreover, Boudreaux *et al*. (2023) revealed a negative but insignificant relationship between the severity of natural disasters and start-up activity. They have also emphasized that in situations where the quality of institutional governance is high, entrepreneurs tend to capitalize on the business opportunities that may arise in the wake of a disaster. A positive effect on entrepreneurs' behavior is confirmed also by Monllor and Altay (2016), who consider natural disasters as a source of creative destruction.

Overall, the literature does not provide conclusive evidence about the short and medium-term impacts on the economy of natural disasters. The effects are highly dependent on the type of shock and the characteristics of the impacted territories. As a result, the aim of this paper is to assess the short and medium-term impact of the 2016 earthquake in the AMU regions. Specifically we look at the short (one year) and medium-term (three years) effects of the earthquake on the stock of employees and the stock of firms at municipality level.

3. Data and Methodology

Our dependent variable is the number of Local Units (LU) and Employees (Emp) over the resident population, between 18 and 65 years, in the municipality (labelled *LU_op* and *EMP_op*, respectively).

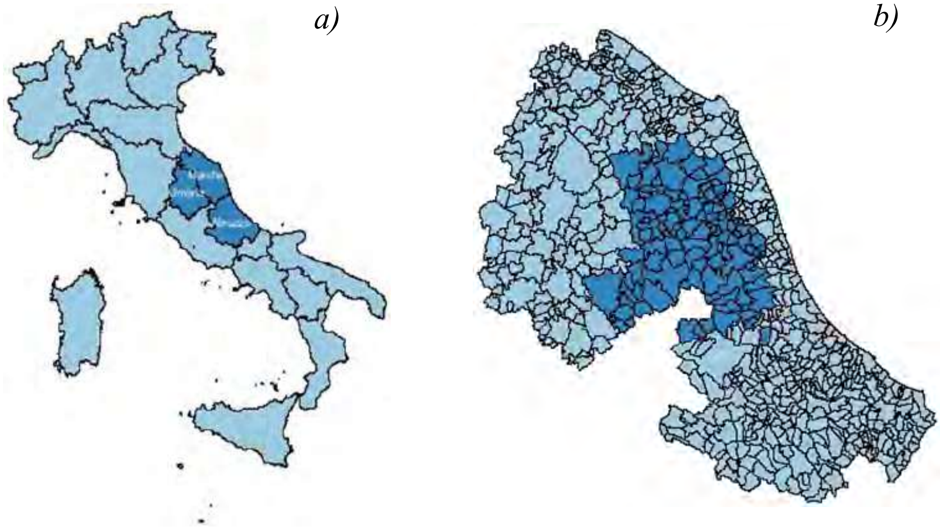
To assess the treatment effect of the earthquake on these variables and provide a possible causal relationship several estimation methods can be used, such as the Lagged dependent variable approach, the Propensity score matching, or the Synthetic control method. These methods rely on the assumption that, in the absence of treatment, the expected outcomes for the treated and control groups would have been the same, conditional on their past outcomes and covariates. This is 'independence conditional on past outcomes' (O'Neill *et al*., 2016). In this paper we use the Difference in difference (DiD) estimation method, which assumes that, in the absence of treatment, the average outcomes for the treated and control groups would have followed parallel trends over time (Abadie, 2005).

Our specification models is:

$$Y_{it} = \beta_0 + \beta_1\ after + \beta_2\ affected + \beta_3\ after * affected + \beta_4\ F_i + \varepsilon_{it} \qquad [1]$$

where Y_{it} is either the number of Local Units (*LU_op*) or the number of Employees (*EMP_op*) over the resident population; *affected* is a dummy variable equal to 1 for those municipalities included in the 2016 earthquake affected area (see Figure 1); *after* is a dummy variable equal to 1 after 2016, when we aim to observe the effects after / caused by the seismic event. Finally, F_i are the fixed effects at municipal, province NUTS-3 and regional NUTS-2 level, and ε_{it} is an error term. We also estimate the model in log terms, so the estimated coefficients in equation (1) are the elasticities.

Figure 1 – NUTS-2 Italian Regions (Panel a) and Municipalities within the 2016 Earthquake Affected Area (darker areas) in the Abruzzo, Marche, and Umbria (AMU) Regions (Panel b)



Source: Authors' elaborations

Our study encompasses the entire population of municipalities in the Abruzzo, Marche, and Umbria regions, with yearly observations from 2010 to 2019. We specifically compare the municipalities located within the affected area, which experienced significant impacts from the earthquake, with the unaffected municipalities in the same regions. To establish a counterfactual scenario, we treat the municipalities outside the affected area as a comparison group, assuming that their employment and industrial dynamics would have followed a similar pattern to those within the affected area had the earthquake not occurred.

4. Descriptive Statistics and Empirical Results

Figure 1 shows the geographical location of the municipalities hit by the earthquakes within the AMU regions. It is clear how majority of the municipalities is in the Marche region (75% of the total), while the remaining are equally distributed between Abruzzo and Umbria. The summary statistics about the variables observed in 619 municipalities for 10 years, from 2010 to 2019 are in Table 1. There is also a low level of correlation among the variables used for the estimation (Table 2).

Figure 2 shows the yearly dynamics in the level of Local Units (*LU_op*) (a) and Employees (*EMP_op*) (b) over the resident population in the whole region

(a) There are two interesting points to notice. First, for both variables the dynamics between municipalities inside and outside the affected area are very similar before 2016, which is a relevant precondition for the validity of the estimation approach used. Second, the number of *LU_op* increased right after the seismic event especially in the municipalities inside the affected area. The increase in the number of Local Units has been mainly driven by the municipalities in the Marche region (see panel d). A higher level in the aftermath of the seismic event can also be observed in the municipalities in the Abruzzo and Umbria regions, both inside (d) and outside (c) the affected area. As for Employees (*EMP_op*), there are less remarkable differences in the trends observed after 2016 for municipalities inside and outside the affected area (see panel b). Indeed, in both

Table 1 – Summary Statistics

	est1					
	obs	*mean*	*sd*	*median*	*min*	*max*
LU_op	6,190	0.117	0.035	0.114	0.000	0.469
EMP_op	6,190	0.346	0.200	0.311	0.000	2.346
lnLU	6,321	4.968	1.543	4.883	0.000	9.685
lnEMP	6,321	5.928	1.797	5.936	0.000	10.931
lnpop	6,190	7.193	1.362	7.089	3.466	11.546
affected	6,320	0.184	0.387	0.000	0.000	1.000
after	6,321	0.299	0.458	0.000	0.000	1.000

Source: Authors' elaborations

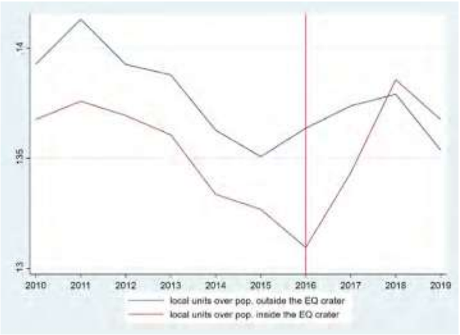
Table 2 – Correlation Table

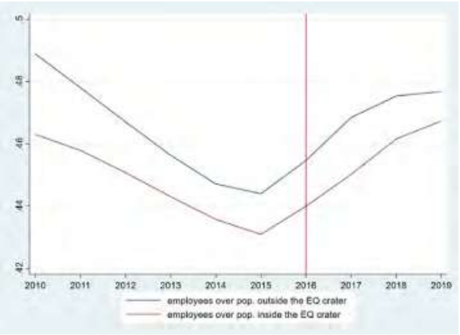
Variables	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
(1) LU_op	1.000						
(2) EMP_op	0.627	1.000					
(3) lnLU	0.456	0.505	1.000				
(4) lnEMP	0.463	0.628	0.981	1.000			
(5) lnpop	0.283	0.411	0.981	0.957	1.000		
(6) affected	0.052	-0.026	-0.074	-0.074	-0.094	1.000	
(7) after	-0.005	0.012	-0.018	-0.013	-0.018	-0.000	1.000

Source: Authors' elaborations

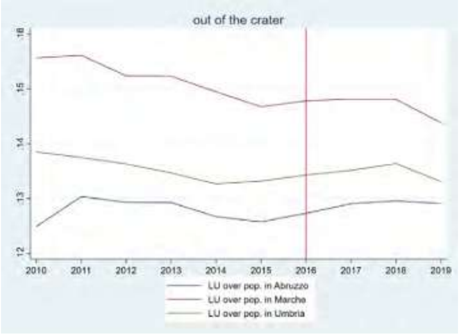
Figure 2 – New Established Firms Over Population (between 18 and 65 years old) by year

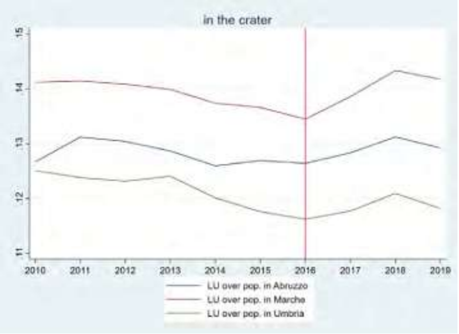
a) Local units *b) Employees (in local units)*
over population in the Abruzzo, Marche and Umbria regions



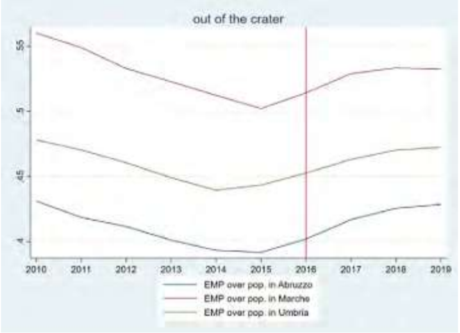


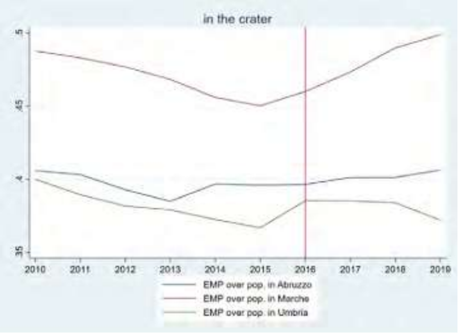
Local units over population by region, taking into consideration the municipalities
c) outside of the affected area *d) inside the affected area*





Employees over population by region, taking into consideration the municipalities
e) outside of the affected area *f) inside the affected area*





Source: Authors' elaborations

groups of municipalities, the level of employees increases. However, in the case of Marche and Abruzzo differences in the level Employees (*EMP_op*) between municipalities outside (f) and inside the affected area (e) are more evident.

In Table 3, we report the results of the model of our analysis adopting a difference in difference (regression based) model estimated with the inclusion of fixed effects at the municipality level and standard errors clustered at the municipality level. We also include fixed effects at the year and province level, to further control for unobserved variables. Our findings indicate a not significant impact on Local Units over the population (18-65) when examining the overall effect during the 2017-2019 period. However, distinct patterns emerge when we look on a yearly basis. Specifically, a negative effect is estimated for 2017, while positive results are estimated for 2018 and 2019.

Moving to columns 3 and 4, we replicate the analysis by using the number of employees in the Local Units over the entire population. The outcomes are very close to the previous analysis, revealing an overall negligible effect across the entire 2017-2019 period, with significant effects observed specifically in 2017 and 2019. In 2017, a negative impact is identified, while in 2019, a positive effect is found. The results for 2018 show statistical insignificance.

Conducting the same analysis using the logarithms of the previous variables – Local Units and number of employees (columns 5-8) – reveals an absence of any significant effect, both across the aggregate period and on a yearly basis. Conversely, a notably significant negative effect emerges when focusing on the population (represented by the logarithm of population). We find a negative impact both throughout the entire 2017-2019 period and on a yearly basis for 2017, 2018 and 2019.

5. Conclusions

This paper assessed the impact of the earthquake that hit Central Italy in 2016 on firms and employment level. The paper used data at municipality level for the Abruzzo, Marche, and Umbria (AMU) regions and estimated the impact with a difference in difference approach.

When considering the overall three-years period after the earthquake the shock has not a significant impact on the levels of firms and employees in the affected municipalities. However, the picture changes when analysis the dynamics within the period. The results of the difference-in-difference estimates show that the seismic event was initially detrimental for the municipalities inside the affected area, both in terms of the stock of firms and employees. Moreover, the seismic shock has a positive impact on the level of local units and employees starting from two or three years after the event.

Table 3 – Estimating EQ effects on local units, employees and population – Difference in difference model

	(1) *LU_op* *b/se*	*(2)* *LU_op* *b/se*	*(3)* *EMP_op* *b/se*	*(4)* *EMP_op* *b/se*	*(5)* *lnLU* *b/se*	*(6)* *lnLU* *b/se*	*(7)* *lnEMP* *b/se*	*(8)* *lnEMP* *b/se*	*(9)* *lnpop* *b/se*	*(10)* *lnpop* *b/se*
affected_area=1	-	-	-	-	-	-	-	-	-	-
after=1	-	-	-	-	-	-	-	-	-	-
affected_area =1 # after=1	0.001		0.003		0.026		0.033		-0.016 ***	
	(0.001)		(0.005)		(0.039)		(0.048)		(0.005)	
affected_area =1 # after=1 # Year=2017		-0.003 **		-0.010 **		-0.006		-0.010		-0.008 *
		(0.001)		(0.005)		(0.039)		(0.047)		(0.005)
affected_area =1 # after=1 # Year=2018		0.002 *		0.007		0.031		0.044		-0.017 ***
		(0.001)		(0.005)		(0.040)		(0.048)		(0.005)
affected_area =1 # after=1 # Year=2019		0.005 ***		0.012 **		0.052		0.066		-0.022 ***
		(0.001)		(0.006)		(0.041)		(0.050)		(0.006)
constant	0.117 ***	0.117 ***	0.346 ***	0.346 ***	4.967 ***	4.967 ***	5.928 ***	5.928 ***	7.193 ***	7.193 ***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)	(0.002)	(0.003)	(0.003)	(0.000)	(0.000)
N. observations	6190	6190	6190	6190	6320	6320	6320	6320	6190	6190
N. municipalities	619	619	619	619	636	636	636	636	619	619
N. municipalities in the affected area	113	113	113	113	116	116	116	116	113	113
R2	0.932	0.932	0.955	0.955	0.955	0.955	0.949	0.949	0.999	0.999
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Province FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Model	FE	FE	FE	FE	FE	FE	FE	FE	FE	FE

Note: Standard errors in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

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Sommario

La terra trema: come il terremoto del 2016 nel centro Italia ha influenzato attività economiche e posti di lavoro

Questo studio analizza le conseguenze economiche in Abruzzo, Mache e Umbria (AMU) del terremoto del 2016. Sfruttando dati relativi a tutti i comuni dal 2010 al 2019, il nostro lavoro valuta quelli che sono stati gli effetti del terremoto sulle attività economiche e sui livelli di occupazione. Per fare questo, confrontiamo i comuni direttamente colpiti dal sisma con quelli non interessati dallo stesso. Attraverso un modello difference-in-difference, la nostra analisi mostra un significativo calo del numero di attività economiche pro-capite e dell'occupazione nei comuni colpiti, con però un recupero negli anni immediatamente successivi.

The Geography of Green Innovation in Italy

Adriana C. Pinate, Martina Dal Molin*, Maria Giovanna Brandano**

Abstract

This paper aims to analyse the specialization and geographical patterns of green innovation in Italy. The study utilises patent application data from 2019 to map green-related technologies by integrating three different approaches to identify green patents using their code classification: the IPC Green Inventory, the ENV-TECH and the Y02/Y04S Tagging scheme. Data is aggregated at the Local Labour Systems level and includes mapping green innovations along the urban gradient and examining spatial dependence using measures of global and local spatial autocorrelation. Results emphasize significant disparities in regional green innovation within Italy, in terms of the "North-South" divide and "urban non-urban" gradient.

1. Introduction[1]

According to the United Nations Environment Programme (UNEP) a "Green Economy" is one that significantly reduces environmental risks and ecological scarcity while improving human well-being. In green economy discourse, green innovation plays a central role to ensure environmental sustainability and economic growth (Galliano *et al*., 2023; Losacker *et al.*, 2023a; Sheng, Ding, 2023; Wang *et al.*, 2021; Mazzanti, 2018; Antonioli *et al*., 2016). At the more general level, green innovation (sometimes also referred as "eco-innovation") is defined as a new technological paradigm involving the creation of novel concepts, products, services, procedures, and managerial frameworks, while adhering to ecological principles and that prevents, eliminates, or mitigates environmental problems (Favot *et al.,* 2023; Galliano *et al*., 2023; Zhou *et al*., 2021; Antonioli *et al*., 2016; Kemp, 2010; Rennings, 2000).

* Gran Sasso Science Institute, L'Aquila, Italy, e-mail: adriana.pinate@gssi.it, martina.dalmolin@gssi.it, mariagiovanna.brandano@gssi.it (corresponding author).

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Green innovation, as a fundamental issue for green growth, has been studied from a variety of perspectives, such as, technology push and market pull factors (Montresor, Quatraro, 2020; Zhang *et al.*, 2019), path development (Trippl *et al.*, 2020; Grillitsch, Hansen, 2019), their effect on both sustainability transition (Rohe, Chlebna, 2021) and firm performance (Marin-Vinuesa *et al.*, 2020; Antonietti, Cainelli, 2011). However, the regional and local viewpoint has been only scantly addressed, even though regions are the key place in which green innovations are developed (Galliano *et al.*, 2023; Losacker *et al.*, 2023a; 2023b), fostering, in turn, regional development (Sun *et al.*, 2020; Belik *et al.*, 2019). Put simply, in Losacker *et al*. (2023) words "*the regional studies community lacks a critical overview of the importance of regions in the development and diffusion of environmental innovations*" (Losacker *et al*., 2023b, p. 293).

Starting from this premise, the aim of this paper is twofold: *i*) to analyse the specialisation of the Italian regional green innovation and *ii*) to understand its geographical patterns of localization. To do that, we use local stocks of green-related patent applications based on the integration of the three different existing methodologies. Indeed, as suggested by Favot *et al.* (2023) the mutual integration of data identified by the World Intellectual Property Organization (WIPO), the Organisation for Economic Co-operation and Development (OECD), and European Patent Office (EPO), is recommended.

Patent application data come from the OECD-REGPAT database and refer to 2019. Given the significant impact of the pandemic on the Italian economy (Bruni *et al*., 2023; Cepparulo, Jump, 2022), and the correlation between innovation and economic growth (Fagerberg, Mowery, 2006), we decided to use the pre-COVID year to obtain a more realistic view of the geographical distribution of green innovations in Italy. The patent data are considered a good proxy for technological green innovation (Favot *et al*., 2023; Ghisetti, Quatraro, 2017). Data used provide information on the respective International Patent Classification (IPC) and Cooperative Patent Classification (CPC) codes and are linked to regions and the addresses of patents' applicants and inventors. The data are available at a NUTS-4 level and they were then aggregated at Local Labour Systems (LLSs). LLS represents a territorial grid whose boundaries are defined using the flows of daily home/work trips (commuting) detected during the general population and housing censuses. The adoption of this spatial unit is suitable for examining the geographical patterns of innovation as it relies on the social and economic connections within the territory, rather than on administrative boundaries. LLSs reflect, as closely as possible, local economies (O'Donoghue, Gleave, 2004). In fact, by working at this level ISTAT provides the level of urbanization, being possible to assess the urban dimension of LLSs.

From a methodological point of view, two steps of analysis are applied. First, we map green-related technologies across LLS's and thus detect differences along the urban gradient. Second, we focus on the spatial dependence to detect spatial autocorrelation between the co-location of green innovations and whether they occur in neighbouring LLS's. Two measures based on a spatial weight matrix that tracks contiguities between LLSs are used: the global Moran index, a general measure of association across the country, and the local indicators of spatial association (LISA).

This paper proceeds as follows. The extant literature is synthesized in section 2, data and methods are described in section 3; results are presented in section 4 and discussed in section 5.

2. Literature Review

Starting from the Rio+20 Conference on Sustainable Development in 2012, the concept of sustainable development and "green growth" gained momentum in policy discourses and international institutions. The OECD, the United Nations Environment Program and the World Bank have increasingly paid attention to the so-called "green growth", as an effective way to pursue a more "sustainable" development (Hickel, Kallis, 2019; Capasso *et al.*, 2019; Guo *et al.*, 2017; Bowen, Hepburn, 2014; Nielsen *et al.*, 2014), i.e. a development that does not imply the over-exploitation of our planet with consequent depletion of natural resources (Song *et al.*, 2020; Capasso *et al.*, 2019; Shapira *et al.*, 2014).

Studies on green growth are often linked with that on innovation, particularly eco- or green innovation (Favot *et al.*, 2023; Galliano *et al.*, 2023; Zhou *et al.*, 2021; Castellacci, Lie, 2017), a concept usually referring to new products and/or new processes that increase business value while decreasing environmental impacts and ensuring efficient use of natural resources (Favot *et al.*, 2023; Galliano *et al.*, 2023; Rennings, 2000). When studying green innovations, the extant literature has mainly investigated the internal and external factors (i.e. technology push and market pull factors) facilitating the adoption of such innovation (Montresor, Quatraro, 2020; Zhang *et al.*, 2019; Horbach *et al.*, 2013; Kesidou, Demirel, 2012; Rennings, 2000), the linkage between green innovation, often measured by green patents (e.g. Van Hoang *et al.*, 2020; Acs *et al.*, 2002) and firm performance (Marin-Vinuesa *et al.*, 2020; Padilla-Perez, Gaudin, 2014; Antonietti, Cainelli, 2011; González-Benito, González-Benito, 2006).

Among these studies, the geographical and regional perspectives have received scant, but increasing, relevance. This growing attention is justified due to the relevant role regions might have in fostering the development and adoption of green innovation (Galliano *et al.* 2023; Losacker *et al.*, 2023a; Montresor, Quatraro, 2020; Antonioli *et al.* 2016). Moreover, the geographical perspective is much more relevant among European countries, where small-medium enterprises (SMEs) and regional and local industrial districts play a central role in the development and diffusion of innovation (Antonioli *et al.*, 2016).

The relevance of space to understand the diffusion of green innovation and technologies found its justification in the different sources of knowledge creation for firms, i.e., internal sources and external collaborations, where the spatial proximity of different firms creates the conditions for knowledge diffusion and new idea generation (Scott, Storper, 2007). Moreover, previous innovation studies pointed that the diffusion of specific technologies occurs faster within the same and similar geographical clusters (Lengyel *et al*., 2020), due to the geographical proximity to the innovator (Losacker *et al.*, 2023a).

Extant studies generally found an important role in the geographical dimension also for the specific case of green technologies. Antonioli *et al*., (2016) in a study of the Emilia-Romagna region in Italy found that local conditions and agglomeration economies play a fundamental role in supporting the development and adoption of green technologies. Montresor and Quatraro (2020), focusing on smart specialization strategy and green technologies, found that the acquisition of such technologies follows a process of regional branching and that regions innovate incrementally and according to a path-dependent approach. More recently, Losacker *et al.* (2023a), focusing on green innovation in China, provide evidence that geographical proximity to the inventor matters and is associated with a faster time to adoption. Moreover, regions where a pre-existing green specialisation already exists favour the faster adoption of green innovation also in the neighbouring regions. Similarly, Galliano *et al.* (2023), focusing on France, found that spatial externalities played an important role in shaping innovative behavior at the firm level and this may depend on their locations.

Starting from these premises, this study focuses on both the specialisation of regional green innovation and its geographical patterns of localization in Italy, where growing attention to green innovation has been devoted by national and regional policy makers.

3. Data and Methodological Approach

To examine the geographical distribution of sustainable innovations in Italy we retrieved green-related patents through three code classification methodologies available: 1) the "IPC Green Inventory" concerning Environmentally Sound Technologies (ESTs) developed by WIPO; 2) the "ENV-TECH" concerning Environmental Technologies developed by the OECD; and 3) the "Y02/Y04S Tagging scheme" concerning Climate Change Mitigation Technologies (CCMTs) developed by EPO. The use of classification codes is the most common approach being based on detailed knowledge of patent examiners and it is necessary when a large dataset is available, as for our analysis. Indeed, the three methodologies are considered a good proxy of eco-innovation and have been used by several scholars to measure inventions in green-related technologies (Durán-Romero and Urraca-Ruiz, 2015; Cvijanović *et al.*, 2021; Cohen *et al.*, 2021; Bellucci *et al.*, 2023). Moreover, to get the broadest possible coverage and to ensure the findings are not influenced by the selected classification method, we follow authors such as Favot *et al.* (2023) and Ghisetti and Quatraro (2017), who recommended integrating them.

To classify patents dealing with green-related technologies WIPO, OECD and EPO use an alphanumeric code[2]. The WIPO methodology is based on the IPC and is distributed into seven macro areas. The OECD uses both the IPC and CPC codes and is also divided into seven macro areas. The EPO methodology is based on the CPC coding scheme and is composed into two classes (see Table 1 for a detailed description of these classifications).

Table 1 – WIPO, OECD and EPO Green Classification

	WIPO IPC Green Inventory		*OECD ENV-TECH*		*EPO Y02/Y04S Tagging scheme*
1	Alternative Energy Production	1	Environmental management	1	Y02 Climate Change Mitigation Tecnologies
2	Transportation	2	Water-related adaptation technologies	2	Y04s Smart Grid
3	Energy conservation	3	Biodiversity protection and ecosystem health		
4	Waste management	4	Climate Change Mitigation related to Energy generation, transmission of distribution		
5	Agriculture / Forestry	5	Capture, storage, sequestration or disposal of greenhouse gases		
6	Administrative, regulatory or design aspects	6	Climate Change Mitigation related to Transportation		
7	Nuclear power generation	7	Climate Change Mitigation related to Buildings		

Source: Authors' elaborations

2. For full OECD code classification see WP "Measuring environmental innovation using patent data" OECD (2015). For full WIPO classification see: https://www.wipo.int/classifications/ipc/green-inventory/home. For full EPO classification see: https://www.epo.org/en/news-events/in-focus/classification/classification/updatesYO2andY04S.

For our analysis, we use a database from the OECD-REGPAT for Italian patents in 2019. The record contains over 2,234 patent applications, each accompanied by the corresponding CPC/IPC codes and the addresses of the applicants. Given that the data is available at a NUTS-4 level, we combine[3] the three methodologies and we spatially aggregated them at the Local Labour Systems level (LLSs). In particular, the NUTS4 data has been matched with the respective LLS-2011 by using the correspondence national matching tables developed by the Italian National Institute of Statistics (ISTAT). Local labour systems, also known as Labour market areas (LMAs) or Sistemi locali del lavoro (SLL) in Italy, refer to sub-regional geographical areas where most of the workforce resides and works. Since each local system is the place where the population resides and works and where therefore exercises most of the social and economic relations, the home/work trips are used as a proxy of the existing relations on the territory. The adoption of this spatial unit, compounded by 611 district areas, is suitable for analysing the geographical patterns of innovation since it is based on the social and economic connections within the region, rather than on administrative boundaries, useful to accurately depict local economies (O'Donoghue, Gleave, 2004). Furthermore, we can identify urban and inner polycentric structures of LLSs since ISTAT provides the level of urbanization, divided into three typologies: main urban reality "Core" (21 units); medium-sized city "Medium" (86 units); and Other LLSs (the remaining 504 units). To the best of our knowledge, spatial analyses of green innovations in Italian regions, or any other EU country, have not been conducted yet (an example can be found instead for China, for instance, see Zhou *et al.*, 2021).

3.1. Geographical Patterns

To identify the geographical distribution of green innovation two steps of analysis are used. First, we map green-related technologies across LLS's and thus detect differences along the urban gradient. Second, we focus on the spatial dependence to detect spatial autocorrelation between the co-location of green innovations and whether they occur in neighbouring LLS's. Two measures based on a spatial weight matrix are used: the global Moran index, a general measure of association across the country, and the Local Indicators of Spatial Association (LISA)[4]. The neighbouring structure across LLSs is measured by a spatial queen contiguity weights matrix. Due to the skewed distribution of the data (skewness above 1), with most

3. Based on Favot *et al.* (2023), the three techniques were merged by creating a list of non-duplicated green codes inside the same LLSs. We have found that approximately 17.7% of the total filings can be attributed to eco-inventions.
4. Geoda (Anselin *et al.*, 2006) are used to perform the spatial analyses.

regions exhibiting low performance levels, particularly in the South as depicted in Figure 1, we have adopted the square root transformation methodology employed by the European Commission Innovation Scoreboard (2023).

3.2. Local and Global Spatial Correlation

Following Zhou *et al.* (2021), who examined the regional patterns of green innovation in China, we utilise the global Moran's I index and the local Moran's I LISA. The former index quantifies the extent to which the entire region exhibits correlation at the spatial level, expressed by Equation 1 (Wrigley *et al.,* 1982):

$$I = \frac{n}{\Sigma_i^n \Sigma_j^n w_{ij}} \frac{\Sigma_i^n \Sigma_j^n w_{ij} \left(y_i - \underline{y}\right)\left(y_j - \underline{y}\right)}{\Sigma_i^n \left(y_i - \underline{y}\right)^2} \quad [1]$$

where n represents the number of spatial units, which are referred to LLSs, w_{ij} is the weight between locations i and j, y represents the variable of interest – in this study, the number of green-related patent applications – and $\underline{y}$ represents the average value over all locations of the variable (i.e., the mean of y). The range of values is between +1 and -1. A number close to +/-1 suggests a high positive/negative spatial autocorrelation, whereas a value of 0 shows a random spatial pattern.

At the local level the spatial correlation has been computed through a local Moran Index LISA (Anselin, 1995; Crociata *et al*., 2022). LISA enables us to precisely evaluate the level of spatial autocorrelation at each individual site, specifically in our investigation at LLSs level, by applying a contiguity criterion, which is the same criterion used in the global Moran I index (Brandano *et al*., 2023). The local version of the Moran in spatial entity i, I_i is defined in Equation 2 (Anselin, 1995):

$$I_i = \frac{n\left(y_i - \underline{y}\right)}{\sum_i^n \left(y_i - \underline{y}\right)^2} \sum_j^n w_{ij} \left(y_j - \underline{y}\right) \quad [2]$$

The result of the LISA quantifies the connections between spatial units and their neighbouring units, and maps out statistically significant clusters of the analysed phenomenon (Cerqua *et al.,* 2021). The LISA maps can reveal positive spatial autocorrelation, indicated by the clustering of high values surrounded by high values (High-High, HH) or low values surrounded by low values (Low-Low, LL); or negative spatial autocorrelation observed when low values surround high values (High-Low, HL) or vice versa (Low-High, LH). To assess the significance of the coefficient I, we adopted the methodology used by Frigerio *et al.* (2018) and Cerqua *et al.* (2021) and implemented a randomised simulation using 999 permutations.

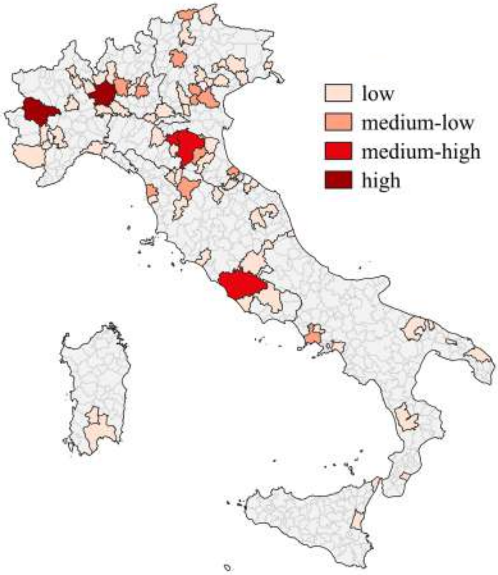
4. Results

Figure 1 shows the geographical distribution of green patent applications in the Italian LLSs in 2019. In general, we can see that the majority of green patents are located in the northern part of Italy (82%). A minor percentage is present in the Centre (14%) and very few examples can be found in the South and Islands (4%). Moreover, if we look at the number of these patents, we can conclude that the North is the part of the country with the highest concentration of LLS hosting the most applications, in fact, the urban centres of Turin and Milan account for 38% of the national total (see Table 2). The only exception in the Centre is given by Rome and Pisa with a medium-high and medium-low number of applications (see Figure 1). In the South and Islands, the level of patents is very low and also spatially limited in core urban centres.

4.1. Local and Global Spatial Correlation Results

The global Moran's I shows a value of 0.088 that is positive and significant, indicating that spatial autocorrelation is present in the distribution of green patents. This means that LLSs with a similar number of green patents tend to cluster, namely, to be located next to each other. However, it is important to note that the value of the index is very low, signalling that the concentration is small. Indeed, it is very spread out in space having a small degree of spatial clustering. As a confirmation of that, Figure 2 (panel a) identifies LLSs that are similar in their values of green patents at a 95% significance level of spatial concentration. More specifically, positive spatial autocorrelation is observed in 20 LLSs labelled high-high (HH), while no LLSs labelled low-low are found. The two most important clusters of specialization in green patents are concentrated around Milan and Bologna. This means that these two core cities generate positive spillover effects in their neighbour LLSs. Another relevant finding pertains to the North of the country and corresponds to the case of Turin and Padua. These two main urban realities appear surrounded by LLSs with lower degrees of green patenting in proximity to those with higher levels. It is worth noting that in the Central region of the country spatial dependency is weak, despite the presence of medium-high and high levels of patent applications (Figure 1). Take the case of Rome, a main urban city that exhibits a higher volume of applications but does not seem to produce any spillover effects. This trend becomes much more evident when we shift to the Southern region of the country, where the major urban areas exhibit negative spatial correlations, resulting in isolation and a lack of spillover effects. Cheeking for the distribution of these clusters according to the degree of urbanization, we find that in 48% of core LLSs shows significant spatial autocorrelation (see Panel b, Figure 2). This percentage decreases to 8% in peripheral areas.

Figure 1 – Green Patents, LLSs in Italy (2019)



	Core	Medium	Other	Total
North	8	14	25	47
	73%	44%	14%	21%
Centre	2	8	6	16
	100%	32%	8%	15%
South	5	4	5	14
	63%	14%	2%	5%
Total	15	26	36	77
Total LLS	21	86	504	611
	71%	30%	7%	13%

Note: The map displays the distribution of green patents 'natural break'. The table displays the total number -and percentage- of LLSs with at least one green patent application per macro-area and level of urbanization.

Source: Authors' elaborations

Table 2 – Top-10 LLSs with the Highest Green Patent Applications

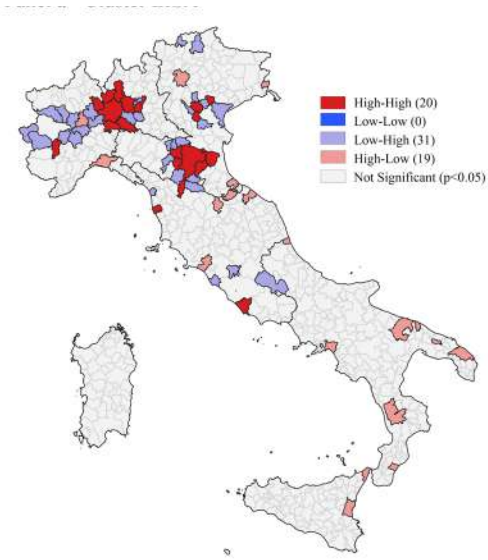
LLSs	*Macro-area*	*Level of Urbanization*	*Green Patents*
Milan	north	Core	92
Turin	north	Core	59
Modena	north	Medium	37
Bologna	north	Core	31
Rome	centre	Core	28
Padua	north	Core	13
Vicenza	north	Medium	10
Vipiteno	north	Other	9
Pisa	centre	Medium	8
Imola	north	Other	8

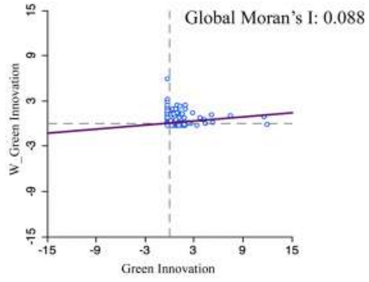
Note: Total number of green patent applications per macro-area and level of urbanization.

Source: Authors' elaborations

Figure 2 – LISA, Local and Global Indicator of Spatial Association, LLS in Italy (2019)

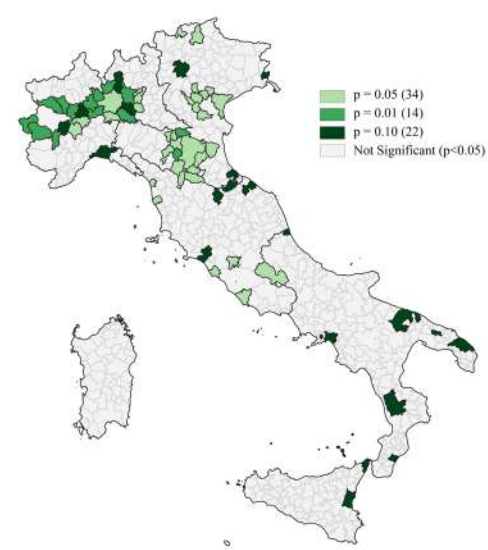
Panel a) Cluster LISA Map





		Core	*Medium*	*Other*	*Total*
North	HH	5	4	8	17
	LH	1	4	20	25
	HL	1	3	1	5
Centre	HH		3		3
	LH		1	4	5
	HL		1	3	4
South	HH				
	LH			1	1
	HL	3	3	4	10
Total		10	19	41	70
Total LLS		21	86	504	611
		48%	22%	8%	11%

Panel b) Cluster LISA Significance



		Core	*Medium*	*Other*	*Total*
North	p=0.05	3	5	17	25
	p=0.01	3	2	9	14
	p=0.10	1	4	3	8
Centre	p=0.05		4	4	8
	p=0.01				
	p=0.10		1	3	4
South	p=0.05			1	1
	p=0.01				
	p=0.10	3	3	4	10
Total		10	19	41	70
Total LLS		21	86	504	611
		48%	22%	8%	11%

Note: The abbreviations refer to: low-low (LL), low-high (LH), high-low (HL), high-high (HH). The tables display the number of LLS per macro-area and level of urbanization. Spatial association is calculated at squared root.

Source: Authors' elaborations

5. Conclusions and Policy Implications

Attention to green innovation is growing not only among scholars but also outside academic boundaries, especially among national policy makers, since its role in fostering green growth is widely recognized. As a result, literature on this topic has grown fast in recent years, leading to relevant results in different disciplines. However, in this growing literature the regional and local dimensions have been scantly addressed and this is a relevant gap to be addressed, since regions and local conditions play a fundamental role in green innovation development and diffusion (Galliano *et al.* 2023; Losacker *et al.,* 2023a; 2023b).

Starting from this premise, this paper wants to address this gap by investigating both the specialisation of regional green innovation and its geographical patterns of localization in Italy, where growing attention to green innovations has been devoted to by national and regional policy makers. Moreover, since green innovation plays a central role in ensuring environmental sustainability and economic growth (Galliano *et al*., 2023; Losacker *et al*., 2023a; Sheng, Ding, 2023), Italy represents an interesting case study given the well-known North-South divide (Iammarino, Marinelli, 2015; Fratesi, Percoco, 2014).

The use of high spatial resolution as LLSs has enabled a more accurate identification of the patterns of green innovation. The findings of our study align with the recent existing body of research (Losacker *et al*., 2023a; Schwab, 2023) which emphasises the significance of spatial factors. Our research demonstrates significant disparities in regional green innovation within Italy, characterised by the presence of both the "North-South" divide and the "urban non-urban" gradient. The country's dualism division is evident, with a greater concentration of green innovation in the wealthier Northern region, which also appears to be able to generate spillover effects from major urban areas 'core' to medium-sized neighbouring cities. In contrast, the Southern regions have a much lower capacity to generate eco-innovation. This is primarily limited to the main core cities, which do not have the ability to generate spillovers. These cities appear isolated and negatively spatially correlated.

Furthermore, employing high spatial resolution, such as LLSs, to map and detect spatial patterns offers empirical information that is valuable for public authorities and policy makers. In fact, understanding which regions can contribute to the greening of the country is of paramount relevance for policy makers (Schwab, 2023), as well as to design and implement evidence-based "green" policy to foster green innovation in the lagging Italian regions. Considering the significant disparity observed among regions and urban gradients in our findings, it is crucial to develop policies that take into account the specific characteristics of each region. There are several policy instruments to support green innovation also in the South of the country. First, as already highlighted by Schwab (2023) in their European study on twin transition, interregional cooperation plays a fundamental role in supporting the development of the lagging regions (Pontikakis *et al.* 2022). Moreover, "complementarities" in interregional cooperation is fundamental, i.e. searching "*for capabilities in other regions that are absent at home*" (Schwab, 2023, p. 30). Third, it is crucial to prioritize human capital and promote the growth of green skills and competencies. This is because skilled human capital plays a vital role in driving green innovation, specifically in facilitating the development and the adoption of products and processes innovation (Montresor, Quatraro, 2020).

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Sommario

La geografia dell'innovazione green in Italia

Il presente lavoro si propone di analizzare il grado di specializzazione e la distribuzione geografica dell'innovazione green in Italia. A tal fine, vengono utilizzati i dati brevettuali relativi al 2019 per mappare le tecnologie green, integrando tre diversi approcci: l'IPC Green Inventory, l'ENV-TECH e lo schema di tagging Y02/Y04S. I dati sono aggregati a livello di Sistemi Locali del Lavoro e comprendono la mappatura delle innovazioni green in base alla classificazione urbano – non urbano e l'esame della dipendenza spaziale utilizzando misure di autocorrelazione globale e locale. I risultati sottolineano le significative disparità nell'innovazione green regionale in Italia, in termini di divario Nord-Sud e classificazione urbano-periferia.

Sustainable Rural Development and Territorial Intelligence Innovation

Vincenzo Provenzano, Maria Rosaria Seminara**

Abstract

Over time, regional economic models for rural development have been subject to various interpretations of rurality. The first part of this article provides a comprehensive overview of the sequential emergence of approaches to rural development. In the current context, pursuing sustainability as a fundamental goal of rural development requires innovative strategies for territorial intervention. We recognize the immediate need for a renewed vision of sustainable development, which actively involves the territories and their stakeholders in long-term strategic planning. The article explores the need for innovative development paradigms in rural areas. As an original contribution to the existing literature, we introduce the framework of Territorial Intelligence Innovation (TII). This framework is designed to foster democratic participation processes within rural communities. The investigation is stimulated by the significant economic disparities in the European spatial landscape, highlighting the urgency of transformative approaches to rural development.

1. Introduction

In recent years, European political turmoil relates economic inequality with a broad sense of citizens' discontent, such as the disparity between cities and regions across the EU and the same disputes of the green and digital transitions that "may create winners and losers depending on the local conditions and capacities" (Rodríguez-Pose, 2018). The EU has launched several initiatives to support the recovery and resilience of its member states, such as the Next Generation EU Fund and the European Green Deal. However, the implementation and effectiveness of these measures may vary depending on the national and local contexts and require place-based solutions considering each locality's needs and potential (Barca *et al.*, 2012). For balanced and inclusive growth

* University of Palermo, Department of Economics, Business and Statistics and Center for Sustainability and Ecological Transition, Palermo, Italy, e-mail: vincenzo.provenzano@unipa.it (corresponding author); mariarosaria.seminara@unipa.it.

in Europe, special attention must be paid even to rural areas, whose role and importance have been undervalued and underrecognized for a long time. Many European rural areas share common challenges, such as demographic decline, low income and lack of economic opportunities, poor access to services and connectivity, low education and digital skill levels, and low employment rates (EU, 2021). The depopulation of rural areas is one of the main challenges to sustainable and inclusive development. Rural regions currently represent 28% of the European population. Still, a decrease in the number of people in rural regions by 7.9 million is expected by 2050, and an increase in cities from a current 40% to a higher percentage than 50% of the population (Eurostat, 2016). The leading cause of rural depopulation is population aging. Especially in recent decades in Southern European countries such as Portugal, Spain, and Italy, the number of rural regions with low population density has steadily increased. Therefore, it becomes essential to maintain a fair trade-off between urban and rural areas, avoiding overcrowding of the cities and depopulation of the other regions (United Nations Department of Economics, 2021).

Rural areas represent ecosystems being protected and valued as fundamental for collective well-being. This diversity and uniqueness require local responses and solutions corresponding to each territory's needs and possibilities. It is precisely the territory that becomes the central element of the research. Attention to the territory allows us to grasp the uniqueness and diversity. Paradoxically, globalization has restored the value of identity to places, and it is precisely in conjunction with a flattening of the world (Friedmann, 2005) that territories take on a strategic role in the global competitive landscape. The factors underlying the different economic outcomes in rural regions are related to the interaction of local and global forces. The relevance of these factors is interesting from a scientific and political point of view for achieving the socio-economic cohesion desired by European policies (Fratesi, Wishlade, 2017). A new research agenda requires a better development of knowledge of rural territories (Perpiña Castillo *et al.*, 2022). The path to rural development must recognize the diversity of different rural areas by integrating the sustainable concept of growth inside the current megatrends, defined as the long-term driving forces that are observable now and will continue to have a global impact on future generations (Garcilazo, 2022). The transitions in the act are long-term, multidimensional, and fundamental transformation processes through which socio-technical systems are established and shifted towards more sustainable modes of production and consumption (Markard *et al.*, 2012). A transition to sustainability should be intentional and represent a path development as a socially and spatially just process, with socially and spatially equity outcomes, and consequently, economic change should be evaluated through its contribution to human and ecological well-being (Eadson, van Veelen, 2023). Therefore, the right approach to developing rural areas is critical to trigger processes of growth and sustainability. Economic theories only in the late seventies of the last century, with the beginning of the debate within the regional sciences, have incorporated a broad concept of rurality, thus turning the attention towards these areas (Terluin, 2003). The evolution of rural development approaches has shifted from exogenous policies in the 1970s, prioritizing urban-centric development, to bottom-up, territorial-based strategies in the 1980s (Cheshire *et al.*, 2015; Cejudo, Navarro, 2020). Today, a neo-endogenous approach, blending elements of both exogenous and endogenous approaches, prevails, emphasizing decentralized policies that harness the potential of territories for sustainable development (Ray, 2006; Shucksmith, 2010; Gkartzios, Scott, 2014).

Supporting a neo-endogenous approach to rural development requires a new territorial management logic, knowledge dissemination, innovation processes, and democratic participation in a long-term vision of growth and sustainability. To this end, Territorial Intelligence (Girardot, 2009) overlaps with a neo-endogenous approach to rural development, allowing one to grasp the status of a territory and its dynamism via new technologies for more accurate knowledge and awareness. Territorial Intelligence (TI) emerges as a critical framework for understanding and leveraging territorial dynamics, especially when combined with technological innovations (Girardot, 2009; García-Madurga *et al.*, 2020). The value of technology is widely recognized and can significantly contribute to new territorial management models: "Technologies such as geospatial mapping are powering the fifth industrial revolution and have the potential to help us solve our climate goals. These technologies are powering organizations to solve traditional problems. We must use digital technology to engage and empower governments, companies, and citizens to adopt environmentally sustainable practices, policies, and business models" (UNEP, 2023). A further step includes a combination of Territorial Intelligence, technology, and social innovation mechanism, which we call Territorial Intelligence Innovation (TII), a holistic combination with a broad concept of technology-related innovation. Information technology (IT) enables communities to contribute to new forms of participatory democracy where private and public actors make decisions and bring together their experiences to enhance local resources (Battistoni *et al.*, 2022). This article is structured as follows: the second paragraph reviews the differential elements of exogenous, endogenous, and neo-endogenous approaches to the development of rural areas. The third paragraph highlights the features of Territorial Intelligence (TI), and the fourth paragraph describes how Territorial Innovation Intelligence can identify local assets and develop strategies to enhance them, stimulating democratic participation in rural development. Finally, the conclusions and policy implications follow.

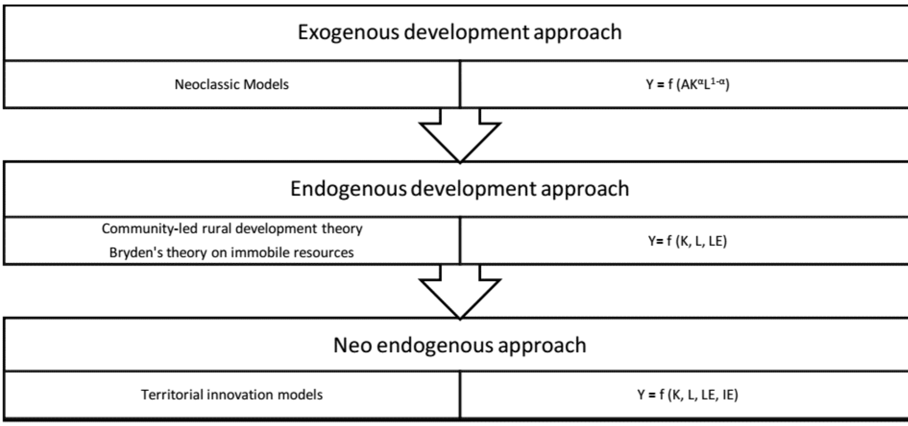
2. Development Models of Rural Areas

Space complexity, with various physical, economic, social, and relational variables, summarizes crucial dimensions of the functioning of economic systems. Isard (1956) began to investigate the space dimension of economic phenomena. In this direction, regional economic theories are well suited to explain the determinants of rural development. Over time, the approaches to developing rural areas have been different, and consequently, the economic models and the policies support the growth mechanism of these areas. Furthermore, the current issue is understanding how space contributes to determining growth that incorporates sustainability in a long-term territorial development vision. The approaches to developing rural areas have been different and have implied using other economic models. Until the 1970s, the exogenous approach to development was the dominant decision rule for describing rural development, with a passive role of the territory. The urban-rural dichotomy has supported a dualistic interpretation of the development process, with a subordinate part of rural to urban areas as the last effective growth engine. (Cejudo, Navarro, 2020). Since the 1980s, models with an exogenous approach in rural development policies have been brought into disrepute as they have not significantly contributed to the sustainability of the economic development of rural regions (Lowe *et al.*, 1995). In rural policies, an endogenous approach prevailed, and a territorial vision of bottom-up development processes progressively replaced the top-down functionalist development vision.

Today, the approach to developing rural areas is a mix of the methods used in the past decades. The neo-endogenous approach to development combines the dualistic 'top-down' or 'bottom-up' perspectives. Rural development occurs through local resources and integrated actions within wider networks (Cejudo, Navarro, 2020). Figure 1 illustrates the different perspectives on rural development and the linkage with regional economic theories. It starts from a typical production function that evolved by adding elements such as the Local Environment (space, human capital, technology, networks, trust, culture, and politics) and incorporating an Innovation Ecosystem.

A concise description of the exogenous, endogenous, and neo-endogenous approaches is at the base of the following subparagraphs related to the regional economic models and the development policies of rural areas.

Figure 1 – Different Perspectives on Rural Development and Linkage With Regional Economic Theories



Notes: $Y = AK^{\alpha}L^{1-\alpha}$, with $0 < \alpha < 1$, Where: *Y*=Income or production; *A*= Technical Progress; *K*= Capital; *L*=Work. *Y*= f (*LE, L, K*) Where: *Y*= Income or production; *L*= Work; *K*= Capital; *LE*= Local Environment that includes space, human capital, technology, networks, trust, culture, and politics. *Y = f* (*I, LE, L, K*) Where: *Y*=Income or Production; *L*=Work; *K*= Capital; *LE*= Local Environment, including factors such as space, human capital, technology, networks, trust, culture, and politics; *EI*= Innovation Ecosystem.

Source: Authors' elaborations

2.1. Exogenous Models and Regional Economic Theories

The exogenous approach to development has interpreted rural areas as a "repository" of agricultural and forestry input available and exploitable according to the predetermined needs of urban centers. In this view, rural is a synonym of agriculture, a primary sector with low productivity and workforce reservoirs for migration toward the cities (Sotte *et al.*, 2012).

Therefore, the weight of agriculture in rural areas in terms of employment and the gross domestic product was predominant. Favoring rural development meant implementing aid towards agriculture. In European countries, the development policy encourages the modernization of the agricultural sector and its productivity. Until the end of the 1970s, the traditional theories of regional growth aimed at capital and labor input mobility were underlying the policies implemented in the territories. In the urban-rural contrast, the regional and local areas disparities are explained by the availability and inter-regional mobility of the factors of production: capital, labor, and technical progress. Within these theories, the factor endowment is a source of territorial competitiveness and growth from interregional relations. In the neoclassical models, the growth is a function of technical progress and the growth of labor and capital production factors:

$$Y = AK^{\alpha}L^{1-\alpha} \qquad [1]$$

With $0 < \alpha < 1$, where Y=Income or production; A= Technical Progress; K= Capital; L=Work.

The source of advantage is the mobility and concentration of labor and capital in a specific place, which gives rise to external effects or economies of scale. Nevertheless, the persistence of gaps between advanced and backward regions has proved that more than factor reallocation for rebalancing territorial disparities is needed. Capital often is not mobile, remaining in the rich regions thanks to cumulative processes and synergies with innovation. Technological progress, accumulation of know-how, and economies of agglomeration amply the tendency of firms to invest continually in wealthy regions, quicker to recuperate new investments. Often, rural areas have suffered selective migration and underwent depopulation and aged phenomena, thus losing new generations and local human capital. A few regional economic models have been used in rural areas; Perroux (1950) developed the theory of development poles, which conceives a selective growth in some points of space, "poles of development." The casual presence of a leading industry influences the investment decisions of the local companies connected, as Higgins (1977) explains:

$$IB = f\left(IA\right) \quad with \quad \Delta IB / \Delta IA > 0 \qquad [2]$$

The investment of a group of firms B (IB) is a function of the dominant firm A's investment (IA). The efficient and dominant industry responds to the needs of an external market, generating positive effects within its sector (Capello, 2015). The initial presence of the prevailing industry is exogenous and related to political choices. Many public interventions have been aimed at rural areas. Nevertheless, in practice, local businesses in rural areas often needed more time to seize the driving stimuli of big business. Furthermore, there have been crowding-out effects on local productive activities, which required to bear the increase in the cost of living, land rent, and wages generated with the presence of the dominant firm.

According to circular cumulative causation, Myrdal (1957) explains how underdevelopment may occur in rural areas. In contrast to neoclassical models, which impose automatic rebalancing processes, the theory of circular cumulative causation describes the persistence of interregional imbalances.

The regional disparity gap is a vicious process that feeds itself. Without an idiosyncratic shock, the disparities persist and are more pronounced if market forces are not regulated. It induces expansion cycles in wealthy regions: new firms are attracted by the existing concentration by market size, allowing for economies of scale. This cumulative concentration and expansion of business economies in rich regions have harmful implications for so-called lagging areas lacking capital and labor, which are very low in rural areas.

The economically weakest rural areas are destined to suffer an inevitable decline, with depopulation, poverty, the degradation of infrastructure, a poor education and health system, and a decline in public services (Terluin, 2003). In this context, space is hierarchical, with cities the only protagonists of growth. The urban areas affect the structure and the future of the rural areas, which remain confined to the margins and dominated by city evolutions. The policies have been aimed at the modernization of the agricultural sector, creating poles of development, and financing the localization of large companies in peripheral areas to create job opportunities. Table 1 highlights some characteristics of the exogenous approach to developing rural areas. The scheme offers the critical elements of development, the spatial vision following top-down and urban-rural dichotomy, correlated to hierarchical political strategies, with institutions able to manage a typical central control.

Table1 – Characteristics of Exogenous Models

Key Elements of Development	*Economies of Scale and Agglomeration*
Spatial Vision	Urban Hierarchy Urban-Rural Dichotomy Periphery of Rural Areas
Political Strategies	Modernization of the Agricultural Sector- Poles of Development, Driving Industry

Source: Authors' elaborations

2.2. Endogenous Approach and Regional Economic Theories

Since the 1980s, the economic models used with an exogenous attitude have fallen into disrepute since they did not lead to the economic development sustainability of rural regions (Lowe *et al*., 1995), and the endogenous approach has prevailed to reinforce rural policies. In other words, the top-down functionalist vision is no longer appreciated. The importance of bottom-up development processes becomes a central territorial methodology.

The new approach adopted was closely related to the Local Milieu concept (Camagni, 1995; Capello, 1999) and the model of Italian industrial districts

(Becattini, 1991; Marshall, 2009), where the growth process is endogenous, and the institutional context plays a significant role. In this view, development corresponds to an outcome of local impulses generated with local resources (Picchi, 1994). Also, the development benefits remained within the local economy (Slee, 1994). Following the bottom-up approach, rural policy models have paid attention to the diversification of economic activities in the local context, supporting local activities with the creation of appropriate training (Lowe *et al*., 1995). The development of a rural area results from the efficiency of territorial organization, entrepreneurial capacity, local productive resources, and the networking and capacity building of institutional and local actors.

Furthermore, another theory linked to rural areas is that of Bryden (1998), which focuses on the potential of immobile resources. The competitive advantage of the rural regions should be based on resources, not open to competition, considering local knowledge and the social, cultural, and environmental capital. Therefore, the economic development of rural areas depends on a combination of tangible and intangible resources, which cannot be reproduced elsewhere, and on how these interact with each other in the local context (Terluin, 2003). Endogenous rural development indicates the ability to efficiently use local resources, whether economic, natural, cultural, or human.

A production function of endogenous growth takes this form:

$$Y = f\left(K, L, LE\right) \qquad [3]$$

Where: Y= Income or production; K= Capital; L= Work; LE= Local Environment that includes space, human capital, technology, networks, trust, culture, and politics.

However, not all rural areas can have a self-centered, conservative, and independent development from external influences, such as globalization, international trade, or global institutions (Ray, 2001; Lowe, 2006). Furthermore, not all rural areas can use resources efficiently.

Table 2 – Characteristics of Endogenous Models

Key Elements of Development	*Tangible and Intangible Resources of an Area*
Spatial Vision	Uniqueness of the Territories, Diversified and Relational Space
Political Strategies	Ability To Use Efficient Local Resources

Source: Authors' elaborations

Table 2 highlights some characteristics of the endogenous approach. The scheme offers, such as in Table 1, the critical elements of rural development, the spatial vision of the approach, and the strategies adopted for developing rural regions.

2.3. The Neo-endogenous Approach

Today, the vision of rural areas has changed, and new trends prevail. In short, the importance of an equal distribution of territorial growth, the quality of life in less congested areas, and the globalization of new development ideas related to intangible elements.

The neo-endogenous development approach offers an alternative to dualistic 'top-down' or 'bottom-up' perspectives summarized in the previous paragraphs. Rural development with a neo-endogenous approach aims to unlock local potential through local resources and action integrated within wider networks (Cejudo, Navarro, 2020).

The purely endogenous elements (van der Ploeg, van Dyck, 1995) are contemplated in the new approach, where "extra-local" factors are present (Ray, 2001). So, the neo-endogenous vision is holistic, enclosing local emancipation, capacity building, overcoming marginality, adding value to local resources, increasing connectivity, and promoting innovation (Lacquement *et al.*, 2020).

The neo-endogenous approach highlights the path toward better socio-economic conditions in rural areas by reversing public intervention away from individual sectors in favor of a mosaic of local/regional territories (Ray, 2006). The local area assumes a part of the responsibility to realize its socio-economic development. The physical and human resources indicate a cluster of local communities' needs, capacities, and perspectives.

Neo-endogenous reflection embraces the endogenous model in the elements such as the multi-sectorally and territoriality, adding the need to build internal and external networks (Bosworth *et al.*, 2016; Gkartzios, Lowe, 2019). In addition, other elements that come into play are institutional integration (local, regional, national, and European), arranging connections between town and country, and new urban-rural and local-global relationships (Scott, Murray, 2009) in planning (Gkartzios, Lowe, 2019).

A neo-endogenous approach foresees an economic dynamic that derives from the interaction of local and external forces, where innovation flows are exchanged. Therefore, the model assumes local participation in planning and implementing a development intervention by adopting the specific territory's cultural, environmental, and community values, with similarity to the Innovation Ecosystem models (de Vasconcelos Gomes *et al.*, 2018; Granstrand, Holgersson, 2020).

Innovation Ecosystem converges on the non-linear complexity of knowledge-based economies, where new processes are co-created interactively at the level of collaborative networks (Russell, Smorodinskaya, 2018).

Innovation Ecosystem includes the ecological variable: "What is new in the innovation ecosystem is its ecological aspect, characterized by the interdependence between different collaborative actors and the co-evolution/co-creation that binds them together over time, together with the development dimension sustainable." (Cai *et al*., 2019). In other words, the Innovation Ecosystem results from the collective actions of interconnected actors that produce a particular development result that includes sustainability.

The Neo-Endogenous approach emphasizes the interaction between local and extra-local arenas that deliver sustainable local nature conservation. Local participation contributes to sustainable development by introducing local knowledge, volunteer effort, and commitment to the nature conservation planning and policy arena (Marango *et al*. 2021).

The models of development foresee an extended function:

$$Y = f\left(K, L, LE, IE\right) \qquad [4]$$

Where: Y= Income or Production; K= Capital; L=Work; LE = Local Environment, including space, human capital, technology, networks, trust, culture, and politics; IE = Innovation Ecosystem.

The increased complexity of the different conceptions of rural geographical space brings a new interpretation of rurality, and the neo-endogenous approach interprets rural development. For example, community-led rural development has been significantly applied to rural areas (Murray, Dunn, 1995). It focuses on the ability of local actors to act on growth, a condition highlighted as a preliminary to trigger and support local economic development. Independent skills of local actors are necessary to increase the organizational capacities of rural communities in group processes, conflict resolution, mediation, leadership, and understanding of government activity to achieve a shared vision of development. Partnerships and adjustments of institutional structures are the primary tools in strengthening the autonomous capacities of local actors, aiming at bottom-up initiatives. In the neo-endogenous perspective, new interpretations and the representation of territorial capitals can be the result of social innovations, such as "organizational" changes (Belliggiano *et al*., 2018; De Rubertis *et al*., 2018), i.e., the ability of some actors to propose new paths of cooperation inside and outside the community (Neumeier, 2012). The success of these initiatives involves permanent changes in the configuration of the relational space, unraveling conflicts between divergent expectations, creating new relationships, and modifying the perception and representation of territorial capital.

Table 3 – Characteristics of Neo-Endogenous Approach to Rural Development

Key Elements of Development	*Tangible and Intangible Resources of an Area, Extra Local Factors, Ecosystem Innovation*
Spatial Vision	Uniqueness of the Territories, Diversified and Global Relational Space
Political Strategies	Ability To Use Efficient Local Resources and Build Relations Local and Extra Local

Source: Authors' elaborations

Table 3 summarizes all these aspects, indicating where the ecosystem concepts enlarge the capacity to intervene in rural environments where the area's potential shows an intrinsic value, a prerequisite before any market appreciation.

3. Knowledge of the Territory With a Neo-endogenous Approach to Sustainability Management

An approach to rural development necessitates sustainability, which is essential in building long-term growth strategies. The accurate knowledge of the territories that consider extra-local elements influencing the path of sustainable strategic planning leads to the search for new concepts encompassing those distinctive elements for rural areas and new practices or techniques. In this sense, Territorial Intelligence (TI) indicates a new vision of the rural regions.

Girardot's first definition of TI (2009) highlights the association with a development action: "Territorial Intelligence is a way for researchers, for the actors and the territorial community to acquire a better knowledge of the territory and have better control of its development." Appropriate information and communication technologies are necessary for stakeholders to enter a learning process. TI is well suited to help the territorial actors plan, define, stimulate, and estimate the policies of sustainable territorial development.

Laurini (2017) defined the concept of TI as "... an approach regulating a territory (maybe a city) which is planned and managed by the cross-fertilization of collective human intelligence and artificial intelligence for its sustainable development". In addition, TI includes a collective process focused on collaboration to favor sustainable territorial development. The territory and its actors are the protagonists of the design and implementation of strategic planning. Territorial Intelligence is an evolving polysemous concept that addresses the shift from economic to sustainable development and from a competitive to a cooperative development vision (García-Madurga *et al.*, 2020). In this sense, economics and sustainability reflect the current definition of circular economy as restorative and regenerative by design (Ellen MacArthur Foundation, 2015).

Three main traits characterize Territorial Intelligence (García-Madurga *et al.*, 2020). The first element is the consideration of TI as a collective process that requires the participation of local, political, economic, and social stakeholders. The second characteristic is integrating and processing internal and external information for territorial planning (Laurini *et al.*, 2020). In other words, they are abandoning the competition strategy between clusters or groups with different interests within a territory towards an intra-territorial and inter-territorial collaboration for sustainable development. Neo-endogenous elements are at the base of Territorial Intelligence—accurate territorial and collaborative knowledge results from tangible and intangible resources, relationships, and territories' uniqueness. The ability to use the territorial shared resources presupposes a transition from a competitive vision to a collaborative idea, triggering ecosystem innovation processes and sustainable development. (Table 4).

The TI validates information and communication technology to accelerate a concerted action for sustainable development. It enables the creation of multidisciplinary and cross-sector knowledge, strengthening the effectiveness of collective participation in territorial planning (Girardot, Brunau, 2010).

Territorial Intelligence consists of a set of scientific methodologies, analysis tools, and measurement systems that mobilize the stakeholders of a determined territory. The territory is not only a productive enclave but includes all local relationships. Coordination among stakeholders is the basis of territorial intelligence

Table 4 – Characteristics of Neo-Endogenous Approach to Rural Development and Elements of Territorial Intelligence

Characteristics of the Neo-Endogenous Approach	*Elements of Territorial Intelligence*
• Tangible and intangible resources • The uniqueness of the territories • Global relation space • Ability to use efficient local resources to build local and extra local networks. • Innovation Ecosystems	• A collective process that requires the participation of local political, economic, and social actors • Integrating and processing information, internal and external, for territorial planning • Abandoning competition within a territory towards an intra-territorial and inter-territorial collaborative behavior of stakeholders

Source: Authors' elaborations

favoring the collective dimension of sustainable development: economy, society, and environment.

Developing territorial intelligence means collecting information on the various processes active in the area, using analytical tools for their analysis and dissemination, increasing the know-how of the people and organizations on the territory, and building metadata platforms searching for strategies for territorial governance and development.

TI is an organization's innovative network of information and valuable knowledge for the development and competitiveness of a territory to achieve community objectives. It also enhances resources, extending their awareness through shared communication involving the several actors in the area. In a rural environment, it is fundamental to overcome the initial conditions of a competitive disadvantage (Foronda-Robles, Galindo-Pérez-de-Azpillaga, 2021). Territorial Intelligence increases communication and knowledge of unknown local resources, preserving natural resources, which have often been the object of overuse.

4. Democratic Governance and Territorial Intelligence Innovation (TII)

Territorial Intelligence involves the information and cooperation of all interested actors, leading to an Innovation Ecosystem. In short, innovation requires shared information, knowledge, and collective territorial participation to sustain development.

Solis-Navarrete *et al*. (2021) consider standard definitions of innovation to be insufficient because "An innovative environment with a territorial and sustainability perspective makes it possible to shift the concept of innovation from that oriented to economic competitiveness to another geared towards development, having the resources, activities, and capabilities as key factors and indissociable elements of the territorial context." It requires multi-actor, multilevel, and multi-perspective paths (Van Der Ploeg, Roep, 2003; Di Iacovo, 2011).

Adherence to an ecosystemic vision of innovation identifies the territory's ability to set off mechanisms and invest in resources linked to the territorial context through spatial relations.

The role of innovation, especially in rural areas, assumes a social value characterized by the desire to achieve sustainable benefits through new forms of collaborative action.

Territorial Intelligence Innovation (TII) follows a pattern that includes (Girardot, Brunau, 2010; Laurini, 2017):
- use of multidisciplinary knowledge
- dynamic vision of territories
- involvement of communities and practitioners

- sharing, co-constructing, and cooperating among local actors
- participatory territorial governance.

Multidisciplinary knowledge enables an understanding of the links between socio-ecological Transition and growth and the role of innovation. Information-sharing between scientific disciplines, sectors, and territorial scales is the basis of knowledge-building and collaborative projects combining sustainable development's economic, social, environmental, and cultural objectives. Spatial observation thus provides stakeholders and citizens with democratic and transparent access to information and knowledge.

A dynamic vision of the territory combines the potential of spatial geography and the capabilities of a community. In this sense, the outcome is the self-determination of an authentic rural development process.

The collective vision of the territories enhances innovative and sustainable development projects with a cooperative, collaborative, and shared approach.

Finally, coordinated and participatory governance allows local actors to develop, manage, and evaluate sustainable development projects, improving the well-being of communities. Constructing the iterative process with a dense network ensures mutual ownership and accountability, influencing policymakers to consider multiple collaborative projects to achieve long-term sustainability in their regional settings (Hakeem *et al*., 2023). The interactive participation of all territorial actors, including researchers and decision-makers, aims to increase the confidence of those concerned and allow them to define, express, and analyze their reality without adopting the opinion of the more assertive and more dominant voices (Patel *et al*., 2007; Sisto *et al*., 2018; Wilson, 2013) facilitating a democratic process.

At the core of TII lies the principle of democratic participation, where the combined involvement of all stakeholders actively shapes the path of development, fostering an atmosphere of trust.

Understanding the themes of the Transition creates a new paradigm of rural development, i.e., the Territorial Intelligence Innovation (TII). TII needs to be closely related to governance and institutional aspects, considering the management and application of rural development policies.

The concept of governance presupposes decision-making methods based on consensus among different actors linked via a dynamic interaction between various actors. Decision-making processes are correlated to the analysis of the territory and the active participation of citizens, using a comprehensive negotiation process, a backbone to build coordinated decisions in a changing society (Saccheri, 2008).

Emphasizing the pivotal role of democratic participation, it is crucial to note that it serves as the cornerstone of TII, guiding decision-making processes and nurturing inclusive development strategies.

In the case of rural areas, governance involves diverse levels of government (supranational, national, regional, sub-regional, local), i.e., a multilevel approach to rural development related to bottom-up processes where the leading local stakeholders follow a Neo-Endogenous approach.

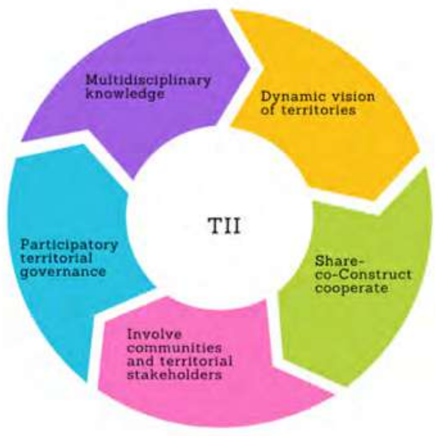
New institutional governance arrangements allow constant control positions in a formal democratic governance environment. In this case, the issue's substantial drawback is the long-lasting impediment to opening society to innovation with closed and self-referential networks. Nevertheless, the hypothesis is that an efficient system of governance (Georgios, Barraí, 2021) makes it possible to achieve results in implementing policies for rural development and, consequently, in the growth processes of the territories. Good governance connects participation, trust, and the presence of learning mechanisms and procedures for managing conflicts and decision-making to shape models of Democratic Participation.

Democratic participation allows actors to search for valuable, innovative solutions for local systems. Innovative governance solutions with satisfactory answers widen the involvement in sustainable development, allowing new options for territorial planning (Provenzano, Seminara, 2022). The role of public institutions becomes crucial in recognizing and supporting the actors of the territories capable of generating processes of change and, consequently, territorial innovation inside a Territorial Intelligence framework. The presence of territorial innovators becomes essential to enlarge the same concept of innovation better related to social processes.

Rural areas must enlarge their ability to simultaneously trigger practices, create economic, social, and environmental values through innovative organizational formulas, and propose new roles and responsibilities in planning development. Interpreting governance as a creative process capable of creating local value-added implies operating unconventionally, facilitating tools for transitioning to a new sustainable territory management model. New forms of participatory and democratic governance are necessary to make citizens the protagonists of the rural areas without auto-limitations.

Figure 2 illustrates the basic structure of Territorial Intelligence Innovation, the outcome of several interactions where innovative mechanisms are no longer related to the Marshallian urban atmosphere (Marshall, 2009).

Figure 2 – The Basic Structure of Territorial Intelligence Innovation (TII)



Source: Authors' elaborations

For this purpose, collecting information and data on the various processes and phenomena in the area is necessary to develop territorial intelligence, using tools for their analysis and dissemination. In this way, the level of know-how of the people and organizations in the area increases, and it is worthwhile to search for strategies for territorial governance and competitive development.

5. Conclusions

The regional economic models guiding rural development policies have embraced diverse interpretations of rurality to propel sustainable development in rural areas and fortify local communities.

Territorial Intelligence Innovation (TII) emerges as a potent force, leveraging multidisciplinary innovation knowledge concerning territories and their dynamics (Girardot, 2009). This framework envisions ideal environments, such as intelligent cities rooted in cultural convergence, and redefines rural areas as complementary components within a holistic sustainability vision (Solis-Navarrete *et al*., 2021; Hojer, Wangel, 2015). However, research on innovation often needs to look more into the intrinsic connection between rural areas, the environment, and social innovations (Bosworth *et al*., 2016).

TII finds application in various contexts, spanning urban and territorial planning, public service and natural resource management, tourism, and local culture promotion, thereby bolstering economic and productive activities in rural development (Laurini, 2017). It excels in identifying local assets, formulating strategies to support them, and creating a conducive environment for local economic activities and the well-being of local communities. Nevertheless, it is crucial to acknowledge that TII is not a one-size-fits-all model for all rural areas and regions; its effectiveness yields extraordinary knowledge results contingent upon the intentions of local and central governments in their utilization.

This paper transcends the urban-rural dichotomy through mechanisms of neo-endogenous development, wherein innovation in rural areas emanates from their knowledge base. The current challenge lies in transforming TII into an accurate decision-making and interpretation tool, facilitating a more comprehensive vision of sustainable development.

One limitation of this work pertains to the need for standardized measures of TII. Indicators assessing TII may include the diversity of local economic activities, the presence of public infrastructure and services, the quality of the natural and built environment, active community participation in development processes, and the innovation capacity of local businesses. Findings underscore the necessity for future research dedicated to implementing Big Data techniques (Battistoni *et al*., 2022). Creating digital platforms offering fundamental insights into networks and elements within territories holds promise for overcoming inequalities between rural and urban areas.

The governance dimension, as a political and democratic practice, necessitates further exploration through a vast literature review encompassing professional conference proceedings, technical reports, territorial arrangement projects, government plans, and programs (García-Madurga *et al*., 2020). *TII* emerges as a vital tool to help territories navigate the critical environmental and digital transition of the 21st century, intricately tied to empowering local communities. Focused on local assets and community engagement, *TII* catalyzes residents to actively participate in shaping the future of their areas, stimulating economic activities, and safeguarding the rich cultural heritage of the rural regions. This integration ensures that development aligns with the community's values and identity, emphasizing ecosystem innovation and encouraging interconnectedness among various elements within a territory.

There is a need for inclusive development strategies to maximize the impact of TII, addressing disparities within rural areas and ensuring that the benefits of innovation and development reach all segments of the population, including marginalized groups. The implementation of TII can be significantly enhanced by integrating technology and digital platforms, creating digital tools for community engagement, data analysis for informed decision-making, and online platforms that facilitate knowledge-sharing among different stakeholders.

TII's success relies on the knowledge and skills of the local population, making investment in education and skill development programs crucial (Ward *et al.*, 2005). Governments at both local and central levels play a pivotal role in the success of TII. Integrating TII principles into policy frameworks ensures that innovative strategies align with broader development goals, necessitating collaboration between policymakers, researchers, and local communities for effective implementation.

In addition to standardized measures for TII, there is a need to develop metrics that assess the social impact of innovations, including improvements in quality of life, community cohesion, and the overall well-being of residents. Sustainable rural development is a global challenge, and lessons learned from TII implementations in different regions can be shared globally. Encouraging collaboration and knowledge exchange on an international scale can enrich the understanding of effective strategies for rural development.

TII should not be static; it must evolve and adapt to changing circumstances. Continuous feedback loops, regular evaluations, and a commitment to incorporating lessons learned ensure the framework remains responsive and effective over time. Sustainable rural development through TII requires a holistic and dynamic approach that integrates economic, social, cultural, and environmental considerations while actively involving and empowering local communities.

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Sommario

Lo sviluppo rurale sostenibile e l'innovazione territoriale intelligente

Nel corso del tempo, i modelli economici regionali per lo sviluppo rurale sono stati soggetti a varie interpretazioni della ruralità. La prima parte di questo articolo offre una panoramica completa dell'emergere sequenziale degli approcci allo sviluppo rurale. Nel contesto attuale, la ricerca della sostenibilità come obiettivo fondamentale dello sviluppo rurale richiede strategie innovative per l'intervento territoriale. Riconosciamo la necessità immediata di una visione rinnovata dello sviluppo sostenibile, che coinvolga attivamente i territori e i loro portatori di interesse nella pianificazione strategica a lungo termine. L'articolo approfondisce la necessità di paradigmi di sviluppo innovativi nelle aree rurali. Come contributo originale alla letteratura esistente, introduciamo il framework dell'Innovazione dell'Intelligenza Territoriale. La IIT è progettata per favorire processi di partecipazione democratica all'interno delle comunità rurali. L'indagine è stimolata dalle significative disparità economiche nel panorama spaziale europeo, che sottolineano l'urgenza di approcci trasformativi allo sviluppo rurale.

Throwing Out the Baby with the Bathwater: Consequences of Covid-19 on the ICT Readiness of Italian Teachers

Roberta Cipriano, Antonella D'Agostino°,*
Sergio Longobardi♦, Andrea Regoli♦

Abstract

COVID-19 has accelerated the integration of Information and Communication Technology (ICT) into the Italian educational system; in this perspective, this paper focuses on the integration of ICT in Italian schools, with three objectives: i) to measure the readiness of teachers to integrate ICT into educational practices, ii) to assess whether the pandemic has had a significant effect on this readiness, and iii) to study whether there are significant differences at the regional level. Our findings highlight the multidimensional nature of "ICT readiness," the pandemic's significant influence in some dimensions, and the high level of ICT readiness among teachers in Southern regions, challenging the conventional North-South educational divide in Italy.

1. Introduction

Since the 1990s, countries worldwide have invested substantial resources in equipping schools with technological facilities and training teachers to integrate technology into their teaching methods. International organizations, such as the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the Organization for Economic Co-operation and Development (OECD), have recognized technology as a catalyst for improving education quality. The European Union, through initiatives like ET2020 and the Digital Agenda for Europe, has actively promoted the Integration of Information and Communication

* University of Florence, Department of Statistics, Computer Science, Applications "Giuseppe Parenti", Florence and University of Siena, Department of Economics and Statistics, Siena, Italy, e-mail: e-mail: roberta.cipriano@unifi.it, roberta.cipriano@unisi.it.

° University of Siena, Department of Economics and Statistics, Siena, Italy, e-mail: dagostino10@unisi.it.

♦ University of Naples Parthenope, Department of Business and Quantitative Studies, Naples, Italy, e-mail: sergio.longobardi@uniparthenope.it (corresponding author); andrea.regoli@uniparthenope.it.

Technology (ICT) in schools to enhance students' competencies, foster innovation, and improve creativity (European Commission, 2000).

At the heart of the European cooperation process, there is, among others, the development of educational systems that enhance the individual potential and creativity of pupils and students; in addition, national development is directly related to the quality of education provided (Shoaib *et al*., 2023). ICT could be a powerful tool in this regard and in promoting equity in education too. In Belgium, Denmark, Ireland, Spain, Italy, Hungary, Malta, Poland, Slovenia, Finland, and the United Kingdom, the use of ICT is also promoted to address students with disabilities or learning difficulties and socially disadvantaged students. Despite these efforts, challenges persist in achieving full ICT integration. Figures from the International Computer and Information Literacy Study (ICILS) in 2018 reveal that over 33% of 13-14-year-olds lacked fundamental digital skills. Additionally, there are stark disparities in internet connectivity, with only 6% of children and young individuals under 25 in low-income countries having household internet access compared to 87% in high-income countries, according to UNICEF (2020). In response to the COVID-19 pandemic, the European Union has intensified its commitment to digital education through the Digital Education Action Plan (2021-2027). The pandemic has accelerated the integration of ICT in education (Mesmar, Badran, 2022), particularly in more developed countries, marking a significant shift compared to the pre-COVID period (Tadesse, Muluye, 2020). However, several factors can impede progress, including the availability of school resources, such as hardware and trained support staff. Access to appropriate technological tools is identified as a primary obstacle, alongside the lack of specific training programs for teachers.

The role of teachers is crucial in incorporating ICT in the classroom, regardless of the technological resources available (William *et al*., 2000). Teachers' attitudes, perceptions, and confidence in using ICT influence their choice of incorporating technology into the educational process. Confident and proficient teachers can create interactive and engaging lessons, personalize education, provide access to a broader range of learning materials, and encourage social interaction and collaboration (Phan, Dang, 2017). Teacher beliefs and skills are identified as significant factors influencing technology integration. Educators who lack conviction in the benefits of ICT may hesitate to incorporate technology regularly. Hence, the readiness to use ICT in teaching becomes fundamental, requiring a multidimensional perspective that considers teachers' propensity and the support provided by schools (D'Agostino *et al*., 2023). In Italy, ICT for pedagogical issues is included in the core curriculum for initial education for teachers in secondary education (Ranguelov *et al*., 2011). The digital innovation of the educational system is a fundamental pillar of "La Buona Scuola" school reform

(Law 107/2015): tools, teaching, content, and skills are the main elements of this Plan. Here, too, the Plan stresses that the education field must not focus on technology but on its interactions with new educational models that also include teacher educational innovation training. Nevertheless, the OECD Teaching And Learning International Survey (TALIS) finds that the percentage of Italian school leaders who reported a shortage and inadequacy of digital technology for education is higher than the involved OECD average and that of Italian teachers who feel discreetly prepared to use ICT for teaching is lower (OECD, 2018). In 2022, the Italian Digital Economy and Society Index ranked 18th out of all 27 EU countries, but improved from 2019, before the advent of the COVID-19 pandemic, when it ranked 24th (European Commission, 2020, 2022). Indeed, due to the global COVID-19 crisis prompting the closure of educational institutions in numerous nations, more than 90 percent of ministries of education have implemented several digital and broadcast remote learning policies (UNICEF, 2020). Italy was one of the first countries to face the emergency with a very long period of school closure.

Educators had to adapt quickly and were required to resort to digital resources, often with little training, to ensure the uninterrupted progress of student education and thus enhance their professional skills (Nusche, Minea-Pic, 2020; Sharma *et al*., 2022). This transition has posed an incomparable challenge even for educators with a strong command of ICT (Flack *et al*., 2020). The few previous existing empirical studies concerning Italy focus on the impact of the COVID-19 pandemic on student performance and on how this effect varies between schools and subjects (Bertoletti *et al*., 2023), even fewer those that focus on the teachers' perspective. The study carried out by Giovannella *et al*. (2020) through a survey involving 336 Italian teachers demonstrates, in addition, the capacity of the Italian school system and its technological infrastructures to ensure educational continuity during the COVID-19 pandemic with some concern about inclusivity, technology adequacy and teachers' readiness as the two main factors of the perception of sustainability of e-learning and the desire to continue using it in a third of the teachers; moreover, they have noted that the more technological approaches can simulate traditional ones and the more teacher training is provided, the more favorable the conditions are. In conclusion, while the integration of ICT in education has been a long-standing goal, challenges persist. The COVID-19 pandemic has acted as a catalyst, but the readiness of teachers and support from educational institutions remain critical for successful and sustained ICT integration. Developing a comprehensive framework to measure readiness is essential for shaping policies that promote and accelerate the integration process. From this perspective, the purpose of this study is to measure the teachers' readiness towards ICT from a multidimensional perspective using data from the National Institute for the Evaluation of Education and Training System (INVALSI). In detail, our objectives are to assess the degree to which Italian teachers are prepared to fully integrate ICT into educational practice using a multidimensional perspective; secondly, to evaluate whether the pandemic has had a significant effect on this readiness, and to study if there are significant differences at the regional level.

2. Data

The National Institute for the Evaluation of Education and Training System (INVALSI) annually evaluates Italian students across various school tiers, including primary and secondary education. These assessments involve standardized tests that gauge students' proficiency in reading, mathematics, and english. The INVALSI outcomes contribute to the central government's comprehension of the overall performance of the education system, facilitating comparisons both within and among schools on a spatial scale (at the national, regional, and county levels) and over time. The INVALSI survey comprises two separate surveys with variations in the test administration method. The primary survey is a comprehensive census survey where teachers within each Italian school and class administer the tests. Additionally, a probabilistic sample of schools and classes is selected for test administration, overseen by external observers. This sample survey yields more timely and higher-quality data due to the presence of external administrators, mitigating or eliminating potential instances of teachers' cheating, as highlighted by Longobardi *et al.* (2018). At the same time, the sample survey enhances the depth of information gathered by INVALSI by administering targeted questionnaires to principals and teachers within the sample. This approach broadens the spectrum of available covariates, allowing for the collection of pertinent data at multiple levels of analysis. One of the various facets of school life that the INVALSI explores involves examining how teachers incorporate new technologies to enhance both instructional methodologies and evaluation practices. From this perspective, it is interesting to assess variations in teachers' attitudes toward the use of ICT before and after COVID-19 to verify whether the restrictions due to the pandemic have promoted the integration of new technologies into teaching practices. For this purpose, we pooled the sample data collected before the COVID-19 pandemic (school year 2018/2019) with the most recent data acquired after the pandemic (school year 2021/2022), coinciding with the lifting of school restrictions. Based on self-reports, the data were collected at the regional level (NUTS 2) from a sample of 3,885 teachers of grade 10, comprising 1,993 Italian teachers and 1,892 mathematics teachers. Table 1 reports

Table 1 – Size of Teachers' Sample by Teaching Discipline, Macro-area and School Year

Area	*Before Covid-19 (s.y.2018/19)*			*After-Covid-19 (s.y.2021/22)*			*Total*		
	Italian	*Math*	*Total*	*Italian*	*Math*	*Total*	*Italian*	*Math*	*Total*
North-West	234	229	463	166	173	339	400	402	802
North-East	261	244	505	159	163	322	420	407	827
Centre	293	283	576	199	185	384	492	468	960
South	262	243	505	211	211	422	473	454	927
Islands	123	89	212	85	72	157	208	161	369
Italy	1,173	1,088	2,261	820	804	1,624	1,993	1,892	3,885

Source: Authors' elaborations from INVALSI teacher's questionnaire data

the sample size distribution categorized by teaching discipline, macro-regional area, and school year (pre/post-Covid).

To compare the information between the two surveys and examine a comprehensive array of items from the teachers' questionnaire associated with integrating ICT into teaching practices, we selected only common variables between the two surveys. Following the COVID emergency, the structure of the teachers' questionnaire for the school year 2021/22 was modified by INVALSI, contextualizing and focusing the questions on the changes in teaching processes caused by the pandemic. Consequently, although it is not possible to fully exploit the entire informational "heritage" of both surveys, the set of items usable for pre and post-COVID comparison consists of 13 items, which represent a sufficient number to outline a framework of the dimensions composing ICT readiness.

Table 2 provides the list and description of these items measuring a particular action or teacher assessment that enables us to measure the ICT readiness of teachers. These variables represent the potential set of indicators that are single observable manifestations of the latent multidimensional concept of "readiness to ICT". The scale of each item has been reversed, when needed, to ensure they move in the same direction: a higher value of the indicator corresponds to a greater likelihood that teachers possess a high level of readiness for ICT[1].

1. In addition, the answer "I don't know" of the items from D1a and D1b has been recoded by assigning them the median value.

Table 2 – List of Common Items Selected from Invalsi Teachers' Questionnaire Over the Surveys Conducted Before and After the Covid-19 Pandemic (s.y.2018/19 and s.y. 2021/22)

Item	*Survey Questions*	*Type of Variable (answers) Categorical variable*
D1a	How much does the teacher believe that the transition from the paper test to the computer test helped in the understanding of the questions?	(1=Strongly Disagree; 2=Little agree; 3=Fairly agree; 4=Strongly agree; 5=I do not know)
D1c	How much does the teacher believe that the computer test increases the assessment objectivity?	(1=Strongly Disagree; 2=Little agree; 3=Fairly agree; 4=Strongly agree; 5=I do not know)
D2a	Frequency of use of computer tests made available on the INVALSI site	(1=Never or almost never; 2=Sometimes; 3=Often Always, 4= Nearly always)
D2b	Frequency of use of computer tests on other platforms	(1=Never or almost never; 2=Sometimes; 3=Often Always, 4= Nearly always)
D2c	Frequency of use of computer tests prepared by the teacher	(1=Never or almost never; 2=Sometimes; 3=Often Always, 4= Nearly always)
D2d	Frequency of use of the computer lab	(1=Never or almost never; 2=Sometimes; 3=Often Always, 4= Nearly always)
D10a* D6a**	Frequency of use of ICT supports for teaching (computer)	(1=Regular use; 2=Occasional use; 3=Not use; 4=Not present at school)
D10b* D6b**	Frequency of use of ICT supports for teaching (Multimedia Interactive Whiteboard)	(1=Regular use; 2=Occasional use; 3=Not use; 4=Not present at school)
D10d* D6d**	Frequency of use of ICT supports for teaching (Smartphone)	(1=Regular use; 2=Occasional use; 3=Not use; 4=Not present at school)
D10e* D6e**	Frequency of use of ICT supports for teaching (Tablet)	(1=Regular use; 2=Occasional use; 3=Not use; 4=Not present at school)
D10f* D6f**	Frequency of use of ICT supports for teaching (e-learning platforms)	(1=Regular use; 2=Occasional use; 3=Not use; 4=Not present at school)
D10g* D6g**	Frequency of use of ICT supports for teaching (educational software)	(1=Regular use; 2=Occasional use; 3=Not use; 4=Not present at school)
D11f* D7f**	Assessment method: Frequency of use of assessment platforms	(1=Never or almost never; 2=Sometimes; 3=Often Always, 4= Nearly always)

Note: * Item of the questionnaire for math teacher; ** Item of the questionnaire for Italian teacher.

Source: Authors' elaborations from INVALSI teacher's questionnaire data

3. Method

We used the approach proposed by D'Agostino *et al.* (2022) to synthesize the information provided from the list of items described in Table 2. We first employed Exploratory Factor Analysis (EFA) to check whether there are one or more underlying dimensions to the multidimensional concept of ICT readiness. Then, Confirmatory Factor Analyses (CFA) were performed to test and confirm what was detected by EFA. To summarize the information on each dimension, we implemented the fuzzy approach proposed by Betti *et al.* (2016). This methodology allows us to preserve the richness of the data information being based on the computation of a membership function that measures different degree levels of the ICT readiness of teachers instead of the simple dichotomy of being ready or not ready for ICT.

Formally, let x_{ij} be the category of item j (j=1…J) observed for teacher i (i=1…n) and let the levels of each item j be ordered from the lowest value of readiness for using ICT – $\min(x_j)$ – to the highest value – $\max(x_j)$. The membership function for the *i-th* teacher and the *j-th* indicator is defined as:

$$\mu_j\left(x_{ij}\right) = \frac{F\left(x_{ij}\right) - F\left(\min\left(x_j\right)\right)}{F\left(\max\left(x_j\right)\right) - F\left(\min\left(x_j\right)\right)} \qquad [1]$$

where $F(x_{ij})$ is the corresponding cumulative distribution function of x_{ij}.

When the teacher's degree of readiness for using ICT is insufficient then $\mu_j(x_{ij})=0$; on the contrary, if it is completely adequate, $\mu_j(x_{ij})=1$; an intermediate level of readiness for using ICT is defined by $0 < \mu_j(x_{ij}) < 1$.

Let d (d = 1, …, D) be one of the possible dimensions that summarize teachers' readiness to use ICT. The multidimensional fuzzy index for *i-th* teacher in the *d-th* dimension is given by computing the weighted average across all the indicators of that dimension d:

$$\mu_d\left(i\right) = \sum_j w_{(d)j}\mu_j\left(x_{ij}\right) / \sum_j w_{(d)j} \qquad [2]$$

where $w_{(d)j}$ is the system of weights proposed by Betti and Verma (2008), computed as the product of two factors:

$$w_{(d)j} = w^a_{(d)j} * w^b_{(d)j}. \qquad [3]$$

The first factor $w^a_{(d)j}$ is directly proportional to the variability of the *j-th* indicator. Thus, if an indicator has a low percentage of teachers associated with the lowest levels of ICT readiness and is therefore judged to be critical, it will receive a high $w^a_{(d)j}$ weight component. The second factor $w^b_{(d)j}$ is inversely proportional to the average correlation between the *j-th* indicator and all other indicators of the same *d-th* dimension. Therefore, an indicator that is highy correlated with the other indicators within the same dimension will have a low $w^b_{(d)j}$ weight component.

The average value of individual values $\mu_d(i)$ defines the overall fuzzy readiness to use ICT of the entire population of teachers as follows:

$$\mu_d = \frac{1}{n}\sum_{i=1}^{n}\mu_d(i) \qquad [4]$$

4. Results

Table 3 summarizes the results obtained using EFA in combination with CFA, taking the 13 elementary items described in Table 2 as input. The selected items load in different dimensions that we named D1 (ICT for teaching), D2 (ICT for assessing), and D3 (Expectations for ICT). While considering different items compared to D'Agostino *et al.* (2022)[2], our findings similarly reveal that more than one dimension describes the readiness to use ICT. The first dimension encompasses various facets of the teacher's ability to facilitate teaching through ICT tools (hereinafter referred to as ICT for TEACHING). Specifically, within this dimension, seven items show how frequently teachers employ technology. This dimension involves the application of diverse ICT tools, including computers, Multimedia Interactive Whiteboards, smartphones, tablets, e-learning platforms, and assessment platforms.

The second dimension evaluates teachers' proficiency in efficiently using computer-based testing and assessments, hereafter referred to as ICT for ASSESSING. The widespread adoption of computer-based testing in recent years has been extensively discussed in the literature, with various studies outlining both the advantages and challenges associated with implementing such assessments for students (McFadden *et al.*, 2021; Jeong, 2014). Within the ICT for ASSESSING dimension, three indicators assess the frequency with which teachers employ computer tests, either provided by the INVALSI or other platforms. Furthermore, this dimension considers the extent to which educators utilize the computer lab and its resources. The third dimension allows us to assess the teacher's attitudes and expectations toward adopting new educational tools, hereafter denoted as EXPECTATIONS for ICT.

The two items of this dimension are related to teachers' expectations regarding how computers contribute to the efficient and effective implementation of assessments for student learning outcomes. This dimension focuses on some topics, including whether computer-based testing impartially caters to the diverse needs of all students, assists in understanding assessment questions, and improves the objectivity of evaluating student performance.

2. As already mentioned, the selection of items was constrained by the availability of the same set of indicators in both periods during which the survey was conducted.

Table 3 – Description of the Three Fuzzy ICT Readiness Dimensions

Dimension	*Description*	*Number of Items*	*List of items*
D1: ICT for teaching	It reflects the capacity to support the teaching process using Information and Communication Technology	7	D10a*/D6a**, D10b*/D6b**, D10d*/D6d**, D10e*/D6e**, D10f*/D6f**, D10g*/D6g** D11f*/D7f**
D2: ICT for assessing	It expresses the ability to make effective use of computer tests	4	D2a, D2b, D2c, D2d,
D3: Expectations for ICT	It reflects a positive attitude toward new educational tools	2	D1a, D1c

Note: * Item of the questionnaire for math teacher; ** Item of the questionnaire for Italian teacher.
Source: Authors' elaborations from INVALSI teacher's questionnaire data

Table 4 reports the values of the fuzzy index of the readiness to use ICT for every dimension before and at the end of the COVID-19 pandemic and the 95% bootstrap confidence intervals of these differences, respectively. Focusing on dimension 1, which expresses the frequency of ICT tools usage, there is a substantial increase in the mean value of the fuzzy index, rising from 0.57 to 0.75. This difference is statistically significant based on the bootstrap interval. It can be explained as an effect of the pandemic, which compelled all teachers, even those less inclined to use it before COVID, to integrate ICT into teaching. Dimension 2, related to the use of ICT for assessment, shows a higher average after COVID-19, but this difference is not statistically significant. The pandemic

Table 4 – Differences in the Fuzzy ICT Readiness Dimensions Before and After the Covid-19 Pandemic

Dimension	*Before Covid-19 (s.y. 2018/19)*	*After Covid-19 (s.y. 2021/22)*	*Difference (2021-2018)*	*95 % Bootstrap confidence interval*	
D1: ICT for teaching	0.573	0.756	0.183	0.172	0.194
D2: ICT for assessing	0.367	0.378	0.011	-0.006	0.028
D3: Expectations for ICT	0.660	0.624	-0.036	-0.053	-0.019

Source: Authors' elaborations from INVALSI teacher's questionnaire data has likely increased teachers' inclination to use digital tools for teaching. Still, at the same time, it has not influenced the methods of assessing students' competencies, which have remained tied to traditional approaches. Unexpectedly, it seems that the COVID-19 pandemic has resulted in a reduction of expectations regarding the effectiveness of ICT in teaching. The average values for this dimension significantly declined post-COVID. Before the pandemic, teachers likely harbored high expectations for these tools, even though they were not extensively utilized in teaching. Subsequently, these expectations partially disappointed after these tools were employed effectively, possibly due to a lack of a systematic path to understanding and integrating these technologies.

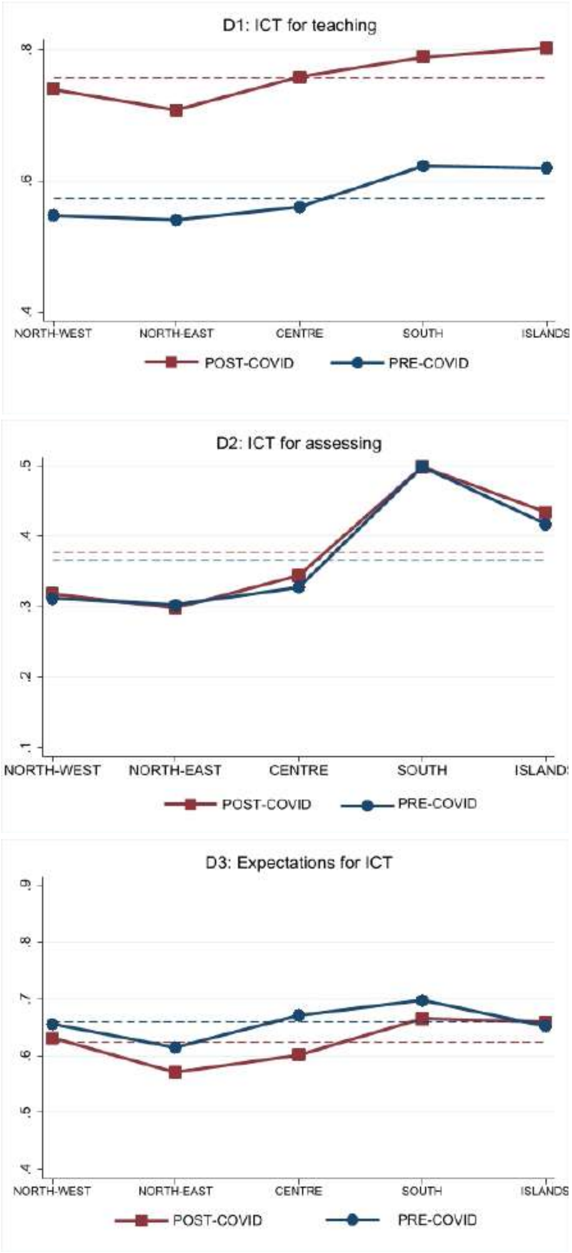
The analysis disaggregated by macro-regions adds further interesting conclusions. Figure 1 shows the index μ_d by the five macro-regions usually used in official statistics for regional comparisons (Northern-west, Northern-east, Centre, South, and Islands) over the two periods. For all three dimensions, the dynamics observed at the national level are substantially replicated at the macro-regional level. As a result, an increase in ICT for teaching is observed in each area, while variations in ICT for assessing appear small within each area. At the same time, the values of expectations for ICT are decreasing, except for the Islands area, where the averages for the two periods seem unchanged.

The differences between areas deserve more attention. Indeed, interesting differences emerge between teachers in Northern Italy and those in the Southern regions, with the latter demonstrating a higher ICT readiness for each dimension, regardless of pre- or post-pandemic period.

In Table 5, the aspect of territorial differences is emphasized by testing them both before and after the pandemic compared to the country's average. As indicated by the fuzzy indicator, positive deviations from the national average suggest that a specific area is more favourably positioned regarding the dimension under examination. Our findings underline that teachers from the southern area and the Islands report higher values than the country's average for each dimension. On the contrary, northern teachers consistently consistently rank below the Italian average in all three aspects of ICT readiness. At the same time, the position of teachers in the Central region is less well defined, as they align around the national average for dimensions 1 and 3 but fall significantly below for dimension 2. These results are particularly noteworthy as they deviate significantly from the typical North-South gap observed in Italy, where teachers and students from the North usually outperform their counterparts in the South (Longobardi, Pagliuca, 2013).

Up to this point, we have examined the impact of the pandemic on territorial differences in teachers' readiness to use ICT, without considering their individual characteristics.

Figure 1 – Averages by Regional Macro-area of the Fuzzy ICT Readiness Dimensions Before and After the Covid-19 Pandemic



Source: Authors' elaborations from INVALSI teacher's questionnaire data

Table 5 – Differences Between the Averages of Each Italian Macro-area and the National Average for the Three Fuzzy ICT Readiness Dimensions Before and After the Covid-19 Pandemic

Area	*D1: ICT for Teaching*		*D2: ICT for Assessing*		*D3: Expectations for ICT*	
	Pre Covid	*Post Covid*	*Pre Covid*	*Post Covid*	*Pre Covid*	*Post Covid*
North-West	-0.025***	-0.017*	-0.054***	-0.060 ***	-0.004	0.007
North-East	-0.032***	-0.049***	-0.063***	-0.080 ***	-0.045***	-0.053***
Centre	-0.013	0.002	-0.037***	-0.034 ***	0.012	-0.022
South	0.050***	0.032***	0.133***	0.120 ***	0.037***	0.041***
Islands	0.047***	0.046***	0.052***	0.056 ***	-0.007	0.035*

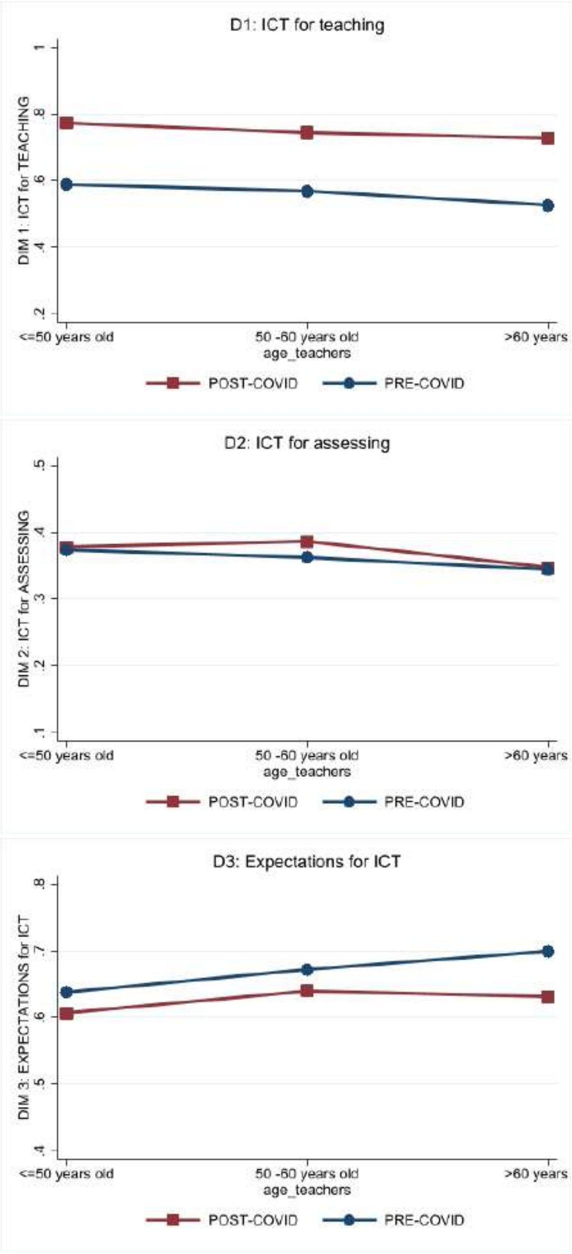
Note: Statistical significance level estimated by bootstrap procedure (reps=1000): * p < 0.1; **p < 0.05; ***p < 0.01.

Source: Authors' elaborations from INVALSI teacher's questionnaire data

Several studies analyze the relationship between ICT integration and teacher characteristics (Šabić *et al.*, 2022; Gil-Flores, 2017) focusing on the age of the teacher, which emerges as one of the elements that most significantly determines the teacher's inclination toward the use of technological tools (Peng *et al.*, 2023; Lucas *et al.*, 2021, Mannila *et al.*, 2018). To explore this relationship, we computed the weighted average of the overall membership function $\mu_d(i)$ defined in equation [2] for each of the three dimensions by the age of the teacher (see Figure 2). A notable increase in the average values of the first dimension (ICT for teaching) is observed across all age groups following the COVID-19 pandemic. Concurrently, it is noteworthy that, during both periods, teachers aged over 60 show a lower average level in dimension 1 compared to their counterparts under 50, confirming that younger teachers show a stronger inclination to integrate ICT into their teaching practices.

The difference in the use of ICT for assessing (D2) among different age groups of teachers seems negligible in the comparison before and after the pandemic, mirroring what has been observed both at the national level (Table 4) and within macro-areas (Figure 1). The expectation regarding the effectiveness of ICT experienced a decline after the pandemic, but this decline is more pronounced among teachers above the age of 60. A broader interpretation of the results suggests that COVID-19 has promoted a greater diffusion of ICT, especially among older teachers who initially exhibited a lower inclination to change their teaching methods. However, this forced march towards ICT integration has led to a decline in expectations, particularly for this category of teachers who may have been more intrigued by new technologies but did not necessarily used them.

Figure 2 – Averages by the Teacher's Age of the Fuzzy ICT Readiness Dimensions Before and After the Covid-19 Pandemic



Source: Authors' elaborations from INVALSI teacher's questionnaire data

5. Conclusions

The availability of INVALSI data, which surveyed 2,261 and 1,624 representative teachers across all Italian regions in 2018/2019 and in 2021/2022, allowed us to measure the degree of readiness of Italian teachers to integrate ICT into their educational practice from a multidimensional and fuzzy perspective. With respect to the contribution of D'Agostino *et al*. 2022 we added an empirical investigation to test whether the COVID-19 pandemic has accelerated the process of ICT integration. Findings could serve as a starting point for proposing policies at the national and regional levels to promote and enhance this process, which the onset of the COVID-19 pandemic has already spurred.

Based on the set of items selected to be common over the two surveys, we confirm the multidimensional nature of the readiness of ICT as in D'Agostino *et al*. 2022: the readiness to ICT can be summarized by three different dimensions. Synthesizing measurements such as the frequency of computer use, interactive platforms, educational software, computer labs, and computer testing, the first and second dimensions reflect the capacity to support the teaching and assessment processes using Information and Communication Technology. Conversely, the third dimension is associated with teachers' perceived likelihood of success in utilizing ICT for educational purposes. After the pandemic, at the national level, there has been a significant improvement in the D1 dimension "ICT for teaching." In contrast, dimension 2, concerning ICT use for assessment, exhibits a higher average but lacks statistical significance, indicating that assessment methods remained traditional despite increased digital teaching. Surprisingly, dimension 3 reveals a reduction in expectations regarding ICT effectiveness in teaching post-COVID-19, possibly stemming from pre-pandemic high expectations and subsequent partial disappointment due to effective yet non-systematic technology integration.

The variations observed at the national level for each of the three dimensions are reflected similarly in each macro area of Italy. Finally, the most intriguing finding is that southern regions exhibit higher readiness levels for digital innovations, particularly for the first two dimensions. In contrast, the northern macro area consistently falls below the overall national average, both before and after the COVID-19 pandemic. The reasons for the ranking of Italian macro-regions across the four dimensions are complex to detect. A large majority of investment spending in education in the southern region has been on ICTs (Giusti *et al*., 2015). This may have pushed teachers in southern Italy to invest time and effort in ICT. Second, in a period of restriction of national public spending on education, EU structural funding disproportionately favored the southern regions (Giusti *et al*., 2015; Römisch, Jestl, 2017). The interaction between this "technology shock [...] to change the teaching culture" and the overall financial resources in education might play a role in understanding the variation in our indicators among Italian regions: teachers in Southern Italy may have tried to make the best use of their ICT resources.

In order to propose and implement further research developments, it is essential to outline some limitations of the present study. Firstly, the results focus on comparing the academic year prior to the pandemic (2018/19) with the academic year 2021/22, during which the critical phase had been surpassed but the emergency was not yet completely resolved. However, to obtain a more comprehensive picture of the COVID's effect in the short-to-medium term, extending the comparison to data from subsequent academic years would be beneficial.

Additionally, measuring the long-term effect of COVID on ICT readiness presents challenges. Departing from the pandemic period, it becomes increasingly difficult to distinguish between the direct effects of COVID and those resulting from the growing pervasiveness of new technologies in the educational sector. For instance, simply consider the burgeoning and swift dissemination of AI algorithms (AI), which were once confined to a select group of experts, these algorithms have now permeated various domains, including education.

Another limitation of the analysis pertains to data availability. As mentioned (section 2), the variables used to define fuzzy indices were selected based on common items in both INVALSI surveys. However, Italy currently lacks a systematic assessment of digital competencies among both teachers and students. Therefore, conducting targeted investigations to evaluate teachers' ICT readiness in greater detail – examining not only their technology usage but also how it impacts their teaching methods – would be desirable.

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Sommario

Gettare via il bambino con l'acqua sporca: le conseguenze del COVID-19 sull'ICT readiness degli insegnanti italiani

Il COVID-19 ha accelerato l'integrazione della Tecnologia dell'Informazione e della Comunicazione (ICT) nel sistema educativo italiano; in questa prospettiva l'articolo analizza l'integrazione dell'ICT nelle scuole Italiane focalizzandosi su: i) come misurare la preparazione dei docenti ad integrare l'ICT nelle pratiche educative; ii) valutare se la pandemia abbia significativamente accelerato l'utilizzo dell'ICT; iii) evidenziare eventuali differenze a livello territoriale. I risultati indicano la multidimensionalità del concetto di "prontezza" all'uso dell'ICT, rivelando un'accelerazione selettiva su alcuni dei suoi aspetti durante la pandemia. Inoltre, contrariamente al tradizionale divario Nord-Sud, si nota una maggiore propensione verso l'ICT tra i docenti delle regioni meridionali.

Digitalization As a Way to Repopulate Peripheral Areas? Some Evidences From the Italian Case

Chiara Agnoletti, Claudia Ferretti*, Leonardo Piccini**

Abstract

The more widespread use of smart working has reduced, at least in part, the need to travel to cities. At the same time, the reduced need to travel to the main urban centers has made some peripheral areas more attractive than in the past. Among the factors that guide localization choices, it is necessary to consider the provision of immaterial networks which benefit those territories with the best digital accessibility. To understand whether the greater or lesser supply of immaterial networks has represented a factor in the attractiveness of peripheral areas, we proceeded with a counter-factual estimate whose results can constitute an interesting element in the current political debate also in relation to the strategies outlined by the NRRP.

1. Introduction

The Covid-19 pandemic, especially in the most acute phase, represented a moment of transformation, not only from an economic and health point of view, but also in terms of social behavior; some of these transformations produced effects, probably in a permanent way, in collective lifestyles (Mariotti, 2021; Nathan *et al.*, 2020). In particular, the lockdown imposed due to the health crisis has gone through a series of remote activities showing that there are radically different ways of living, made possible by digital tools. It is reasonable to consider that the remote transition of work, shopping and education although reduced in the post-emergency phase, not disappear completely. These activities – smart working, e-commerce and distance learning – reduce travel times and commute flows. Symmetrically, the fact of spending much more time at home has

* IRPET – Regional Institute for Economic Planning of Tuscany, Florence, Italy, e-mail: chiara.agnoletti@irpet.it (corresponding author), claudia.ferretti@irpet.it, leonardo.piccini@irpet.it

generated a demand for better quality of living, based on different parameters than in the past (Agnoletti *et al.*, 2022).

For both of these reasons it is probable that some territories have become, more attractive than they have been until now, changing the geography of location choices: in particular this might be true for those places that will offer living contexts with larger homes, yards or terraces and in healthier places, with a new balance between the cost of living and the cost of commuting. Accessibility remain essential to define the location choices, but the availability of intangible networks, rather than transport ones, is decisive, so much so as to suggest at least a partial revision of the concept of proximity and urban concentration (Amankwah-Amoah *et al.*, 2021).

We find an initial confirmation of this evidence by looking at the trend followed by the population in Italian metropolitan cities, which indicates how these have been affected by a reduction in residents starting from the pandemic phase. This trend followed by the main cities could be associated with the factors which, in this new post-pandemic context, guide the choice of location, represented by the greater or lesser endowment of intangible networks, rather than by the transport network. Moving from these initial considerations, we set out to identify the demographic dynamics, in historical series, relating to the major Italian cities, their belts and the more peripheral areas, in order to understand which of these territories have been most involved by phenomena of depopulation and, conversely, of repopulation.

We subsequently try to infer to what extent immaterial accessibility may have represented a disincentive to the depopulation of some Italian peripheral territories, in particular by comparing, in a counterfactual framework, types of municipalities belonging to homogeneous categories (based on a series of covariates of geographical, demographic and economic nature) but which have experienced a different degree of digital infrastructuring. Finally, the possible effects of these structural changes on the front of the demand for mobility and environmental sustainability will be outlined.

2. Peripheral Territories: A Multidimensional Concept

Until now, we have understood peripheral territories as areas physically distant from places of greatest concentration of population and activity, which show a condition of geographical, economic, institutional and social fragility. The concept of peripherality, in fact, is therefore a multidimensional concept that concerns the economic-territorial, socio-cultural and technological-infrastructural aspects (Iommi *et al.*, 2017; Ceriani, 2012). The condition of disadvantage, which characterizes territories with reference not only to social, but also economic and territorial aspects, is identified with concepts of "socio-economic and infrastructural marginality" and "territorial deprivation" (Ferlaino, Rota, 2008).

The effects of the structural weakening of a local system produced by the depopulation process generate a combination of recessive effects (negative feedback): the demographic decline weakens the structure of the population, the potential for consumption and income production, the system of local services, and this ends up generating further pressure for depopulation, producing a perverse mechanism. These are processes that consolidate the marginality of these territories and accentuate the distance, in a broad sense, with the more populous and productive areas, with consequences on territorial disparity. This theme has gained importance within the debate on EU policies, which have paid particular attention to the effects of territorial rebalancing. Also the "place based" policies falls within this perspective, which identifies development strategies that respond to local objectives and needs (Rodriguez-Pose *et al.*, 2006; Pike *et al.* 2006; 2017; Barca *et al.* 2012; OECD, 2009; 2011; 2018; World Bank, 2009).

Marginality is therefore a relative condition as it can only be defined through comparison with other contexts; it is also a dynamic condition, because it is influenced by various factors that can change over time. The dynamic characterization therefore makes marginality a process, which can evolve over time both as a function of the socio-economic, geo-political and technological contexts, which can favour or disfavour the strengthening of the phenomenon itself. From this perspective, the Covid 19 pandemic represented a factor that had (at least potential) positive repercussions on the concept of proximity thanks, in particular, to the spread of remote activities. In fact, the health emergency expeditiously precipitated the prospect of living in a radically different way from in the past, made possible by digital tools (Delventhal *et al.*, 2021). This evolution, also known as the "zoom shock" (De Fraja *et al.*, 2020), was mainly supported by the fact that there was less need to move around due to the shift to being able to work remotely, as well as online consumption and learning possibilities, and although this has been scaled down in the post-emergency period, it does not seem set to disappear altogether and will also leave clear traces in the near future. The spread of smart working, e-commerce and distance learning has produced a twofold effect: while it has reduced, and is still reducing, the time and need to travel on the one hand, on the other it raises the question of new location requirements for businesses and different living standards for families. In fact, on the business front, the health emergency has led to both a profound crisis in terms of urban activities linked to the mobility of people, and a change in the location preference of some businesses, which until now favored the city, but could now lean towards a less concentrated territorial distribution. As for families, on the other hand, having to spend much more time inside their homes, both for work purposes but also to slow the spread of the virus, has raised questions about the quality of life based, in this case too, on different parameters than in the past. For families, in fact, decisions about where to live are made considering the difference in the cost of housing between the centre and the suburbs, nowadays taking into account new needs and a different concept of accessibility (Mouratidis, 2021). Moreover, if we consider residential costs, it should be borne in mind that the latter are not only connected to the location but also to the apartment size and to the quality of life. It follows that once the amount of income to be spent has been defined, this sum can be divided among the costs deriving from the location (size of the city and reduced cost of transport) and those relating to the size of the apartment. This element should also be cross checked with the growing demand for better quality of life, referring to both housing in itself and the external territorial context (more green areas, less congestion), conditions that are easier to find outside of large urban concentrations like peripheral territories.

2. The Depopulation of Peripheral Areas and Its Consequences

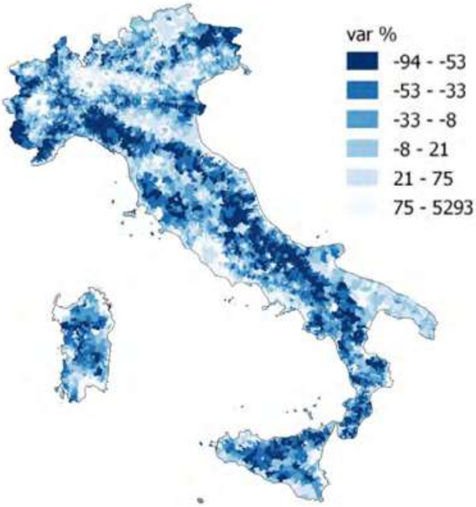
The peripheral condition of the territories fuels the processes of demographic decline, leading to a strong reduction in human presence and triggering significant changes in both economic activities and the environment (Iommi *et al.*, 2023).

Depopulation has been a characteristic of peripheral areas for a long time. Looking at the last 70 years – from 1951 to today – we observe how in the territories classified as peripheral and ultra-peripheral there has been a drop around 18% and 26% respectively. On the contrary, in the hub municipalities – barycentric in terms of services – the population increased by 31%, as well as in the surrounding municipalities, hinterlands of the major cities, where the increase was even more significant (49%) as a result of the suburbanization processes which affected our main urban centers (Figure 1).

Analyzing the demographic dynamics, referring only to the last 20 years, we observe how the peripheral areas are the most disadvantaged, where the greatest population losses are recorded (Table 1). If we then look at the population trend by geographical area, we note that the reduction in the population occurs mainly in the peripheral areas of the south (Figure 2).

The overall decrease in the population in peripheral areas is often accompanied by a deterioration of the demographic base (Istat, 2022). In fact, among the consequences that we can highlight of depopulation is the smaller share of children aged 0-4 years over total population (Figure 3). This criticality is also destined to become accentuated in the future, since these same areas are likely to be affected by a lower birth rate as a consequence of the further thinning of the demographic base in the active age of the coming years.

Figure 1 – Variation in the Resident Population Between 1951 and 2019. Percentage Values, Italy



Source: Authors' elaborations on ISTAT data

Table 1 – Variation in the Resident Population. Percentage Values, Italy

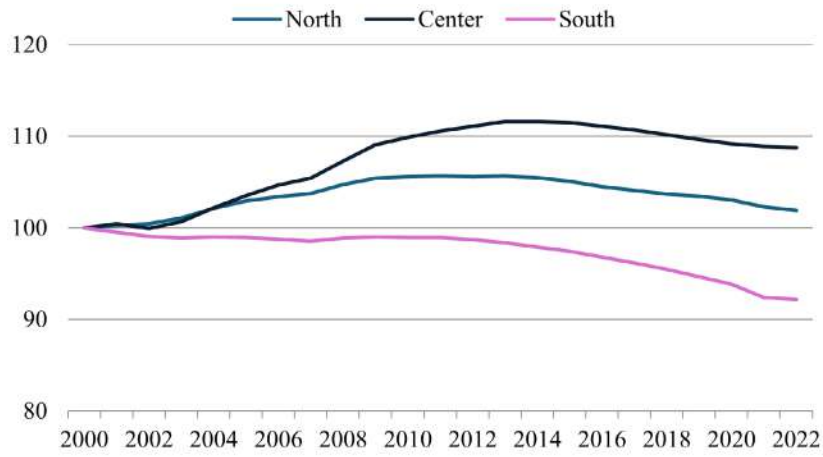
	2000-2010	*2010-2020*	*2020-2022*
Centre	1,6	1,4	-1,5
Inter-municipal centre	3,1	-0,8	-1,1
Belt	9,9	0,7	-0,3
Intermediate (27-40' from the Centre)	4,8	-2,6	-1,1
Suburb (40-67' from the Centre)	-0,8	-5,3	-1,8
Outlying region (> 67' from the Centre)	-3	-5,5	-2,2
Italy	4,9	-0,1	-1,0

Source: Authors' elaborations on ISTAT data

In parallel with the decrease in the population, in peripheral areas we have witnessed an increase greater than elsewhere in the share of elderly people (Figure 4). This is a generalized phenomenon, which however takes on a more visible trend in these areas.

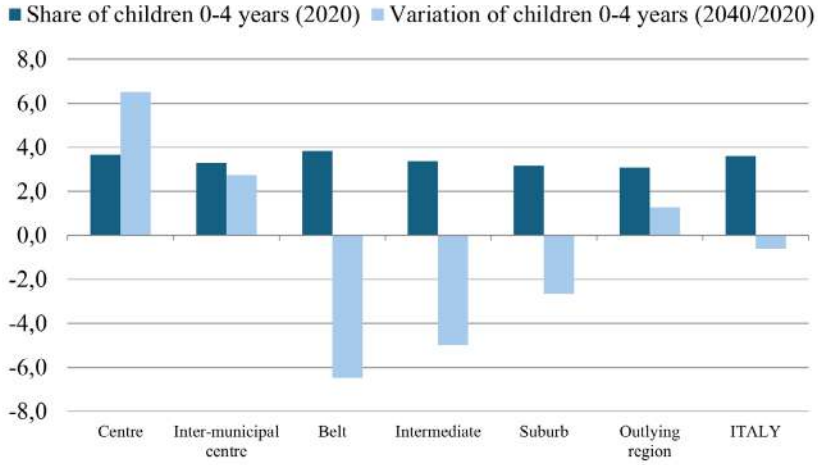
It is clear that the demographic evolution described has also produced repercussions from an economic point of view in terms of income production (Figure 5).

Figure 2 – Population in Peripheral Areas. Index Numbers 2000=100, Italy



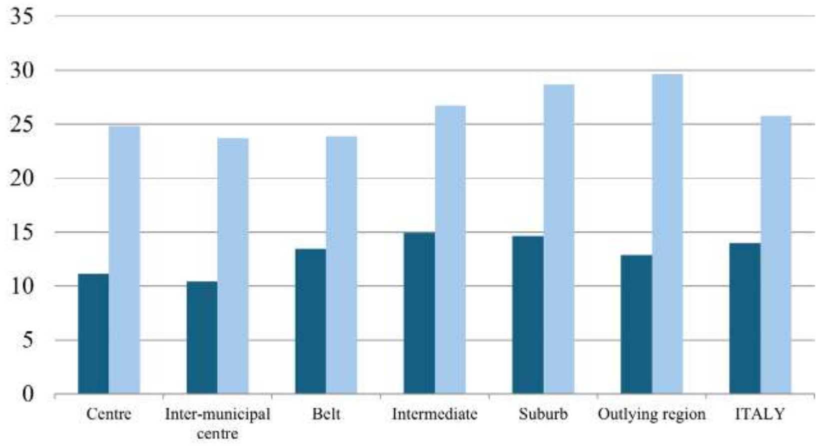
Source: Authors' elaborations on ISTAT data

Figure 3 – Share of Children Aged 0-4 Years 2020 and Variation in Children 2040/2020. Percentage Values, Italy



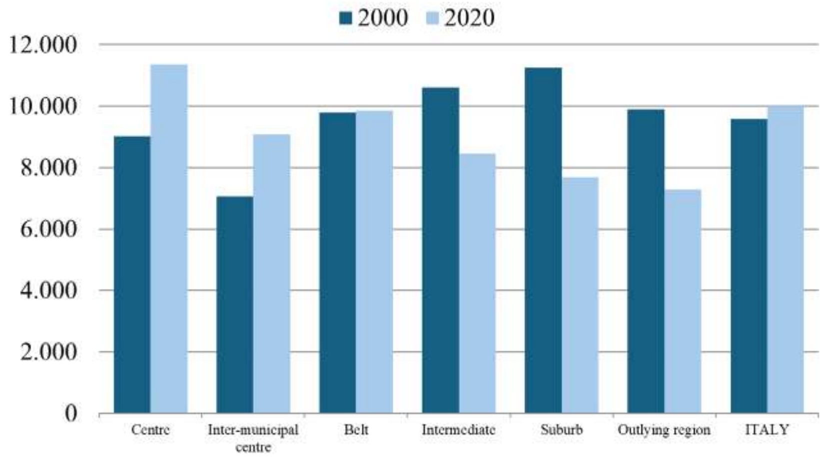
Source: Authors' elaborations on ISTAT data

Figure 4 – Share of Population Aged Over Sixty-five Years. Percentage Values, Italy



Source: Authors' elaborations on ISTAT data

Figure 5 – IRPEF taxable income in current Euros. Average Value per Capita, Italy



Source: Authors' elaborations on ISTAT data

In particular we can highlight how the peripheral areas have progressively become impoverished. In fact, IRPEF taxable income has decreased in the last 20 years in peripheral areas, while it has increased in the hubs and belt areas.

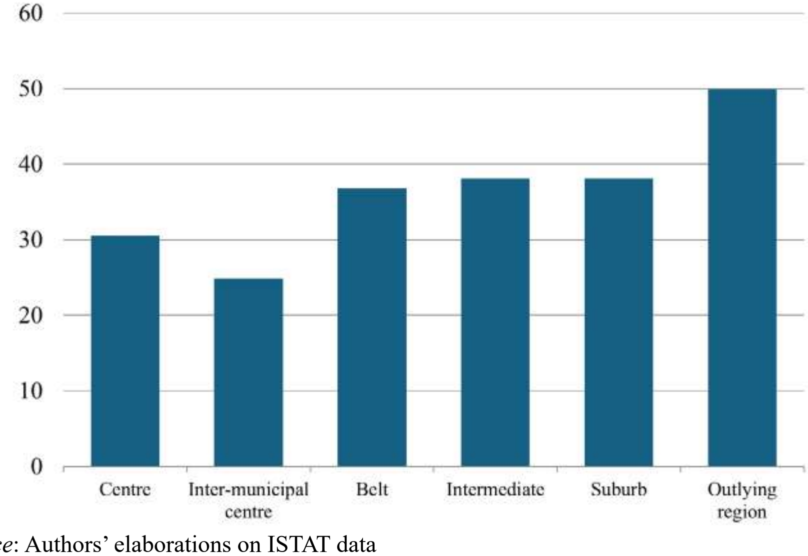
The erosion and deterioration of the demographic base has the effect of further increasing the diseconomies of scale in spending connected to the small size of peripheral municipalities (Figure 6). In fact small administrations have very high per capita costs that depend on the need to maintain essential services (e.g. registry office, waste collection, etc.).

On the other hand, this leads to the scarcity in the offer of local services mainly determined by the high management costs. Looking, for example, at the nursery school service, we observe how available places per capita in peripheral areas are much lower than those in other areas (Table 2).

This is a phenomenon that can act both as a cause and as an effect of demographic contraction, as a decrease in the supply of services represents a factor that negatively reflects on the attractiveness of the territories; symmetrically the contraction in the demand for services generates diseconomies of scale that require a smaller offering and higher management costs associated with them.

In this context, the digitalization of essential services has been proposed as a feasible policy to at least partly contrast these negative spiral of depopulation

Figure 6 – Current Expenditure of Municipalities. Percentage Variation 2021/2000, Italy



Source: Authors' elaborations on ISTAT data

Table 2 – Average Number of Places Authorized in Nursery School per 100 Children Aged 0-2 years. Percentage values, Italy

Centre	32,0%
Inter-municipal centre	26,1%
Belt	25,8%
Intermediate	18,2%
Suburb	15,3%
Outlying region	9,0%
ITALY	21,3%

Source: Authors' elaborations on ISTAT data

and marginality. By reducing the need for phisycal proximity, it can enhance the attractiveness of remote areas which offer reduced housing prices and a better living context. But in order to be able to exploit this solution, one of the preconditions to be met is the existence of a reliable and effective digital infrastructure.

Since digital divide is a well known and analyzed phenomenon (especially in geographically diverse territories like Italian regions), we may ask ourselves to what extent the different levels of territorial digitalization have played a role in recent years in addressing and reducing depopulation trends in peripheral municipalities, and in which way can the answer to this question inform territorial public interventions.

3. The Methodology

In the realm of policy evaluation, understanding the true impact of an intervention or policy change is often a complex challenge. Traditional methods may struggle to provide accurate assessments due to inherent biases and confounding factors. Counterfactual methods have emerged (Imbens, Rubin, 2015) as a powerful approach to address this issue, offering a robust framework for estimating causal effects by comparing observed outcomes with what might have happened in the absence of the policy.

At its core, counterfactual analysis involves constructing a hypothetical scenario, often referred to as a counterfactual or "what-if" scenario, that represents a world where the policy under consideration did not take place. By comparing the observed outcomes with these hypothetical scenarios, we aim to isolate and measure the causal impact of the policy. This methodology is particularly relevant in situations where randomized controlled trials are impractical or impossible (as it is often the case in social sciences), making it difficult to establish a clear causal link between the policy and its outcomes.

Within the family of counterfactual methods we may encompass various techniques, such as propensity score matching, difference-in-differences, instrumental variables, and synthetic control methods. Each approach has its strengths and limitations, and the choice of method depends on the specific characteristics of the policy, available data, and the underlying research question. The overarching goal is to rigorously estimate the causal effect of a policy by carefully constructing and comparing plausible counterfactual scenarios.

In our case, we need to find a way to isolate the effect of digitization on migration flows at the municipality level. Since we cannot assume that the implementation of the digital infrastructure is independent from the same factors that may affect location decisions (e.g., more densely populated municipalities may receive more investments in digital connectivity since there are economies of scale at play, but more densely populated areas may also offer a wider variety of services and thus be more attractive for people that migrate), we apply propensity score matching to our dataset.

Propensity score matching is a powerful statistical technique widely employed in the field of counterfactual policy evaluation. As researchers seek to determine the causal impact of interventions or policies, addressing the challenge of selection bias becomes paramount. Propensity score matching (PSM) offers a solution by creating balanced comparison groups, thus enabling a more accurate estimation of causal effects. The propensity score represents the conditional probability of receiving the treatment given a set of observed covariates (in the example given above, the population density). In other words, it summarizes the likelihood of being in the treatment group based on observable characteristics. The key advantage of the propensity score is that it condenses multiple covariates into a single scalar, simplifying the matching process. The primary goal of propensity score matching is to achieve balance in the distribution of observed covariates between the treated and control groups. By creating comparable groups, we aim to mimic a randomized control trial, mitigating the impact of selection bias. This balance ensures that any observed differences in outcomes can be attributed more confidently to the treatment rather than pre-existing differences in characteristics.

Once the propensity scores are estimated, we can apply various methods to match treated and untreated units with similar or identical scores. Nearest neighbor matching, kernel matching, and stratification are common techniques employed in this process. Nearest neighbor matching (NN) pairs each treated unit with one or more untreated units that have the closest propensity scores. Kernel matching assigns weights to each observation based on the similarity of their propensity scores, while stratification involves grouping units into strata based on their propensity scores. In our case, the matching algorithm is nearest neighbor. It involves running through the list of treated units and selecting the closest eligible control unit to be paired with each treated unit. It is a greedy algorithm, in the sense that each pairing occurs without reference to how other units will be or have been paired, and therefore does not aim to optimize any criterion. Nearest neighbor matching is one of the most common form of matching used in the social sciences (Thoemmes *et al*., 2011).

In summary, within this work, for the purpose of understanding whether the greater or lesser supply of immaterial networks has represented a factor of attractiveness towards peripheral territories in the recent past, a counter-factual estimate was used on three explanatory variables: the migratory balance and the number of canceled and registered at the registry office of each Italian municipality in the years from 2018 to 2021. Each of these variables is represented in per capita terms compared to the resident population. This method allows us to evaluate if intangible accessibility can represent a disincentive to depopulation, comparing homogeneous territories (based on a series of geographical, demographic and economic covariates) but with a different degree of digital infrastructure. The group of treated municipalities is represented by those that have a connection speed greater than 30MBps, while that of untreated municipalities is identified through a matching procedure. In particular the matching

Table 3 – Explanatory and Covariates Variables Used for the Estimation

Name	*Index*	*Years*	*Scale*
Explanatory			
migratory balance	(registered-canceled)/pop*1000	2018-2020	municipal
nr. of canceled	canceled/pop*1000	2018-2020	municipal
Nr. of registered	registered/pop*1000w	2018-2020	municipal
Covariates			
old age	(pop > 65 years/ pop) *100	2014	municipal
income	IRPEF taxable income/pop	2014	municipal
property values	municipal average of (housing property value / housing square metres)	2014	municipal
unemployment rate	(jobseekers / total labour force)*100	2014	LLS
long-term population change	(pop 2011-pop 1951)/pop 1951)*100	2014	municipal
protected areas	protected areas surface (Ha)	2014	municipal

Source: Authors' elaborations

takes place on the basis of a series of economic, demographic and territorial covariates: old age index, per capita income, property values per square meter, SSL unemployment rate, long-term population change, percentage of surface area in protected areas (Table 3).

In addition, the National Cohesion Strategy (SNAI) was used to classify peripheral areas, which identifies them on the basis of their distance from the centres of services. In this way, the level of services has also been indirectly taken into account for the estimation. Furthermore, an exact matching is carried out within each region. All the covariates are fixed over time and refer to a period before the treatment (2014). The control group is identified through a propensity score matching (PSM) and using the Nearest Neighbor (NN) as the matching algorithm.

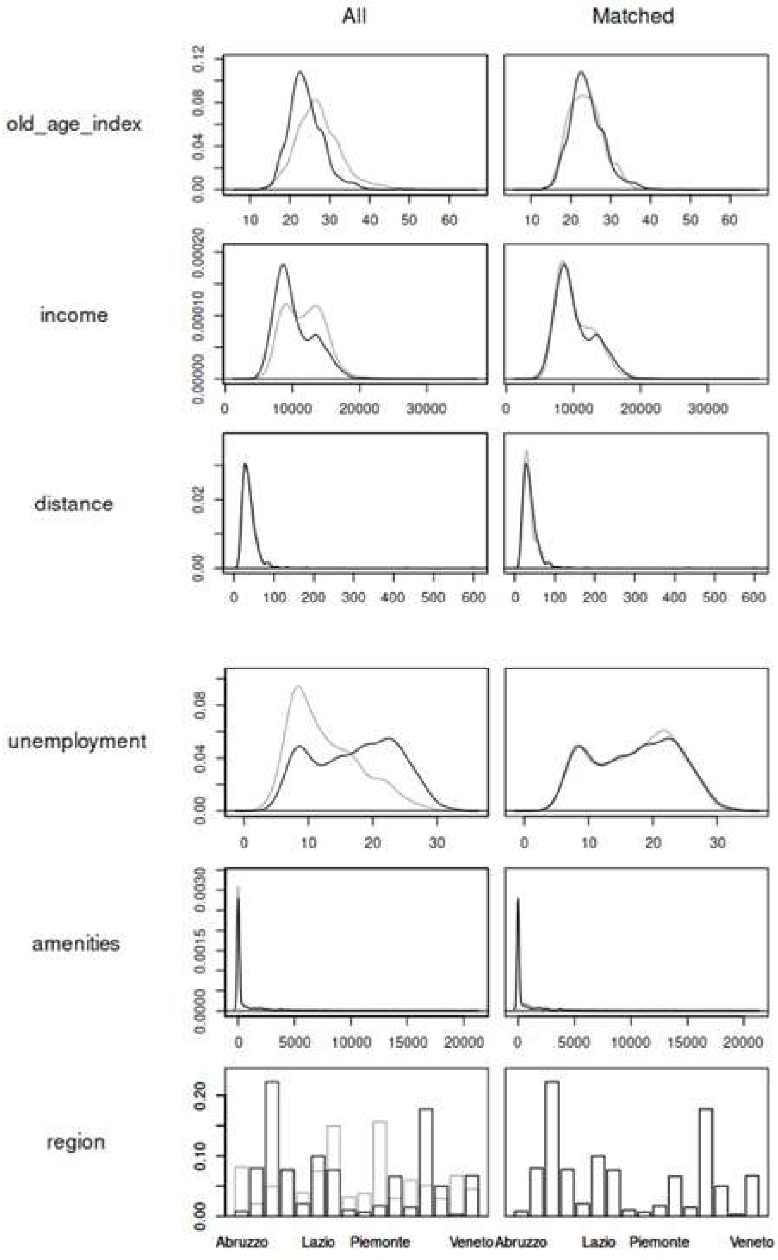
After the matching we end up with a database of treated unites and a matched sample. To estimate the average effect on the treated (ATT), we run a regression of the outcome on the treatment and covariates in the matched sample (including the matching weights to improve robustness) and perform a G-computation (Robins, 1986; Snowden *et al.*, 2011). For each treated unit, we compute their predicted values of the outcome under each treatment level. We then compute the overall mean of each of this measures and, finally, compare their difference as a measure of the average effect on the treated of the digitalization.

4. The Results

A first series of results concerns the method of identifying the control municipalities; this procedure, in fact, reduces the variability of all the covariates used for their identification (Figure 7), providing, in other words, a control group as similar as possible to that of the treated ones.

As regards the counterfactual estimate, this reported significant results both in reference to the migratory balance (Table 4) and to the cancelled. On the contrary, the results are not significant regarding the number of incoming registered per capita. In the first case, the data shows how digitalization has had, in general, a positive and significant effect on the migratory balance in the years 2019 and 2020. At the same time, it is demonstrated that this effect is differentiated by geographical area. In particular, in the municipalities of the centre-north, digitalization influenced the migration balance only in 2019, when the maximum diffusion of the network led to a greater influx of residents towards the peripheral areas. In the southern regions, however, this effect also continued in 2020, during the pandemic period, when the peripheral areas represented more attractive places also because they were less at risk of contagion (Agnoletti *et al.*, 2022).

Figure 7 – Distribution Curves of the Covariates Used to Identify the Control Municipalities



Source: Authors' elaborations on ISTAT and AGCOM data

Table 4 – Results of the Counterfactual Estimation on the Migratory Balance (per capita)

	Estimate	*P.value*
Italy		
2018	-0.727	0.287
2019	2.5	<0.001****
2020	1.09	0.0722
2021	0.523	0.432
Centre-North		
2018	0.069	0.966
2019	3.26	0.052*
2020	-1.2	0.450
2021	0.21	0.884
South		
2018	-0.799	0.32
2019	4.32	<0.001****
2020	1.49	0.056*
2021	1.05	0.215

Note: (***) <0.001; (**) tra 0.001 e 0.01; (*) tra 0.01 e 0.5.

Source: Authors' elaborations on ISTAT and AGCOM data

However, making reference to the number of cancelled per capita the results are always significant (Table 5). It is demonstrated how the effect on the migratory balance can be attributed exclusively to the lower number of cancelled persons and not to the greater number of registered for whom, however, the estimate is not significant. In other words, in the group of peripheral municipalities with the best connectivity (treated) the share of cancellations in each year is lower than that observed in the group of municipalities with lower connectivity (controls). On the other hand, the possibility of having a high connection does not have any significative effect on new registrations. Ultimately, it can be stated that connectivity represents above all a containment factor, reducing the tendency to leave peripheral territories. At the same time we highlight how a greater provision of intangible infrastructures is not, however, capable of acting on the attractiveness of these places and therefore of influencing the new acquisitions of inhabitants.

Table 5 – Results of the Counterfactual Estimation on Cancelled Persons (per capita)

	Estimate	*P_value*
Italy		
2018	-3.86	<0.001***
2019	-3.52	<0.001***
2020	-2.35	<0.001***
2021	-3.17	<0.001***
Centre-North		
2018	-4.13	<0.001***
2019	-5.45	<0.001***
2020	-3.2	<0.001***
2021	-4.15	<0.001***
South		
2018	-5.08	<0.001***
2019	-1.41	0.0398*
2020	-1.8	0.0222*
2021	-3.26	<0.001***

Note: (***) <0.001; (**) tra 0.001 e 0.01; (*) tra 0.01 e 0.5.

Source: Authors' elaborations on ISTAT and AGCOM data

In conclusion, we can highlight how, according to our estimates, infrastructure policies are not sufficient to encourage the repopulation of peripheral areas for which, in addition to interventions to support endogenous development, policies aimed at improving and acquiring local services would be necessary.

5. Conclusions

Over the years, peripheral areas have generally been characterized by strong depopulation which has resulted in fewer children and a greater number of elderly people. At the same time, the demographic evolution has produced repercussions from an economic point of view in terms of income production: in fact IRPEF taxable income has decreased in the last 20 years in peripheral areas, while it has increased in the hubs and belt areas. Furthermore, in these same areas, often characterized by small municipalities, the services offered are undersized compared to the number of citizens, while the expenditures are higher due to diseconomies of scale.

During the health emergency, some peripheral locations have become more attractive both due to the greater use of remote activities (which reduces the opportunities to travel to cities) and due to the lower risk of contagion. Naturally, in this period, the availability of immaterial networks rather than transport networks may have had a bigger role in determining the new location choices. From this point of view, therefore, it is important to know if and in what way accessibility to the digital network has really led to a greater population of peripheral areas.

So, in order to understand whether the greater or lesser supply of immaterial networks has represented a factor of attractiveness towards peripheral territories in the recent past, a counter-factual estimate was used on three explanatory variables: the migratory balance and the number of canceled and registered at the registry office of each Italian municipality in the years from 2018 to 2021.

The results are significant both in reference to the migratory balance and to the cancelled. On the contrary, the results are not significant regarding the number of registered per capita. In the first case, the data shows how digitalization has had, in general, a positive and significant effect on the migratory balance in the years 2019 and 2020. At the same time, it is demonstrated that this effect is differentiated by geographical area. In particular, in the municipalities of the centre-north, digitalization influenced the migration balance only in 2019, when the maximum diffusion of the network led to a greater influx of residents towards the peripheral areas. In the southern regions, however, this effect also continued in 2020, during the pandemic period, when the peripheral areas represented more attractive places also because they were less at risk of contagion.

In regards to the number of registered per capita the results are always significant. It is demonstrated how the effect on the migratory balance can be attributed exclusively to the lower number of cancelled persons and not to the greater number of registered for whom the estimate is not significant. In other words, connectivity represents above all a containment factor, reducing the tendency to leave peripheral territories. At the same time we highlight how a greater provision of intangible infrastructures is not, however, capable of acting on the attractiveness of these places and therefore of influencing the new acquisitions of inhabitants.

In conclusion, we can underline how, according to our estimates, infrastructure policies are not sufficient to encourage the repopulation of peripheral areas for which, in addition to interventions to support endogenous development, policies aimed at improving and acquiring local services would be necessary.

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Sommario

La digitalizzazione come fattore per ripopolare le aree periferiche? Alcune evidenze dal caso italiano

Il più diffuso utilizzo dello smart working *ha ridotto, almeno in parte, le esigenze di spostamento verso le città. Parallelamente, la minore necessità di recarsi nei principali centri urbani, ha reso alcuni territori periferici più appetibili rispetto al passato. Tra i fattori che guidano le scelte localizzative occorre considerare la dotazione di reti immateriali che avvantaggia quei territori con la migliore accessibilità digitale. Per comprendere se la maggiore o minore dotazione di reti immateriali abbia rappresentato un fattore di attrattività delle aree periferiche, si è proceduto con una stima controfattuale i cui risultati possono costituire un interessante elemento nell'attuale dibattito politico anche in relazione alle strategie delineate dal PNRR.*

The Main Evidence of Climate Change in Capital Cities

Francesca Allegra, Paola F. Cortese*, Graziella Fusaro**

Abstract

The extreme climatic phenomena that have characterized recent years have greater consequences the more densely the affected territories are inhabited. On the other hand, the anthropization of territories and the consequent human activity contribute significantly to determining the progressive change of the climate. The work focuses on the 21 regional capital cities and autonomous provinces. First, their demographic dynamics and geographical characteristics will be highlighted, subsequently, some statistical measures will be used to describe the recorded climate change. Finally, the data relating to the main climate-altering elements and their historical series trends will be examined.

1. Introduction[1]

The history of our planet is marked by natural phenomena that have altered the climate, affecting habitats and life. Since the industrial era, this dynamic of change has faced the impact of human activities, accelerating its course towards global warming. In recent decades, human-induced pressure on the climate has become increasingly urgent and hardly sustainable. The rise in industrial activities, growing energy demands, indiscriminate use of natural resources, and the rapid increase in the world population have defined a scenario of change that daily raises alarms and needs to be understood in its actual capacities through accurate production of quantitative and statistical information.

An examination of measurements available from official sources tasked with measuring and monitoring climatic and meteorological variables can indeed help understand and manage the fundamental interconnections needed to address the impacts of climate change and develop adaptation and mitigation strategies, especially in more vulnerable contexts such as cities. It is precisely within urban

* ISTAT, Italian National Institute of Statistics, Rome, Italy, e-mail: allegraf@istat.it, pacortes@istat.it (corresponding author), fusaro@istat.it.

1. Paola Francesca Cortese authored paragraphs 1, 4 and 5; Graziella Fusaro paragraph 2 and Francesca Allegra paragraph 3.

settings, characterized by population concentration, structural fragility, limited presence of green spaces, and significant emission of pollutants, that the impacts of climate change reach the highest levels of criticality.

2. The Anthropization of Capital Cities

The ongoing climate changes are causing an increase in the frequency of extreme rainfall events (short but intense or persistent) and, consequently, an increase in the frequency of floods and landslides with risks of personal injury (dead, missing, injured, evacuated). Together with climate changes, however, some anthropic activities are taking on an increasingly decisive role among the predisposing causes of landslides and floods and are worsening their negative impacts. Italy is a country with a high hydrogeological risk, but it is also a highly anthropized country (Istat, 2020); the increase in urbanized areas, often in the absence of correct territorial planning, and the waterproofing of the soil brought to a considerable increase in elements exposed to risk, which are goods and people present in areas subject to danger from landslides and floods.

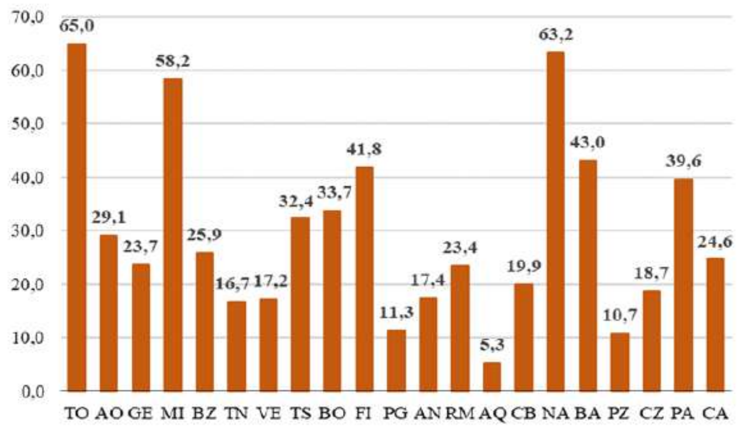
A key indicator of the pressure exerted on the environment by the urbanization of the territory is represented by land consumption: percentage of artificially covered land on the total municipal area (Figure 1). Land consumption is very high in Torino (65.0 percent), Napoli (63.2) and Milano (58.2). An incidence of more than 40 percent of anthropic territory is also recorded in Bari (43.0) and Firenze (41.8).

The interaction between the population and the environment causes the process of anthropization of the territory to increase as the population increases itself. In fact, the cities in which the anthropic surface area is lowest – L'Aquila (5.3), Potenza (10.7) and Perugia (11.3) – are those with the lowest population density. On the other hand, Napoli, Milano and Torino, which have the highest values of land consumption, are also the most densely populated capital cities of the country (Figure 2).

In recent years, the decrease of the resident population in Italy has caused a population contraction also in most of the capital cities (Figure 3). In fact, there are only seven municipalities that present positive percentage changes in the period considered (2006-2020); the largest increases concern Milano (8.8 percent), Bolzano (8.3) and Trento (7.3). The decrease of population, however, has not slowed down land consumption (Mufanò, 2022) which continues to increase even in cities where the population is decreasing. Catanzaro stands out among all where, a significant decrease in population (-7.4 percent) corresponds to an increase in land consumption of 12.1 percent.

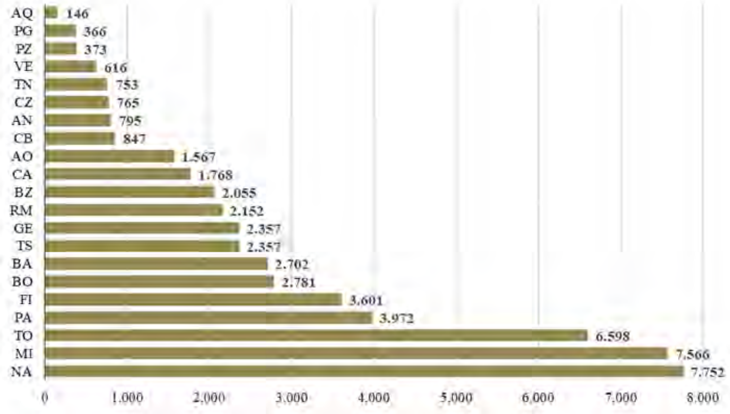
Italy is most affected the European country by landslide phenomena which affect an area of almost 24,700 km^2, equal to 8.2 percent of the national territory.

Figure 1 – Land Consumption by City Capital, 2020 (values percentage)



Source: Authors' elaborations on ISPRA data

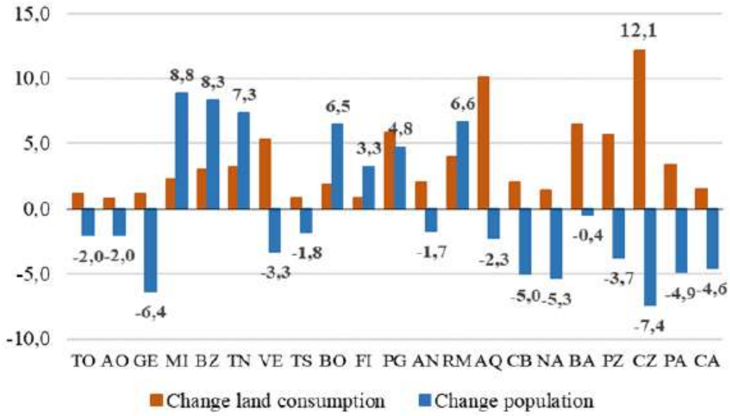
Figure 2 – Population Density of Capital Cities, 2020 (inhabitant/Km²)



Source: Authors' elaborations on Istat data

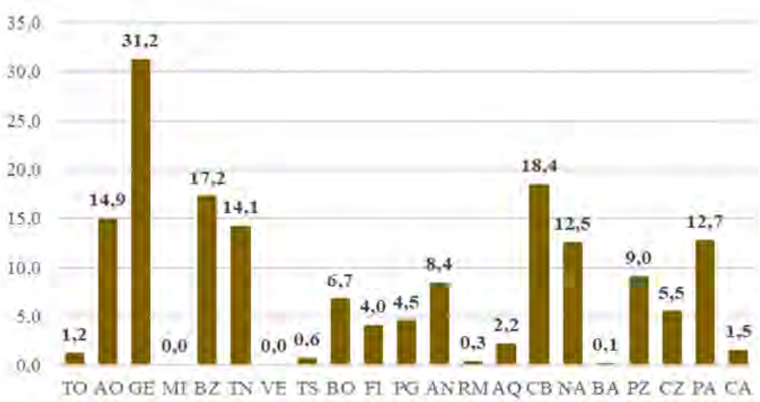
The capital city with the highest percentage of land surface covered by areas with high or very high landslide danger (Figure 4) is Genova (31.2 percent). Following are the capital municipalities with a percentage of land area at risk of landslides greater than 10 percent are Campobasso (18.4), Bolzano (17.2), Aosta (14.9), Trento (14.1), Palermo (12.7) and Napoli (12.5).

Figure 3 – Change of the Resident Population and In Land Consumption by Capital City, 2006-2020 (percentage values)



Source: Authors' elaborations on Istat and ISPRA data

Figure 4 – Surface at Risk of Landslides by the Capital City, 2019 (percentage values)



Source: Authors' elaborations on Istat and ISPRA data

The extremely widespread landslide phenomena in our country are also caused by the geo-morphological characteristics of the territory, which is 75 percent mountainous and hilly. Among the capital cities (Figure 5; Istat, 2024) only a third fall within the altimetric plain area (Torino, Milano, Venezia, Roma, Bari, Palermo and Cagliari); 66.7 percent, however, are hill or mountain municipalities,

Figure 5 – Classification of Capital Cities by Altimetric Zone

Torino	Plains	Ancona	Coastal hill
Aosta	Inner mountain	Roma	Plains
Genova	Coastal mountain	L'Aquila	Inner mountain
Milano	Plains	Campobasso	Inner mountain
Bolzano	Inner mountain	Napoli	Coastal hill
Trento	Inner mountain	Bari	Plains
Venezia	Plains	Potenza	Inner mountain
Trieste	Coastal hill	Catanzaro	Coastal hill
Bologna	Inner hill	Palermo	Plains
Firenze	Inner hill	Cagliari	Plains
Perugia	Inner hill		

Source: Istat – Statistical classifications and size of municipalities

in particular 33.3 percent are inner or coastal hills ones and the remaining 33.3 percent are in mountains ones (inner or coastal).

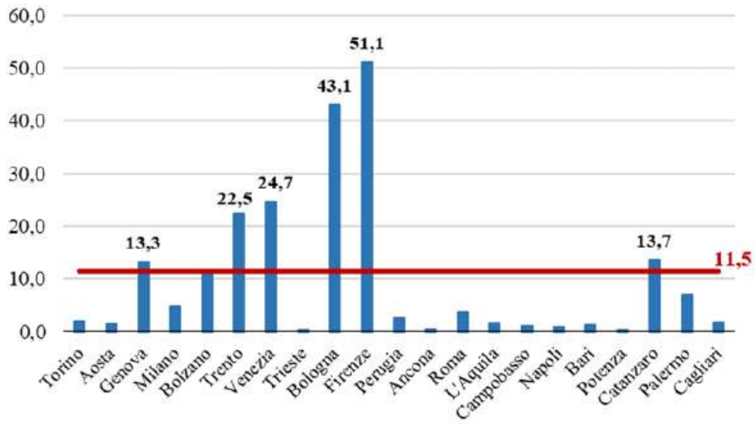
The subtraction of the spaces of natural expansion of floods with the occupation and exploitation of floodplains by man (building of residential, industrial, commercial structures and development of the infrastructure network) and the reduction of the natural flow of water and drainage capacity of the surfaces due to a significant and progressive consumption of land confine the watercourses to increasingly restricted areas.

In 2020, the national territory at risk of floods (average hazard scenario) reaches 10.0 percent of the total surface area (ISPRA, 2023a) compared to 8.1 in 2015 and the resident population exposed to flood risk in Italy (Figure 6) is equal to 11.5 percent (6,818,375 inhabitants). The most fragile and vulnerable cities are those developed on the banks of major waterways or along the coasts. The capital city with the highest percentage is Firenze (Lastoria *et al*., 2021), where the risk of flooding involves more than half of the resident population (51.1 percent); followed by Bologna, where 43.1 percent of the population lives in floodable areas, Venezia (24.7) and Trento (22.5).

It is also worth highlighting the increase of exposed to flood risk inhabitants from 2015 to 2020 (Figure 7). The most significant increases are recorded in the cities of Trento, Bolzano and Catanzaro, +19.9, +10.9 and +8.7 percentage points respectively; significant increases were also detected in Palermo (+5.3) and Venezia (+2.9).

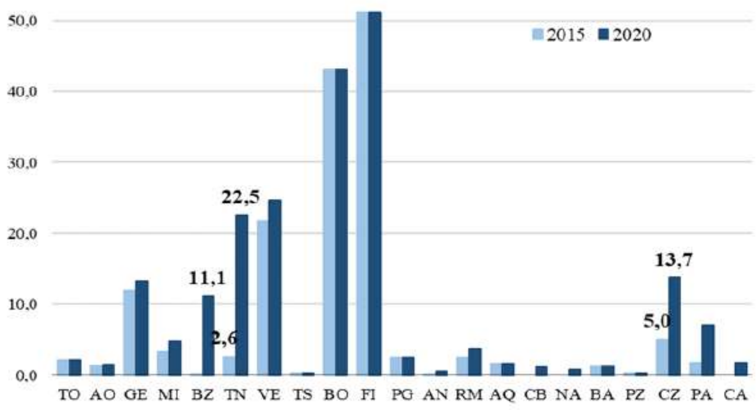
The amount of the population exposed to the risk of landslides is less significant than the exposed to the risk of floods one (Figure 8). The population residing in areas with high or very high landslide danger in Italy (Tragila *et al*.,

Figure 6 – Population Exposed to Flood Risk in Italy and by Capital City, 2020 (percentage values)



Source: Authors' elaborations on ISPRA data

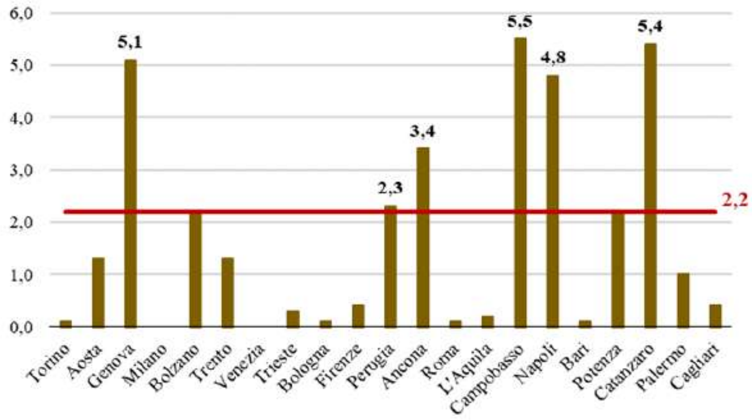
Figure 7 – Population Exposed to Flood Risk By Capital City, 2015 and 2020 (percentage values)



Source: Authors' elaborations on ISPRA data

2021) is equal to 2.2 percent of the total (1,303,666 inhabitants). Campobasso is the capital city with the largest share of the population exposed to the risk of landslides (5.5 percent). The other two capital cities where landslides put more than five percent of the population at risk are Catanzaro (5.4 percent) and Genova (5.1). Compared to 2015 there are no significant changes, only the city of Perugia recorded an increase of 2.2 percentage points.

Figure 8 – Population Exposed to the Risk of Landslides In Italy and By Capital City, 2020 (percentage values)



Source: Authors' elaborations on ISPRA data

3. Some Statistical Measures of Climate Change In Capital Cities

Given the close interconnection between the anthropization of the territory and climate change, it may be interesting to observe the changes referring to the capital cities of the regions and autonomous provinces (hereinafter "city capitals"), 21 municipalities in which over 9.5 million people live (about 16 percent of the national total).

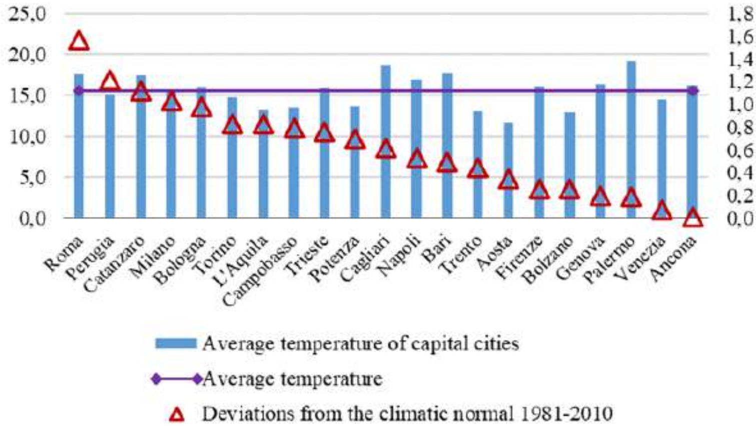
In 2021, the city capitals overall recorded an average temperature of 15.5°C (Istat, 2023a), a value exceeded by the average recorded in 11 of the 21 cities involved (Figure 9), with Palermo (19.1°C) in the lead and Aosta (11.7°C) at the end of the ranking.

The overall average exceeded that of the Climatic Normal (CLINO) 1981-2010 by more than half a degree. In particular, Rome measured the most significant anomaly (1.6°C) while Ancona remained perfectly in line with the CLINO 1981-2010.

Another way to represent climate change is to look at the number of Summer days. On average, 114 were identified in the capital cities (13 more than the 1981-2010 climatic normal) (Istat, 2023b).

In 2021, the cities most affected by this phenomenon (Figure 10) were Roma and Cagliari (both at 145), on the opposite side, we find Campobasso (84) and Genova (81). Palermo was the third city for Summer Days (130), followed by Napoli and L'Aquila (both at 129), the latter recording the largest gap (+29) compared to the 1981-2010 average.

Figure 9 – Annual Average Temperature Of Capital Cities. Year 2021. Deviations From the Climatic Normal 1981-2010 (right-hand scale)



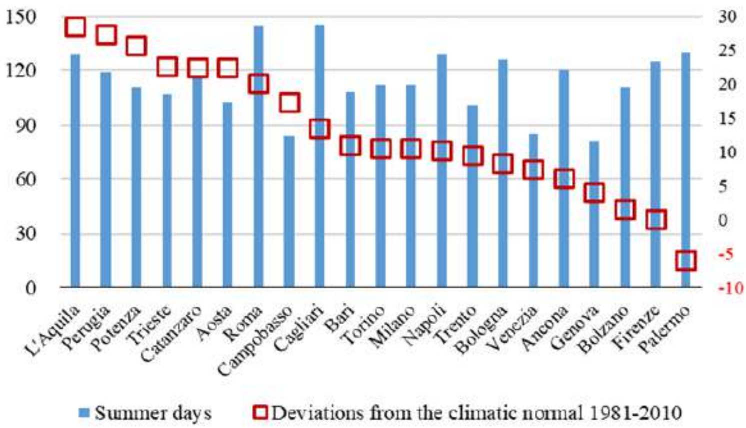
Source: Authors' elaborations on Istat data

As regards the dynamics of the "anomalies", the two cities at the top of the ranking of Summer days register, respectively, 20 and 13 days of difference compared to the 1981-2010 climatic normal, while the last two cities, 17 and 4 days. Positive anomalies are detected in Perugia (+27) and Potenza (+26); only Palermo, however, presents a negative anomaly (-6).

Climate change can also be measured by the number of Tropical Nights that occur over the course of the year. In 2021 they averaged 54: the maximum number occurred in Palermo (105, +14 on the CLINO 1981-2010) followed by Bari (100, +22 on the CLINO 1981-2010). The phenomenon was irrelevant in L'Aquila (1) and absent in Aosta (Figure 11). The most significant anomalies concerned Napoli and Milano (respectively 37 and 34 Tropical nights more than the climatic normal 1981-2010), followed remotely by Roma and Cagliari (both at +24); no deviation from the long-term average for L'Aquila and -1 day for Aosta. Climate changes are also well described by the Warm Spell Duration Index (WSDI), which allows identifying prolonged and intense periods of heat regardless of the season.

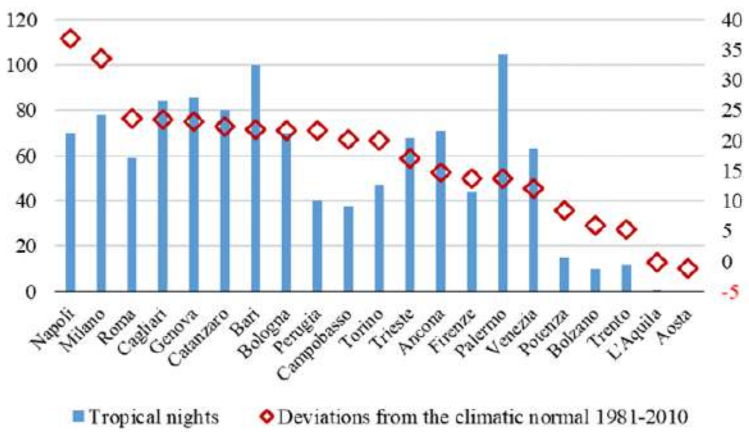
In 2021, the cities that presented the highest values of the WSDI index were Roma (48), Catanzaro (20) and L'Aquila (17); in eight of the 21 cities considered there was no "heat wave", in the remaining ten the index fluctuated between 6 (in Cagliari, Potenza and Trento) and 14 (in Bari and Perugia). Compared to the average for the period 2006-2015 (Figure 12) the most significant positive anomalies concerned Rome (+20), Catanzaro (+15), Bari (+13) and Palermo (+11) while on the opposite side we find Milan (- 28), Trieste and Ancona (-15). Overall, 16 cities present a negative anomaly.

Figure 10 – Summer Days Of Capital Cities. Year 2021 (number of days). Deviations From the Climatic Normal 1981-2010 (right-hand scale)



Source: Authors' elaborations on Istat data

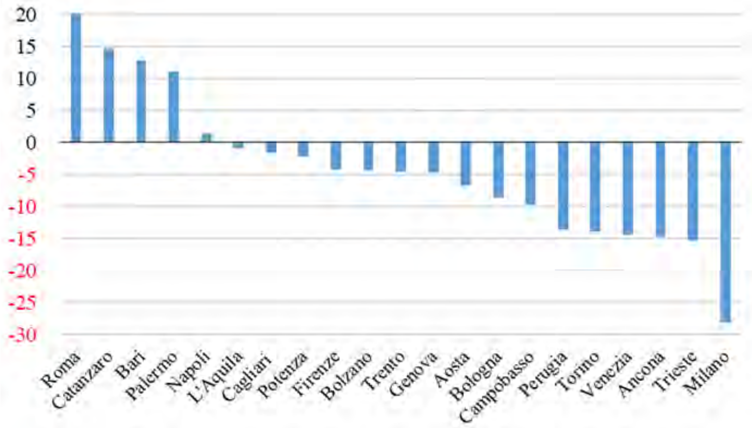
Figure 11 – Tropical Nights Of Capital Cities. Year 2021 (number of days). Deviations from the climatic normal 1981-2010 (right-hand scale)



Source: Authors' elaborations on Istat data

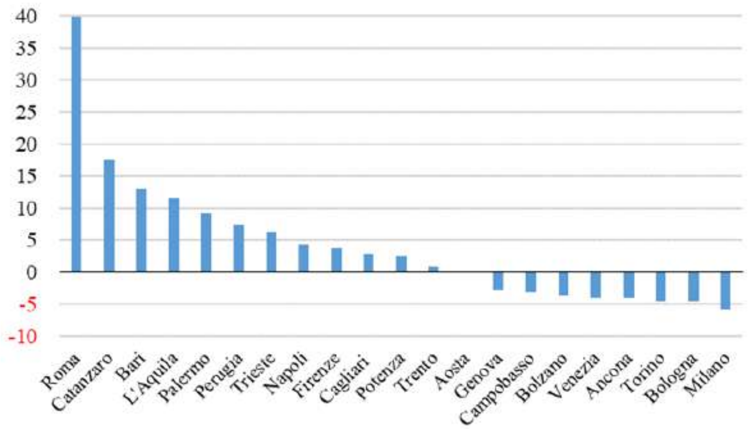
A different situation emerges from the comparison of the 2021 data with the 1981-2010 climatic normal (Figure 13): although the three cities with the greatest positive anomalies are always Roma (+40), Catanzaro (+17) and Bari (+13), nine other cities present a positive difference. Eight of the 21 cities observed, however, recorded a negative anomaly compared to the thirty-year average (CLINO)

Figure 12 – Warm Spell Duration Index of Capital Cities: 2021 Difference Compared To the 2006-2015 Average Value (Number of days)



Source: Authors' elaborations on Istat data

Figure 13 – Warm Spell Duration Index Of Capital Cities: 2021 Deviations From the Climatic Normal 1981-2010 (number of days)

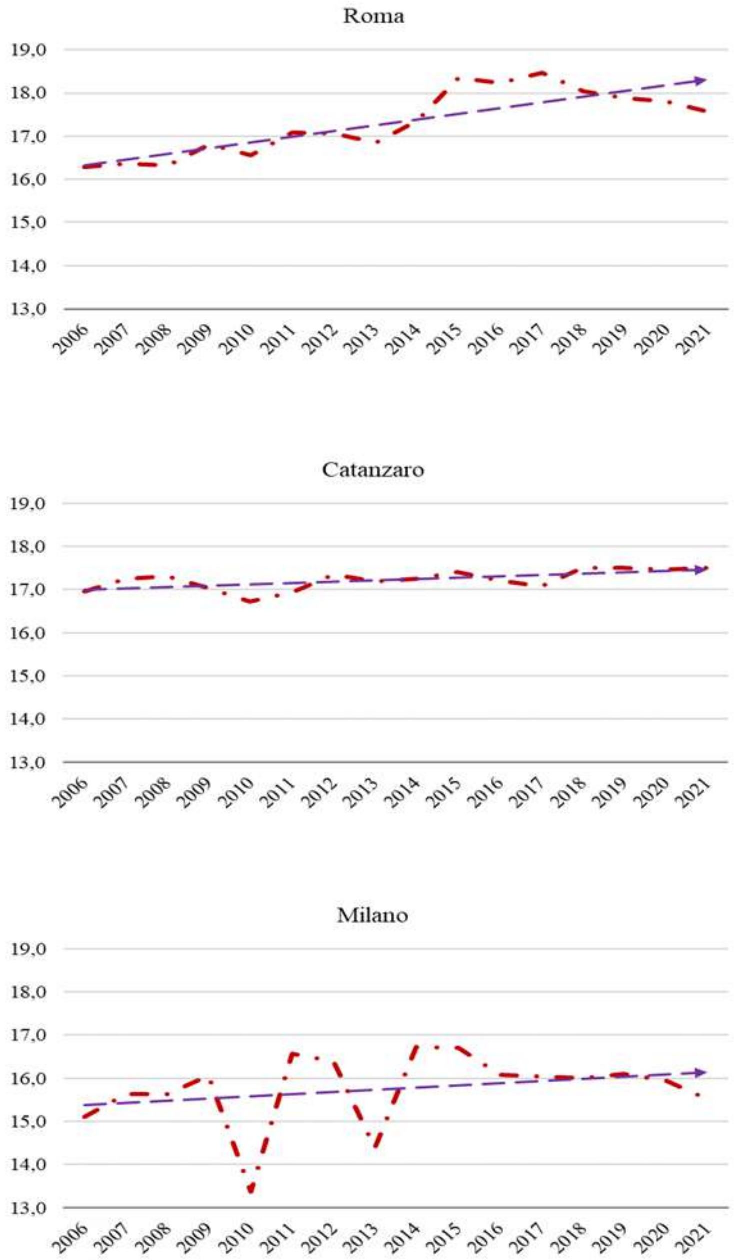


Source: Authors' elaborations on Istat data

1981-2010, with values of this anomaly ranging between -6 in Milano and -3 in Genova and Campobasso. Aosta has no differences.

From the following figure we can observe how the significant positive anomalies recorded for Rome and Catanzaro must be read in a framework of average annual temperature characterized by an increasing trend (Figure 14). An upward

Figure 14 – Average Annual Temperature. Years 2006-2021



Source: Authors' elaborations on Istat data

trend in temperature is also observed for Milan in the period 2006-2021, but with more marked fluctuations.

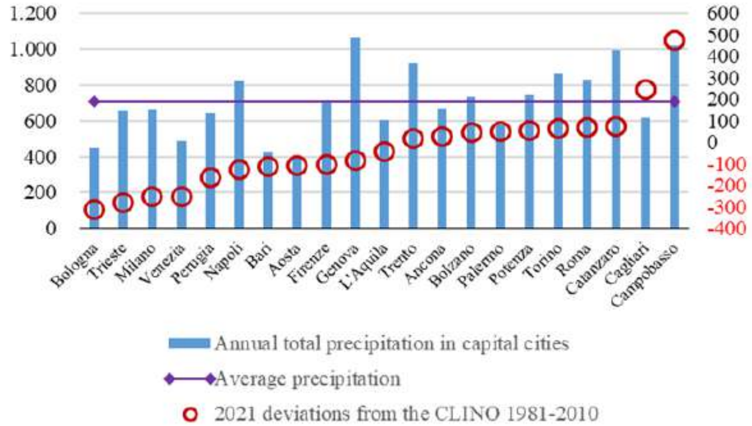
Another phenomenon of interest is that of rainfall. In 2021, all the cities considered recorded an average total precipitation of 708.8 millimeters (34.3 mm less than the CLINO 1981-2010).

In 2021 (Figure 15) the city that had the maximum total precipitation was Genova (1,063.0 mm), followed by Campobasso (1,015.4 mm); the one with the lowest rainfall was Aosta (405.7 mm). Over half of the observed capital cities recorded a decrease in rainfall compared to the climatic normal 1981-2010, the most affected has been Bologna (-311.5 mm) and Trieste (-281.9 mm). Significant increases concerned Campobasso (+472.6) and Cagliari (+247.6).

In 2021, the number of dry days in the capital cities recorded the minimum value in Trieste (258) and the maximum in Bari (307); on average, there were 285 days without rain in the cities observed. Compared to the average value recorded in the period 2006-2015 (Figure 16), the difference in Trento stands out (+51), clearly higher than that of the city that follows in the ranking: Bologna (+19). The biggest negative differences were in Cagliari (-17), Trieste (-16), Catanzaro and Napoli (both -11). Overall, 13 cities see an increase in the number of days without rain (or dry days) compared to the 2006-2015 average.

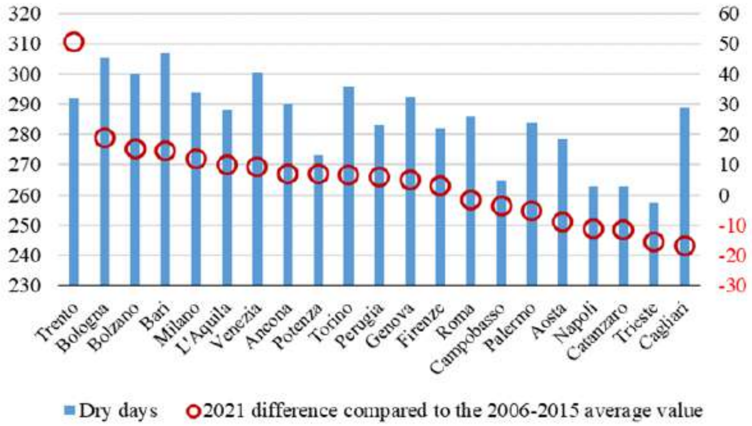
Comparing the 2021 data with the climatic normal 1981-2010 (Figure 17) we note that Trento always leads the ranking of positive anomalies, with an increase

Figure 15 – Annual Total Precipitation in Capital Cities. Year 2021. Values in mm. Deviations from the CLINO 1981-2010 (right-hand scale)



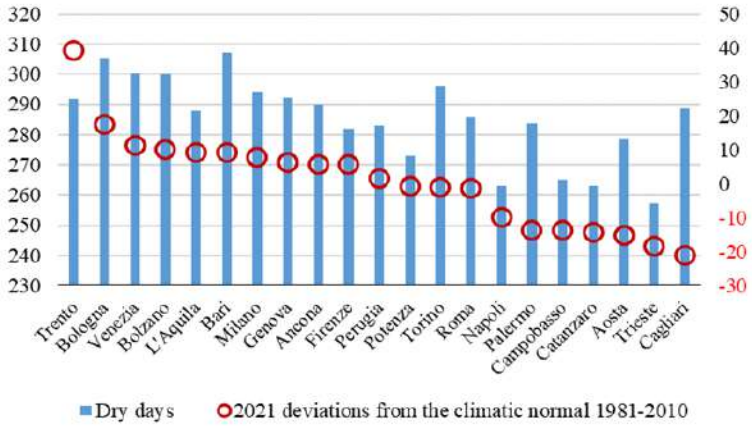
Source: Author's elaboration on Istat data

Figure 16 – Dry Days in Capital Cities: 2021 Difference Compared To the 2006-2015 Average Value (number of days)



Source: Authors' elaborations on Istat data

Figure 17 – Dry Days in Capital Cities: 2021 Deviations From the Climatic Normal 1981-2010 (number of days)



Source: Authors' elaborations on Istat data

of 39 days, followed by Bologna (+17), Venezia (+11) and Bolzano (+10). Overall, in 2021 the increase in dry days compared to the CLINO 1981-2010 affects more than half of the cities observed. On the other hand, days without rain significantly decrease in Cagliari (-21), Trieste (-18), Aosta (-15), followed by Catanzaro, Campobasso and Palermo at -14.

Observing the data of the five largest Italian cities, we see how they, during 2021, were characterized by a different climatic condition (Table 1). Palermo records the highest average temperature and the greatest number of tropical nights while Rome leads the ranking of summer days. Regarding rainfall, however, Turin is the city which, despite recording the highest number of days without rain, had the highest total rainfall.

For further and more in-depth information, please refer to the results of the "*Dati meteoclimatici ed idrologici*" survey, thanks to which it was possible to create this contribution.

Table 1 – Climatic Values Of the Major Italian Cities. Year 2021

	Average temperature	*Summer days*	*Tropical nights*	*Total precipitation*	*Dry days*
Roma	17,6	**145**	59	828,9	286
Milano	15,5	112	78	659,2	294
Napoli	17,0	129	70	822,8	263
Torino	14,7	112	47	**860,8**	**296**
Palermo	**19,1**	130	**105**	578,2	284

Source: Authors' elaborations on Istat data

4. Some Determinants and Measures of Climate Change

Climate change is the result of the complex interaction between natural phenomena and human activities.

However, today, a significant part of the scientific community identifies human activities as the primary catalyst for both the trend of global warming and its acceleration, some even describing it as "exponential" (ISPI|90, 2021). This position is supported by broad consensus, including the Intergovernmental Panel on Climate Change (IPCC) of the United Nations, the American Association for the Advancement of Science (AAAS), and the American Meteorological Society (AMS). It is based on robust scientific evidence that incorporates observational data, climate models, and an enhanced understanding of the physical laws governing climate behavior.

In recent years, the annual global and Italian climate balance (temperatures) has constantly set new records (Esa, 2021), including in 2023, topping the exceptional values recorded in 2022, especially in the cities of as Emilia-Romagna, Tuscany, Latium, Sardinia, and Sicily. In 2023, extreme weather events increased by 22 percent (378 events) compared to the previous year, resulting in 31 direct deaths (Legambiente, 2022). The costs of recovering areas affected by these calamities are also growing substantially. Greenpeace (2021), which calculated these costs only for floods and landslides declared as a state of emergency, they amount to 23 billion euros (2013-2019).

One of the main causes of current climate dynamics is the significant increase in the concentration of climate-altering gases in the atmosphere, especially those responsible for warming, such as carbon dioxide, methane, and nitrous oxide. International recommendations call for a 45 percent reduction in greenhouse gas emissions by 2030 to keep the maximum global temperature increase below 2°C, with a more ambitious goal of limiting warming to 1.5°C, considered a safer threshold for life and the environment on the planet.

According to the Paris Agreement, emission reductions should be measured against 2010 levels. To achieve this goal, reduction of global climate-altering gas emissions must remain higher than 43 percent compared to 2019 levels, as indicated in COP27[2] in Sharm El-Sheikh in 2022 and COP28 in Dubai in 2023.

In Italy, from 2008 to 2022[3], greenhouse gas emissions (ISPRA, 2022) have fluctuated and shown a decreasing trend. The peak occurred in 2008 (583,498,807 tons in CO_2eq.), while the minimum value was in 2020 (391,780,558 tons in CO_2eq.), a year significantly affected by the global pandemic. However, from 2020 to 2022, there was an increase in emissions (+9.5 percent | Figure 18), and it is crucial to understand if this recent trend reversal represents a future pattern.

In a recent report ISPRA (2023b), presents an emission scenario indicating that the change between 2010 and 2030 will be a reduction of 34.3 percent, but insufficient to meet international targets by that date.

The acceleration of global warming is mainly driven by carbon dioxide emissions (81.6 percent of total emissions | 2022) and methane emissions. Although methane emissions remain at much lower levels than carbon dioxide, they have a much higher warming potential.

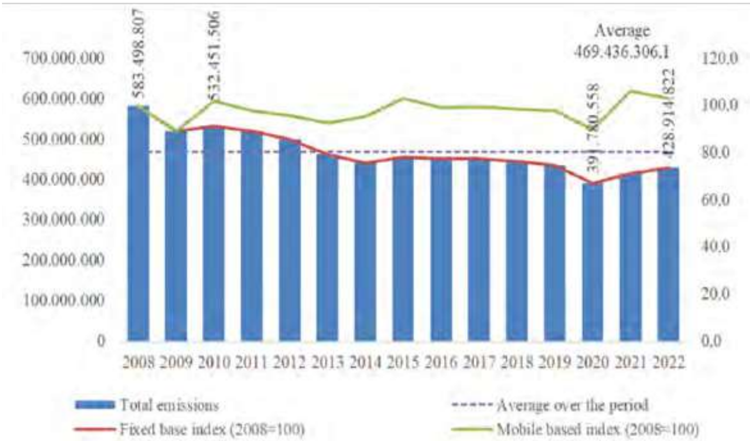
In 2022, methane accounted for 10.8 percent of the total greenhouse gas emissions calculated in terms of CO_2 equivalent. Following, with much lower emissions, are nitrous oxide and hydrofluorocarbons (Figure 19).

Industrial activities alone, major contributors to CO_2 equivalent emissions, account for two-thirds of the total (65.08 percent | 2022). They are followed by household activities (25.35 percent) and agricultural production (9.56 percent | 2022).

The impact of transportation is particularly significant (industrial and household activities 24.78 percent | 2022), with a substantial contribution from households (14.94 percent).

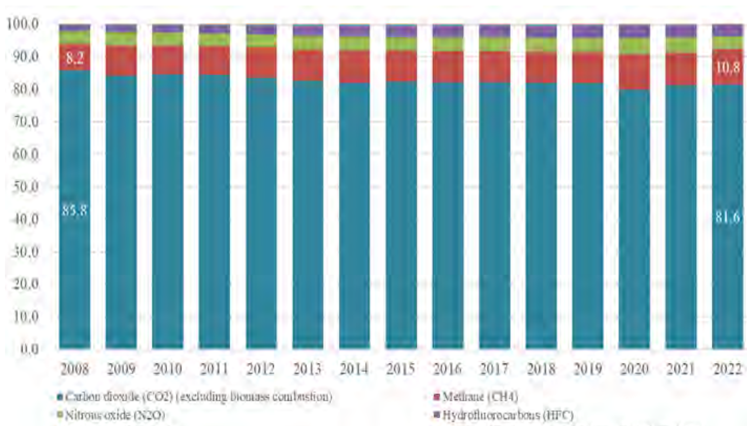
2. United Nations Framework Convention on Climate Change (UNFCCC).
3. Some data for the year 2022 are provisional.

Figure 18 – Total Greenhouse Gases According To National Accounts Of Atmospheric Emissions. Italy, Years 2008-2022 (tons of CO_2 equivalent on the left axis and percentage values on the right axis)



Source: Authors' elaborations on Istat-ISPRA data

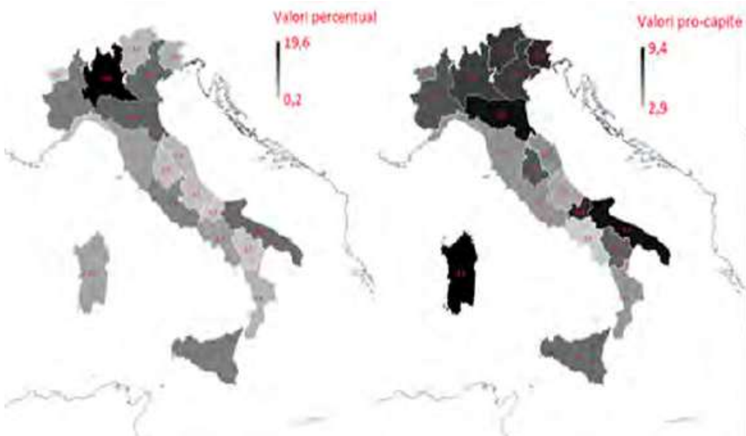
Figure 19 – Climate-altering Substances Emitted Into the Atmosphere According To the National Accounts Of Atmospheric Emissions. Italy. Years 2008-2022 (percentage incidence in CO_2 equivalents)



Source: Authors' elaborations on Istat-ISPRA data

The manufacturing industry, supply of electricity, gas, steam, and air conditioning also make a substantial contribution (20.12 and 19.26 percent, respectively), along with household heating/cooling equipment (10.30 percent | Istat and ISPRA data).

Figure 20 – Greenhouse Gas Emissions by Region. Year 2019 (Percentage incidence and per capita in tons of CO_2 equivalent)



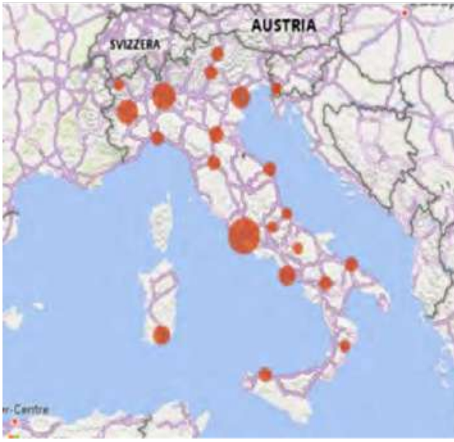
Source: Authors' elaborations on ISPRA data

At a sub-national level (2019) (ISPRA, 2022b), greenhouse gas emissions vary significantly based on different anthropic and demographic development. Northern Italy is responsible for the most climate-altering gas emissions compared to the Centre and the South, with Lombardy contributing to about one-fifth of national emissions (19.6 percent). Even though Emilia-Romagna's values are almost half compared to Lombardy, it contributes to defining the record of Northern Italy in total greenhouse gas emissions (10.4 percent). In the North, Veneto is the third region in contribution to total national emissions (9.6 percent). Among Southern regions, Puglia contributes 9.3 percent, and Sicily contributes 7.7 percent. In the Central region, Latium represents a significant figure at 7.2 percent (ISPRA, 2022 | Figure 20).

The per capita distribution of total emissions by region significantly redraws the map of emission capital. In the South, the top two regions for per capita emissions are Sardinia (9.4 tons of CO_2 eq.) and Puglia (8.9). Considering provincial emissions as a proxy for the emission behavior of regional capitals reveals significant differences between various territories (Figure 21).

Rome takes the lead (23,727,649.4 tons of CO_2 eq. | 2019), followed by Milan in second place. The top four provinces (Rome, Milan, Turin, and Venice) account for 52 percent of the emissions considered here and 13.2 percent of national emissions. Pescara, Aosta, and L'Aquila record much lower emissions, well below one million tons.

Figure 21 – Greenhouse Gas Emissions for Some Italian Provinces. Year 2019 (values in tons of CO2 equivalent)



Province of the regional capital	Tons in CO_2 equivalent
Roma	32.775.236,5
Milano	20.066.864,9
Torino	12.641.235,6
Venezia	11.070.351,9
Napoli	10.027.297,1
Cagliari	9.094.135,9
Bologna	7.246.966,9
Palermo	5.984.919,9
Bari	5.435.342,0
Ancona	5.043.982,9
Genova	4.394.564,5
Firenze	3.903.207,5
Trento	3.667.497,8
Bolzano	3.424.623,8
Trieste	3.292.885,7
Catanzaro	2.289.572,9
Campobasso	1.792.241,3
Pescara	1.564.281,2
Potenza	1.441.431,1
L'Aquila	1.151.790,4
Aosta	884.485,1

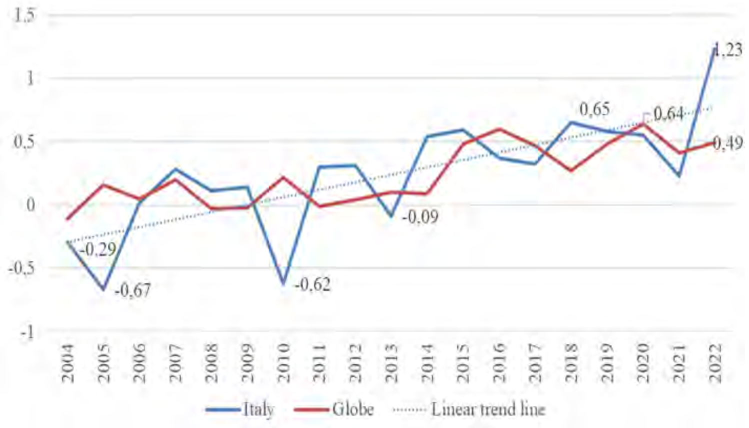
Source: Authors' elaborations on ISPRA data

One direct consequence of excessive greenhouse gas emissions into the atmosphere, as previously mentioned, is the rise in temperatures. According to the report from the United Nations Framework Convention on Climate Change (UNFCCC, 2022), in the absence of further mitigation measures, the planet is on a trajectory for a temperature increase of 2.7°C by the end of the century, which could be catastrophic. In Italy, the increase in average annual temperatures (last thirty years) is almost always higher than the global land average. However, in 2022, despite the improved performance in 2021, the increase is greater than the global average, with a temperature anomaly (climatological average 1991-2020) of +1.23°C. This is significantly higher than the anomaly recorded in 2021 (+0.23°C) and the global anomaly for 2022 (0.49°C) (Figure 22).

Between 2004 and 2022, negative values of the average temperature anomaly in Italy were recorded only in 2004, 2005, 2010, 2013, with 2022 obtaining the highest value. These are climate emergencies that need to be addressed to contain one of the most odious effects of climate change: deaths. A measure of human cost is available in a recent report (Ballester *et al.*, 2023) stating that, in Europe, the heatwaves of the summer of 2022 caused 61,672 deaths, including 18,010 in Italy. Beyond the data from the summer of 2022, the month of June 2023, with half a degree more than the average of the last thirty years, reached the highest heat peak ever recorded by a meteorological observatory.

Climate change also increases levels of air pollution, particularly those of PM2.5 particulate matter, considered one of the main indicators of air quality levels. Legislative Decree 155/2010 (Annex II) establishes the maximum allowed

Figure 22 – Annual Average Temperature Anomalies in Italy. Years 2004-2022 (absolute values in degrees Celsius)



Source: Authors' elaborations on Istat-ISPRA data

values for PM2.5 concentrations in the ambient air, with limits of 25 micrograms per m^3 for the annual average human tolerance and 17 micrograms per m^3 as the maximum annual average value. However, as early as 2005, the World Health Organization (WHO) set the maximum annual threshold for PM2.5 at 10 micrograms per m^3 [4]. Italy has exceeded these safety thresholds for years (Figure 23).

Out of 100 valid PM2.5 concentration measurements (monitoring stations), 74.7 percent (2020) exceeded the annual average threshold of 10 micrograms per m^3. The average exposure of the urban population to PM2.5 air pollution is estimated at 15.0 micrograms per m^3. Nationally, in 2021, the annual average emission threshold (WHO) was exceeded in 15 out of 21[5] provincial capitals (data from Istat, ISPRA, and Eurostat).

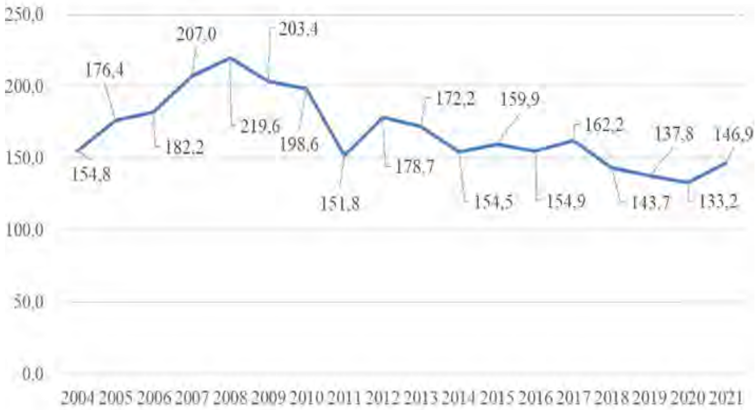
In the 15 Italian regional capitals that exceeded the annual average thresholds of PM2.5 (WHO), 510 valid measurements beyond the allowed limit were recorded. Rome accounts for 16.7%, followed by Venice and Naples, with a double-digit percentage of incidence. The remaining cities show much lower incidences (Figure 24).

According to the statistical measure "Average annual concentration of PM2.5 in provincial capitals", between 2004 and 2022, there are only four negative average temperature anomaly values in Italy (2004, 2005, 2010, 2013), while

4. In 2021, the World Health Organization (WHO) updated the threshold to a maximum annual average value of 5 micrograms per cubic meter. Since this threshold has consistently been exceeded in the territorial contexts considered here, the text will refer to the WHO 2005 threshold.

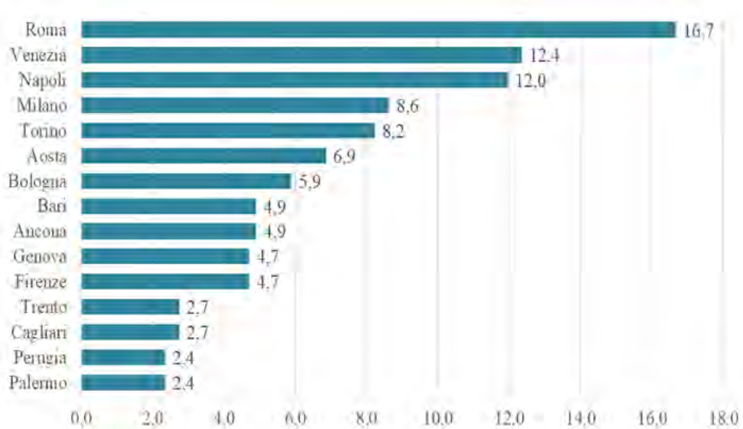
5. The autonomous provinces of Trento and Bolzano are treated separately.

Figure 23 – National Emissions of PM2.5, Years 2004-2020 (values in thousands of tons)



Source: Authors' elaborations on ISPRA data

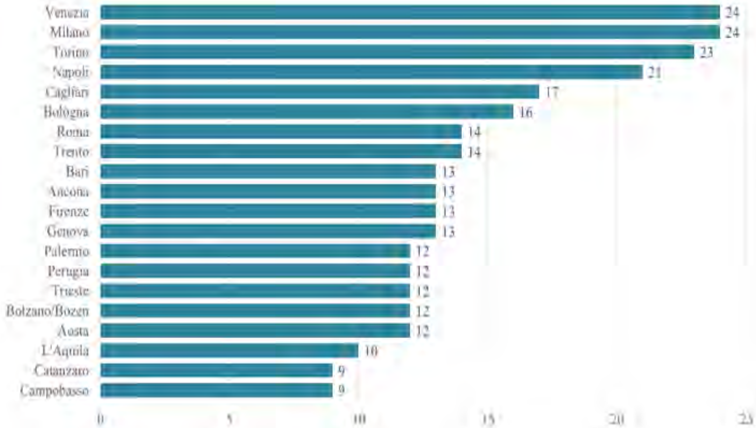
Figure 24 – Incidents Of Exceeding the Annual Average Threshold of PM2.5 (WHO) in Provincial Capitals Where the Event Occurred. Year 2021 (percentage incidence)



Source: Authors' elaborations on ISPRA data

2022 has the highest value in metropolitan areas (Figure 25). The most critical situations are observed in Venice and Milan, with an annual average of PM2.5 at 24 micrograms per m³, significantly exceeding both WHO limits and

Figure 25 – PM2.5 Annual Average Concentration in Provincial Capital Cities. Year 2021 (values in micrograms per m³)*



Note: * Missing data: Potenza.
Source: Authors' elaborations on Istat data

legislative decree 155/2010, surpassing the lower values by 2.7 times (Catanzaro and Campobasso, 9 micrograms per m³). The provincial capitals of Piemont and Campania also show high criticality, with annual averages of PM2.5 at 23 and 21 micrograms per m³, respectively.

Overall, the most critical situations are in the North, although there is a trend towards reducing the phenomenon (Figure 26).

The only municipalities with an annual average concentration of PM2.5 below the WHO critical thresholds are in the Center and the South: L'Aquila, Campobasso, and Catanzaro.

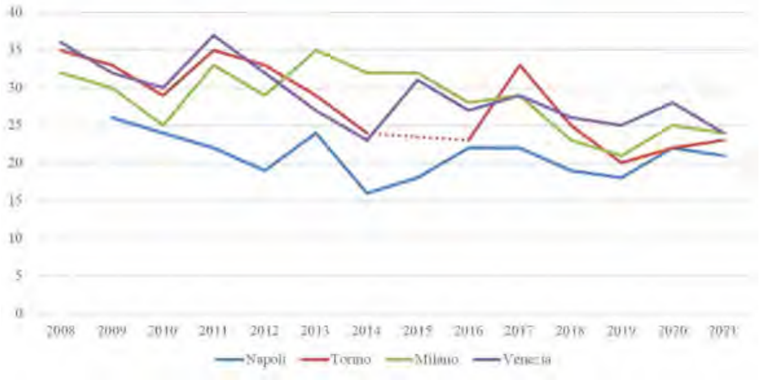
5. Conclusions

Climate change is a significant challenge for Italian cities as it impacts structural vulnerabilities, amplifying associated risks.

Capital cities witness a worrying increase in soil consumption, sometimes linked with substantial demographic reductions (as seen in the case of Catanzaro).

Mountain and hill cities face a high risk of landslides, exposing the population from North (Genoa) to South (Campobasso, Catanzaro, Naples) to life-threatening events and overall precarious living conditions. Florence, Bologna, and Venice also confront significant flood threats.

Figure 26 – Turin, Milan, Venice and Naples for Annual Average Concentration of PM2.5, Years 2008-2021 (micrograms per m³)



Source: Authors' elaborations on Istat data

The higher average temperature in the Central and Southern regions, with notable increases in Rome, Perugia, Catanzaro, Milan, and Bologna (with anomalies on the CLINO 1981-2010 ranging from 1° to 1.6°C), indicates a sustained growth trend. Particularly in the capitals of the Central and Southern regions, 2021 is marked by an increase in anomalies in the duration of warm periods (CLINO 1981-2010).

Precipitation significantly decreases in Bologna, Trieste, Milan, and Venice, while it increases in Campobasso and Cagliari. Greenhouse gas emissions are on the rise, especially in the North, but Rome stands out among the capital cities.

PM2.5 levels are increasing, and in 2021, 15 capitals exceeded the WHO's annual average threshold. Venice, Milan, and Turin are the most affected in terms of annual average concentrations.

The complexity of the phenomenon emerges in statistical analysis, emphasizing the urgent need to identify general and specific adaptation and mitigation strategies for each capital city. Urban planning and conscientious resource management are essential to ensure the resilience of these cities in the face of continually evolving climatic impacts.

Glossary

Altimetric zone: classification, for statistical purposes, of Italian municipalities based on their altimetric threshold values into five zones. We distinguish mountain, hill and plain altitude areas. The mountain and hill altitude zones have been divided, to take into account the moderating action of the sea on the climate, respectively into internal mountain and internal hill altitude zones and coastal mountain and coastal hill altitude zones, including in the latter the territories, excluding from the plain area, bathed by the sea or close to it.

Climatic anomaly: the difference between the average climate over a period of several decades or more (Climatic normal 1971-2000 or 1981-2010), and the climate during a particular month or season.

Climate Normal: a 30-year average of a climate variable (CLINO).

CO_2 Equivalent: a measure expressing the global warming potential of all greenhouse gas emissions by converting various emissions into an equivalent of carbon dioxide.

Land consumption: percentage of artificially covered land linked to settlement dynamics on the total municipal area.

Population density: ratio between the number of inhabitants and the surface area of the territory (number of inhabitants per square kilometre).

Population exposed to flood risk: percentage of the population residing in areas of medium hydraulic risk (return time 100-200 years pursuant to Legislative Decree 49/2010), identified on the basis of the ISPRA national Mosaic of hydrogeological management Plans (PAI) and related updates, with reference to the P2 risk scenario. The considered population is the one from the 2011 Census.

Population exposed to the risk of landslides: percentage of the population residing in areas with high and very high risk from landslides, identified on the basis of the ISPRA national mosaic of hydrogeological planning plans (PAI) and related updates. The considered population is the one from the 2011 Census.

Summer days: number of days on which the maximum air temperature is at least 25.0°C.

Surface at risk of landslides: percentage of territorial surface covered by areas with high and very high landslide danger (areas P3-P4) identified on the basis of the ISPRA national Mosaic of hydrogeological management Plans (PAI) and related updates.

Temperature Anomalies: differences from a reference average (CLINO | 30 years) of temperatures, used to evaluate climate change.

Tropical nights: days when the temperature does not fall below 20 °C (68.0 °F) during the nighttime.

Warm Spell Duration Index (WSDI): annual or seasonal count of days with at least 6 consecutive days when the daily maximum T exceeds the 90th percentile.

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Sommario

Le principali evidenze del cambiamento climatico nelle città capoluogo

I fenomeni climatici estremi che hanno caratterizzato gli ultimi anni hanno conseguenze tanto maggiori quanto più densamente sono abitati i territori colpiti. D'altra parte, l'antropizzazione dei territori e la conseguente attività umana contribuiscono in maniera significativa a determinare il progressivo cambiamento del clima. Il lavoro si focalizza sulle 21 città capoluogo di regione e provincia autonoma. Prima verranno messe in evidenza la loro dinamica demografica e le caratteristiche geografiche, successivamente si utilizzeranno alcune misure statistiche per descrivere il cambiamento climatico registrato. Infine saranno presi in esame i dati relativi ai principali elementi climalteranti e il loro andamento in serie storica.

Detecting the Exposure of the Italian Regional Food Systems to Climate Shocks

Sara Turchetti, Tommaso Ferraresi*, Leonardo Piccini*, Leonardo Ghezzi*, Renato Paniccià**

Abstract

This work provides a configuration of interregional-international value chains activated by Italian domestic food consumption and shows how some countries and regions produce most of the agricultural goods necessary to supply final demand. Second, it provides a conceptual framework to assess the vulnerability of the Italian food regional systems, based on food products criticality. Finally, a spatial- and product-based disaggregation of agricultural production in Italian regions which well captures the exposure of the Italian food system to the flood that hit Emilia-Romagna in May 2023 will be presented.

1. Introduction[1]

In a time in which climate shocks are expected to dramatically affect agriculture and food production also in comparison with competing shocks (e.g., FAO, 2023; Devot *et al*., 2023; FAO, 2021; Naumann *et al*., 2021), it is becoming day-by-day more relevant to evaluate the vulnerability of food systems. In this respect, in assessing the potential impact of climate shocks on the food supply, the interregional input output framework represents a powerful tool of analysis (see, e.g., Avelino, Hewings, 2019; Koks, Thissen, 2016; Okuyama, 2007), given the configuration of the current production systems in interregional (e.g., Capello

* IRPET – Regional Institute for Economic Planning of Tuscany, Florence, Italy, e-mail: s.turchetti@irpet.it (corresponding author), t.ferraresi@irpet.it, l.piccini@irpet.it, l.ghezzi@irpet.it, r.paniccia@irpet.it.

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et al., 2023; Van Oort, Thissen, 2021; Bentivogli *et al.*, 2019) and international value chains (e.g., Baldwin, 2016; World Bank, 2019). Indeed, since climate related shocks are often circumscribed in space (e.g. De Siano *et al.*, 2020), as well as their impacts on economic activities (e.g., Faggian, Modica, 2020), the identification of regional economic specializations and inter-sector interrelations stemming from specific regions constitutes a prerequisite when assessing potential propagation mechanisms.

At the same time, to fully control for the spatial granularity of climate shocks, economic specializations need also to be finely distributed in space (see, e.g., Inoue, Todo, 2019). Moreover, the heterogeneous impact of climate related disasters on the overall provision of food (see, e.g., Mairech *et al.*, 2021; Burke, Emerick, 2016; Merloni *et al.*, 2018) can be captured only if the products entering the food value chains are disaggregated at an adequate level. In this regard, input-output data at regional (and very often at national) level usually foresees aggregated both agricultural and food processing industry and products, leaving the evaluation of potential damages on the production network relatively blurred.

This research aims to better understand how the Italian regional food systems (henceforth RFSs) – implicitly, food security in the context of Italian regions – are vulnerable to the overall consequences of climate change. In this respect, the contribution of the work is threefold. First, using an interregional input-output table, we assess how the Italian food system is spatially organized, in terms of concentration of different production stages of the food value chain, regarding agricultural and food processing steps. Moreover, we evaluate to what extent it depends upon both direct and indirect imports by integrating the interregional input-output data with an inter-country IO table.

Second, we provide a conceptual framework to assess the degree of "criticality" of each food product from a value chain perspective. Being aware that some food products are more critical than others, their "criticality" is evaluated based on: i) their economic and nutritional importance, ii) the cost-opportunity for substitution, iii) the risk associated with the disruption of the value chains due to climate shocks.

Third, once the product-based nature of RFSs vulnerability has been assessed, we finally start developing a disaggregated accounting system in which regional agricultural production is highly, and properly, disaggregated by products and sectors. This conceptual framework is then used to give a first assessment of the exposure of the RFSs to the 2023 flood in Emilia-Romagna, with a focus on the production of fruits, which has been dramatically hit by that flood, causing an economic significant economic loss not only at the local level but also reducing fruit supply at the national level., We also provide data with regional spatial information about agricultural cultivations and administrative information about the affected areas. Finally, to evaluate to what extent the lack of fruits due to the disruption of the local supply chain has been filled by imports, we use (quasi) real-time information about regional exports and national imports.

The paper is organized as follows. Section 2 nests the issue of measuring the vulnerability of Italian regional food systems within a value chain framework based on interregional-international input output tables. Given the limits of this preliminary assessment, Section 3 provides a conceptual framework to evaluate the level of criticality of the food products. Section 4 implements such a framework and disaggregates agricultural production in several products and industries. Moreover, it distributes cultivations in space and shows how such a framework can be used to give a preliminary assessment of the impact of the flood that hit Emilia-Romagna in May 2023 on food production.

2. Nesting the Vulnerability of Italian Regional Food Systems Within a Value Chain Approach Based on Interregional-international Input-Output Tables

We first insert the Italian food system within a value chain framework based upon an interregional-international input output table to emphasize the potential sources of vulnerability when it comes to RFSs. Although regional and local resilience to disasters provoked by climate and non climate related shocks has been increasingly addressed by the literature (e.g., Marin *et al.*, 2021; Faggian, Modica, 2020), the approach through value chains represents an advancement since it consistently allows to connect in a systemic way the locations of food consumption and those of food production.

Moreover, via the intermediate inputs linkages connecting sectors and regions, it recognizes that production is spatially (in terms of regions and countries) and technologically (in terms of sectors and products) dispersed (see also Turchetti, Ferraresi, 2024; Ferraresi *et al.*, 2023a, 2023b) and explicitly models the connections among nodes of the supply chains.[2]

Indeed, a value chain approach allows to go beyond the analysis of isolated economic sectors by considering that different, but interconnected, sectoral production activities carried out in different locations must jointly be activated to satisfy the needs/demand expressed by a community of consumers spread region wide. Isolating the role of each node in each supply chain is crucial in assessing the vulnerability of the RFSs, since it is a first, preliminary, step to identify potential sources of stress stemming from the impact of specific events hitting production somewhere in the

2. Apart from input-output literature, evidence about the connections among existing nodes in the production chains is well recognized by other approaches to the assessment of the regional vulnerability to natural disasters (see, e.g., Antonioli *et al.*, 2022; Cainelli *et al.*, 2019).

world economy (see, e.g., Chepeliev, 2022). In this Section, therefore, we give a first, rough, picture of the configuration of the value chain activated by household food demand in Italy. Both at an international and at an interregional level.

Before proceeding with the results, we provide both an intuitive and a formal definition of what is meant here for food value chain. A definition that is consistent with that of the vertically integrated sector (Pasinetti, 1973). Intuitively, we define a food value chain as the bundle of production steps activated in any part of the world to satisfy the final demand for food arising in a specific area, either a region or a country. In this framework, the food consumption basket is mostly directly "served" by firms belonging either to the agricultural sector or to the food processing industry. At the same time, their production processes will require raw materials as well as intermediate goods and services provided by other firms and plants, which do not necessarily belong to the same industry/region. This gives rise to a second production step. The process may be further extended, as firms engaged in the second step also demand intermediate inputs and may activate additional production stages. The value chain associated with food demand is therefore defined by the set of firms (and sectors) involved in all the production processes originating from it.

More formally, in the context of an interregional input-output table (see Appendix A) like the one used in this context (i.e., IRPET interregional input-output table: IRIOT), let $Fd_{z,s}$ be an *(MxN)x1* final food demand shock vector[3] expressed by region *s* (net of foreign import), and *A* the *(MxN)x(MxN)* matrix of input coefficients obtained by dividing the intermediate input demand of each sector (*i*) in every region (*j*) by its total output.[4] In terms of production, a food value chain can be defined as Taylor series approximation as:

$$Fd_{z,s} + AFd_{z,s} + A(A)Fd_{z,s} ... + A(A^{(n-1)})Fd_{z,s}$$
$$= (1-A)^{-1} Fd_{z,s} = Y_{z,s} \qquad [1]$$

with n→∞ defining the iteration step. The left-hand side of the equation reports the chain of production steps activated by the food final demand shock as a power series approximation. First, the shock itself, which is accommodated by a particular industry, or set of industries; then the first round of demand for intermediate inputs required to accommodate the final demand shock; subsequently, the production of intermediate inputs needed to produce the intermediates demanded in the previous round; and so on.

3. The number of rows (*MxN)* in an inter-regional framework is equal to the number of regions (M) times the number of sectors (N).

4. In a interregional framework letting *T* be the matrix representing the flows of intermediate inputs demanded by sector *j-nth* in region *r-nth* to sector *i-nth* in region *s-nth* ()and *Y* a diagonalization of the output of each sector in every region, the matrix *A* is obtained by post-multiplying *T* by the inverse of *Y*, i.e., .

From equation [1] we can then get sectoral/regional value added activated by the final demand shock as:

$$V_{(z,s)} = \hat{V} \bullet (I - A)^{-1} \bullet Fd_{(z,s)} \qquad [2]$$

with $\hat{V}$ being a diagonal matrix containing along its main diagonal the value-added coefficients. Within an interregional framework, in which international exports have to be considered as exogeneous, and foreign import are recursive endogenous, the foreign value added content within the value chain identified in [2] can be roughly approximated by the difference between the sum of the initial shock ($i \cdot Fd_{z,s}$)[5] and that of the total value added domestically activated ($i \cdot V_{z,s}$).[6] However, to provide a better and more robust assessment of the foreign value added, the most proper way is to fully endogenize the rest of the world by inserting the interregional framework in an inter-country I-O structure. More precisely, we aggregate the IRPET IRIOT to fit the full Italian economy and use it to compute the shock to be applied to the inter-country input output (ICIO) table provided by OECD. We then use the latter one to retrieve the sector/country value added contributions in terms of intermediate input supply to serve the Italian household's final demand for food.

Going back to the interregional production value chain framework defined by equation [1], pre-multiplying $Y_{z,s}$ by the matrix of input coefficients A, we can reconstruct the intermediate input interregional trade network that serves the final demand for food associated to the shock $Fd_{z,s}$. Such matrix can be analyzed using standard network analysis techniques. For instance, the degree of a node is given by:

$$s_i = C_D^w(i) = \sum_j^N w_{ij} \qquad [3]$$

where w is the weighted contiguity matrix; w_{ij} is greater than 1 if i is connected to j, and its value is given by the trade flow. Being it directed, we can analyze the network both in terms of out-degree and in terms of in-degree.

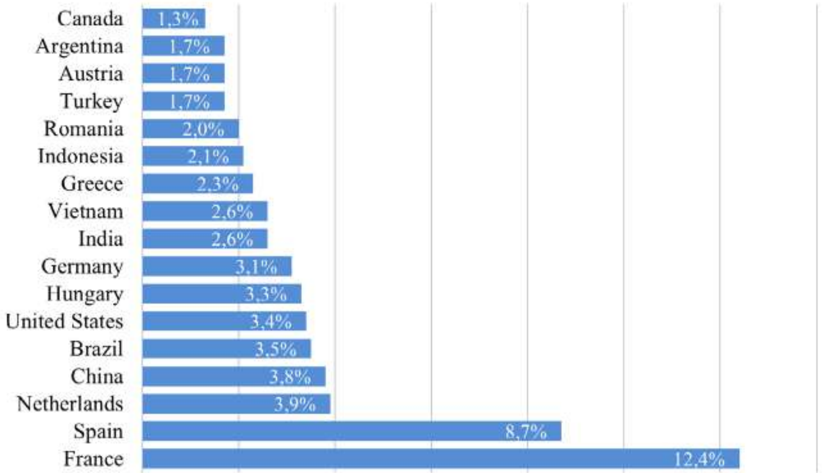
As to the shock examined in this work, we consider the food value chain activated by internal household final demand for food in Italy. Moreover, we concentrate only on the production side of food, and not on commercial and transportation services connecting the final producers to the consumers.

In terms of results, 80% of final food products demanded by households in Italy is provided by Italian firms, while the remaining 20% is directly imported

5. With i being a row vector of ones. Notice that this sum only refers to foreign value added indirectly activated. In order to retrieve total foreign value added serving internal food demand, international imports of final goods have to be added.

6. Given the exogeneity of the international export and recursivity of foreign import, the foreign value added estimated here will be upwardly biased. Indeed, we cannot track the contribution of Italian regions to the production of the intermediate inputs imported by Italian regions to serve the final demand for food.

Figure 1 – Country Shares in Terms of Agricultural Value-Added Contribution to the Value Chain (2018)



Source: Authors' elaborations on IRPET IRIOT, OECD ICIO

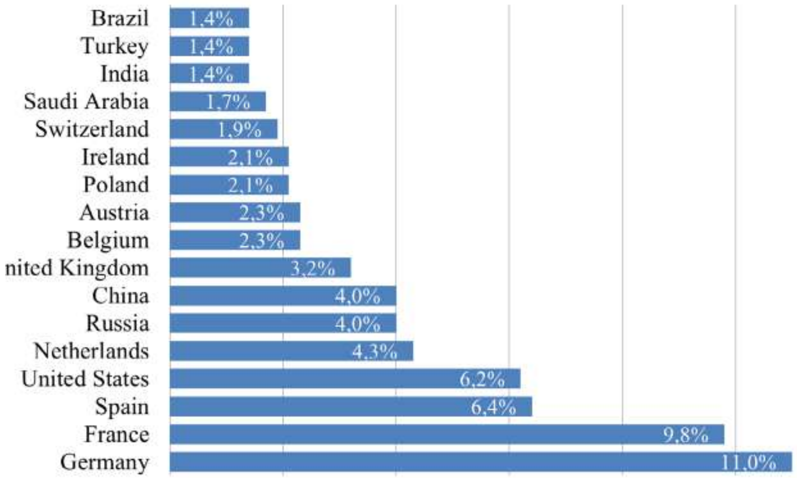
from abroad. However, the contribution of foreign countries in the provision of intermediate inputs accounts for 26% of the value added. Considering both the final goods directly imported from abroad and the intermediate inputs demanded from Italian firms serving the demand for food, for every Euro spent in food by Italian households,[7] 40 cents remunerate factors located abroad.

Considering the supply of intermediate inputs of foreign countries to the Italian firms in charge of production of the final food products, in Figure 1 and 2 we report the contributions of different countries as shares in the world total value-added contribution of the agricultural sector (Figure 1) and of all aggregated sectors (Figure 2). As to the agricultural sector, France and Spain contribute for more than 20% of foreign value added.[8] Considering all the sectors in the world economy, instead, Germany represents the most important supplier.

When it comes to measuring the vulnerability of the regional food systems to climate shocks in a value chain approach, aggregating sectors at the country level is not satisfactory since production and climate related events are usually heterogeneously distributed in space. For instance, as to Italy, Figure 3 depicts

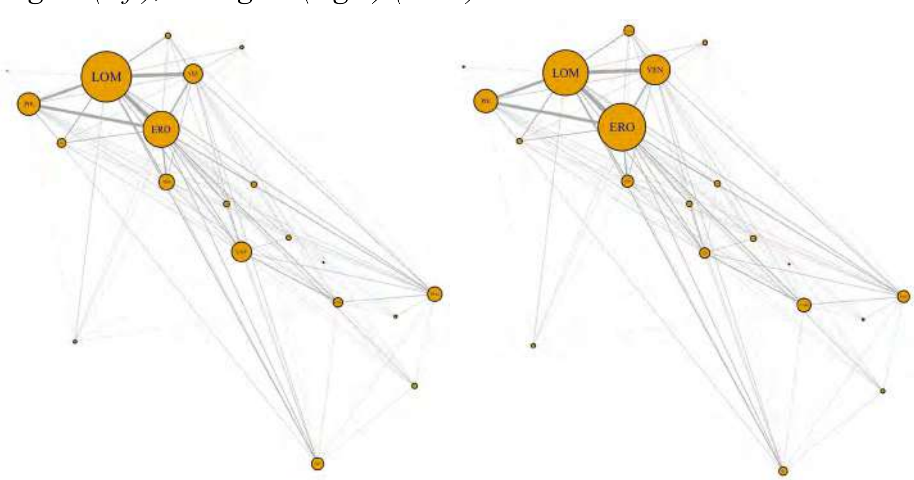
7. Excluding net taxes on consumers and commercial and transport margins related to the provision of the final products.
8. A drawback of OECD ICIO table is given by the fact that a substantial economic contribution to the world economy stems from a residual area (Rest of the world) which is mostly composed by African countries. In terms of agricultural value added contribution to the Italian demand for food, rest of the world accounts for 23% of value added.

Figure 2 – Country Shares in Terms of Total Value-Added Contribution to the Value Chain (2018)



Source: Authors' elaborations on IRPET IRIOT, OECD ICIO

Figure 3 – The Interregional Production Network of Intermediate Input Flows Generated by the Italian Household Demand For Food. Out-degree (left), In-degree (right) (2018)



Source: Authors' elaborations on IRPET IRIOT the interregional production network of intermediate input flows generated by the Italian household demand for food in terms of out-degree (left) and in-degree (right). In this respect, it is quite evident that production is highly concentrated into few regions, namely Veneto, Emilia-Romagna (especially in terms of in-degree) and Lombardy (especially in terms of out-degree).

In terms of regional value added contributions to the food value chain, Figure 4 and 5 report the regional shares as to the national value added contribution of agriculture (Figure 4) and food processing industry (Figure 5). Although agricultural production is more fragmented than food processing, about 40% of the agricultural value added generated by the demand for food stems from 4 regions in the North (Lombardy, Emilia-Romagna, Veneto and Piedmont). Lombardy, Emilia-Romagna and Veneto represent also the three most important regions in terms of value added generated by the food industry.

In synthesis, whereas the interregional-international value chain serving Italian demand for food is highly spatially fragmented – with several countries and regions engaged in producing both the final goods and the intermediates needed to produce them – some countries and regions have emerged as crucial in the provision of food to Italian households.

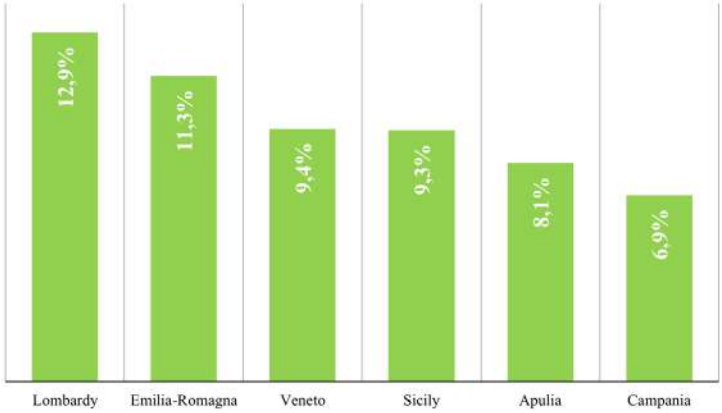
Such primary results provide a general picture of the potential exposure of Italian regional food systems to the impact of shocks hitting the world economy. However, to grasp the granularity of climate shocks, economic specializations need to be finely distributed in space. Moreover, the industry-based configuration of the value chain given in the present Section does not tell us anything about the goods, final and intermediate, which are traded along it, and their level of "criticality". Finally, the heterogenous impact of climate related disasters on the overall provision of food can be captured only if products of the food value chains are disaggregated at an adequate level, as their resilience to different kinds of events might highly differ.

3. Evaluating the "Criticality" of a Food Product

As already mentioned, not all food products can be considered as equally critical. The reduced supply of some of them may negatively affect the overall vulnerability of the food systems, while some others can be replaced with no excessive economic and environmental costs.

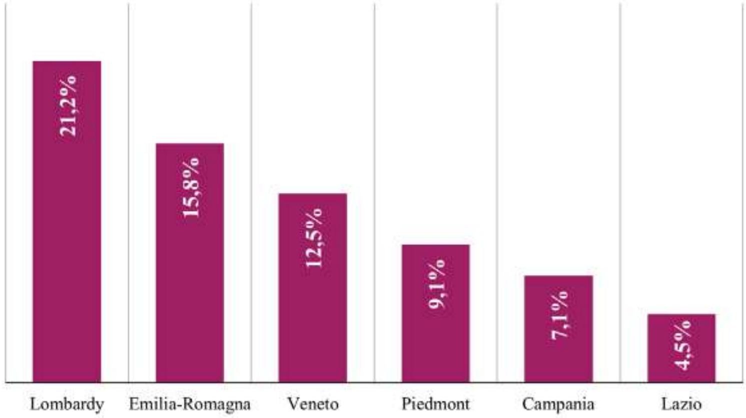
To evaluate the "criticality" of food products, we refer to the most recent versions of the methodology developed by the European Commission to provide a list of critical raw materials for the European industry (EC, 2023). The concept of "criticality" is based on the idea that both the relevance of some products and the conditions of supply may increase the vulnerability of the economic system. It reflects the current situation and not the capacity of a member state or a region to adequately respond

Figure 4 – Regional Shares in Terms of Value Added Contributions in Agricultural Sectors (2018)



Source: Authors' elaborations on IRPET IRIOT

Figure 5 – Regional Shares in Terms of Value Added Contributions In the Food Processing Industry (2018)



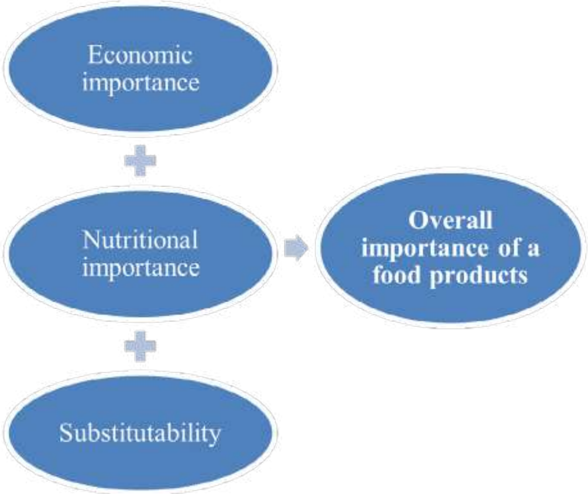
Source: Authors' elaborations on IRPET IRIOT

to these critical situations (Nuss, Ciuta, 2018; Blengini *et al*. 2017). This approach, with some adjustments and simplifications, can be advantageously used to assess the criticality of food products and, therefore, evaluate the vulnerability of the RFSs.

The assessment of critical products is based on two main dimensions: a) economic importance (EI) and b) supply risk (SR). The EI indicates how much the materials is fundamental for industry, grounded on the distribution of products among the end-users (shares of net demand) and the gross value added generated by its use. In the case of food systems, the overall importance (OI) can also be assessed in terms of nutritional intakes of products and their relevance for human health. A cross-component of the OI is *substitutability on the demand side*, which can be evaluated as the cost-opportunity of substitution (both economically and environmentally), the nutritional balance of substitution and the level of acceptance by the consumers (Figure 6).

The SR accounts for the risk associated with any possible disruptions in the supply chain that may trouble the capacity of the food system to meet the dietary needs of consumers. In our case, we mainly consider the disruptions caused by the extreme events associated to climates change, which are likely to reduce the global supply of agricultural products and their availability on the markets, with possible consequences on either the adequate provision of food and nutrients or prices. Moreover, the higher the concentration of production into few producers, the higher the risk of disruption of the supply chains. The SR is based on two dimensions: a) adequate amount of available food on the markets, both domestic and foreign (import dependency); b) *substitutability on the supply side*, which reflects the suitability of the available alternatives on the markets (Figure 7).

Figure 6 – Assessment of the Overall Importance of a Food Product

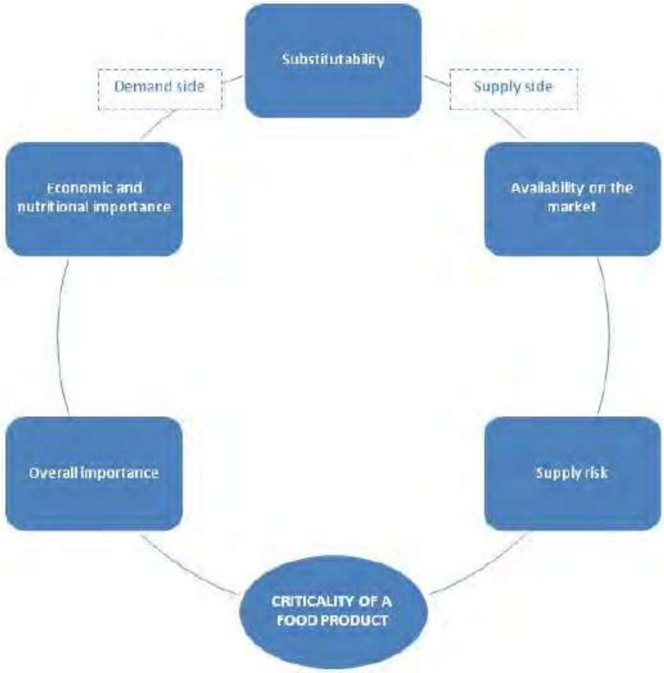


Source: Authors' elaborations

Substitutability is, therefore, a component that enters both dimensions of criticality. In this respect, it must be considered that, intrinsically, agricultural products are more homogenous if compared to industrial products and, from a theoretical perspective, their margins of differentiation have always been considered very low. However, over time the so-called "fictitious differentiation" – i.e., based on some additive characteristics determined by marketing, including advertising, branding, labeling, and any other element that can confer specificity to the product – has increased, because of the ever-increasing focus on the territories of origin, quality, health, safety, and production methods characterized by environmental or social sustainability (Saccomandi, 1999).

Even though some food may be available on the markets as a substitute, it does not entail that its characteristics technically fit the demand of the food industry or they are accepted by the consumers; moreover, other effects have to be evaluated, i.e. effects on prices and the environmental impact.

Figure 7 – Assessment of the "Criticality" of a Food Product



Source: Authors' elaborations

4. Beyond Sectors and Regions: Regional Food Related Products Augmented With Spatial Data On Cultivations

Given the product-level of the conceptual framework illustrated in the previous Section, we can integrate the assessment of criticality within the input-output framework. In this section, we do present a disaggregation of Italian regional agricultural production in terms of industries and products. Moreover, we augment regional accounts with spatial data about cultivations to obtain a one-to-one mapping from the (potential) territorial disaggregation of climate related shocks and the exposure of RFSs to them. Once illustrated some of the main features of this newly constructed database, we do use it to assess the exposure of regional food systems to the flood which hit Emilia-Romagna in late May 2023 (hence, 2023 flood). Finally, we corroborate our results with evidence stemming from (quasi) real-time international trade data both at the regional (NUTS3 level) and at the national level.

Entering the details of the work, by using different data source (see Appendix A), we disaggregate agricultural sectors and products at the regional level. More precisely, we use Istat agricultural regional accounts and Farm Accountancy Data Network (FADN)[9] accounts to regionally disaggregate agriculture in 8 sectors and up to 31 agricultural goods.

Our analysis focuses on the impact of the 2023 flood on the production of fruits, namely peaches, pears and apples, serving the Italian RFSs. There are two reasons as justification to this choice. Firstly, if we consider the agriculture specializations in terms of products, Emilia-Romagna does emerge as one of the main suppliers of fruits and vegetables, accounting for about one third of national production (Figure 8). According to this picture, the economic relevance of this production for RFSs, with strong linkages with food industry and serving both the domestic and the foreign markets, is self-evident.

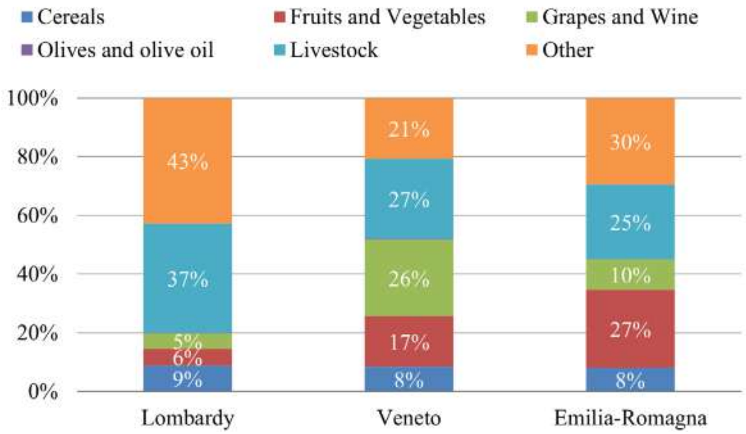
Moreover, the daily consumption of fruits and vegetables is recommended by the Italian food-based dietary guidelines, because of the low calories' intakes and the provision of fibers, vitamins and minerals (CREA, 2018). From a nutritional perspective we can consider fruits as critical products.

Secondly, the areas specialized in the cultivation of fruits have been largely hit by the 2023 flood. Using the Piani Colturali Grafici of Emilia Romagna,[10] we overlap the map of the hit municipalities according to the

9. The FADN is a European information system based on the production of economic and financial statistics collected annually through interviews to a representative sample of agricultural holdings classified according to size, type of production and region.

10. The Piani Colturali Grafici are the crop plans presented periodically by farmers who intend to demand economic support within the common agricultural policy (CAP) framework. They are geo-referenced and allow the identification and localization of the single parcels of the farms and

Figure 8 – Composition of Agricultural Production in Lombardy, Veneto and Emilia-Romagna (%; 2018)



Source: Author's elaborations on Istat, Eurostat data

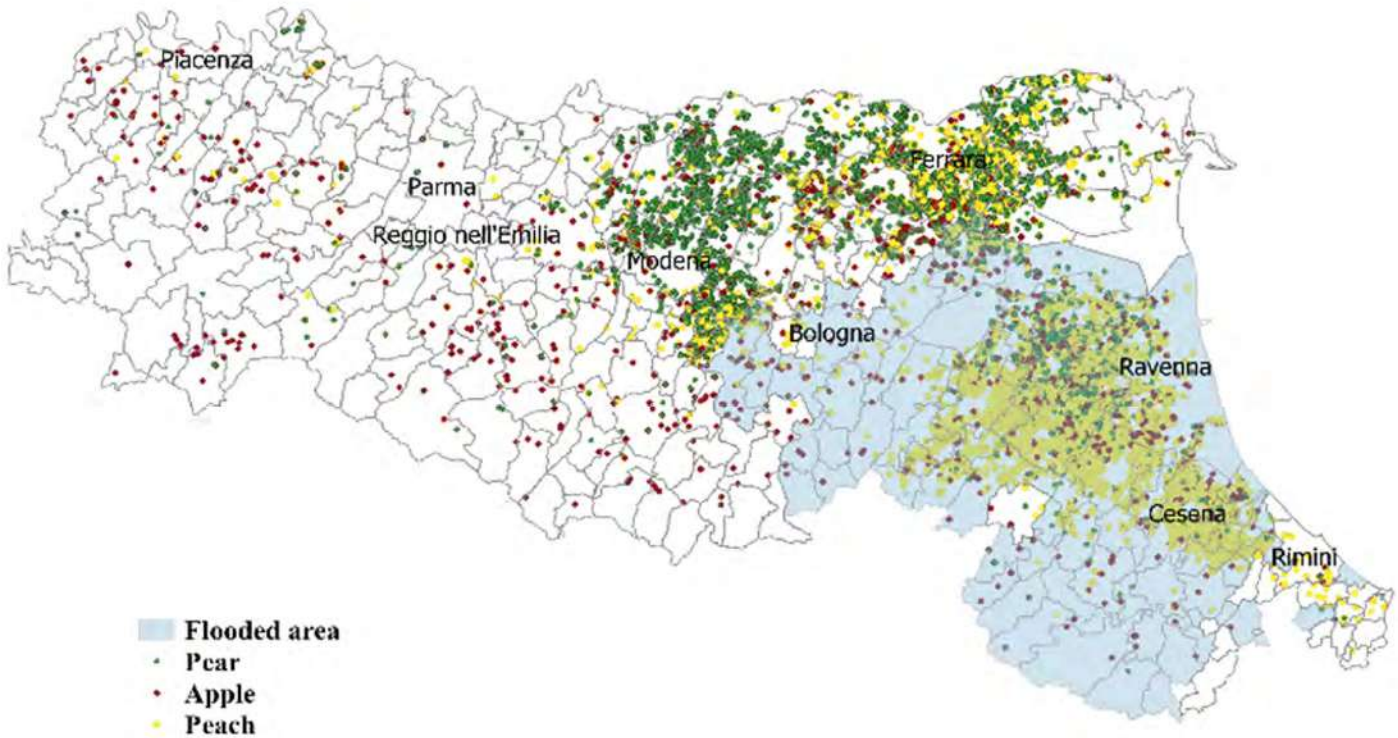
regional government with that of their main specializations in terms of cultivations. The most hit provinces are Forlì-Cesena, Ravenna and Bologna. In terms of cultivations, such areas are specialized in the production of pome fruits and stone fruits. In particular: pears, apples and peaches (Figure 9). Since the flood hit the region during the harvesting season of peaches, thus putting at risk almost the whole yearly production, we cannot exclude that some damages to capital goods (i.e., the trees) as well as land might have troubled the production for several years.

The shares of yearly production exposed to the flood are 93.4% of peaches, 42.8% of apples and 21.4% of pears. As to the national production at risk for 2023, the hit zones produce 13.9% of pears, 13.5% of peaches and 3.0% of apples.

If such results capture the amount of production exposed to the flood, they don't tell anything about the impact of the fall of production on the national consumption. In this respect, data about production and consumption are still not available, but international trade flows at the national and at the subnational (NUTS3) level are released with very short lags. In this respect, at the time of writing we can already observe:

their main uses. Results based on Asia Agricoltura are not dissimilar from the one obtained here. However, Piani Colturali Grafici have to be preferred since they are based upon the localization of the cultivations and not upon the one of the firm headquarters. This latter operation has been implemented thus far for Emilia-Romagna and Tuscany.

Figure 9 – The Spatial Distribution of Cultivations of Pears, Apples and Peaches in Emilia-Romagna and the Municipalities Mainly Hit by the 2023 Flood



Source: Authors' elaborations on Piani Colturali Grafici Emilia-Romagna, Istat, Eurostat

1) *if there has been a substantial and significant fall of international exports of agricultural goods in the third quarter of 2023 in the provinces which have been severely hit by the flood.*

We deal with the first issues by employing Istat Coeweb data at the provincial and product (CPA 3 digit) level. This are at disposal on a quarterly basis since 2011Q1. We aggregate exports of 3-digits CPA agricultural products distinguishing between hit vs. non-hit provinces and estimate the following econometric model:[11]

$$y_{(i,t)} = \alpha + \beta Flood_t + \gamma Hit_i + \eta\left(Flood_t \bullet Hit_i\right) + \varepsilon_{(i,t)} \qquad [4]$$

where $y_{i,t}$ is given by the yearly rate of change of exports at quarterly frequency; *Flood* is a dummy variable being 1 in 2023Q3 and 0 in all other quarters; *Hit* is a dummy variable being 1 in case the region has been affected by the flood and 0 otherwise. The coefficient of interest is η. We considered as hit provinces Forlì-Cesena, Ravenna and Bologna.[12]

We concentrate upon perennial crops, which are the ones mainly hit by the flood. In this respect, Figure 10 reports the yearly rates of change in Q3 vis-à-vis Q2 of exports of the product of interest of the main exporters among Italian provinces (at quarterly basis), among which the three hit regions stand (in red). As it can be seen all of them are characterized by significant falls in Q3, especially in comparison with other Italian provinces.

The results from the econometric model, reported in Table 1, confirm such visual evidence. Independently from the time span considered, the coefficient capturing the impact of the flood is always statistically and economically significant. Indeed, the flood has caused a drop of 15/16% of international exports in the hit regions in 2023Q3.[13]

2) *If there has been an increase in international imports of Italy of the agricultural goods whose production was more exposed to the flood (i.e., pome fruits and stone fruits)*.[14]

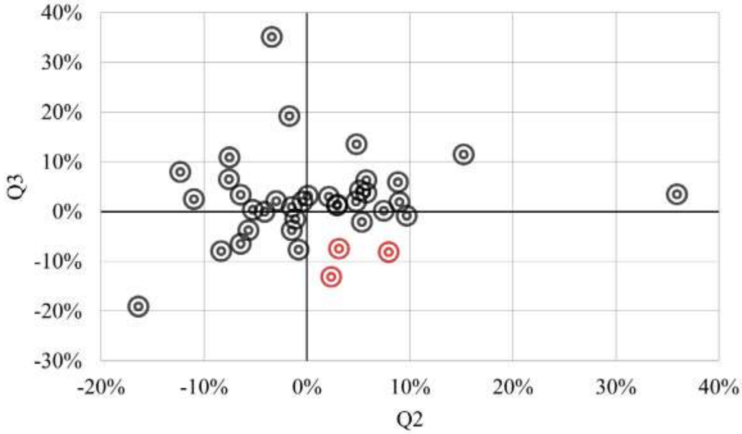
11. We also estimate an alternative model in which NUTS 3 regions are held disaggregated. In such case, we did discard from the sample all the provinces with negligible exports. We end up with 38 provinces with which we estimate the very same model. Results are robust and coefficients stable and statistically significant.

12. We exclude Rimini from hit regions since it was marginally hit by the flood (see Figure 9) and its contribution to total regional exports of perennial crops rather marginal.

13. This corresponds to a 60% fall on an annual basis.

14. As to international imports, data at the national scale has to be preferred. First, imports at the regional scale, especially of goods destined to final consumption, are largely biased by the uneven distribution of firms in charge of logistic services. Second, they are at disposal in quantities and on a monthly basis.

Figure 10 – Rates of Growth of Exports of Perennial Crops of the Main NUTS3 Regions in Italy. Yearly Rates of Change at Quarterly Basis. Q2 2023 vs. Q3 2023



Source: Authors' elaborations on Istat Coeweb data

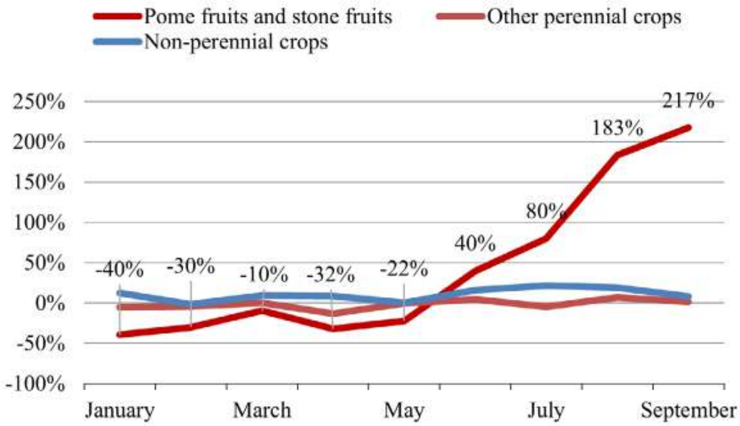
Table 1 – The Impact of the 2023 Flood in Emilia-Romagna

Model	*η*	*SE*	*t-test*	*p-value*	*Adj. R2*	*Obs.*
2011Q1-2023Q3	-0,14	0,067	-2,15	0,034	0,10	94
2021Q1-2023Q3	-0,16	0,063	-2,55	0,021	0,34	22
2022Q1-2023Q3	-0,16	0,039	-4,07	0,002	0,62	14

Source: Authors' elaborations on Istat Coeweb data

Whereas the fall of regional exports is an important symptom of a decrease in production, they might not really capture the extent of the fall of the latter one. Indeed, for the kinds of products which were more exposed to the flood, foreign markets might represent a relatively small share with respect to domestic destinations. That is why we shift our focus to the dynamics of Italian international imports of pome fruits and stone fruits (CPA code 01240) in the aftermath of the 2023 flood. In this respect, Figure 11 reports it in terms of yearly % changes in imported tons on a monthly basis. As it can be seen from the graph, international imports dramatically rose since June 2023 (+40%), to peak at +217% in last period of observation (i.e., September). Such a dynamics is significantly different from the ones characterizing other perennial crops and non-perennial crops.

Figure 11 – Italian Imports of Pome Fruits and Stone Fruits in 2023. Tons (Yearly % Changes)



Source: Authors' elaborations on Istat Coeweb data

Table 2 – Summary Table of the Criticality of Fruits Production of Emilia Romagna

Criticality	*Overall importance*	*Supply risk*
Economic importance	+++	
Nutritional importance	+++	
Availability on the market		+++
Substitutability on the demand-side (cost-opportunity)	+-	
Substitutability on the supply-side (suitability)		+-

Source: Authors' elaborations

The impressive increase in imports of both pome and stone fruits in the aftermath of the 2023 flood is clear evidence that the products were available on international markets and they were adequate substitutes for both food industry and final consumers (Table 2). However, about substitutability we cannot evaluate: 1) if there were any differences in terms of safety of the products (i.e. chemical residuals) and the overall impact on health and environment (i.e. emissions, use of inputs); 2) the impact on prices. In the third quarter, on average, the consumer prices of fruits in Italy increased by 10% if compared to the same quarter of 2022. However, to detach the net effect generated by the 2023 flood from the effect of inflation/other factors more in-depth analysis is needed.

5. In Lieu of a Conclusion

Whereas climate change is expected to dramatically affect agriculture and food production in the very next years, there is a lack of toolkits in economic research to correctly track the paths from the places affected by climate shocks to those in which food is consumed. In this respect, value chains approaches based on interregional input-output tables represent an appealing solution as they are able to connect the places of consumption to those where production takes place. However, both the geographic lenses and the level of sector/product disaggregation of such models leave often unsatisfied.

The present work contributes to the existing research in many respects. First, it provides a configuration of interregional-international value chains activated by Italian internal food consumption and show how fragmented it appears. Moreover, it shows how some countries and regions are in charge of producing most of the agricultural goods necessary to finalize production. Second, it provides a conceptual framework to assess the vulnerability of a RFS, starting from the assessment of criticality of a food product and encompassing all the final as well as the intermediate goods necessary to produce it or providing it via imports. Finally, a primary version of this framework of spatial- and product-based disaggregation of agricultural production in Italian regions has been applied to the case of the flood occurred in Emilia Romagna in May 2023, in order to capture the exposure of Italian food system to the reduced supply of fruits.

In our intention, future research will expand the conceptual framework presented in this study over several dimensions. First, disaggregation of industries and sectors involved in serving the consumers final demand for food, as well as the food consumption basket, will be considered in the implementation of a comprehensive food satellite account for Italian regions. Second, the spatial module now implemented for Emilia-Romagna and Tuscany will be extended to all the regions for which spatial data are available. Moreover, apart from cultivations, the final spatial archive will include plants linked to livestock and to the food processing industry. Third, firm level data will be considered so as to include the potentially heterogeneous impact of climate shocks on firms balance sheets. Fourth, international trade data and a multi-country Supply and Use based model will complete the international module of the value chain configuration. Finally, a climate related module about the impact of climate shocks on food production will be envisaged.

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Sommario

L'esposizione dei sistemi agro-alimentari regionali italiani a shock legati al cambiamento climatico

Questo lavoro fornisce una configurazione delle catene del valore interregionali-internazionali attivate dal consumo alimentare interno italiano e mostra come alcuni paesi e regioni producono la maggior parte dei beni agricoli necessari per finalizzarne la produzione. In secondo luogo, fornisce un quadro concettuale per valutare la vulnerabilità dei sistemi regionali alimentari italiani, basato sul concetto di criticità dei prodotti alimentari. Infine, fornisce una disaggregazione spaziale e di prodotto della produzione agricola nelle regioni italiane che ben cattura l'esposizione del sistema alimentare italiano all'alluvione che ha colpito l'Emilia-Romagna nel maggio 2023.

Appendix

A. Data

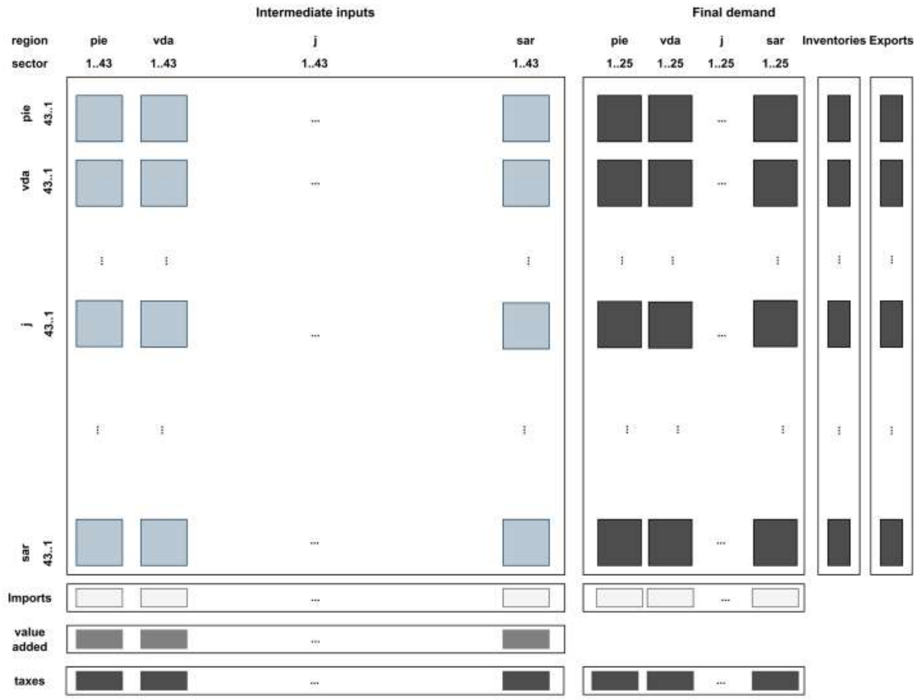
In order to implement the analysis performed in Section 2 we use the IRPET interregional input-output table graphically represented in Figure A1 (see Paniccià, Rosignoli, 2018 and Bentivogli *et al.*, 2019 for the methodology). The interregional input output table (IRIOT) contains information for 43 sectors and 20 Italian administrative regions (plus extra-regio). Each row of the matrix indicates the destination of the production generated by a sector j located in a region s distinguishing, in terms of intermediate uses, the region and the sector demanding such inputs; in terms of final uses, the region and the specific final demand component. Moreover, the last two columns identify changes in inventories and foreign exports.

Reading the IRIOT by column provides information about production requirements in terms of intermediate inputs and productive factors services of each single sector/region. Evidently, in IRIOT, the origin of the intermediate inputs is distinguished by sector and geographical area of origin (apart from foreign imports). The total of each single column of the intermediate part of IRIOT is the sectoral total output as the sum of demand for intermediate inputs, value added at basic prices and net indirect taxes.

The accounting structure of the table can be summarized by the following identity, for each j-th sector and r-th region:

$$\sum_{s=1}^{N}\sum_{i=1}^{M} x_{ij}^{sr} + va_j^r + tax_j^r + imports_j^r \equiv \sum_{s=1}^{N}\sum_{i=1}^{M} x_{ji}^{rs} + \sum_{s=1}^{N}\sum_{z=1}^{Z} Fd_{s,z}^{rs} + inv_j^s + exports_j^s \quad [A1]$$

Figure A1 – A Graphical Representation Of the IRPET Interregional Input Output Table (IRIOT). 2018



where: N = number of regions; M = number of sectors; Z = number of final demand components; x = intermediate goods and services; va = value added at basic prices; Fd = final demand; tax = indirect taxes; *imports* = intermediate input imports; *inv* = changes in inventories of final products; *exports* = international exports.

Final demand components at the regional level in the IRIOT foresee household consumption divided into 12 COICOP expenditure functions;[15] public

15. The 12 (2-digits) COICOP household expenditure functions include: 1) food and non-alcoholic beverages; 2) alcoholic beverages, tobacco and narcotics; 3) clothing and footwear; 4) housing, water, electricity, gas and other fuels; 5) furnishings, household equipment and routine household maintenance; 6) health; 7) transport; 8) communication; 9) recreation and culture; 10) education; 11) restaurants and hotels; 12) miscellaneous goods and services.

Table A1 – Data Sources

Database	*Website*
IRPET IRIOT	
OECD ICIO	https://www.oecd.org/industry/ind/inter-country-input-output-tables.htm
Farm accountancy data network (FADN)	https://agriculture.ec.europa.eu/data-and-analysis/farm-structures-and-economics/fadn_en
Conti della branca agricoltura, silvicoltura e pesca	http://dati.istat.it/
Piano Colturale Grafico Emilia-Romagna	https://agreagestione.regione.emilia-romagna.it/agrea-file/
Flood May 2023 hit zones	Decreto legge 61/2023 – Interventi urgenti per fronteggiare l'emergenza provocata dagli eventi alluvionali verificatisi a partire dal 1° maggio 2023
Coeweb international trade data	https://www.coeweb.istat.it/

administration consumption divided into 10 expenditure functions;[16] fixed capital formation; non-profits institutions serving households; valuables.

The reference year for the analysis is 2018.

Further data used in Section 2 includes the OECD inter-country input-output (ICIO) table, whose main characteristics can be found at www.oecd.org.

In order to carry out the analysis reported in Section 4, several sources of openly available data were used. Table A1 provides summary information about all the data sources used in the present work.

16. The 10 Public Administration expenditure functions include: 1) general public services; 2) defence; 3) public order and safety; 4) economic affairs; 5) environmental protection; 6) housing and community amenities; 7) health; 8) recreation, culture and religion; 9) education; 10) social protection.

The Energy Transition in Europe and MENA Countries: An Exploratory Analysis On the Main Energy Sources Demands and Supplies

Irene Bosco, Giovanni Canitano°*

Abstract

The transition towards renewable energy is crucial for safeguarding planet Earth and slowing down global warming. Supranational institutions have intervened by issuing directives that provide for the reduction of CO2 emissions and encourage the consumption of renewable energy. The document examines the dynamics of global trade in the main fossil fuels and the consumption patterns of renewable energy sources, with specific attention to the shocks generated by international conflicts and their effect on prices. The study specifically looks at countries in the MENA region as major suppliers of fossil fuels and major European nations as major energy importers.

1. Introduction

The Mediterranean basin[1], thanks to its strategic geographic position and rich concentration of energy sources, plays a crucial role in global energy supply. Trade flows from the MENA[2] region, known for its substantial reserves of oil and

* LUMSA University, Law Department, Rome, Italy, e-mail: i.bosco.dottorati@lumsa.it.
° ISMed – CNR, Italian National Research Council, Napoli, Italy, e-mail: giovanni.canitano@ismed.cnr.it (corresponding author).

1. Although the Mediterranean Basin is a geographical area related to the states bordering the Mediterranean Sea, this paper refers to the Mediterranean countries as the "Greater Mediterranean" as defined on the DataMED website (http://datamed.cnr.it/). A geopolitical and geo-economic horizon involving non-homogeneous contiguous areas of great international importance, ranging from the Middle East and North Africa to the Sahel countries, Iran, Turkey and the Gulf States.
2. According World Bank geographic classification, 21 countries or territories constitute the Middle East and North Africa (MENA) region. Six Gulf Cooperation Council (GCC) members (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and United Arab Emirates [UAE]), and 15 other countries or territories: Algeria, Djibouti, the Arab Republic of Egypt, Iraq, the Islamic Republic of Iran, Israel, Jordan, Lebanon, Libya, Malta, Morocco, the Republic of Yemen, the Syrian Arab Republic, Tunisia, and West Bank and Gaza.

natural gas, are primarily directed towards European Union (EU) member states, which are among the main consumers of these energy resources. The Mediterranean basin serves as a key hub for energy provision to countries worldwide. The paper addresses the urgent climate emergency facing the Earth, marked by phenomena like a 2°C temperature increase, melting glaciers, floods, and fires, all attributed to human activities disrupting the natural balance. Emphasizing the critical need for transitioning to renewable energy to mitigate global warming, the study investigates trade flows and energy supplies in the Mediterranean basin. Supranational institutions have issued directives to reduce CO2 emissions and promote renewable energy consumption. Focusing on fossil fuels (oil, gas, carbon) and renewable sources (hydroelectric, solar, wind energy), the research covers MENA countries as major suppliers e producers of fossil fuels and European nations that overlook Mediterranean basin, particularly, Italy, France, and Spain, with the addition of Germany, as key importer.

The study will starts by providing a brief overview of the current climate framework in Mediterranean countries, followed by an exploration of energy trade within these nations. Subsequently, the fourth and fifth paragraphs will delve into the transition towards green energy and its interconnectedness with international relations.

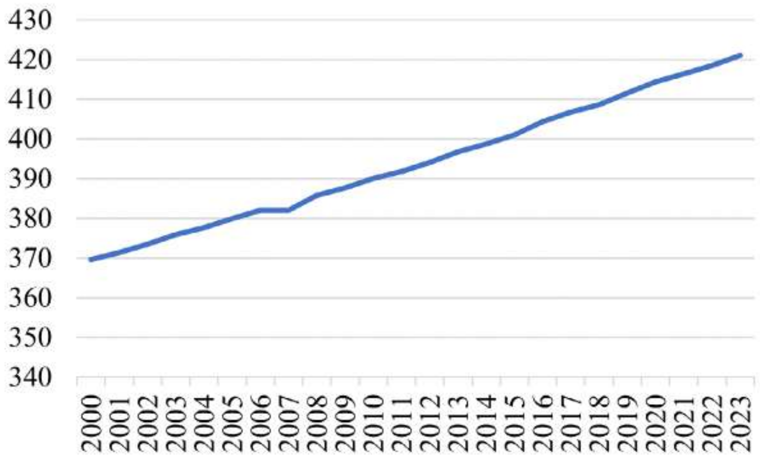
2. Climate Framework of the Mediterranean Countries

The Mediterranean Basin is experiencing a warming trend characterized by a rise in the frequency and severity of heat waves extended and hotter summers, shifts in precipitation patterns, and decrease in rainfall amounts. This region, known for substantial socio-economic disparities between the North (Europe) and South (Africa), faces challenges such as population growth, migration, heightened water demand, and an increased risk of forest fires. As a result, the vulnerability of the Mediterranean population to health risks is significantly elevated.

As shown in Figure 1, the CO2 level (world average) has followed an increasing path, undoubtedly attributed to globalization and the intense industrialization of developed countries. This increase in CO2 levels is closely correlated with the rise in surface temperature.

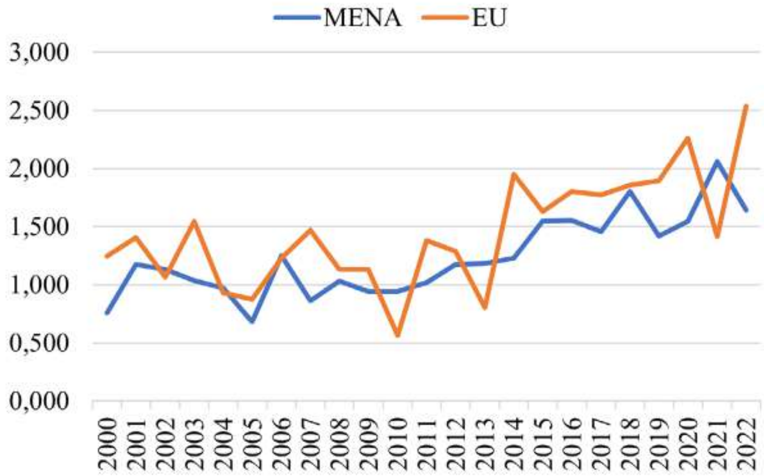
Figure 2 shows the change in temperature for the MENA region and EU countries (France, Germany, Italy, and Spain) respectively. The change in temperature for the European countries is more pronounced compared to that in MENA countries, indicating the high levels of CO2 emissions associated with extensive industrialization. In relation to this, the Mediterranean region is experiencing a warming trend that is 20% faster than the global average, according to the United Nations Environmental Programme on Climate Change in the Mediterranean.

Figure 1 – World Average CO_2 Level (Parts per Million)



Source: Authors' elaborations on data from International Monetary Fund (2023), Climate Change Indicators

Figure 2 – Temperature Change With Respect To a Baseline Climatology, Corresponding to the Period 1951-1980 (Degree Celsius)



Source: Authors' elaborations on data from International Monetary Fund (2023), Climate Change Indicators

Cities in Mediterranean climates along coastlines and surrounded by mountains face dual risks. They are vulnerable to the impacts of sea level rise, including flooding, erosion, and the salinization of river deltas and aquifers. Additionally, these cities are at risk of increased wildfires due to their geographical characteristics (Mavromatidi *et al.*, 2018; Moreira *et al.*, 2011).

3. Energy Demand and Supply In the Mediterranean Countries

Thanks to their strategic geographical positions and abundant natural deposits, the southern Mediterranean region, along with the Arabian Peninsula, Iran, and Iraq, plays a significant role in the global trade of fossil fuels, making these areas key players in global energy resources.

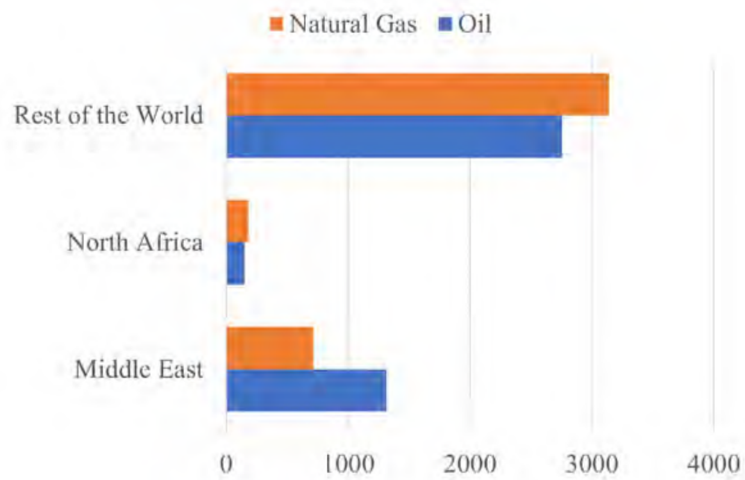
The Middle East and North Africa (MENA) region is central to the world's highest concentration of oil and natural gas resources. In 2020, the Middle East held almost half of the total oil reserves, with a quantity of 113.2 million tonnes, while North Africa held 3.4%, amounting to 8.3 million tonnes.

These statistics underscore the significant role of the MENA region in global energy resources, encompassing both oil and natural gas. Regarding natural gas production, Iran, alongside Qatar, emerges as a major producer. In 2020, Iran produced 249.5 billion cubic meters of natural gas, while Qatar's production amounted to 179.9 billion cubic meters (Bosco, Canitano, 2023).

Figure 3 shows the production of fossil fuels in 2021, for oil and natural gas, respectively. The Middle East covers a substantial share of overall production in both natural gas and oil. This is attributed to the southern Mediterranean region, including the Arabian Peninsula, Iran, and Iraq, which holds significant reserves of fossil fuels, positioning it as a crucial player in the global energy landscape. These countries play a key role in trade with European nations due to their strategic geographical location and natural deposits. The abundance of fossil fuel deposits in this region positions it as a major contributor to the global energy supply, underscoring its importance in international trade dynamics, particularly with European countries.

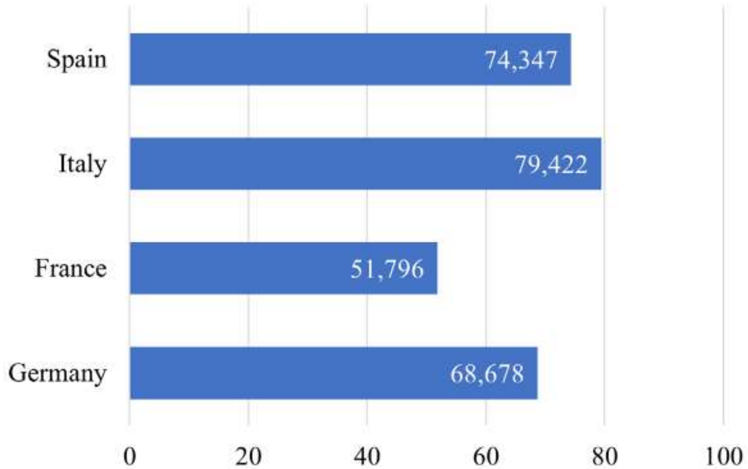
Figure 4 illustrates the energy import dependency for Spain, Italy, France, and Germany in 2022. The chart delineates the share of a country's total energy needs met by imports from other countries. This rate represents the proportion of energy that an economy must import, defined as net energy imports divided by gross available energy, expressed as a percentage. This measure can be defined for all products as well as for individual fuels (Eurostat Metadata). Among the four countries, Italy has the highest level of energy dependency, followed by Spain, Germany, and, lastly, France. The level of energy dependency is a variable that could impact the transition towards green energy and could be influenced by international relations turmoil. We will analyze these two aspects in the following paragraphs.

Figure 3 – Production of Fossil Fuels in MENA Countries in 2021 (Oil in Million Tonnes and Natural Gas in Billion Cubic Metres)



Source: Authors' elaborations on data from British Petroleum (2022), Statistical Review of World Energy 2022

Figure 4 – Energy Imports Dependency (Percentage)



Source: Authors' elaborations on data from Eurostat Database. Date retrieved: 26th December 2023

4. The Energy Transition Across the Mediterranean Countries

4.1. Targets and Feasibility

The energy transition, driven by the climate emergency, is a widely discussed topic that requires a combination of expertise from engineering, economic, social, and environmental perspectives. Supranational institutions have issued directives aimed at accelerating the green transition. The REPowerEU plan, published on May 18, 2022, outlines three fundamental targets: energy savings, the production of clean energy, and the diversification of the EU's energy supplies. Among the targets to be achieved by 2030, the Renewable Energy Directive EU/2023/2413 sets a minimum binding target of 42.5% for renewable energy, with the goal of reaching 45%.

Focusing on the Mediterranean countries, the southeast Mediterranean countries (SEMCs) are experiencing a population growth that consequently implies an increase in energy demand. Since 2010, energy demand has increased by 6%, and it is expected to rise up to 118% by 2040. To satisfy this consumption need, fossil fuels will remain the main energy source, and the use of renewable energy sources is expected to triple by 2040 (Drobinski *et al.*, 2020).

Moreover, in the Mediterranean region, maximizing growth in power generation from renewable sources depends on the strategic development of interconnections that facilitate seasonal complementarities between the northern and southern parts of the region. Well-established interconnections can enhance the efficiency and reliability of the energy system, enabling a more effective utilization of renewable resources and contributing to the overall transition toward sustainable power generation in the Mediterranean (World Energy Council, 2019). This transition not only reduces CO2 emissions but also emphasizes the production of energy from renewable sources. However, it must be noted that the availability of such sources is constrained by factors such as seasonal variations, geographical location, climate change, and other environmental factors beyond human control. Energy sources like wind and solar energy are subject to natural laws, necessitating the implementation of an energy storage plan to address potential shortages in these sources.

4.2. Assessment of Energy Potentials and Utilization of Renewable Sources in Mediterranean Countries

Mediterranean countries benefit from a consistent energy potentials derived from renewable energies including wind, solar, hydro, bioenergy, waves and currents (Soukissian *et al.*, 2017). Indeed, thanks to its geographical position, the Mediterranean basin gives to the lying countries a geological structure constituted by a temperate climate, mild winters and warm summers, all factors which contribute to an energy supply located on site. Notably, the Gulf of Lions, the Alboran Sea, and the Aegean Sea are key contributors to wind energy potential in the Mediterranean Sea (Balog *et al.*, 2016; Onea *et al.*, 2016; Omrani *et al.*, 2017; Soukissian *et al.*, 2017; Rusu, Rusu, 2019). More in general, the Mediterranean countries boast the advantage of being subject to regular and predictable breezes both from land and sea. Presently, 80 gigawatts derived from wind source are installed in Mediterranean countries (Drobinski *et al.,* 2020).

The Mediterranean region also taps into reliable energy potentials from solar power and hydropower, although both are susceptible to climate variability. Solar power is influenced by surface solar radiation and cloud cover, while energy production from solar panels depends on factors such as air temperature, the presence of snow and ice, cell temperature, and near-surface speed (Hadjipanayi *et al.,* 2016).

The Mediterranean Energy Transition Scenario, outlined by the Mediterranean Association of National Agencies for Energy Management (MEDENER), which brings together agencies in the Mediterranean region in charge of energy efficiency and the promotion of renewable energy sources, and the Observatoire Méditerranéen de l'Énergie (OME) which is the institute devoted to promote the green energy in the Mediterranean area, in 2015 outlines a shift towards a more sustainable energy system in the region. This transition relies on the implementation of currently mature measures in terms of technology, economics, and politics. Rather than depending on major technological breakthroughs, the focus is on deploying existing technologies and effective energy efficiency policies across all Mediterranean countries. The scenario aims to achieve widespread adoption of renewable energies and energy efficiency without waiting for significant advancements in technology (Drobinski *et al.,* 2020).

In 2018, the OME presented an updated edition of the Mediterranean Energy Perspectives, outlining two expected scenarios: the Reference Scenario, which relies on past trends, current policies, and ongoing projects; and the Proactive Scenario, which depends on the implementation of programs focused on energy efficiency and diversification. According to these scenarios, by 2040, the energy demand in the North Mediterranean is projected to be approximately 10% lower than the 2015 level in the Reference Scenario and about 21% lower than the 2015 levels in the Proactive Scenario (Drobinski *et al.,* 2020).

On the contrary, the Reference Scenario and the Proactive Scenario indicate that the South and East Mediterranean will experience an increase in energy demand by 118% and 72%, respectively, from the levels in 2015.

In the supply scenario, according to the Proactive Scenario, the share of renewable energy is projected to reach 24% by 2040. In contrast, the Reference Scenario estimates a share of 13%, with approximately 1137 TWh of electricity produced by renewables, corresponding to 34% of the total electricity generation in Mediterranean countries. Solar and wind energy are expected to be the majorly exploited sources.

According to Figure 5, European countries, namely France, Germany, Italy, and Spain, have the highest share of consumption in renewables compared to the Middle East and North Africa. This highlights the significant dependence of the Middle East and African countries on fossil fuel sources. The energy transition in these countries depends on factors of different nature, each of them necessary for sustainable growth in the consumption of green energy. For instance, African countries require a profound transformation in the energy sector, which is closely related to economic and political objectives (Pye, Bataille, 2016). As a consequence, the interconnection among the energy needs, economic, and political goals represents an obstacle to the feasibility of the green transition. It adds to the cost of renewables, especially since domestic production of fossil fuels costs less. Hence, the promotion of financing for green projects is needed to incentivize and accelerate the transition.

5. International Relations and the Green Transition

5.1. The Russian-Ukrainian Conflict and its impact on Energy Trade

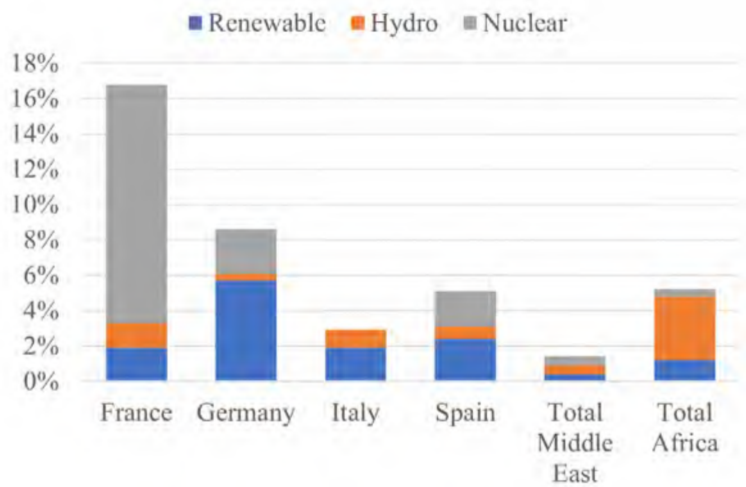
Nations heavily reliant on energy imports may face vulnerabilities in their supply chains during periods of international conflict, impacting both demand and supply. Indeed, global economic shifts can be triggered by international conflicts, subsequently influencing the demand for energy and the ability to meet that demand.

The Russian-Ukrainian conflict has had profound effects on the supply of energy sources, particularly in European countries. One significant consequence has been the rise in inflation, a direct result of disruptions in the alignment of energy demand and supply.

As a response to geopolitical tensions and uncertainty surrounding energy supplies from Russia, several European nations, including France, Germany, Italy, and Spain, have taken measures to reduce their dependency on Russian fossil fuels. This strategic shift involves establishing new agreements and partnerships with non-EU countries to secure alternative primary energy resources. The goal of this strategic diversification is not only to ensure a stable energy supply but also to safeguard against potential geopolitical risks associated with heavy reliance on a single energy provider.

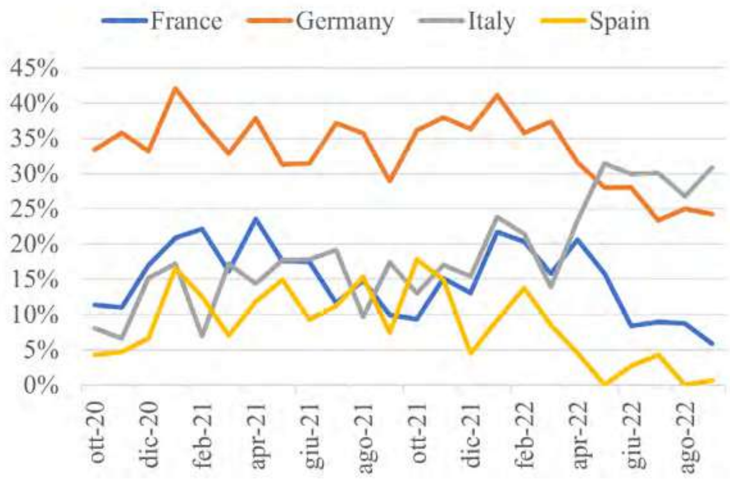
The oscillating path of oil imports described in Figure 6, underscores the prior fluctuations in the reliance on Russian oil, suggesting a certain level of dependency on this energy source among the mentioned European nations. However, following the invasion of Ukraine, a notable shift is evident in the graph, indicating

Figure 5 – Share in Energy Consumption by Non-fossil Sources in 2021



Source: Authors' elaborations on data from British Petroleum (2022), Statistical Review of World Energy 2022

Figure 6 – Monthly Reliance on Russian Oil (Total Oil Imports from Russia / Oil Demand %)



Source: Authors' elaborations on data from IEA (2022), Monthly Reliance on Russian Oil.

a change in the procurement strategies of these countries. Italian import levels exhibited a reverse trend, with oil imports increasing from March 2022 until May 2022, followed by a gradual decline, and then picking up again in August 2022.

In conclusion, the Russian-Ukrainian conflict has reshaped the energy framework in Europe, prompting nations to reevaluate their energy procurement strategies.

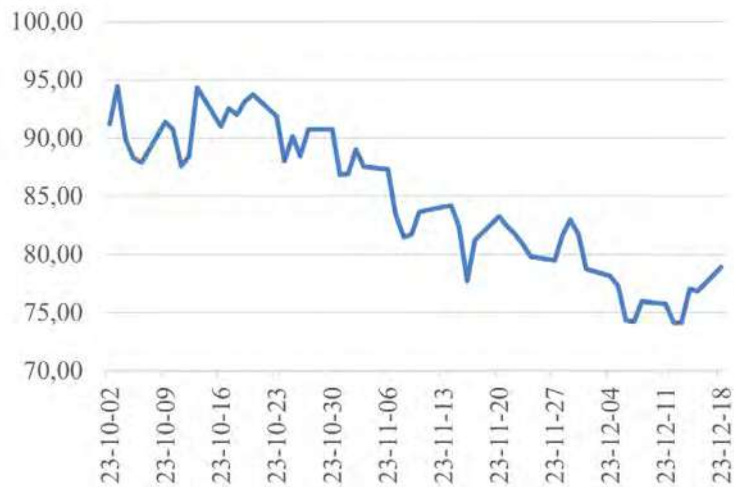
5.2. The Israeli-Palestinian Conflict, The Oil Trade and the Energy Transition

Similar to the Russian-Ukrainian conflict, the outbreak of the Israeli-Palestinian conflict and the subsequent Halmas-Israel war on October 8, 2023, induced uncertainty that reverberated through the financial markets and the broader international economic framework.

In contexts characterized by such uncertainty, the price of oil, considered as a safe haven asset, absorbs uncertainty during periods of geopolitical or economic turmoil, making it susceptible to inflation. However, the impact provided by Halmas-Israel conflict seems to be scaled down in short time. As a matter of fact, Figure 7 illustrates the trend of Brent Crude prices, showing an initial increase a few days after the outbreak, followed by a return to its descending trajectory. This means that the Halmas-Israel conflict did not provoke such uncertainty, probably due to the previous conflicts that preceded it. In fact, it should be observed that the decline in such prices seems to reflect the contraction in global oil demand coincided with the strength in supply of non-OPEC+ countries in the months of November and December. Specifically, there is a notable shift in global oil supply dynamics, moving away from traditional Middle Eastern oil-producing nations toward emerging key players like the United States and other Atlantic Basin countries. In this context, regions to the East of Suez have increased their oil supply imports from Russia and Iran, particularly in the aftermath of the Ukraine invasion. Meanwhile, China's substantial oil demand surge, primarily propelled by the rapid growth of its petrochemical industry, is significantly reshaping global oil trade patterns (IEA, 2023).

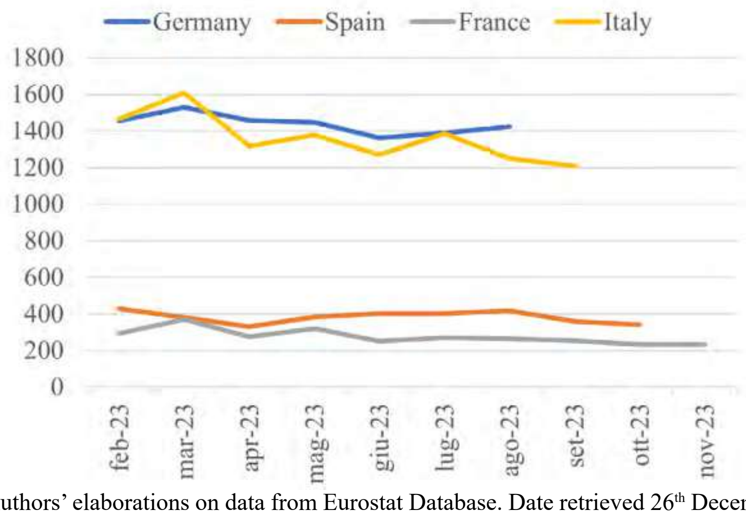
Such correlation between the reduction in oil demand and oil prices is given by the increase in renewable energy demand. In the context of transitioning towards green energy, there has been an increase in the production of net electricity from renewable sources such as hydro and wind in Germany, France, Italy, and Spain over the last few months. However, there was a decrease in the production of net electricity from solar sources, while the production from renewable combustible fuels remained stable. Net electricity production by renewable combustible fuels is described by Figure 8, while net electricity productions by hydro, wind and solar sources are described by Figure 9, 10 and 11 respectively. These shifts in energy sources contributed to a reduction in oil demand, leading to a decrease in

Figure 7 – Daily Price of Brent Crude Oil – Europe (Dollars per Barrel)



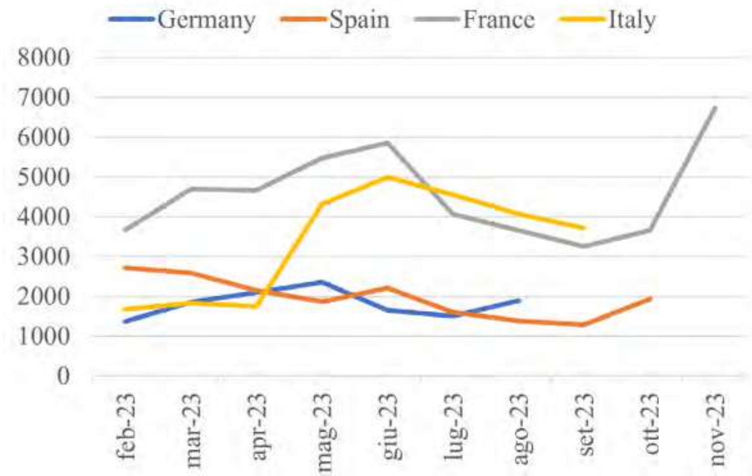
Source: Authors' elaborations on data from FRED, Crude Oil Prices: Brent – Europe, date retrieved 26th December 2023

Figure 8 – Net Electricity Production By Renewable Combustible Fuels (GWh)



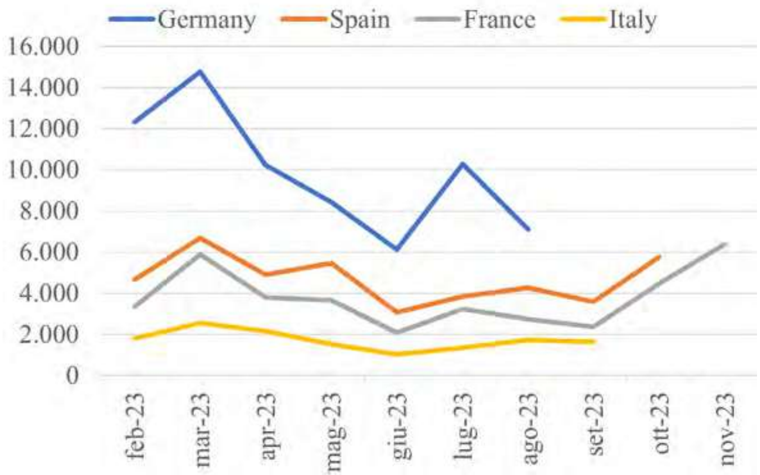
Source: Authors' elaborations on data from Eurostat Database. Date retrieved 26th December 2023

Figure 9 – Net Electricity Production by Hydro (GWh)



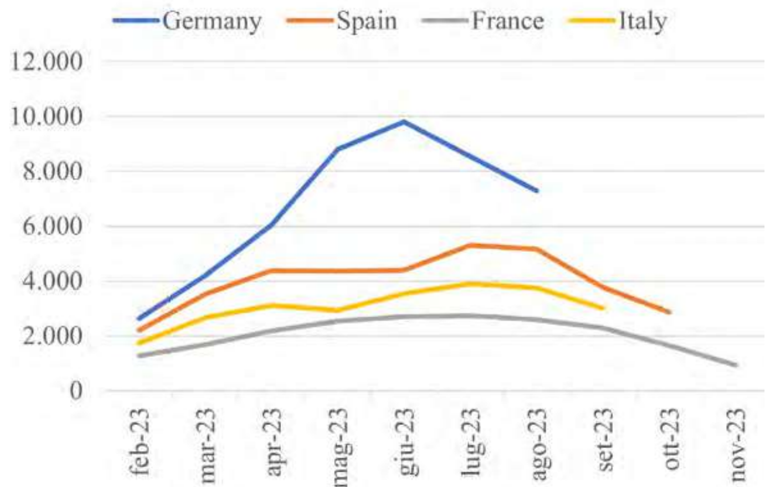
Source: Authors' elaborations on data from Eurostat Database. Date retrieved 26th December 2023

Figure 10 – Net Electricity Production by Wind (GWh)



Source: Authors' elaborations on data from Eurostat Database, Date retrieved 26th December 2023

Figure 11 – Net Electricity Production by Solar (GWh)



Source: Authors' elaborations on data from Eurostat Database, date retrieved 26th December 2023

oil prices. This trend signals an acceleration in the implementation of the targets outlined in supranational policies related to the green transition.

In conclusion, the decrease in oil prices owes its reason to the contraction in its demand rather than to the uncertainty generated by the Halmas-Israel conflict, which remitted in few days. As matter of fact, the acceleration towards the green energy enhanced the demand in renewable energy sources, and therefore a reduction in oil demand and in its price.

6. Conclusions

The southern Mediterranean region, alongside the Arabian Peninsula, Iran, and Iraq, stands as a crucial hub in the global energy landscape, contributing significantly to the fossil fuel trade. The significance of the Middle East in global energy supply is underscored by its enduring role as a major contributor to oil and natural gas production, emphasizing its continued importance in shaping the trajectory of the international energy market. Moreover, Mediterranean countries are endowed with consistent and diverse renewable energy potentials, encompassing wind, solar, hydro, bioenergy, waves, and currents. This allows them to be a favourable region to the development of the energy production by renewable sources, supported by policies aimed at facilitating the green transition.

The geopolitical uncertainties stemming from both the Russian-Ukrainian conflict and the Israeli-Palestinian conflict, culminating in the Halmas-Israel war in October 2023, have reverberated throughout the financial markets and the broader international economic landscape.

Given these developments, the intricate interplay among geopolitical events, supply dynamics, and changing demand patterns highlights the complexity of the global oil market. As the world moves through these uncertainties, the resilience and adaptability of key players in the energy landscape will persist in shaping the trajectory of global oil trade.

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IEA Data and statistics – www.iea.org/data-and-statistics.
IMF Climate Change Dashboard – climatedata.imf.org

Sommario

La transizione energetica in Europa e nei Paesi MENA: Un'analisi esplorativa sulla domanda e sull'offerta delle principali fonti energetiche

La transizione verso le energie rinnovabili è cruciale per la salvaguardia del pianeta Terra e per il rallentamento del riscaldamento globale. Le istituzioni sovranazionali sono intervenute attraverso l'emanazione di direttive che prevedono la riduzione delle emissioni di CO2 e incentivano il consumo di energie rinnovabili. Il documento esamina le dinamiche del commercio globale dei principali combustibili fossili e i modelli di consumo delle fonti energetiche rinnovabili, con uno specifico riguardo agli shock generati dai conflitti internazionali e al loro effetto sui prezzi. Lo studio esamina specificamente i paesi della regione MENA come principali fornitori di combustibili fossili e le principali nazioni europee come principali importatori di energia.

Analysing the Energy Stocks Dynamics in European Countries Under an Energy Transition Framework

Emna Kanzari, Stefano Fricano*, Gioacchino Fazio**

Abstract

In recent years, threats to economic development due to escalating tensions related to fossil fuel use in the global energy landscape, have accelerated the need to stimulate the energy transition towards the use of renewable energy. Consequently, renewable energy, which today is seen as an important opportunity and the primary solution, has become the focus of international and local policymakers, mainly, in the developed countries that depend on fossil fuel imports such as European countries. The objective of this paper is to examine the dynamics of renewable energy in European nations by analysing the energy stock changes as a function of a set of variables mainly the production and the consumption of renewable energy. To do this, we used a Probit model considering the energy characteristics of countries as a function of their potential economic impact. The findings suggest that the increase of renewable energy proportion in the total energy supply results in a reduction in the energy stock levels in the countries studied, while greater openness to international energy markets results in an increase in energy stocks to deal with market shocks. Stretching further the analysis, the estimated parameters obtained from the Probit estimation were employed to divide the countries used in the sample into three groups based on their propensity towards a decrease in their energy stocks.

1. Introduction

In the context of energy production and consumption, the association between energy risk and fossil fuels is undeniable (Khan *et al.*, 2023). Fossil fuels, including coal, oil, and natural gas, have long been the primary sources powering the global economy (Wu, Chen, 2017). However, their dominance comes with inherent risks that span environmental, economic, and geopolitical dimensions. Firstly, the environmental risks associated with fossil fuels are manifold. Burning these fuels releases greenhouse gases, primarily carbon dioxide, into

* University of Palermo, Department of Economics, Business and Statistics, Palermo, Italy, email: emna.kanzari@unipa.it (corresponding author), stefano.fricano@unipa.it, gioacchino.fazio@unipa.it.

the atmosphere, intensifying the greenhouse effect and contributing to global climate change (IPCC, 2023).

Geopolitically, regions rich in fossil fuel reserves often experience significant geopolitical tensions and conflicts. The scramble for control over these resources has historically led to power struggles, interventions, and wars, underscoring the geopolitical risks intertwined with fossil fuel dependence.

Economically, the volatility in fossil fuel prices can destabilize national and global economies. Dependence on these exhaustible resources creates vulnerability to supply disruptions, geopolitical tensions, and market fluctuations. Furthermore, the transition away from fossil fuels towards renewable energy sources represents both an economic challenge and opportunity, with nations and industries seeking to balance energy security, affordability, and sustainability. Unlike fossil fuels, renewable energy is characterised by its abundance and not being concentrated in a specific geographic area, providing more energy independence for countries (Khan *et al.*, 2023). Many countries around the world, specifically, European countries, consume fossil energy more than they produce, which makes them heavily rely on foreign sources to meet their needs and be closely linked to the fossil exporting countries. This strong reliance can be used in some cases as a means by exporting countries to exert pressure, particularly in times of political conflicts and crises, and the tensions between Russia and the European countries are a clear and recent example of this. This crisis has highlighted Europe's over-dependence on fossil sources imports from Russia and has brought to the fore the necessity to reduce them, accelerate energy transition programs and policies, and increase the share of renewables in the energy mix, in order to obtain a more robust energy system and gain energy security (European Commission, 2022).

While fossil fuels have played a pivotal role in powering human progress, their associated risks underscore the urgent need for diversifying the global energy mix and accelerating the transition towards cleaner, renewable alternatives.

However, while renewable energies promise a sustainable future, doubts persist about their ability to fully mitigate energy risks for nations. The intermittent nature of sources like wind and solar can pose challenges to consistent energy supply, potentially leaving gaps in demand coverage. Additionally, the infrastructural demands and initial investment costs associated with renewables can be substantial, especially for developing nations. Concerns also arise regarding the scalability and storage capabilities of renewable technologies to meet growing energy demands. Hence, while renewables offer promising solutions, questions about their comprehensive role in offsetting energy vulnerabilities remain (Cergibozan, 2022).

This contribution tries to understand, through the study of the energy trends of European countries, the attitude of the various countries and whether there has been a positive effect of renewable energy on the mitigation of energy risk.

For this purpose, an analysis was developed of the trend of energy stocks in various countries over the last two decades and, which to our knowledge has never been reported in the literature, the possible interconnections with the development of renewable energy have been highlighted.

The dynamics between energy stock levels and perceived energy risk offer intriguing insights into global energy security and market sentiments. When energy stocks are abundant and surpass demand, it typically signifies a more stable energy landscape. Countries with high energy reserves, such as oil-rich nations or those with extensive renewable energy capacities, often experience reduced perceived energy risks. As the global energy landscape evolves, understanding this interplay becomes paramount for policymakers and industry stakeholders to ensure both energy resilience and public confidence.

The structure of this paper is as follows. The next section will discuss the literature review on renewable energy and energy security. In the third section, we will introduce the data and the methodology employed in the empirical work. Subsequently, we present the results and the discussion and finally, the last section summarizes and concludes.

2. Literature Review on Renewable Energy and Energy Security

Energy security is a multifaceted concept that includes different dimensions. In general, the concept refers to the ability of the country to obtain energy sources uninterruptedly and affordably to satisfy its needs. Energy security contains four main dimensions namely the availability, accessibility, affordability and acceptability (Gökgöz, Güvercin, 2018). The availability of energy resources refers to the physical existence of energy, its accessibility means the ability to reach and use energy resources despite geographical and technological constraints. As for affordability, it implies access to energy at affordable and reasonable prices. Acceptability, on the other hand, is related to the use of energy with low environmental impacts (Gökgöz, Güvercin, 2018). As commonly understood and based on several studies, fossil fuel energy is highly associated with energy security risk. Firstly, because fossil fuels are finite and will be completely consumed in the long run (Holechek, *et al*., 2022). Secondly, they are not equitably distributed across countries and regions, which makes some countries heavily rely on imports from the other countries to satisfy their energy needs (Murshed, *et al*., 2020). Thirdly, over the last decades, oil, gas and natural gas prices have shown significant instability (Scholten, *et al*., 2020). Fourthly, the use of fossil fuels is strongly associated with carbon emissions and negative environmental impacts (Maji, *et al*., 2019). That said, according to previous research, renewable energy is considered an alternative to fossil fuels in different ways and can positively affect energy security (Cergibozan, 2022). Renewable energy (RE) contributes to the reduction of CO_2 emissions, and it has less negative environmental impacts, making it more acceptable than fossil fuels (Bilgili, *et al*., 2016).

Additionally, despite its land and technical constraints, RE remains a better alternative to fossil fuels in terms of long-term sustainability and geographical availability, since it is characterised by its abundance all over the globe (Moriarty, Honnery, 2016). Also, renewable energy includes solar power, wind power, hydropower, geothermal energy and bio-energies. The diffusion of each of these powers generates more capacities from various sources and adds to the total energy supply of the country. According to Aslani *et al*. (Aslani, *et al*., 2012), the higher the diversification of the energy resources in a country, the higher the diversification of the energy supply and the higher the energy security of supply. The diversification of the energy system including resources with low environmental impact and available in abundance such as renewable alternatives can allow energy security as it offers new capacities with various sources, unlike the single-energy system especially that with high environmental and security supply risk such as fossil fuels, which represent a real obstacle to sustainable development and energy security achievement (Akrofi, 2021).

The diversity in the energy resources will allow countries to have more than fossil fuels in their energy mix and may be beneficial, especially for countries that do not have high fossil production and import it from foreign markets. Energy poor countries depend on external energy countries to satisfy their increasing energy demand. By doing so, they are more exposed to market risks and dependence on other countries. By employing more renewables produced domestically, energy importing countries may reduce their reliance on external suppliers and decrease their high budget expenditure (Aslantürk, Kiprizli, 2020).

It is clear that for fossil fuel importing countries, renewable energy will guarantee a secure supply from domestic production. However, when these countries decrease their imports, it can represent a challenge for the economy and budget revenues of exporting countries which heavily depend on the revenues of energy exports. For these countries, it is important to maintain their energy exports and ensure their energy security of demand (Novikau, 2022). The Organisation of the Petroleum Exporting Countries (OPEC), are the first to be affected by the reduction of their exports as they control the oil market and between 2011 and 2019, they have seen a significant decrease in their oil exports. For OPEC, ensuring the energy security of demand is as important as the security of supply (Fan *et al*., 2023).

Another aspect of energy security is the geopolitical conflicts between different countries to control the energy market. The use of fossil fuels is historically related to geopolitical tensions, wars and conflicts. Unlike fossil fuels, renewable energy is expected to reduce these tensions between countries as renewable resources such as solar, wind, hydro, ocean and geothermal are equally distributed across regions. The fact that renewable resources are available for every country will offer self-sufficiency to many countries, which will decrease the energy conflicts between them (Agaton, 2022).

As previously mentioned, renewable energy plays a significant role in ensuring energy security. Despite that, the relationship between energy security and renewable energy has not been sufficiently studied empirically in the literature.

Numerous studies examined composite energy security indicators and frameworks from various angles, including inconsistencies, measurement challenges, and methodological limitations. (Siksnelyte-Butkiene, *et al*., 2024) examined 40 different composite indicators that have been developed and used in recent years. The results indicate that many energy security indicator sets are insufficient in capturing the entirety of changes in the energy market, economy, policy, international trade, and other external factors. Despite this, many authors have reported some general considerations about some results that can be stylized. For example, analysing how renewable energy affects energy security in Lithuania, (Augutis, *et al*., 2014) employed a scenario analysis and concluded that the development of renewable energy technologies increases energy security in the country. This effect is stronger when the share of renewables in energy production does not exceed 60-70%. (Brahim, 2014) studied this relationship in the Philippines and reached the same conclusions. The Philippines has huge untapped renewable energy and by harnessing it, it is expected to offer the country more energy security and sustainability. (Lucas, *et al*., 2016) tested this nexus for 21 European Union countries from 1990 to 2013, making use of a set of indicators to proxy energy security: security of supply, sustainability and competitiveness. The results show the existence of a long-term relationship between renewable energy deployment and energy security. Based on the Long-range energy alternative planning (LEAP) system, (Aized, *et al*., 2018) identified four scenarios to discuss energy plans in Pakistan. The results suggest that the green scenario which includes renewable energy sources is the best choice that the country can adopt to have low environmental and externality costs. According to (Wang, *et al*., 2018), renewable energy can help China to enhance its energy security and reduce CO2 emissions since the country is the world's largest oil importer and the largest CO2 emitter. (Viviescas, *et al*., 2019) showed that solar PV, wind and hydropower can ensure energy security in Latin America through the complementarity of these resources and regional integration. Brazil, in particular, can be a key player in renewable energy integration as it has the strongest capacity of complementarity with other Latin American countries. In the context of Eastern Europe, Caucasus and Central Asia (EECCA) countries, (Trifonov, *et al.*, 2021) made conclusions about the contribution of renewable energy to energy security through energy resource diversification. An increase in the share of renewable sources in the energy mix, the development of different renewable technologies and the structure of the energy complex played a significant role in boosting energy security. The growth of renewables share is accompanied by a reduction in energy dependency, which increases energy security in these countries. (Cergibozan, 2022) has empirically studied the nexus between renewable energy and energy security risk in 23 OECD, focusing on the effect of total renewable energy and renewable technologies separately mainly solar, wind, hydro and biomass on energy security risk. The study shows that there is a positive impact of wind, hydroelectric and total renewables together on reducing energy security risk, while the biomass and solar powers do not show a significant effect on energy security.

In this study, we aim to add to the literature review by focusing empirically on European countries as they are not enough discussed in the literature. In addition, we use energy stock change as a new proxy for energy security, and to the best of our knowledge, it is the first time that it has been employed in this context. Energy stocks can give information about the energy dynamics in an economy. Generally, countries that tend to increase their energy stocks are more exposed to energy security risk and aim to increase them to be protected in short-term market shocks, whilst those reserving less are likely to be surer or satisfied by their energy production.

3. Data and Methodology

3.1. Data

To discuss the dynamics of the energy stocks in Europe, we employed a set of variables that may influence them, collected from different databases mainly the International Energy Agency (see Table 1). The sample employed in this work includes variables for 20 European countries between the available time span from 1992 to 2020. We have chosen the largest 20 European countries[1] in terms of GDP.

To develop our analyses, we started by analysing some of the main variables linked to the energy trends of the various European countries considered:

- *Energy stock changes*: the difference between the initial stock levels on the first day of the year and the last day of the year of the stocks. Energy stocks are the related energy stocks held within a national territory by producers, importers,

1. The countries are as follows: Germany, United Kingdom, France, Italy, Spain, Netherlands, Switzerland, Poland, Sweden, Belgium, Norway, Ireland, Austria, Denmark, Romania, Finland, Czech Republic, Portugal, Greece and Hungary.

Table 1 – Summary of the Variables Considered in the Work (for country details see Table A.1)

Variables	*Description*	*Source*	*Mean*	*SD*	*Min*	*Max*
Energy stock changes	Expressed in Tera-joule (TJ).	IEA*	1,385.5	60020.2	-299,024.6	505,685.4
RE production	Renewable energy production in TJ.	IEA*	314,995.1	307,563	6,472.9	1889,791
Energy production	Total energy production expressed in TJ.	IEA*	2211,906	2635,305	53,244.5	1.18e+07
Energy consumption	Total energy consumption expressed in TJ.	IEA*	2416,222	2452,789	317,702.1	1.01e+07
Energy imports	Total energy imports expressed in TJ.	IEA*	2732,246	2822,925	189,065.3	1.12e+07
Energy exports	Total energy imports expressed in TJ.	IEA*	1324,720	1981,303	8989,084	32,849.5
GDP growth	Annual percentage of GDP growth.	WDI**	1.9	3.1	-11.3	24.4

Notes: * Bought from the International Energy Agency, World Energy Balances (IEA, 2023); ** The World Bank Group. DataBank, World Development Indicators (World Bank, 2023).

Source: Authors' elaborations

energy transformation industries and large consumers. A negative number refers to a stock build while a positive number shows a stock draw (IEA, 2023).

- *Renewable energy production*: is the sum of the production of renewable energy sources including wind energy, solar photovoltaic, solar thermal, hydropower, geothermal, tide energy, biogas, bio gasoline, biodiesel and municipal waste.
- *Energy production:* the total production of primary energy namely hard coal, lignite, peat, crude oil, natural gas liquids (NGLs), natural gas, biofuels and waste. It also involves nuclear, hydro, geothermal and solar as well as heat derived from heat pumps extracted from the ambient environment (IEA, 2023).
- *Energy consumption*: total consumption in end-use sectors and non-energy use excluding energy used for transformation processes and for the internal operations of energy-producing industries. It represents the deliveries made for consumers (IEA, 2023).
- *Energy imports*: the quantities that have crossed the country's national territorial borders whether customs clearance was completed or not. Coal is considered the quantities imported (excluding coal in transit) from other countries without considering the existence or the absence of an economic or customs union

between them. For oil imports, it excludes oil in transit and includes crude oil and oil products imported under processing agreements. Crude oil, natural gas and natural gas liquids (NGL) are reported based on their country of origin, while refinery feedstocks and oil products are recorded based on the country of last consignment. Additionally, imported NGL that is later exported to another country after regasification is treated as both import and export (IEA, 2023).

- *Energy exports*: the quantities that have crossed the country's national territorial borders whether customs clearance was completed or not. Coal is considered the quantities exported (excluding coal in transit) to other countries without considering the existence or the absence of an economic or customs union between them. Oil exports include the crude oil and oil products which are exported under processing agreements. For the imported oil for processing within bonded areas, when it is re-exported, it is recorded as exported from the processing country to the final destination. Additionally, imported NGL that is later exported to another country after regasification is treated as both import and export (IEA, 2023).
- *GDP growth*: refers to the annual percentage increase of Gross Domestic Product at market prices using constant local currency. The aggregates are expressed in U.S. dollars (using constant 2015 prices).

3.2. Methodology

3.2.1. The Variable Selection

As already mentioned, in our analysis we focused on the stock change measure provided by the International Energy Agency for the countries considered over the last two decades. The "stock change" variable, as referenced by the International Energy Agency (IEA), pertains to the variation or alteration in the levels of energy reserves or supplies over a specified period. Specifically, in the context of the IEA's analyses and reports, the stock change provides insights into the net increase or decrease in energy stockpiles, such as oil, gas, or coal, considering factors like production, imports, exports, and consumption. A negative number refers to a stock build while a positive number shows a stock draw (IEA, 2023). Following these indications, our interest was therefore to understand in which circumstances, for each country considered, there was an increase or decrease in energy stocks. Consequently, we decided to construct a dichotomous dependent variable which, starting from the sign of the stock changes variable (*Schng*), represents the possible underlying propensity towards a decrease in energy stocks (*Schng*=1) that fall along a continuum related to the level of energy security and to test its dependence with five variables as explanatory variables as follows:

- *Energy production / Energy consumption*: the ratio between energy production and consumption used as an indicator to highlight the ability of a country to meet its energy needs by consuming what it produces. A high value indicates that the country produces more than it consumes and its domestic production satisfies its energy needs while a low ratio suggests that the country's energy sufficiency is low and may rely on foreign sources to fulfil its energy necessities.
- *Energy imports / Energy consumption*: the fraction between energy imports and energy consumption specifies the share of energy needs of a country that are met through importation compared to its energy consumption. It highlights the energy dependency on external energy imports: a low share means less dependency on international energy market and higher energy security.
- *Energy exports / Energy production*: the ratio between energy exports and energy production represents the share of the total energy production of a country that is exported to other countries. A low value implies that the country uses its produced energy domestically and it therefore has a limited economic interest on the international energy market as supplier.
- *Renewable energy production / (Energy production + Energy imports – Energy exports)*: refers to the share of renewable energy production in total energy supply. It indicates the proportion of the energy generated from renewable resources compared to overall provided energy. This represents our variable of greatest interest since it could allow us to understand the relationship between renewable energy and the mitigation of energy risk.
- *GDP growth*: we have decided to also include the variable GDP growth to take into account possible influences on economic growth which may be different for the various countries.
- *Country*: we also considered a fixed effect for each country by introducing an additional multinomial variable.

3.2.2. The Model

The research idea of this contribution is to investigate under what conditions the probability that a country's energy stocks are reduced.

Starting from what was presented above, our objective is to verify the following hypotheses:

- *H1: High capacity to meet internal energy demand through internal production can guarantee the stability of the internal market, and therefore makes high energy stocks less necessary.*
- *H2: Country's greater exposure to international energy markets leads to maintaining high energy stocks.*

Table 2 - Summary of the Variables Used in the Empirical Analysis

Variables	*Description*
Stock changes: (Schng)	Dichotomous variable referred to Energy stock changes: "0" refers to a stock build while "1" to a stock draw.
% of RE in total energy supply (REshare)	Renewable energy production / (Energy production + Energy imports – Energy exports)
Energy auto-sufficiency (EAS)	Energy production / Energy consumption
Energy demand from foreign markets (EDF)	Energy imports / Energy consumption
Energy supply to foreign markets (ESF)	Energy exports / Energy production
GDP growth (GDPg)	Annual GDP growth
Country	Multinomial variable: Germany, United Kingdom, France, Italy, Spain, Netherlands, Switzerland, Poland, Sweden, Belgium, Norway, Ireland, Austria, Denmark, Romania, Finland, Czech Republic, Portugal, Greece and Hungary

Source: Authors' elaborations

- *H3: Greater energy production from renewable sources guarantees a more secure source of supply and can induce countries to reduce energy stocks.*
- *H4: Economic growth trends can lead countries to accumulate energy stocks which can be useful in guaranteeing the growth process.*

To test the hypotheses, we decide to use a probit analysis. Probit analysis is particularly appropriate when trying to estimate the effects of one or more independent variables on a binomial dependent variable. Probit regression assumes that the relationship between the predictors and the probability of the response variable can be modelled using the cumulative distribution function (CDF) of a normal distribution. In other words, probit regression assumes that the probability of the response variable being equal to 1 can be modelled using a normal probability density function and that the values of the predictor variables determine the mean and standard deviation of the distribution (Hong, *et al*., 2022). We use probit regression to model the relationship between the binary variable *Schng* and the predictor variables of Table 2 and its general specification is as indicated in the following equation:

$$Pr\left(Schng_{it}=1\right)= \varnothing\left(\beta_0\, REshare_{it}+\ \beta_1 EAS_{it}+\ \beta_2\, EDF_{it}+\ \beta_3\, ESF_{it}+\beta_4 GDPg_{it}+\ u_i+\varepsilon_{it}\right) \quad [1]$$

Where $Schng_{it}$ is the binary dependent variable for country *i* and year *t*, [Equation 1] refers to the cumulative distribution function of a standard normal distribution, β_0, β_1, β_2, β_3, β_4, are the coefficients to be estimated, u_i, indicates the country fixed effects and ε_{it} is the random error.

4. Results and Discussion

Although the general purpose of this analysis is to verify the various hypotheses of the model, the main objective of this study is to understand what effect has a greater production of renewable energy on changing the amount of energy stocks owned annually by each country, in particular, we intend to perceive whether a greater production of renewable energy can increase the probability that the stock decrease and therefore obtain a value of "1" for the dependent variable. To do so, we developed a Probit analysis using Mathematica® on our data and the fitting results are shown in Table 3.

As can be noticed from the results, both variable Energy auto-sufficiency (EAS) and variable GDP growth (GDPg) are not significant in our analysis, whereas the variables related to the external market relationship namely the energy demand from foreign markets (EDF) and the energy supply to foreign markets (ESF), especially the variable measuring the amount of renewable energy produced in relation to all available energy (REshare), are significant.

The lack of significance of the variable Energy auto-sufficiency (EAS) would seem to *deny Hypothesis H1* and, at first glance, it might appear uninteresting. In our opinion, however, it is very significant and reflects an important signal of the energy behaviour of the various countries. In fact, it tells us that the "current" ability to satisfy internal demand with internal production does not seem to sufficiently "ensure" the country systems. This aspect is indeed intriguing and has also been emphasized by several analyses (Dyatlov, *et al.*, 2020), which underscore the fact that in certain countries where new initiatives for diversifying energy supply have been initiated, they stem from concerns regarding the lack of long-term guarantees offered by the current production capacity.

For the variables related to the external market relationship, it is interesting to note that the sign of the coefficients associated with the interaction with the external market is negative for both variables (-1.79274 and -0.757505): this confirms that greater exposure to international energy markets induces individual countries to keep high values of energy stocks instead of reducing them in order to contain the risk that may arise from price volatility. *This affirmation verifies our Hypothesis H2*.

Indeed, when there is a price spike in the international market, energy importing countries (for example: Germany, Italy, France, Netherlands, United Kingdom and

Table 3 – Empirical Results

Probit Results Cox&Snell PseudoR2 = 0.3132 Pearson ChiSquare = 638.5 Dependent variable: Stock changes				
	Estimate	*Standard Error*	*z-Statistic*	*P-Value*
REshare	3.079	1.566	1.966	0.049
EAS	-0.106	0.186	-0.572	0.567
EDF	-1.793	0.510	-3.517	0.001
ESF	-0.757	0.288	-2.634	0.008
GDPg	-0.020	0.018	-1.151	0.249
Country effect				
Austria	0.883	0.606	1.458	0.145
Belgium	1.631	0.662	2.465	0.014
Czech Republic	0.840	0.504	1.668	0.095
Denmark	1.447	0.616	2.349	0.019
Finland	0.927	0.626	1.480	0.139
France	1.470	0.578	2.540	0.011
Germany	1.917	0.563	3.403	0.001
Greece	2.036	0.687	2.964	0.003
Hungary	1.190	0.541	2.198	0.028
Ireland	1.772	0.552	3.207	0.001
Italy	1.748	0.553	3.157	0.001
Netherlands	2.730	0.941	2.901	0.004
Norway	-0.524	2.058	-0.255	0.799
Poland	0.710	0.456	1.558	0.119
Portugal	0.947	0.610	1.550	0.121
Romania	1.031	0.484	2.128	0.033
Spain	1.728	0.646	2.673	0.007
Sweden	0.759	0.678	1.118	0.263
Switzerland	1.315	0.566	2.322	0.020
UK	1.286	0.524	2.453	0.014

Note: * The time span considerate in the analysis is 1992-2020.

Source: Authors' elaborations

Spain (IEA, 2023)) try to use their reserves of energy to stabilise domestic prices and for them it is important to have an abundant energy stock to better respond to the market. For these countries, it is important also to diversify their energy mix and include alternative resources as a hedge against price volatility and market pressures. In the opposite case, energy exporting countries tend to accumulate stocks to be able to respond promptly in case of a spike in external market demand. This dynamic is well recognized within the EU and over the years multiple initiatives have been put in place to address the volatility of the energy market. As a matter of fact, to ensure a consistent and stable energy supply across member states, the EU has established directives regarding energy emergency stock levels (Directive 2009/119/CE) (European Union, 2009b). These directives mandate that member countries maintain a minimum level of oil and petroleum product reserves equivalent to at least 90 days of average daily net imports or 61 days of average daily inland consumption, whichever is greater. Furthermore, the EU specifies that these emergency stock levels should be accessible and deployable within a short notice period. Member states must also regularly report their stock levels to the European Commission, ensuring transparency and adherence to the established norms. The rationale behind these directives is multifaceted. Firstly, it aims to mitigate the potential impacts of sudden energy supply disruptions, whether due to geopolitical tensions, natural disasters, or other unforeseen events. Secondly, it underscores the EU's commitment to ensuring energy security, promoting stability in energy markets, and safeguarding the interests of both consumers and businesses. Also, energy prices started rising in the EU well before the invasion of Ukraine and the Commission reacted to growing pressure to act by adopting guidance to Member States in the form of a Communication in October 2021 entitled "Tackling rising energy prices: a toolbox for action and support".

The positive sign of the parameter linked to the portion of renewable energy out of the total available energy (Reshare) *confirms the Hypothesis H3* and responds to the question to which this contribution refers. In fact, it shows how a greater percentage of available renewable energy is more likely to lead to a reduction in energy stocks. It is useful to remember in this case how this result is in line with European directives regarding the energy transition towards renewables.

The commitment of Europe to its energy shift is not related to recent conditions and the development of renewable energy has been at the core of its energy policy for many years. Between 2001 and 2009, the European Union adopted a set of initiatives to impose on its countries the increase of renewable sources used to produce energy, to raise the share of renewables in electricity production (Directive 2001/77/EC), to adopt renewable fuels including biofuels in the transport sector (Directive 2003/30/EC) and other renewable resources in different sectors such as heating and cooling (Directive 2009/28/EC) (European Union, 2001; 2003; 2009a). In 2018, another action known as the Renewable Energy Directive suggested that by 2030, at least 32% of the energy produced in the EU has to be generated from renewables.

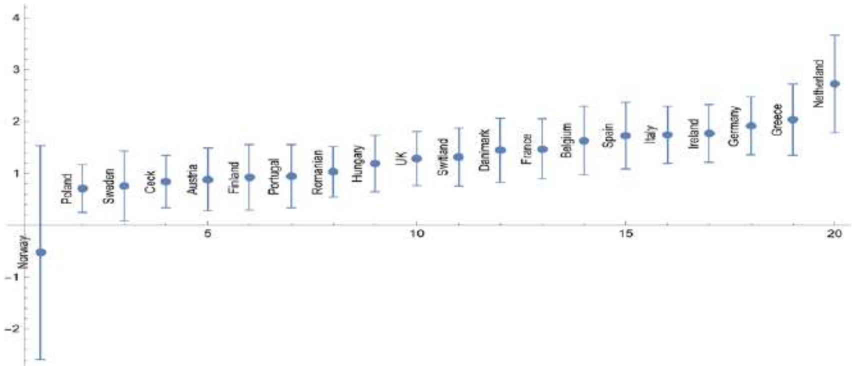
Finally, the findings of our analysis do *not confirm Hypothesis H4*. In this case, however, the result could be connected to the variability of the data which could lead to a distortion of the result. To investigate this possibility and evaluate the robustness of the results, we first repeated the analysis on a subsample relating to narrower time windows and replacing the variable GDP growth by GDP growth per capita. The results confirmed what was obtained before and led to deeper reflections on whether there is indeed a mechanism that can link the growth dimension, possibly with different indices, to that of energy security.

5. Country Fixed Effects

The results deriving from the contribution of country fixed effects also deserve careful discussion. Considering the country fixed effects, it is noteworthy how the parameters related to the country fixed effects are positive, except in the case of Norway for which the parameter, although the estimate has a very large standard error, takes on a negative value (see Figure 1).

This negative value is explained by the fact that, within our panel data, Norway is a unique case in which the value of energy production is much higher than

Figure 1 – The Estimated Parameters for Each Country (u_i)



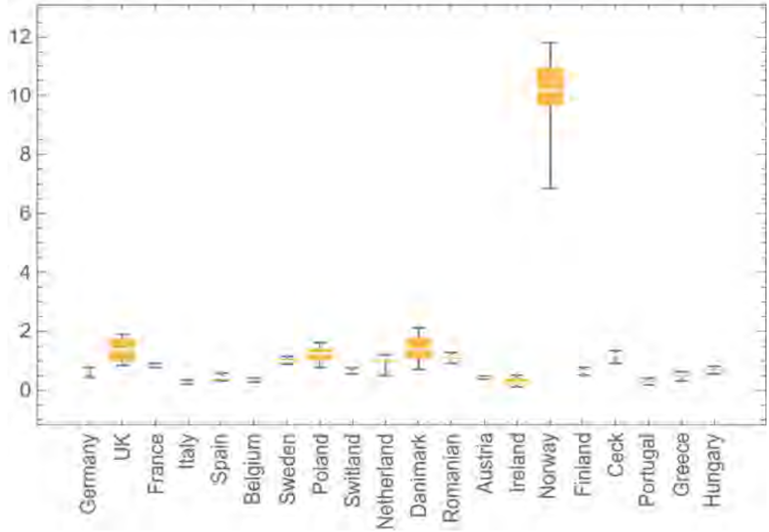
Source: Authors elaborations on values u_i

domestic demand (approximately 5 times the average value of the other countries in our sample, see Figure 2) and in this case, the level of energy risk appears to be considerably low, likely not linked to stock levels at all.

Norway is a remarkable and unique example of energy self-sufficiency in renewable energy and it is more energy secure than almost any other country. Between 1995 and 2020, Norway registered a power surplus and became one of the most energy independent countries, being the world's fifth largest petroleum exporter and seventh largest hydropower producer (Hansen, Moe, 2022).

Excluding Norway, we can identify three distinct groups of countries depending on the parameter values through the definition of some merely symbolic thresholds. The first group of countries is made up of six countries namely Poland, Sweden, Czech Republic, Austria, Finland and Portugal, for which the estimated best fit parameter takes on a value less than 1; for these countries, we can define a general low propensity towards a decrease in stocks. For the countries of a second group which is composed of Romania, Hungary, Denmark, France, UK and Switzerland, the estimated value of the parameter varies within a range of 1 and 1.5; for these countries, we can define a general moderate propensity towards a decrease in stocks. Finally, for the countries belonging to the last group, the estimated parameters are greater than 1.5 with a maximum value of approximately 2.7 for the Netherlands. These countries have a greater propensity

Figure 2 – Energy Auto-sufficiency for Each Country



Source: Authors elaborations

to decrease energy stocks probably because of a progressive transition towards the diversification of energy sources. This last result is interesting and deserves further analysis which could provide useful indications at a macroeconomic level on the nature of any exogenous or endogenous causes that may be at the basis of this variability.

6. Conclusion

In the present study, we were interested in examining how an extensive production and use of renewable energy may affect the energy stocks dynamics in an economy. We mainly focused on 20 European countries as Europe is one of the most exposed regions to energy security risks. The European Union's economy is reliant on fossil fuels, which account for nearly three-quarters of its total energy consumption. Fossil energy is largely imported: the EU's share of global fossil fuel demand stands at 8%, compared to its share in global production of 0.5% for oil and 1% for gas, respectively.

Using a panel sample for the period between 1992 and 2020, we applied a Probit estimation model considering the sign of energy stock change as the binary dependent variable and the share of renewable energy in total energy supply as the main independent variable. We included also other energy related variables: the energy auto-sufficiency and two variables related to the external market relationship which are the energy demand from foreign markets and the energy supply to foreign markets.

We tested the relationship between all variables in the model and we concluded that whether the country is an energy supplier or demander, the exposure to foreign energy markets is highly linked to energy security risks as the coefficients of the energy demand and supply are both negative, which means that those countries tend to increase their stocks to overcome the market risks.

On the other hand, the share of renewable energy in the total supply is significant and positive, suggesting that countries having an important share of renewables in their energy supply are likely to decrease their energy stocks as they are not much exposed to market fluctuations. Expectations of a demand decrease can heighten uncertainty about the future returns on fossil fuel investments, thereby reducing their volume. A decline would manifest in reduced supply and increased prices. However, other supply channels might lead to price decreases. For instance, producers might opt to expedite the exploitation of their reserves, resulting in increased supply and decreased fossil fuel prices. Similar effects – namely, increased investments and reduced costs – might also arise from technological innovations related to fossil fuels, such as carbon capture and storage.

So, renewable energy appears to be an important solution for European countries to gain energy independence and security and considering that, they should improve energy policies and implement renewable plans to accelerate their transition towards green powers.

In this work, we have provided an overview of energy dynamics in European countries focusing on their energy stocks in relation to renewable energy deployment. However, there is a potential for future research to extend our analysis to add other countries beyond Europe. In order to focus on different geopolitical contexts, we aim to provide a better understanding of global energy stocks and the energy transition landscape at the international level.

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Sommario

Dinamica delle scorte energetiche in Europa: un'analisi nel contesto della transizione energetica

Negli ultimi tempi, il crescente rischio energetico dei paesi dovuto alle tensioni geopolitiche internazionali ha accentuato le problematiche relative all'uso di combustibili fossili e le ripercussioni sulle economie hanno spinto verso una rapida transizione verso

fonti energetiche sostenibili come le rinnovabili. La produzione di energia da fonti rinnovabili è diventata una indubbia priorità, specialmente nei paesi avanzati come quelli europei che sono, ancora oggi, fortemente dipendenti dai combustibili fossili, nell'idea di attenuare il rischio energetico. Una maggiore produzione di energia rinnovabile dovrebbe consentire infatti all'economia europea di affrontare più agevolmente un rincaro dei prezzi energetici e una restrizione dell'offerta dei combustibili fossili. Tuttavia, le energie rinnovabili presentano anch'esse svantaggi, quali l'intermittenza nella produzione e il fabbisogno di materie prime necessarie per la costruzione degli impianti. Questo articolo si propone di analizzare il ruolo delle energie rinnovabili in Europa, studiando, attraverso un modello Probit, come le varie dinamiche energetiche dei paesi possano influenzare le riserve di energia dai vari paesi. I risultati mostrano che un incremento nell'uso di energie rinnovabili porta a ridurre le riserve energetiche, di contro una maggiore presenza nei mercati globali può aumentarle. Infine, basandosi sui risultati ottenuti, i paesi sono stati classificati in tre categorie secondo la loro tendenza a ridurre o meno le riserve energetiche.

Appendix

Table A.1 – Means, Maximum and Minimum Values for Each Variable for Each Country, 1992-2020

Country	*Stock Changes*			*RE Production*			*Energy Production*		
	Mean	*Min*	*Max*	*Mean*	*Min*	*Max*	*Mean*	*Min*	*Max*
Germany	35533.24	-299024.56	230432.07	889759.80	212248.20	1889790.86	5631431.57	4045733.32	7794023.35
United Kingdom	32111.97	-189247.91	505685.45	223079,62	42508,99	687714,96	8019592.47	4475511.6	11790263.1
France	-11157.87	-200575.33	111877.43	782264.38	628825.96	1055806.65	5473429.82	4684462.68	5819910.04
Italy	-3172.76	-192781.76	108653.60	628411.99	267144.20	1041004.5	1304292.75	1059992.10	1539343.67
Spain	-1470.39	-112848.62	146928.44	451452.99	213876.79	782052.62	1370295.01	1262357.83	1476089.45
Netherlands	-10158.01	-130001.61	79869.94	110159.18	31235.60	285080.4	2502314.30	1140495.89	3131350.43
Switzerland	5454.36	-8083.34	33920.87	186301.86	148891.66	222543.95	493938.67	428023.93	546670.34
Poland	-22646.66	-174511.70	107385.04	243028.85	56753.99	511632.02	3317894.88	2422563.99	4349069.12
Sweden	-975.15	-130211.99	85704.60	618617.40	460277.40	843279.82	1387885.65	1227354.37	1553774.74
Belgium	-2810.82	-38128.32	52077.03	63726.51	13626.99	160860.68	571013.93	449307.59	668976.98
Norway	-5813.92	-77460.81	87054.75	503857.47	417834.6	598466.83	8474639.51	5002329.67	9915020.44
Ireland	154.88	-35402.38	32082.92	22268.14	6472.88	65062.29	110821.51	53244.49	209159.47
Austria	-490.87	-106493.13	48323.23	314649.08	208927.20	423223.28	434727.35	340643.30	530130.61
Denmark	686.72	-60236.89	50851.56	99858.92	43192.80	167538.39	836706.95	385790.01	1308726.17
Romania	686.72	-56424.16	44198.21	186934.47	66291.60	255210.11	1209539.53	937327.64	1693785.98
Finland	13481.56	-96320.47	86167.02	348173.19	212674.80	481268.64	665241.38	467634.47	822591.19
Czech Republic	3663.24	-57943.72	76867.1	112152.82	47757.60	207227.28	1345075.91	991379.58	1723507.64
Portugal	-39.65	-20675.7	36688.47	182488.86	119287.40	248591.90	186882.37	123080.42	254419.45
Greece	-1511.89	-44166.38	80826.56	76185.11	46249.60	118028.34	381334.85	190709.95	438622.11
Hungary	-5629.39	-112442.57	55202.35	76032.36	33065.80	138750.96	499688.54	428578.15	614946.28

Country	*Energy Consumption*			*Energy Imports*			*Energy Exports*		
	Mean	*Min*	*Max*	*Mean*	*Min*	*Max*	*Mean*	*Min*	*Max*
Germany	9616169.22	8955070.99	10135123.5	9964868.57	7919295.25	11216628	1511259.9	710480.72	2540401.8
United Kingdom	5807995.05	4774851.22	6341465.98	4881078.31	3104474.73	6971992.56	3885570.34	2724007.82	5421132.12
France	6563809,61	5777900	7064125.17	6554297.00	5339183.53	7521777.14	1229611.23	837947.30	1597543.16
Italy	5246566.60	4498109.71	5915407.07	6784612.46	5485335.58	8044942.00	1068024.79	729799.49	1396980.02
Spain	3455625.24	2544476.15	4266733.92	4661820.36	3048456.62	5720997.07	690293.11	297735.99	1364112.66
Netherlands	2477465.78	2256918.86	2732261.54	6216008.06	4224289.29	8625565.11	4903683.55	3480540.25	6728642.18
Switzerland	801591.571	720001.98	860696.83	739525.93	622273.34	816843.38	131700.77	89426.68	155482.19
Poland	2745054.45	2397955.33	3288439.32	1611228.10	859578.28	2685069.76	796306.88	534684.20	997873.19
Sweden	1422507.98	1329976.47	1542490	1325529.89	1128871.98	1528932.62	552312.85	386824.74	879647.40
Belgium	1663156.63	1349099.61	1789743.39	3168257.77	2536660.13	3677122.83	1118945.44	818630.14	1591070.99
Norway	831533.29	713074.75	892610.18	294733.26	189065.29	486669.92	7584920.65	4228435.85	8989083.78
Ireland	430105.84	315729.31	527161.21	521790.81	318495.04	651536.89	56365.67	29223.38	84344.58
Austria	1052063.49	827662.7	1173748.57	1103656.98	778687.09	1376803.65	226950.78	50892.09	580660
Denmark	595417.28	544055.92	633771.08	682594.19	554451.77	790773.02	678043.2	301536.05	1019341.73
Romania	622981.56	428061.04	1140236.95	622981.56	428061.04	1140236.95	190878.44	97066.80	268182.39
Finland	1028966.93	924270.43	1114229.47	1010840.6	818682.39	1199666.3	269816.70	72406.69	427749.99
Czech Republic	1134482.02	1054246.48	1380791.49	835274.10	640385.40	1003808.03	357424.49	231256.94	610281.28
Portugal	722629.43	560793.61	856631.20	961445.60	721658.89	1165965.91	160392.93	70342.80	335110.89
Greece	736263.40	606827.97	913908.24	1215049.63	836994.25	1630832.22	384446.08	139887.56	860732.97
Hungary	776817.49	712677.17	866180.12	772270.39	532831.37	1219840.96	167677.61	51796.30	440835.93

Source: Authors' elaborations

The Conference of the Italian Regional Science Association (AISRe), held in September 2023 in Naples, allowed scholars and policy makers to debate on the global issue of conflicts and transitions that are involving many regional economies worldwide, especially in the Euro-Mediterranean area. This book, collecting some contributions that were presented during the conference, aims at increasing the understanding of how regions are navigating and responding to the complex array of challenges they face in a rapidly changing world. The book considers a broad specification of conflicts that are closely related to the idea of exogenous shocks and consequent transitions interpreted as adaptation strategies to those shocks. The book is structured in two parts. The first part presents seven papers dealing with ‘conflicts’ of different nature such as regional disparities and cohesion, respect of law and social norms, occupational safety and health, urban congestion, gendered sectoral segregation, natural disasters. The second part of this book presents eight papers focuses on different types of ‘transitions’ related, for example, to climate change and environment, energy, digitalization and innovation. The book, even if does not cover all global conflicts and local responses comprehensively, however it provides useful insights to the debate on how regions are confronting the profound and often unexpected changes brought about by disruptive challenges.

Marco Modica *is Associate Professor in Applied Economics at the GSSI. He is deputy coordinator of the Ph.D. program in Regional Science and Economic Geography at the GSSI and member of the teaching committee of the Ph. D program Natural Hazard and Disaster Risk Reduction held by the Consortium REDI. He is Associate Editor of Humanities and Social Sciences Communications edited by Springer Nature and Heliyon edited by Elsevier.*

Davide Piacentino *is Full Professor of Economic Statistics at the University of Palermo. He has been visiting scholar at University of Strathclyde and University of Sussex. He has published papers in leading journals such as Regional Studies, Spatial Economic Analysis, Papers in Regional Science, Geographical Analysis, Technological Forecasting & Social Change, Population Space and Place, Journal of Technology Transfer.*

FrancoAngeli
La passione per le conoscenze