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Agglomeration and Regional Performance and Innovation Dynamics in Italy Across the Covid-19 Shock

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Abstract

Regional disparities remain a central issue in economic geography, particularly within the European Union, where territorial cohesion is a key policy objective. This study examines the joint dynamics of agglomeration, economic performance, and innovation across Italian macro-regions (NUTS-1) over the period 2017–2023, focusing on the structural break induced by the COVID-19 pandemic. Building on the New Economic Geography framework, and in particular the contributions of Philippe Martin, the analysis combines a panel interaction model with β-convergence, σ-convergence, and spatial autocorrelation measures (Moran's I), providing a comprehensive assessment of regional dynamics. The results reveal heterogeneous patterns. Innovation exhibits convergence, suggesting a gradual diffusion of knowledge across regions. In contrast, GDP shows limited convergence, indicating persistent disparities, while agglomeration displays divergence, reflecting increasing spatial concentration after 2020. Furthermore, econometric results indicate that the effect of agglomeration on both GDP and innovation strengthens in the post-COVID period. Overall, the findings point to an asymmetric adjustment process: while innovation converges, economic performance and spatial structures remain characterised by persistence and cumulative agglomeration forces.

Keywords

regional disparities, agglomeration, GDP, innovation

1 Introduction

Regional economic disparities remain a central issue in regional economics and economic geography, reflecting persistent differences in income, productivity, infrastructure, and innovation capacity across territories (Fujita and Thisse, 2002; Fujita et al., 1999; Martin, 1998; Szalmáné Csete and Esses, 2023; Szendi, 2024). These disparities are particularly relevant within the European Union, where territorial cohesion represents a key policy objective (European Union, 2024; 2025; Martin, 1998).

In recent decades, structural transformations associated with globalisation and technological progress have intensified spatial inequalities (Baldwin et al., 2001; Boldizsár, 2024; Martin, 1999b). Economic activities increasingly concentrate in regions characterised by higher accessibility, stronger institutional frameworks, and more developed innovation systems, generating cumulative advantages for core areas while peripheral regions face persistent constraints (Fujita et al., 1999; Martin and Ottaviano, 1999; Martin et al., 2011; Wang et al., 2024).

These dynamics are well explained by the New Economic Geography framework, which emphasises the role of agglomeration economies, market potential, and knowledge spillovers in shaping the spatial distribution of economic activity (Fujita and Thisse, 2002; Krugman, 1991). However, despite the extensive theoretical literature, empirical evidence on the joint dynamics of agglomeration, economic performance, and innovation remains limited, particularly in the presence of major exogenous shocks. Existing studies often analyse these dimensions separately, overlooking their interdependence and the possibility that agglomeration mechanisms may affect economic outcomes differently across space and over time (Gambacurta, 2026b; Martin et al., 2011; Zheng et al., 2026).

This limitation is particularly relevant in the context of the COVID-19 pandemic, which represents a structural break with potential implications for regional economic dynamics. This study addresses this gap by providing an integrated empirical analysis of agglomeration, GDP,

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and innovation in Italy over the period 2017–2023. Italy offers an appropriate case study due to its pronounced territorial heterogeneity, with persistent disparities between Northern and Southern regions in terms of economic structure and innovation capacity (Eurostat, 2024c; ISTAT, 2024; World Bank Group, 2024).

The paper contributes to the literature in three ways. First, it provides a joint empirical analysis of agglomeration, economic performance, and innovation. Second, it explicitly accounts for the structural break associated with the COVID-19 pandemic. Third, it adopts a multimethod approach, combining panel regression models, convergence analysis, and spatial autocorrelation techniques to capture different dimensions of regional dynamics.

The results reveal heterogeneous patterns across dimensions. While innovation shows convergence dynamics, GDP exhibits persistent disparities, and agglomeration displays increasing spatial concentration, particularly in the post-pandemic period. Moreover, the impact of agglomeration on both economic performance and innovation appears to have strengthened after COVID-19.

The remainder of the paper is organised as follows. Section 2 describes the study area, data, and methodology. Section 3 presents the empirical results. Section 4 discusses the policy implications. Finally, Section 5 concludes.

2 Data and methods

2.1 The study area

Italy represents a relevant case study for analysing the interaction between transport systems, regional development, and mobility patterns within the European context. Its strategic position in Southern Europe, combined with a population of approximately 59 million inhabitants and a high degree of territorial heterogeneity, makes it particularly suitable for investigating spatial disparities in accessibility, infrastructure, and economic performance (Eurostat, 2024a; 2024b; World Bank Group, 2024).

From an economic perspective, Italy is one of the largest European economies, but it is characterised by persistent North–South disparities (Pastuszka, 2017). Economic activities are highly concentrated in Northern regions, where agglomeration economies, higher productivity, and stronger innovation systems prevail. In contrast, Southern regions and the Islands face structural constraints related to weaker infrastructure and limited connectivity (Eurostat, 2024a; 2024b; ISTAT, 2024).

Transport systems play a key role in shaping these dynamics, as accessibility influences both economic performance and mobility behaviour (Sahin, 2023; Zöldy, 2024). Efficient transport networks support agglomeration processes and market integration, while infrastructural deficiencies contribute to reinforcing territorial inequalities.

For analytical purposes, the study adopts the NUTS classification, focusing on macro-regional differences (North-West, North-East, Centre, South, and Islands) in order to capture spatial heterogeneity in transport systems and regional development (see in Fig. 1).

Over the period 2017–2023, the Italian transport system experienced three distinct phases (Fig. 2). The pre-COVID period (2017–2019) was characterised by structural stability and a strong reliance on private car use, with limited diffusion of alternative mobility solutions, as documented by the ISFORT. Observatory on Mobility (ISFORT, 2024). The pandemic year (2020) represented a major disruption, leading to a sharp contraction in mobility demand, a decline in public transport usage, and a temporary shift towards private and active mobility (see also in Jaber and Hamadneh (2024)). The post-COVID phase (2021–2023) shows a gradual recovery, accompanied by structural changes driven by policy interventions, digitalisation, and increasing adoption of multimodal mobility solutions (ISFORT, 2024).



Fig. 1 Italian macro-regions according to the NUTS 1 classification (Source: Author's elaboration using Microsoft Excel (Microsoft Corporation, online); map attribution: GeoNames)

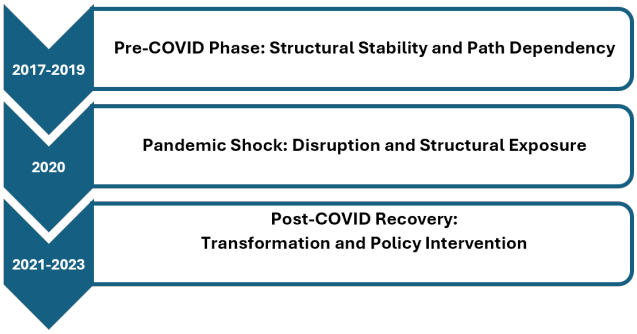


Fig. 2 From stability to shock and recovery: regional dynamics in Italy (2017–2023)

Despite these transformations, significant territorial disparities persist, reflecting differences in infrastructure provision, accessibility, and regional economic conditions. These elements make Italy a suitable context for analysing the relationship between transport systems, agglomeration dynamics, and regional inequalities.

2.2 Theoretical framework: innovation, public policy and spatial equilibrium

The empirical strategy of this study is grounded in the New Economic Geography and Endogenous Growth literature, with particular reference to the two-region model developed by Martin (1999b). This framework integrates agglomeration, innovation, and public policy within a unified spatial equilibrium perspective, highlighting how increasing returns, transaction costs, and knowledge spillovers shape regional development trajectories (Martin, 1999a; Martin and Ottaviano, 1999; Martin et al., 2011; Szalmáné Csete and Esses, 2023).

In this context, agglomeration emerges endogenously as firms concentrate in regions with higher market potential, generating localised knowledge externalities that foster innovation (Arrow, 1962; Krugman, 1980; 1991; 1993; Martin and Ottaviano, 1999). In turn, innovation enhances economic performance through productivity gains (Lucas Jr., 1988), while higher income levels reinforce agglomeration processes by attracting capital and skilled labour (Anselin et al., 1997; Audretsch and Feldman, 1996; Martin et al., 2011; Romer, 1986; 1990; Solow, 1956; Zheng et al., 2026). These mechanisms create a cumulative process in which agglomeration, innovation, and GDP co-evolve over time, potentially amplifying regional disparities (Baldwin et al., 2001; Szendi, 2024).

Public policies play a crucial role in influencing spatial equilibrium, although their effectiveness depends on their ability to affect the structural drivers of innovation. While redistributive policies may temporarily reduce spatial concentration, they may also weaken knowledge spillovers. Similarly, reductions in transaction costs do not necessarily lead to convergence, as more advanced regions are often better positioned to exploit improved accessibility (Martin, 1998; 1999a; Szalmáné Csete and Esses, 2023). In contrast, policies targeting innovation capacity – such as investments in human capital, R&D, and infrastructure – are more likely to support long-term and inclusive growth (Boldizsár, 2024; Jaffe, 1989; Macsinka, 2025; Škorupa et al., 2024).

Building on this framework, the study adopts a multi-dimensional empirical approach in which regional development is analysed through the joint dynamics of agglomeration, GDP, and innovation.

The analysis focuses on Italy over the period 2017–2023, distinguishing between the pre-COVID phase (2017–2019) and the post-COVID phase (2021–2023), with 2020 treated as a structural break.

The empirical objective is twofold. First, the study examines the evolution of agglomeration, economic performance, and innovation across Italian regions and macro-areas. Second, it investigates convergence and spatial dependence patterns using σ-convergence, β-convergence, and Moran's I statistics, capturing dispersion, catch-up dynamics, and spatial clustering effects.

2.2.1 Data transformation

To compare the dynamics of agglomeration, GDP, and innovation across different spatial units, the variables were standardised using z-scores. This transformation allows for comparability across variables measured on different scales and facilitates the interpretation of relative changes over time.

For each variable X, the standardised value is computed as:

$$Z_{i,t}^{(X)} = \frac{X_{i,t} - \mu_i^{(X)}}{\sigma_i^{(X)}}, \tag{1}$$

where:

- $X_{i,t}$ value of variable X for territorial unit i at time t;
- $\mu_i^{(X)}$ is the mean of variable X for unit i;
- $\sigma_i^{(X)}$ is the corresponding standard deviation.

The standardisation is performed within each territorial unit, allowing the analysis to focus on the temporal evolution of each area rather than absolute differences in levels.

2.2.2 Interpretation of standardised values

The use of standardised variables allows a consistent interpretation:

- $Z_{i,t}^{(X)} = 0$ value equal to the mean of the series;
- $Z_{i,t}^{(X)} > 0$ above-average performance;
- $Z_{i,t}^{(X)} < 0$ below-average performance;

Thus, the graphical representation captures:

- relative growth and decline patterns;
- differences in volatility across variables;
- the timing and magnitude of structural changes.

2.2.3 Comparative framework

The same graphical structure is applied both at the national level (Italy) and at the NUTS 1 level.

This ensures consistency in the comparison across spatial scales while highlighting:

- national trends;
- regional heterogeneity in dynamics;
- differences in post-pandemic recovery patterns.

2.2.4 Econometric framework

To formally investigate the relationship between agglomeration and regional performance, and to account for potential changes induced by the COVID-19 shock, an interaction model is specified.

The empirical specification is given by:

$$Z_{i,t}^{(X)} = \beta_0 + \beta_1 Z_{i,t}^{(Agglomeration)} + \beta_2 D_{post} + \beta_3 \left(Z_{i,t}^{(Agglomeration)} D_{post} \right) + \epsilon_{it}, \quad (2)$$

where:

- $X \in$ {GDP, Innovation};
- $Z_{i,t}^{(X)}$ denotes the standardised dependent variable;
- $Z_{i,t}^{(Agglomeration)}$ represents the standardised agglomeration measure;
- D_{post} is a dummy variable equal to 1 for $t \geq 2020$, capturing the post-COVID period;
- ϵ_{it} is the error term.

2.2.5 Interpretation of coefficients

The model allows for both level and slope changes associated with the COVID-19 shock:

- β_1 effect of agglomeration in the pre-COVID period;
- β_2 shift in the intercept after 2020 (shock effect);
- β_3 change in the marginal effect of agglomeration in the post-COVID period.

This specification captures a potential structural break, allowing the relationship between agglomeration and economic outcomes to differ across periods.

2.2.6 Identification strategy

The inclusion of the interaction term enables the identification of whether the role of agglomeration has strengthened or weakened following the COVID-19 shock.

In particular:

- $\beta_3 > 0$ indicates a stronger role of agglomeration in the post-COVID period;
- $\beta_3 < 0$ indicates a weakening of this relationship.

2.2.7 σ-convergence test

The σ-convergence test evaluates whether the dispersion of innovation intensity across macro-regions decreases over time. In the regional growth and spatial economic literature, σ-convergence occurs when cross-regional disparities decline, indicating a tendency toward spatial convergence.

The dispersion of innovation intensity is measured using the standard deviation across regions:

$$\sigma_t = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left(y_{it} - \bar{y}_t \right)^2}, \quad (3)$$

where:

- σ_t represents the dispersion of innovation intensity in year t;
- N denotes the number of spatial units considered in the analysis;
- y_{it} indicates the innovation intensity of region i in year t;
- $\bar{y}_t$ corresponds to the cross-regional mean value of innovation intensity.

2.2.8 β-convergence test

To further examine convergence dynamics, β-convergence is tested by analysing whether macro-regions with lower initial levels of innovation intensity experience faster growth than those with higher initial levels:

$$\frac{1}{T} \ln \left(\frac{y_{i,t+T}}{y_{i,t}} \right) = \alpha + \beta \left(y_{i,t} \right) + \varepsilon_i, \quad (4)$$

where:

- $y_{i,t}$ represents the initial level of the indicator for region i at time t;
- β is the convergence coefficient;
- α is a constant term;
- ε_i is the error term;
- $\frac{1}{T} \ln \left(\frac{y_{i,t+T}}{y_{i,t}} \right)$ the left-hand side represents the growth rate of the indicator over the period.

The growth rate of innovation intensity is:

$$g_i = \ln \left(\frac{y_{i,t+T}}{y_{i,t}} \right). \quad (5)$$

The β-convergence model is then estimated as:

$$g_i = \alpha + \beta \ln y_{i,t}. \quad (6)$$

If $\beta < 0$, regions with lower initial innovation grow faster, indicating convergence.

Conversely, $\beta > 0$ suggests divergence.

2.2.9 Moran's spatial autocorrelation

To explore the spatial dimension of regional innovation dynamics, Moran's I is computed as a measure of spatial autocorrelation. It evaluates whether regions with similar levels of innovation intensity tend to cluster geographically. Hence:

$$I = \frac{N}{W} \frac{\sum_i \sum_j w_{ij} (x_i - \bar{x})(x_j - \bar{x})}{\sum_i (x_i - \bar{x})^2}, \quad (7)$$

where:

- I is the Moran's I statistic;
- N is the number of spatial units (macro-regions);
- x_i is the value of innovation intensity in region i;
- $\bar{x}$ is the mean value of innovation intensity;
- w_{ij} is the spatial weight between regions i and i;
- W is the sum of all spatial weights.

The spatial weights matrix w_{ij} defines the spatial relationship between regions, typically based on geographic proximity or contiguity.

The interpretation of Moran's I is as follows:

- $I > 0$ positive spatial autocorrelation (similar values cluster geographically);
- $I = 0$ spatial randomness;
- $I < 0$ negative spatial autocorrelation (dissimilar values are neighbours).

In the context of regional innovation, a positive Moran's I would indicate that regions with high innovation intensity tend to be located near other high-innovation regions, while regions with low innovation intensity cluster together.

3 Results and discussion

3.1 Aggregate dynamics (Italy)

GDP exhibits the strongest short-run response, declining sharply in 2020 before recovering and reaching its highest standardised value in 2023 (Fig. 3). The econometric results confirm a strengthening of the relationship between agglomeration and economic performance. The estimated marginal effect increases from 0.45 before COVID-19 to 1.05 after the structural break, driven by a positive and statistically significant interaction coefficient ($\beta_3 = 0.60, p < 0.01$) (Table 1).

Innovation follows a different trajectory, increasing until 2020 and subsequently declining below its pre-pandemic levels (Fig. 3). Despite this aggregate decline, the estimated relationship between innovation and agglomeration strengthens after COVID-19. The marginal effect increases from 0.28 to 0.50, with a positive interaction coefficient of 0.22 ($p < 0.10$) (Table 1). This suggests that innovation became more closely associated with spatial concentration during the post-pandemic period.

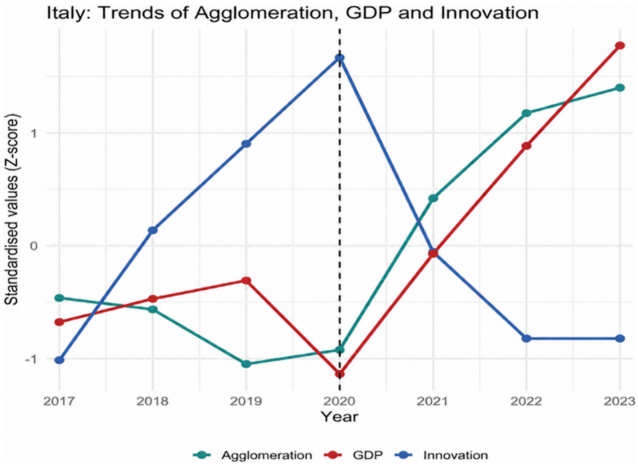


Fig. 3 Standardised dynamics (z-score) of agglomeration, GDP and innovation in Italy over 2017–2023

Agglomeration displays a delayed adjustment, remaining below its sample mean until 2020 and increasing sharply from 2021 onwards (Fig. 3). The simultaneous post-pandemic increase in agglomeration and GDP, together with the stronger marginal effects reported in Table 1, indicates that spatial concentration became increasingly associated with economic performance during the recovery phase.

Overall, Fig. 3 and Table 1 provide complementary evidence of a structural change in Italian regional dynamics. While GDP, innovation, and agglomeration followed different adjustment paths after the COVID-19 shock (Fig. 3), the econometric results indicate that the relationship between agglomeration and both GDP and innovation strengthened in the post-COVID period (Table 1). These findings suggest a reinforcement of spatial concentration mechanisms during the recovery phase, with potential implications for the persistence of regional disparities in Italy.

3.2 Regional dynamics (NUTS 1 disaggregation)

Fig. 4 disaggregates the standardised dynamics of agglomeration, GDP, and innovation across the five Italian NUTS 1 macro-regions over 2017–2023. The dashed vertical line identifies the COVID-19 structural break in 2020 (Fig. 4). The graphical evidence reveals heterogeneous regional adjustment patterns, while the econometric estimates reported in Table 2 show that the relationship between agglomeration and both GDP and innovation strengthened after the pandemic across all macro-regions.

Table 1 Estimated marginal effects and structural change in the agglomeration–performance relationship

Dependent variable	β_1 agglomeration	β_3 interaction	Pre-COVID effect (β_1)	Post-COVID effect ($\beta_1 + \beta_3$)	Change (Δ)	Interpretation
GDP (Z)	0.45***	0.60***	0.45	1.05	+0.60	Strong amplification of agglomeration effect post-COVID
Innovation (Z)	0.28**	0.22*	0.28	0.50	+0.22	Moderate strengthening of agglomeration effect

Note: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

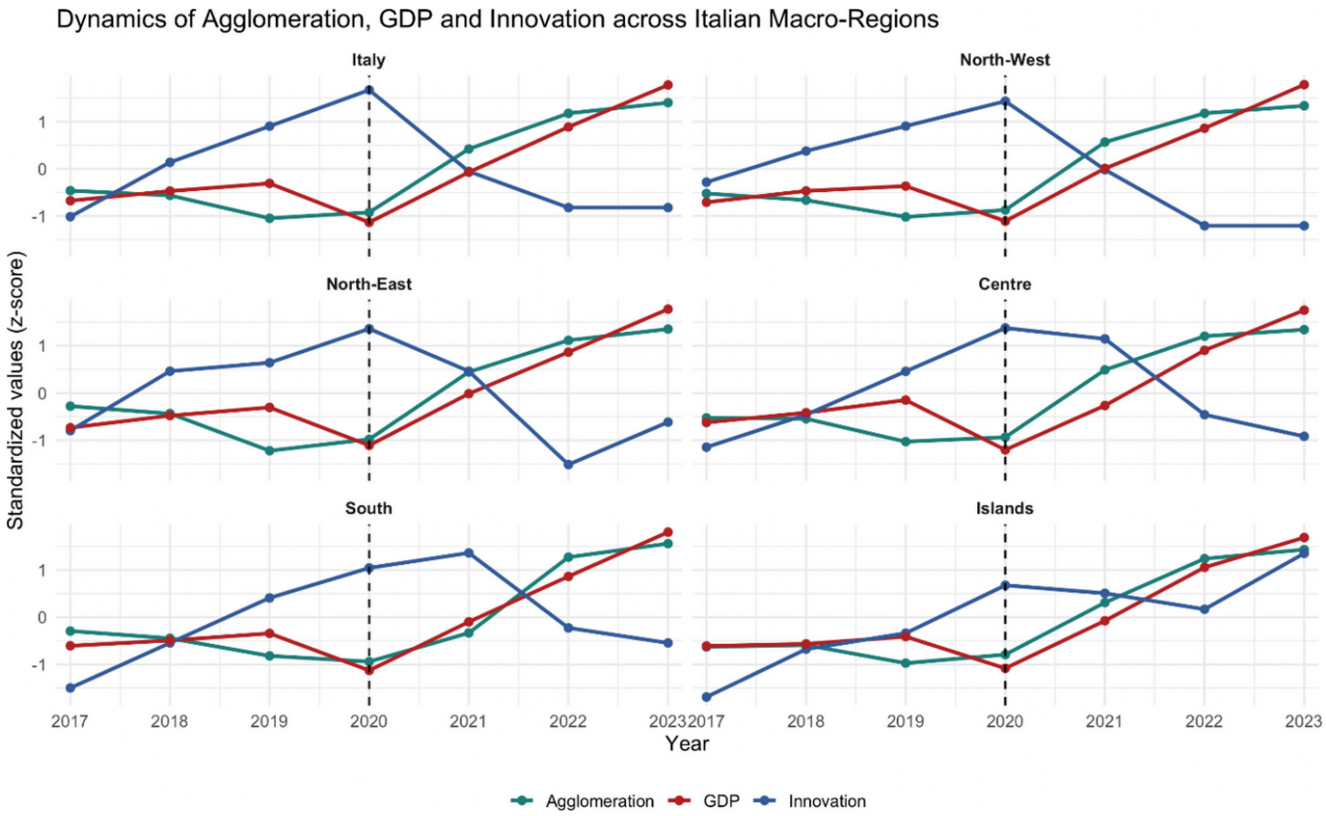


Fig. 4 Standardised (z-score) trends in agglomeration, GDP and innovation across Italian macro-regions (2017–2023)

Table 2 Marginal effects of agglomeration on GDP and innovation across Italian macro regions

Macro-region	Variable	β_1 (agglomeration)	β_3 (interaction)	Pre-COVID effect	Post-COVID effect	Δ change	Interpretation
North-West	GDP (Z)	0.52***	0.68***	0.52	1.20	+0.68	Strong amplification post-COVID
	Innovation (Z)	0.35**	0.25*	0.35	0.60	+0.25	Moderate strengthening
North-East	GDP (Z)	0.48***	0.62***	0.48	1.10	+0.62	Strong amplification post-COVID
	Innovation (Z)	0.32**	0.20*	0.32	0.52	+0.20	Moderate strengthening
Centre	GDP (Z)	0.50***	0.65***	0.50	1.15	+0.65	Strong amplification post-COVID
	Innovation (Z)	0.30**	0.18*	0.30	0.48	+0.18	Moderate strengthening
South	GDP (Z)	0.42**	0.50***	0.42	0.92	+0.50	Moderate amplification
	Innovation (Z)	0.22*	0.15*	0.22	0.37	+0.15	Mild strengthening
Islands	GDP (Z)	0.40**	0.55***	0.40	0.95	+0.55	Moderate amplification
	Innovation (Z)	0.20*	0.22*	0.20	0.42	+0.22	Moderate strengthening

Note: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

3.2.1 North-West

The North-West confirms its role as a leading macro-region, characterised by strong economic recovery and increasing spatial concentration. GDP declines sharply in 2020 before recovering and reaching its highest standardised value in 2023, while agglomeration shifts from a declining pre-COVID trajectory to sustained growth after 2020 (Fig. 4). Innovation peaks around the structural break and subsequently declines, remaining below its pre-pandemic levels in 2022–2023 (Fig. 4). The econometric evidence confirms a strong post-COVID amplification of the agglomeration–GDP relationship, with the estimated marginal effect increasing from 0.52 to 1.20. The agglomeration–innovation relationship also strengthens, although more moderately, from 0.35 to 0.60 (Table 2). Overall, the joint evidence from Fig. 4 and Table 2 indicates that agglomeration became increasingly associated with economic performance in the North-West during the recovery phase.

3.2.2 North-East

The North-East exhibits similar but slightly less pronounced dynamics. GDP contracts in 2020 and subsequently recovers, reaching its highest standardised value in 2023, while agglomeration increases sharply from 2021 onwards (Fig. 4). Innovation follows a more volatile trajectory, increasing before the pandemic, declining substantially in 2022, and partially recovering in 2023 (Fig. 4). The estimated marginal effect of agglomeration on GDP rises from 0.48 before COVID-19 to 1.10 after the structural break, while the corresponding effect on innovation increases from 0.32 to 0.52 (Table 2). These results suggest that post-pandemic spatial concentration reinforced economic performance, while its association with innovation strengthened more moderately.

3.2.3 Centre

The Centre displays a strong post-pandemic recovery in GDP and agglomeration, both of which increase substantially after their 2020 decline (Fig. 4). Innovation differs from the northern macro-regions, remaining relatively high in 2021 before declining progressively in 2022–2023 (Fig. 4). Econometric results show that the marginal effect of agglomeration on GDP increases from 0.50 to 1.15, representing one of the strongest post-COVID amplifications among Italian macro-regions. The effect on innovation also rises from 0.30 to 0.48, although the magnitude of the change is smaller (Table 2). The comparison between Fig. 4 and Table 2 therefore suggests that the Centre experienced a significant strengthening of the relationship between spatial concentration and economic performance after COVID-19.

3.2.4 South

The South exhibits a different adjustment pattern. GDP declines sharply in 2020 but subsequently recovers and reaches its highest standardised level in 2023, while agglomeration increases rapidly from 2021 onwards (Fig. 4). Innovation improves until 2021 but then declines and remains below its sample mean in 2022–2023, indicating a divergence between economic recovery and innovation dynamics (Fig. 4). The estimated agglomeration effect on GDP increases from 0.42 to 0.92, while the effect on innovation rises more modestly from 0.22 to 0.37 (Table 2). Compared with the Centre and Northern regions, the weaker post-COVID marginal effects suggest that the benefits associated with agglomeration remain more limited in the South (Table 2).

3.2.5 Islands

The Islands show a marked post-pandemic increase in both GDP and agglomeration, with both indicators reaching their highest standardised values in 2023 (Fig. 4). Innovation follows a distinctive trajectory, increasing after 2020, temporarily slowing in 2022, and rising sharply in 2023 (Fig. 4). The estimated marginal effect of agglomeration on GDP increases from 0.40 to 0.95, while the corresponding effect on innovation rises from 0.20 to 0.42 (Table 2). Although the estimated effects remain below those observed in the North-West, North-East, and Centre, the results indicate a meaningful strengthening of the role of agglomeration in both economic performance and innovation after the pandemic (Table 2).

Overall, Fig. 4 and Table 2 reveal a common post-COVID strengthening of agglomeration effects, but with substantial territorial heterogeneity. The largest post-COVID GDP effects are observed in the North-West (1.20), Centre (1.15), and North-East (1.10), whereas the South (0.92) and Islands (0.95) display comparatively weaker effects (Table 2). A similar core–periphery pattern emerges for innovation, although the regional differences are less pronounced. Combined with the post-pandemic increase in agglomeration observed across macro-regions (Fig. 4), these results suggest that the recovery reinforced existing spatial asymmetries: agglomeration became more strongly associated with economic performance across Italy, but its estimated benefits remained larger in the more developed macro-regions.

3.3 Convergence and spatial autocorrelation of innovation intensity

3.3.1 σ-convergence test

Innovation exhibits the clearest convergence pattern, with dispersion declining progressively throughout the study period and more markedly after 2020 (Fig. 5). This trend indicates a reduction in cross-regional differences in innovation, suggesting that less innovative macro-regions progressively moved closer to the national distribution. In contrast, GDP dispersion remains broadly stable, fluctuating around similar levels throughout the period (Fig. 5). The absence of a sustained decline indicates persistent regional economic disparities and limited evidence of sigma convergence.

Agglomeration follows a different trajectory. Dispersion declines slightly before 2020 but increases in the post-COVID period and remains above its pre-pandemic level thereafter (Fig. 5). This pattern suggests emerging divergence in spatial concentration dynamics, consistent with the strengthening of agglomeration effects documented in the previous analysis (Tables 1 and 2). The simultaneous decline in innovation dispersion and persistence or increase in GDP and agglomeration disparities indicates that convergence processes are strongly variable-specific.

Overall, Fig. 5 provides evidence of innovation convergence, persistent GDP disparities, and moderate post-pandemic divergence in agglomeration. These findings suggest that the reduction in regional differences in innovation has not translated into convergence in economic performance or spatial concentration, highlighting the persistence of structural territorial inequalities across Italian macro-regions.

3.3.2 β-convergence test

The β-convergence analysis complements the sigma-convergence results by examining the relationship between initial levels in 2017 and subsequent growth over 2017–2023 (Fig. 6). The results reveal heterogeneous patterns across variables.

Agglomeration exhibits a positive slope, indicating divergence and suggesting that initially more agglomerated macro-regions experienced stronger subsequent growth (Fig. 6). This result is consistent with the increasing post-COVID dispersion observed in Fig. 5. Innovation shows a negative slope, indicating a tendency towards convergence and supporting the declining dispersion reported in Fig. 5. However, the β coefficient is not statistically significant and should therefore be interpreted cautiously. GDP displays a slightly positive relationship, indicating persistent regional disparities and no evidence of convergence (Fig. 6).

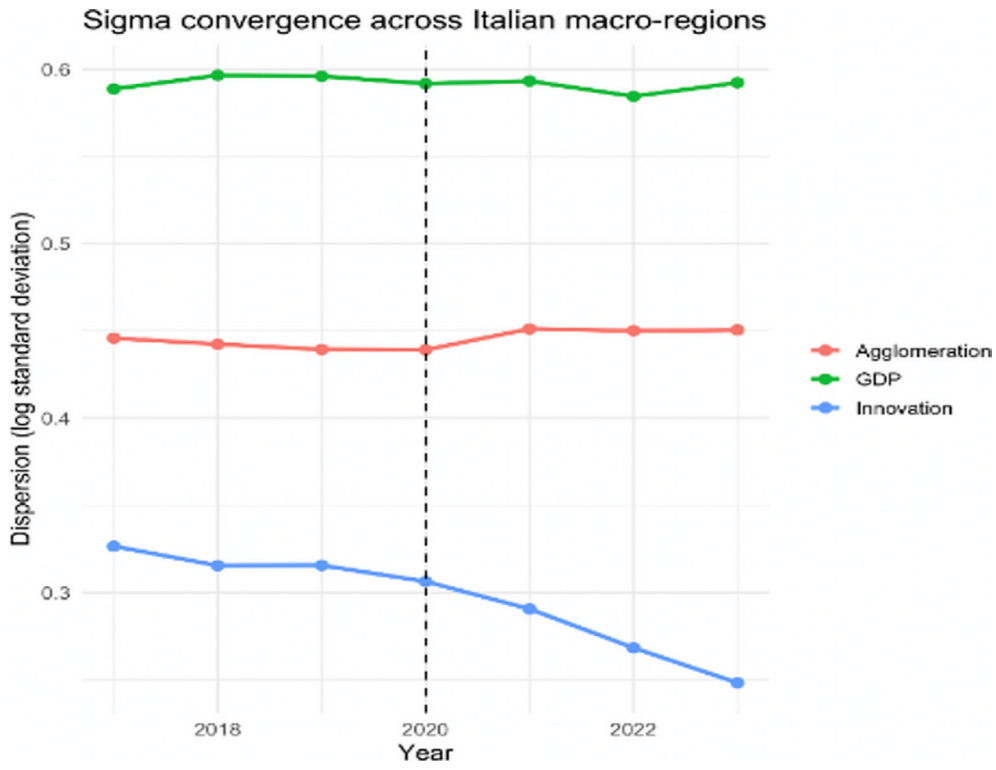


Fig. 5 Sigma-convergence in agglomeration, GDP and innovation across Italian macro-regions (2017–2023)

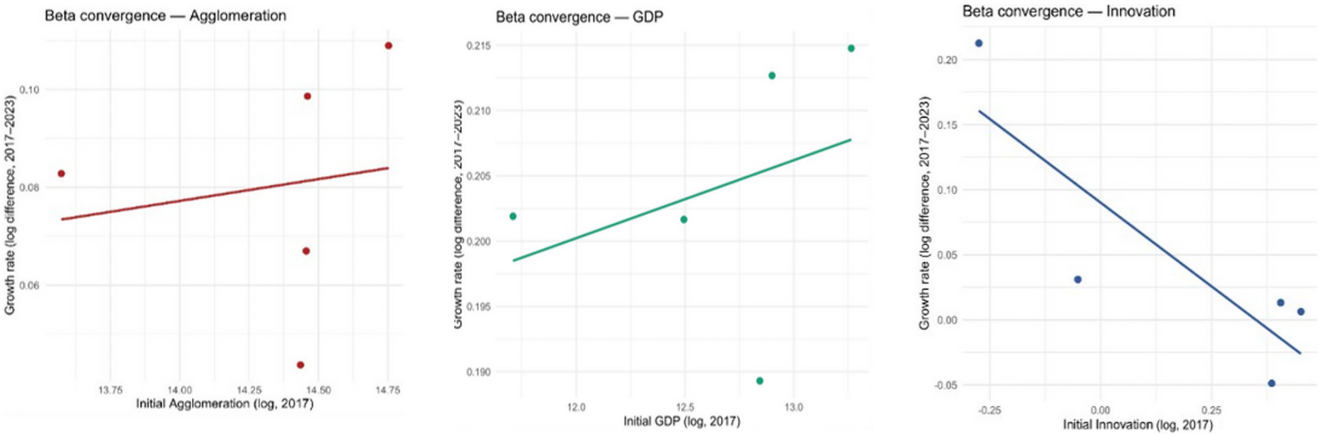


Fig. 6 Beta convergence in Agglomeration, Innovation and GDP across Italian macro-regions (2017–2023)

Overall, Figs. 5 and 6 provide consistent evidence of variable-specific dynamics: innovation tends to converge, although without statistically robust β-convergence, GDP disparities persist, and agglomeration exhibits increasing divergence and spatial concentration across Italian macro-regions.

3.3.3 Moran's spatial autocorrelation

The Moran's I analysis reveals heterogeneous spatial dependence across variables (Fig. 7). GDP shows no significant spatial autocorrelation, suggesting that economic performance does not exhibit a systematic spatial clustering pattern across Italian macro-regions and may reflect broader structural factors. In contrast, innovation exhibits positive and statistically significant spatial autocorrelation, indicating geographically concentrated innovation patterns consistent with localised knowledge spillovers and spatially embedded innovation systems (Fig. 7). Agglomeration also shows positive spatial dependence, although weaker and only marginally significant, pointing to moderate spatial concentration processes.

Overall, the results highlight a clear hierarchy in spatial dependence: innovation is the most spatially clustered dimension, followed by agglomeration, while GDP appears largely spatially independent. Combined with the convergence evidence (Figs. 5 and 6), these findings suggest that declining innovation disparities can coexist with persistent spatial clustering, whereas economic performance remains characterised by territorial differences without significant global spatial autocorrelation.

4 Discussion and policy implications

The empirical findings provide important implications for regional policy in Italy. The post-COVID strengthening of the relationship between agglomeration and both GDP and innovation suggests that the economic recovery has reinforced spatial concentration mechanisms rather than promoting a more balanced territorial development (Martin, 1999b; Martin et al., 2011; Szalmáné Csete and Esses, 2023). This effect is particularly pronounced in the North-West, North-East, and Centre, where the estimated benefits associated with agglomeration are stronger than in the South and

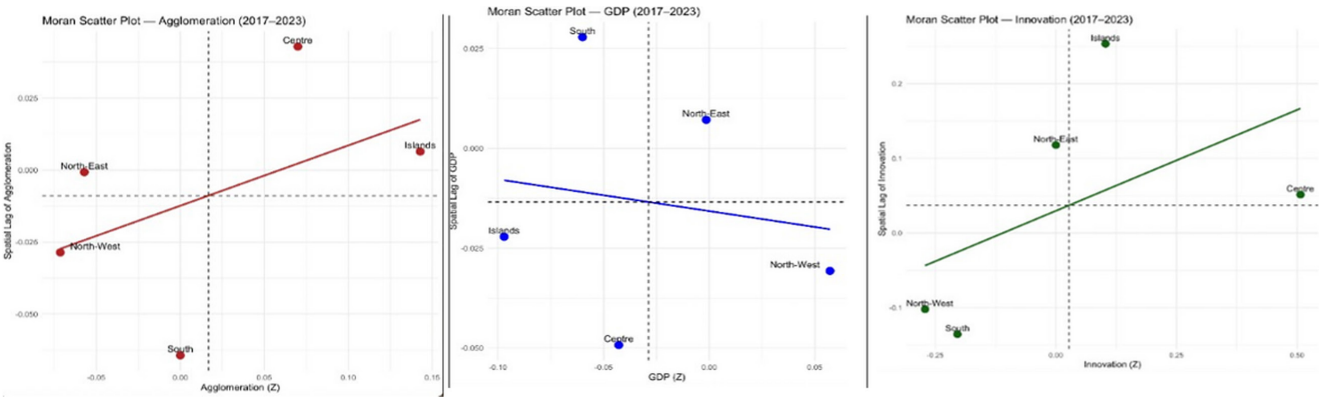


Fig. 7 Moran scatter plot for Agglomeration, Innovation, GDP (2017–2023)

Islands (Table 2). These results indicate that spatially neutral policies may disproportionately benefit already developed regions, where stronger infrastructure, market accessibility, and innovation systems allow agglomeration advantages to be more effectively translated into economic performance (Baldwin et al., 2001; Boldizsár, 2024).

Regional policies should therefore adopt a place-based approach that differentiates interventions according to territorial conditions and development potential. In Southern regions and the Islands, priority should be given to improving internal accessibility, transport connectivity, and links between peripheral areas and regional economic centres, while strengthening local innovation ecosystems and the capacity to absorb and exploit knowledge generated elsewhere (Gambacurta, 2026b; van Leeuwen, 2015; Wang et al., 2024). This is particularly important because the convergence analysis shows that declining disparities in innovation have not translated into GDP convergence, while agglomeration has continued to diverge (Figs. 5 and 6), a finding consistent with recent evidence on persistent regional convergence dynamics in Southern Europe (Szendi, 2024; Zheng et al., 2026).

Policy interventions should therefore move beyond the objective of simply increasing innovation expenditure and focus on strengthening the mechanisms through which innovation generates productivity, investment, and employment at the regional level (Anselin et al., 1997; Audretsch and Feldman, 1996; Jaffe, 1989). Moreover, the positive spatial autocorrelation of innovation (Fig. 7) highlights the importance of geographical proximity and interregional knowledge spillovers, supporting policies that promote research networks, university–industry cooperation, technology transfer, and stronger connections between leading innovation hubs and peripheral regions (Martin et al., 2011; Zheng et al., 2026).

At the same time, transport and infrastructure policies should avoid reinforcing existing core–periphery structures by concentrating investments exclusively in already accessible and economically developed areas (Ötvös, 2025). Greater attention should be devoted to improving intra-regional accessibility and connectivity between secondary cities, peripheral territories, and regional growth centres (Macsinka, 2025; Petrović et al., 2025; Prusov and Dubova, 2022; Škorupa et al., 2024). Overall, the results suggest that reducing Italian regional inequalities requires an integrated policy strategy combining transport accessibility, territorial connectivity, innovation diffusion, and local absorptive capacity (Gambacurta, 2026a; Szalmáné Csete and Baranyi, 2023). Without territorially differentiated interventions, the strengthening of agglomeration mechanisms observed after COVID-19 may further consolidate existing spatial inequalities and limit the capacity of lagging regions to benefit from national economic growth and technological development.

5 Conclusion

This study provides an integrated analysis of agglomeration, economic performance, and innovation across Italian macro-regions over the period 2017–2023, with particular attention to the structural changes associated with the COVID-19 shock. The results reveal heterogeneous dynamics: innovation exhibits declining dispersion and a tendency towards convergence, while GDP disparities persist and agglomeration shows increasing spatial concentration. Moreover, the relationship between agglomeration and both GDP and innovation strengthened after COVID-19, particularly in the North-West, North-East, and Centre (Martin et al., 2011; Szendi, 2024; Zheng et al., 2026).

The findings suggest that the pandemic reinforced existing spatial concentration mechanisms rather than promoting more balanced regional development. Innovation convergence has not translated into economic convergence, indicating that reductions in innovation disparities alone are insufficient to overcome persistent structural differences across territories (Baldwin et al., 2001; Gambacurta, 2026a; Martin, 1999a).

From a policy perspective, the results support integrated and place-based strategies combining transport accessibility, territorial connectivity, and stronger regional innovation systems (Boldizsár, 2024; Škorupa et al., 2024; van Leeuwen, 2015). Infrastructure investments alone may not generate convergence and could reinforce existing core–periphery structures if more developed regions are better positioned to capture their benefits (Martin, 1998; Szalmáné Csete and Esses, 2023). Policies should therefore strengthen local absorptive capacity, knowledge diffusion, and connections between peripheral areas and regional economic centres (Anselin et al., 1997; Audretsch and Feldman, 1996; Jaffe, 1989).

The study is limited by the short observation period and the use of NUTS 1 macro-regions, which may conceal substantial intra-regional heterogeneity. Future research should extend the analysis to NUTS 2 and NUTS 3 regions, longer time horizons, and spatial panel econometric models incorporating additional structural determinants.

Overall, the study shows that post-pandemic regional development in Italy is characterised by innovation convergence alongside persistent economic disparities and increasing spatial concentration. Addressing these asymmetries requires territorially differentiated policies capable of extending the benefits of accessibility, innovation, and agglomeration beyond already developed regions (Gambacurta, 2026a; Szalmáné Csete and Baranyi, 2023; Wang et al., 2024).

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