Unveiling spatial patterns of population in Italy

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1 Exteded Abstract

Population density is a central variable in economic geography and regional science, as it reflects the balance between agglomeration forces – such as productivity gains, labour market pooling, and knowledge spillovers – and dispersion forces, including congestion, housing costs, and environmental constraints. While the urban–rural dichotomy has traditionally structured both empirical research and policy frameworks, it provides only a static and highly aggregated representation of demographic processes that are intrinsically heterogeneous across space. This limitation is particularly relevant in countries characterised by strong territorial disparities and historical fragmentation, such as Italy. Between 1985 and 2020, Italy experienced modest aggregate population growth, yet this aggregate stability conceals marked spatial divergence: persistent densification in already urbanised areas coexists with widespread depopulation in mountainous and inland regions. Understanding these dynamics is crucial for the design and evaluation of place-based policies, including cohesion policy and national strategies targeting disadvantaged territories.

This paper proposes a novel empirical framework to analyse and classify the spatial distribution dynamics of population density at a highly disaggregated level. Moving beyond

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administrative averages and threshold-based classifications, we model the joint evolution of local population density and its spatial lag within municipalities. The core contribution is a dynamic taxonomy of locations derived from projected long-run trajectories implied by an estimated Random Vector Field (RVF) in Moran space. By focusing on trajectories rather than static levels, we provide a forward-looking classification that distinguishes between areas that may appear similar in cross-section but face systematically different long-run demographic regimes.

The analysis relies on the Global Human Settlement Layer Population Grid (GHS-POP), which provides residential population estimates at five-year intervals from 1975 to 2020. To balance granularity and computational feasibility, original grid cells are aggregated into larger cells averaging approximately 3.1 km^2. After excluding cells with zero population in both the initial and final years, the final sample consists of 82,536 locations covering nearly the entire Italian territory. The period of analysis is restricted to 1985–2020, for which intercensal municipal population estimates are sufficiently reliable and harmonised to 2020 administrative boundaries to ensure temporal comparability.

Descriptive evidence highlights several stylised facts. First, mean population density increased slightly over the period, while the median remained almost unchanged, indicating a highly skewed distribution. Population growth has been concentrated in already dense areas, particularly along the Po Valley and in major coastal metropolitan regions, while mountainous and inland areas experienced sustained decline. Second, spatial autocorrelation increased over time, as measured by Moran's I, signalling stronger clustering of high-density locations near other high-density locations and of low-density locations near other low-density ones. These patterns suggest that demographic dynamics have reinforced existing spatial inequalities rather than reducing them.

To model spatial distribution dynamics, we adopt an approach based on the estimation of a Random Vector Field in Moran space. Each location is represented by a two-dimensional vector comprising its own (log) population density and the spatially lagged density of the municipality to which it belongs. Municipal boundaries are used to define spatial dependence, reflecting the institutional and service-related relevance of municipalities in shaping residential decisions. The RVF estimates, for each point in Moran space, the expected movement over time as a weighted average of observed transitions, using an adaptive kernel estimator that accounts for the covariance structure of the data and mitigates the curse of dimensionality typical of multivariate nonparametric approaches.

The estimated vector field reveals clear and differentiated dynamics across the Moran space. In the high–high quadrant, corresponding to dense locations within dense municipalities, the majority of movements point toward further densification, indicating persistent urban concentration. In the low–low quadrant, movements are directed toward further decline, signalling entrenched depopulation in sparsely populated areas. Intermediate quadrants display more nuanced patterns, including cases in which medium-density locations within dense municipalities experience growth (urban peripheries), as well as cases in which relatively dense locations within low-density municipalities lose population. These results remain robust when redefining spatial weights using a nearest-neighbour structure and when restricting the estimation window to more recent years.

To translate these dynamic patterns into a structured and policy-relevant classification, we simulate forward the trajectories implied by the estimated RVF from a dense grid of initial conditions in Moran space. Each initial point is projected over a long time horizon to identify its associated equilibrium. The resulting equilibria are clustered using multiple selection criteria, including measures based on within-cluster dispersion and silhouette analysis, to ensure robustness in the choice of the number of clusters. The baseline specification identifies five distinct basins of attraction, corresponding to five types of locations characterised by different long-run demographic regimes.

The first type, labelled Urban Periphery Increasing Density, comprises medium-density locations within high-density municipalities that are projected to densify and converge toward municipal averages. The second type, Urban Core Increasing Density, includes very high-density locations that remain the primary engines of demographic concentration. Together, these two categories account for the majority of the Italian population but cover a relatively small share of the territory. The third type, Sparse Neighbourhood Decreasing Density, consists of low-density locations within low-density municipalities that are projected to experience continued decline. The fourth type, Remote areas, corresponds to extremely low-density locations with negligible expected change, typically located in mountainous or geographically isolated regions. The fifth type, Sparse Pocket, identifies very low-density cells embedded within otherwise dense municipalities, reflecting localised pockets of underutilised or non-residential land.

The spatial distribution of these five types reveals substantial intra-municipal heterogeneity. Even within large metropolitan municipalities, urban cores and growing peripheries coexist with sparsely populated or declining neighbourhoods. Conversely, many rural municipalities are composed predominantly of locations projected to experience sustained depopulation. The taxonomy therefore challenges simplistic dichotomies between "urban" and "rural" and underscores the importance of fine-grained analysis for understanding territorial dynamics.

The policy relevance of the proposed framework is illustrated through two applications. First, we aggregate the cell-level classification to the municipal level to inform the discussion on Italy's National Strategy for Inner Areas (SNAI), which aims to counteract socio-economic decline in peripheral territories. By constructing a municipal taxonomy based solely on projected demographic trajectories, we provide an "intervention-free" benchmark that can be compared with the official identification of inner areas. The results broadly confirm the targeting of many rural and peripheral municipalities but also highlight potential mismatches, including cases where municipalities projected to face future decline receive limited support and instances of spatial fragmentation in the presence of positive spillovers across administrative borders.

Second, we extend the approach to NUTS 3 regions and compare the resulting forward-looking classification with Eurostat's urban–rural typology. While the latter is based on the current share of population living in urban clusters, our taxonomy groups regions according to projected densification patterns. The two approaches coincide for major metropolitan areas characterised by sustained growth, but diverge in regions where current density does not translate into persistent densification. In particular, some regions classified as urban in cross-section display only moderate projected growth, while several polycentric provinces emerge as highly densifying despite not being predominantly urban according to static criteria. This comparison demonstrates how trajectory-based classifications can complement existing statistical frameworks by distinguishing between "currently urban" and "urbanising" territories.

The contribution of the paper is threefold. Methodologically, it introduces an RVF-based framework that models joint local and municipal population-density dynamics in a flexible and computationally tractable manner. Substantively, it provides new evidence on the spatial evolution of population density in Italy, documenting the coexistence of densification and depopulation and the increasing spatial clustering of demographic outcomes. From a policy perspective, it offers a forward-looking taxonomy that can be flexibly aggregated across territorial levels and used to inform the design and evaluation of place-based interventions.

Although the approach is primarily descriptive and does not identify the causal determinants of population change, it establishes a coherent framework for analysing spatial demographic regimes and their long-run implications. Future research could integrate economic, environmental, and institutional variables into the dynamic framework to explore the drivers of the observed patterns and to assess how policy interventions may alter projected trajectories. More broadly, the methodology can be applied to other socio-economic phenomena characterised by spatial dependence, such as income distribution, poverty, or access to services, thereby contributing to a deeper understanding of spatial inequality and regional development dynamics.

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