

# Natural or migration-driven decline? Demographic components of systemic depopulation at local level: the case of Austria.

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## Short Abstract

This paper investigates systemic depopulation in Austrian municipalities between 2001 and 2023 by combining the Systemic Depopulation Areas Index (SyDAs) with a Singular Value Decomposition (SVD) analysis of population dynamics. While SyDAs has been designed for policy purposes—as a simple binary index to detect self-reinforcing population decline based on stochastic ARIMA trends—the SVD decomposition identifies the main components of population change. The results indicate that 736 out of 2,114 municipalities experienced population decline; however, according to SyDAs, only 68 exhibit characteristics of systemic depopulation, primarily located in Styria and Carinthia. Most SyDAs municipalities combine negative natural growth and net outmigration, confirming the index's ability to capture path-dependent demographic decline. The SVD results are consistent with those obtained from SyDAs, indicating that Factor 1 explains over 95% of the total variance and represents the general depopulation trend, whereas Factors 2 and 3 capture temporal shifts associated with migration flows. This suggests that the SyDAs index can capture the complexities of systemic depopulation while remaining a simple and useful tool for policy planning.

## Introduction, background and study objectives.

Recent studies have focused on two aspects of depopulation that goes beyond the national descriptive approach: geographical heterogeneity and the systemic characteristics of the process of population decline. On the one hand, the national scale often conceals a mosaic of diverse local dynamics (Franklin, 2019, 2020; Sonnino et al., 1990; Benassi et al., 2021). On the other hand, depopulation in this context should be understood both as an outcome and as a path-dependent process (González-Leonardo et al., 2023; Newsham & Rowe, 2022; Franklin, 2020), characterized by a high degree of inertia. Although declining fertility rates may act as an initial trigger, the process of depopulation can become self-reinforcing over time—especially at the local level and within small communities (Reynaud et al., 2020; Elshof, 2014). The formation of such a self-reinforcing population decline is referred to a “systemic depopulation” process (Lallo et al. 2025; Elshof 2014; Benassi et al. 2023a).

Concerns about the negative impact of systemic depopulation on Europe's future economic and social development are becoming more prevalent in official documents (e.g. UNFPA, 2023; EU Parliament, 2021; EESC, 2020) and research papers (e.g. Lallo & Tomassini 2023; Lutz & Gailey 2020; Coleman & Rowthorn 2011; Golini 1997; 2000), which call for policies to be implemented to stop, reverse, or at least manage the potential negative socioeconomic consequences. Effective policies to counteract systemic depopulation need to be locally tailored and place-based (Benassi et al., 2023b; Muti, 2023; Neumark & Simpson, 2015).

Statistical evidence should underpin all rational public policies, particularly those aimed at managing depopulation at the local level. The average population growth rate is the easiest index to access, especially at municipal level (see for example Reynaud et al. 2020). Unfortunately, traditional growth indices are not useful tools for policymakers when it comes to addressing demographic inertia and geographical heterogeneity related to systemic depopulation processes. Firstly, they are essentially averages that depend heavily on the years at which the observation period begins and ends. This hides changes in population trends that occurred within the period under consideration. Secondly, classifying “depopulation severity” based on growth rates requires conventional thresholds to define categorical indices. However, this can mask changes within a category, and can be a limit for comparative studies (see for example Newsham & Rowe 2023).

Lallo et al. (2025) proposed a new index, the Systemic Depopulation Areas Index (SyDAs), to overcome the limitations of monitoring systemic depopulation analysing growth rates at a municipal level. Based on time series analysis and a “symptomatic approach”, this binary index is designed to detect systemic depopulation processes while ignoring some of the volatility in population changes that can occur when analysing very small populations. The index is designed to be

straightforward in terms of its assumptions and calculations, and to require minimal data, i.e. population amounts over a period of time (per year), which is often provided with direct and open access by national statistical institutes. This makes it applicable at a local level and easily replicable by national and local policymakers.

Nevertheless, the SyDAs binary index does not provide a direct measurement of the components that cause systemic depopulation. In theory, systemic depopulation should be driven by a combination of negative natural growth and net migration, as this process is defined as self-reinforcing population decline involving all demographic and socio-economic factors. To assess the ability of SyDAs to accurately distinguish among different trajectories of municipal population growth, this study applies a decomposition analysis to the population dynamics of Austrian municipalities between 2001 and 2023. It is expected that municipalities identified by the SyDAs index as experiencing systemic depopulation will exhibit population decline driven by intertwined natural and migration-related processes, characterized by a sustained long-term negative trajectory. On the contrary, municipalities characterized by population decline, according to classic growth rates, but that are not subject to systemic depopulation, according to SyDAs, should have a more heterogeneous composition. This would reaffirm the SyDAs index's ability to capture the complexities of systemic depopulation while remaining a simple and useful tool for policy planning.

## Data and methods

Data on the population size of 2,114 Austrian municipalities from 2001 to 2023 comes from the Austrian Statistics Institute. The administrative geography was updated and standardised on 1 January 2025.

SyDAs index on Austrian municipalities has been computed following Lallo et al. (2025) methodology. Consider data on the population “Pop” of a given municipality “m”, which has been collected on 1 January each year from year “t” to year “t+n”, encompassing a total period of “n” years. In order to estimate a population trend managing an autoregressive structure of data (demographic inertia) and avoiding volatility (erratic changes at local level) it is necessary for the error component “ $\varepsilon$ ” of a simple OLS linear to contain an ARIMA “ $\eta$ ” process. The ARIMA process is determined by the order of differencing (“d”) and autoregressive and moving average components, including the order of autoregressive (“k”) and moving average (“j”) processes (see also: Hyndman & Athanasopoulos, 2021). This process has been formalized as follows:

$$Pop_{m,t} = Pop_{m,t-d} + \beta_{m,1} + \eta_{m,t} \quad [1]$$

with

$$\begin{aligned} \eta_{(m,t)} &= \delta_{(k,m)} * \eta_{(m,t-k)} + \gamma_{(j,m)} * \varepsilon_{(m,t-j)} + \varepsilon_{(m,t)}. \\ \beta_{m,1} &= \text{growth of municipality "m"} \end{aligned}$$

Finally, the binary SyDAs index is determined by the stochastic trend estimate:

$$SyDAs_{m,t,t+n}^{Stochastic\ ARIMA} = \begin{cases} \mathbf{0} & \text{if } \beta_{m,1} \geq 0 \text{ or } p\text{-value} \geq 0.001 \\ \mathbf{1} & \text{if } \beta_{m,1} < 0 \text{ and } p\text{-value} < 0.001 \end{cases} \quad [2]$$

SyDAs index has been computed using R software environment, the “forecast” package and the automatic stochastic forecast algorithm (see: Lallo et al., 2025; Hyndman, & Khandakar, 2008).

To understand the underlying demographic factors driving the systemic population decline, we structurally decompose the evolution of the logarithm of the population size (with and without migration flows) across Austrian municipalities using the Singular Value Decomposition (SVD). To do so, we define a real  $m \times n$  matrix  $A$ , in which the element  $A_{m,n}$  contains the  $\log(Pop_{m,t+n}/Pop_{m,t})$ . From algebra, it is known to exist matrices that satisfy the following relationship:

$$A = U\Sigma V^T,$$

where  $U \in R^{m \times m}$  and  $V \in R^{n \times n}$  are orthogonal matrices and  $\Sigma \in R^{m \times n}$  is a diagonal matrix. Matrix  $U$  captures variations across municipalities, matrix  $V$  captures time patterns, and matrix  $\Sigma$  contains the weights of each component. This technique allows to approximate

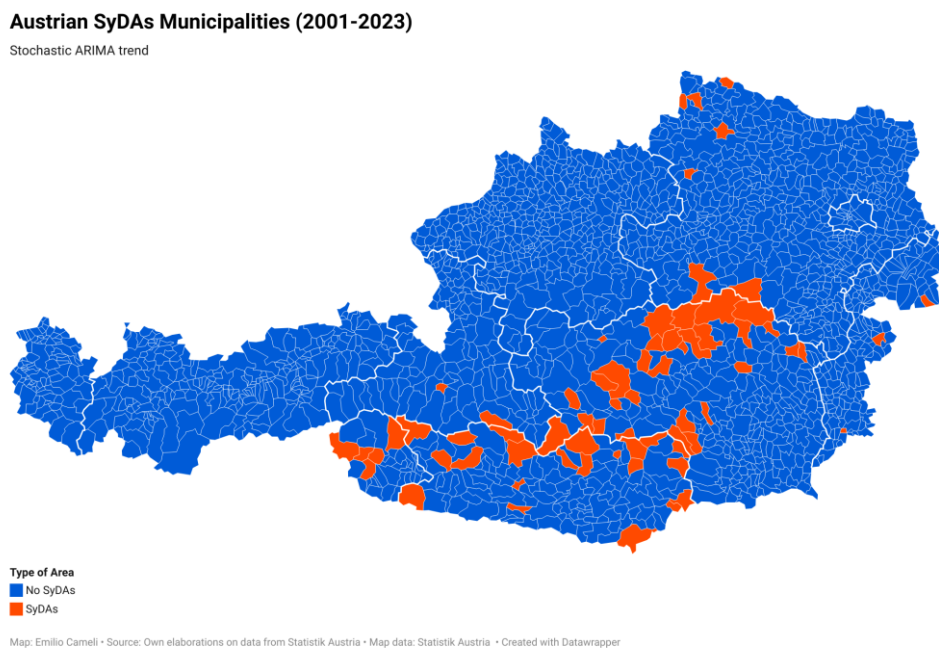
$$A \approx \sum_{i=1}^r \sigma_i u_i v_i^T,$$

where  $\sigma_i = \text{Diagonal}(\Sigma)_{i,i}$ ,  $u_i = U_{.,i}$ , and  $v_i = V_{.,i}$ . The first component ( $i = 1$ ) represents the trend of population growth, and all subsequent components account for temporal changes in the population growth rate (i.e., migration flows).

## Preliminary results

Analysis of Austrian municipal population data revealed that 736 out of 2,114 municipalities experienced a decline in resident population between 2001 and 2023 according to classic average population growth rates, with 68 of these experiencing systemic depopulation according to SyDAs index. About 75% of these are concentrated in the Bundesländer of Styria and Carinthia (see figure 1). Out of the 668 municipalities that registered a population decline but were not affected by a systemic depopulation process according to SyDAs, 262 (39.2%) had positive natural component<sup>1</sup> and 185 (27.7%) had a positive net migration component<sup>2</sup>. Despite the population decline, 180 municipalities (27%) show positive demographic compensation<sup>3</sup> between the two components (positive algebraic sum of the two components). Of the 68 SyDAs municipalities, only 14 (20.6%) have a positive natural component and just four (5.9%) have a positive migratory component. However, none of them displayed positive demographic compensation in any of the years under observation (see tables 1,2 and 3).

**Figure 1.** Austrian municipalities affected by systemic depopulation according to SyDAs, period 2001-2023.



Source: own elaboration based on Statistics Austria data.

**Table 1.** Summary values of natural and migratory components in municipalities affected by population decline according to classic average growth rates but not in systemic depopulation according to SyDAs index.

<sup>1</sup> average relative natural balance (2001–2023)

<sup>2</sup> average residual relative migratory balance (2001–2023)

<sup>3</sup> algebraic sum between average relative natural balance (2001–2023) and average residual relative migratory balance (2001–2023)

No SyDAs Municipalities	Demo components	Absolute values	Perc values
	Natural component > 0	262	39.2
	Natural component < 0	406	60.8
	Migration component > 0	185	27.7
	Migration component < 0	483	72.3

**Table 2.** Summary values of natural and migratory components in municipalities affected by systemic depopulation according to SyDAs index.

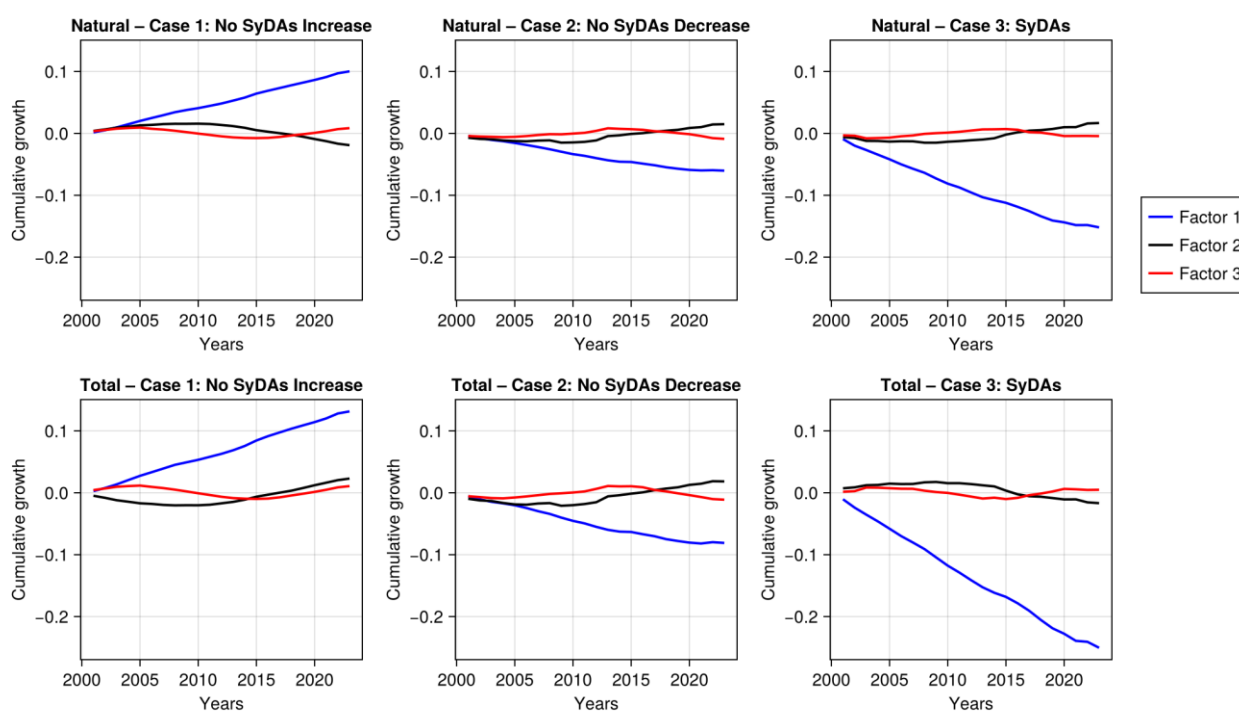
SyDAs Municipalities	Demo components	Absolute values	Perc values
	Natural component > 0	14	20.6
	Natural component < 0	54	79.4
	Migration component > 0	4	5.9
	Migration component < 0	64	94.1

**Table 3.** Municipal distribution (absolute and percentage) of positive demographic compensation between natural component and migration component.

Demo Compensation > 0	Type of Area	Absolute values	Total	Perc values
	No SyDAs	180	668	27
	SyDAs	0	68	0

Figure 2 presents the preliminary results of the decomposition of population growth across Austrian municipalities for the period 2001–2023, obtained using Singular Value Decomposition (SVD). The figure consists of six panels. The top panels display the decomposition based on natural population growth (i.e., excluding migration), whereas the bottom panels include migration flows. The left panels correspond to No SyDAs municipalities that experienced positive population growth rates, the middle panels show No SyDAs municipalities that experienced population decline, and the right panels depict the results for SyDAs municipalities. Factor 1 captures the overall population trend, while Factors 2 and 3 represent temporal variations primarily associated with migration dynamics.

**Figure 2** Decomposition analysis (SVD) of the natural and total population growth across Austrian municipalities from year 2001 to 2023



Our decomposition analysis reveals three key findings. First, Factor 1 explains more than 95% of the total variance, suggesting that this technique is highly effective for population projections. Second, SyDAs municipalities experience a more pronounced population decline compared to No SyDAs municipalities that also exhibit population losses. Third, comparing the second and third factors between the top and bottom panels for the SyDAs and No SyDAs municipalities indicates an increase in outmigration (see blue and black lines). In contrast, municipalities with positive population growth show a rise in immigration (see blue and black lines).

## Preliminary conclusions

Despite its simple binary design, SyDAs was able to identify Austrian municipalities exhibiting qualities indicative of systemic depopulation. These were characterised by either: 1) negative natural and migration components; or 2) opposite signs in demographic growth components, with negative demographic compensation each year of the considered period. Furthermore, the Singular Value Decomposition (SVD) analysis of municipal population growth rates support the results obtained applying the SyDAs index. This suggests that the SyDAs index can capture the complexities of systemic depopulation while remaining a simple and useful tool for policy planning.

## References

- Benassi, F., Mucciardi, M., & Gallo, G. (2023b).** Local population changes as a spatial varying multiscale process: The Italian case. *International Journal of Population Studies*, 9(1). <https://doi.org/10.36922/ijps.393>.
- Benassi, F., Busetta, A., Gallo, G., & Stranges, M. (2021).** Local heterogeneities in population growth and decline. A spatial analysis of Italian municipalities. In *Convegno della Società Italiana di Statistica* (pp. 297-314). Cham: Springer International Publishing.
- Coleman, D., & Rowthorn, R. (2011).** Who's Afraid of Population Decline? A Critical Examination of Its Consequences. *Population and Development Review*, 37, 217–248. <http://www.jstor.org/stable/41762406>.
- Elshof, H., van Wissen, L., Mulder, C.H. (2014).** The self-reinforcing effects of population decline: An analysis of differences in moving behavior between rural neighborhoods with declining and stable populations. *Journal of Rural Studies*, 36, 285–299. <https://doi.org/10.1016/j.jrurstud.2014.09.006>.
- Franklin, R.S. (2020).** I come to bury (population) growth, not to praise it. *Spatial Economic Analysis*, 15(4), 359-373.
- Franklin, R.S. (2019).** The demographic burden of population loss in US cities, 2000-2010. *Journal of Geographical Systems*, 23, 209-230. <https://oi.org/10.1007/s10109-019-00303-4>.
- Golini, A. (1997).** Demographic trends and ageing in Europe. Prospects, problems and policies. *Genus*, 53(3/4), 33–74. <http://www.jstor.org/stable/29788519>.
- Golini, A., Mussino, A., & Savioli, M. (2000).** Il malessere demografico in Italia. Una ricerca sui comuni italiani. Il mulino, Bologna.
- González-Leonardo, M., Newsham, N., & Rowe, F. (2023).** Understanding Population Decline Trajectories in Spain using Sequence Analysis. *Geographical Analysis*, 55(4).
- Hyndman, R.J., & Athanasopoulos, G. (2021).** *Forecasting: principles and practice*, 3rd edition, OTexts: Melbourne, Australia. OTexts.com/fpp3. Accessed on 28.07.2023.
- Hyndman, R.J., & Khandakar, Y. (2008).** Automatic time series forecasting: the forecast package for R. *Journal of Statistical Software*, 26(3), 1-22.
- Lallo, C., Benassi, F., & Tomassini, C. (2025).** Towards the identification of a Systemic Depopulation Areas Index: the case of Molise. *Bollettino della Società Geografica Italiana*, 1/2025.
- Lutz, W. and Gailey N. (2020).** *Depopulation as a Policy Challenge in the Context of Global Demographic Trends*. United Nations Development Programme. ISBN 978-86-7728-292-9

**Muti, Ö. (Ed.). (2023).** Regional population diversity and social cohesion in the local context. *Population Europe*, 20. [https://population-europe.eu/files/documents/dp\\_reg\\_pop\\_div\\_web\\_18.07.pdf](https://population-europe.eu/files/documents/dp_reg_pop_div_web_18.07.pdf).

**Neumark, D., & Simpson, H. (2015).** Place-based policies. *Handbook of regional and urban economics*, 5, 1197-1287. Elsevier.

**Newsham, N., & Rowe, F. (2023).** Understanding trajectories of population decline across rural and urban Europe: A sequence analysis. *Population, Space and Place*, 29(3), e2630.

**Reynaud, C., Miccoli, S., Benassi, F., Naccarato, A., & Salvati, L. (2020).** Unravelling a demographic ‘Mosaic’: Spatial patterns and contextual factors of depopulation in Italian Municipalities, 1981–2011, *Ecological Indicators*, Volume 115, <https://doi.org/10.1016/j.ecolind.2020.106356>.

**Sonnino, E., Birindelli, A.M., Ascolani, A. (1990).** Popolamenti e spopolamenti dall’Unità ai giorni nostri, In: P. Bevilacqua (Ed.), *Storia dell’agricoltura italiana in età contemporanea*, 2, *Uomini e classi*. Venezia, Marsilio, 661-734.