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Descriptive Finding

Refining seasonal mortality estimates through age adjustment: Evidence from Serbia, 2015–2023

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Abstract

BACKGROUND
Seasonal fluctuations in mortality are a persistent demographic and public health phenomenon. The ideal mortality (IDE) framework estimates seasonal excess mortality by comparing observed outcomes with a counterfactual based on the lowest-mortality seasonal window.

OBJECTIVES
This study evaluates the validity of the IDE framework when applied to age- and sex-specific mortality in Serbia and proposes an age-structure adjustment (IDEadj) to address anomalies in age-specific estimates.

METHODS
Using mortality data for Belgrade and Vojvodina for the period 2015–2023, we construct the IDE baseline based on the three months with the lowest total mortality in each year. Age-specific mortality rates and life expectancy at birth (e_0) are compared across observed, IDE, and IDEadj scenarios.

RESULTS
The IDE framework yields higher life expectancy than observed mortality but produces systematic age-specific inconsistencies. IDE mortality rates occasionally exceed observed values at younger ages and fall to implausibly low levels at older ages, reflecting a mismatch between the age distribution of deaths in the lowest-mortality window and the annual pattern. The IDEadj approach corrects these distortions by aligning age-specific mortality with the observed annual age structure, while preserving the overall magnitude of seasonal gains in life expectancy.

CONCLUSIONS
Age-structure adjustment improves the internal consistency and interpretability of seasonal mortality estimates without altering their aggregate magnitude. The IDEadj

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framework refines the original IDE approach and provides a demographically coherent basis for assessing seasonal mortality effects.

CONTRIBUTION
By identifying and correcting age-specific artefacts inherent in the IDE framework, this study provides a demographically coherent extension that enhances the analysis of seasonal mortality patterns.

1. Introduction

Seasonal fluctuations in mortality are a well-documented demographic phenomenon. In most European countries, mortality peaks during winter and reaches its lowest levels in late spring or summer (Healy 2003; Rau 2007). These patterns are largely explained by cold weather, respiratory infections, and influenza epidemics, but factors such as nutrition, social isolation, and limited physical activity among older adults also play a role (Gemmell et al. 2000; Mackenbach, Kunst, and Looman 1992). The persistence of these fluctuations highlights their importance for both demographic analysis and public health research.

A recent methodological innovation in this field is the ideal mortality (IDE) framework introduced by Marinetti et al. (2025a, 2025b). The approach defines the lowest-mortality seasonal window in each year and assumes that mortality throughout the year could follow this ‘ideal’ pattern. The difference between observed mortality (OBS) and IDE provides an estimate of seasonal excess mortality and its impact on life expectancy. This framework offers a simple and elegant way to operationalize seasonal mortality.

The present study builds on this idea by adapting the IDE framework to a different analytical perspective. Rather than decomposing seasonal losses by season, we focus on the overall annual impact of seasonality. When applied in this way, however, inconsistencies emerge in age-specific comparisons: calculations for Serbia showed that in some age groups observed mortality was paradoxically lower than the ‘ideal’ level, an artefact that can also bias estimates of life expectancy at birth (e_0). In practice, winter mortality is disproportionately concentrated among older individuals, while summer excess mortality more often affects younger groups (McKee et al. 1998; Parks et al. 2018). This implies that the age distribution of deaths in the lowest-mortality window cannot be taken as representative of mortality in the absence of seasonal risks. To address this issue, we introduce an age-structure adjustment (IDEadj), which redistributes seasonal deaths according to their annual age profile and thereby yields demographically coherent age-specific mortality rates.

2. Methods

2.1 Study area and data sources

The analysis covers two regions in Serbia (Belgrade and Vojvodina), chosen for their reliable mortality registration, contrasting sociodemographic profiles, and distinct patterns of urbanization and ageing. Belgrade is a metropolitan and administrative and health hub, while Vojvodina is predominantly agricultural with an older population. Together they comprise about half of Serbia's population (≈3.4 million), each roughly one quarter. Four populations are examined: men and women in Belgrade and in Vojvodina.

Mortality data for the period 2015–2023 were obtained from the Statistical Office of the Republic of Serbia (SORS) based on an official request. The database includes the date of death, sex, region of residence, and age at death. Annual population estimates by age, sex, and region, obtained from the official SORS online database, served as denominators for calculating age-specific mortality rates.

2.2 Seasonal mortality window approach

For each region–sex group, the IDE window was defined following the original specification proposed by Marinetti et al. (2025a, 2025b). Specifically, for each year we identified the three months with the lowest total number of deaths, irrespective of whether they occurred consecutively. Mortality in this lowest-mortality seasonal window was then used to construct the IDE scenario, assuming that the mortality conditions observed during these months could prevail throughout the entire year.

2.3 Age-structure adjustment

In the original IDE framework, the mortality rate for a given age group x, year t, and region r is defined as:

$$m_{x,t,r}^{IDE} = \frac{D_{x,t,r}^{l}}{P_{x,t,r}} \times k$$

where $D_{x,t,r}^{l}$ is the number of deaths in the lowest-mortality seasonal window, $P_{x,t,r}$ denotes the exposure-to-risk (person-years), and k is a coefficient scaling the seasonal deaths to annual equivalents, most commonly set to 4 when using three-month window.

The superscript l denotes the lowest-mortality window. This procedure assumes that the age distribution of deaths during the lowest-mortality window reflects mortality in the absence of seasonal risks.

To correct distortions arising from this assumption, we introduce an IDEadj. The procedure has two steps. First, for each region–sex–year we calculate the annual age distribution of deaths where the superscript a refers to the annual total:

$$s_{x,t,r} = \frac{D^{a}_{x,t,r}}{\sum_x D^{a}_{x,t,r}}$$

Second, the total number of seasonal deaths is redistributed across age groups according to these annual shares:

$$D^{IDEadj}_{x,t,r} = s_{x,t,r} \times D^{l}_{x,t,r}$$

The adjusted age-specific mortality rates are then:

$$m^{IDEadj}_{x,t,r} = \frac{D^{IDEadj}_{x,t,r}}{P_{x,t,r}} \times k$$

Standard period life tables (Preston, Heuveline, and Guillot 2001) were used to calculate e_0 under the IDEadj scenario. This approach preserves the total number of seasonal deaths but aligns their distribution with the annual age profile, ensuring that differences between OBS and IDEadj reflect genuine seasonal effects rather than artefacts of temporary demographic shifts. Although confidence intervals were not explicitly calculated, mortality counts were aggregated over seasonal windows of sufficient length to substantially reduce stochastic variation. As a result, random fluctuations in short-term mortality have negligible effects on the resulting life expectancy estimates. We therefore report point estimates only, while acknowledging this as a limitation of both the IDE and IDEadj frameworks.

3. Results

Analysis of mortality in Belgrade and Vojvodina, 2015–2023, showed that the IDE framework is generally robust but produced anomalies in age-specific results. Two patterns were evident: (1) IDE mortality exceeding observed rates among younger groups, and (2) unrealistically low values at older ages relative to observed annual age-specific mortality. The first occurred most often below age 50 (Figure 1), while the second was concentrated in the oldest cohorts (Figure 2).

Figure 1: Heatmap of age-specific ratios between ideal and observed mortality rates (IDE MR / OBS MR ×100), by age, sex, region, and period

Category	Belgrade_male			Belgrade_female			Vojvodina_male			Vojvodina_female		
Period	2015-2019	2020-2022	2023	2015-2019	2020-2022	2023	2015-2019	2020-2022	2023	2015-2019	2020-2022	2023
0	91	140	73	84	77	85	113	104	82	92	141	22
1–4	117	67	80	128	153	0	132	96	50	107	19	67
5–9	71	244	133	147	104	200	79	56	229	74	116	0
10–14	123	51	150	0	33	71	94	122	145	151	0	0
15–19	84	70	189	80	90	0	97	116	150	82	95	0
20–24	105	98	88	104	49	123	134	110	94	76	66	80
25–29	82	68	95	100	107	0	94	104	116	101	76	80
30–34	98	109	95	109	102	114	107	94	111	74	108	93
35–39	94	87	90	91	111	57	106	87	100	80	89	113
40–44	100	87	101	82	86	66	94	83	101	81	92	120
45–49	98	93	104	103	92	86	94	87	90	87	89	81
50–54	99	80	89	99	93	74	94	81	86	96	90	87
55–59	94	87	92	89	86	94	90	91	91	90	90	94
60–64	93	83	89	92	79	92	88	84	86	87	81	91
65–69	92	81	92	93	78	90	88	80	90	89	84	83
70–74	90	81	87	89	77	93	89	78	84	87	80	92
75–79	90	76	96	87	80	98	91	80	85	85	84	91
80–84	85	76	89	88	80	91	88	78	86	87	79	88
85+	87	77	83	90	83	90	87	78	84	86	80	88

Note: Average values for the periods 2015–2019 and 2020–2022 are presented.

Figure 2: Heatmap of differences between ideal and observed mortality rates (IDE MR – OBS MR), by age, sex, region, and period

Category	Belgrade_male			Belgrade_female			Vojvodina_male			Vojvodina_female		
Period	2015-2019	2020-2022	2023	2015-2019	2020-2022	2023	2015-2019	2020-2022	2023	2015-2019	2020-2022	2023
0	-0.40	1.37	-0.99	-0.73	-0.69	-0.58	0.61	0.16	-0.70	-0.23	1.84	-1.76
1–4	0.03	-0.06	-0.06	-0.01	0.08	-0.06	0.04	0.04	-0.11	0.01	-0.09	-0.06
5–9	-0.03	0.13	0.05	0.03	0.00	0.14	-0.02	-0.07	0.20	0.00	-0.01	-0.05
10–14	0.04	-0.06	0.09	-0.06	-0.03	-0.12	-0.05	0.02	0.11	0.06	-0.07	-0.12
15–19	-0.06	-0.07	0.42	-0.03	-0.04	-0.16	-0.01	0.06	0.18	-0.03	0.03	-0.09
20–24	-0.01	-0.02	-0.10	0.03	-0.12	0.07	0.23	0.07	-0.04	-0.06	-0.09	-0.05
25–29	-0.12	-0.25	-0.04	0.00	0.03	-0.20	-0.07	0.06	0.14	0.00	-0.06	-0.11
30–34	-0.03	0.08	-0.04	0.03	0.01	0.05	0.08	-0.06	0.13	-0.13	0.03	-0.04
35–39	-0.08	-0.20	-0.14	-0.05	0.07	-0.31	0.07	-0.29	0.00	-0.17	-0.16	0.12
40–44	0.01	-0.36	0.02	-0.21	-0.20	-0.39	-0.17	-0.57	0.02	-0.25	-0.13	0.31
45–49	-0.10	-0.39	0.15	0.07	-0.19	-0.27	-0.30	-0.67	-0.51	-0.39	-0.31	-0.43
50–54	-0.07	-1.75	-0.71	-0.07	-0.29	-0.84	-0.49	-1.85	-1.06	-0.17	-0.48	-0.53
55–59	-0.73	-1.76	-0.76	-0.69	-0.97	-0.35	-1.52	-1.60	-1.23	-0.69	-0.84	-0.40
60–64	-1.33	-3.99	-1.99	-0.77	-2.53	-0.72	-2.77	-4.24	-3.01	-1.45	-2.51	-1.02
65–69	-2.44	-7.13	-2.27	-1.04	-4.01	-1.58	-4.37	-8.27	-3.07	-1.87	-3.48	-3.03
70–74	-4.16	-10.96	-5.33	-2.69	-6.74	-1.80	-5.60	-12.93	-7.20	-3.79	-6.87	-2.22
75–79	-6.24	-19.49	-2.64	-5.66	-10.69	-0.67	-7.05	-19.03	-10.79	-8.26	-9.79	-4.82
80–84	-16.12	-30.77	-10.50	-10.20	-19.94	-7.20	-14.96	-29.98	-14.35	-13.58	-23.22	-11.08
85+	-26.15	-55.31	-32.62	-18.59	-36.27	-18.24	-27.91	-52.23	-31.66	-28.73	-43.06	-25.16

These issues motivated the development of IDEadj, which consistently improved results: it removed anomalies in younger groups, reduced unrealistic deviations among the elderly, and stabilized middle adulthood (Figure 3). For instance, in Belgrade men in 2023, IDE implied higher mortality than observed in youth and disproportionately low values at ages 85+, both corrected under IDEadj. Detailed comparisons of the age distribution of deaths in the IDE window and the corresponding annual distribution are provided in the supplementary material (Table A-1).

Table 1 summarizes the differences between scenarios. Seasonal gains in life expectancy under the IDE framework (IDE–OBS) were consistently positive, ranging from less than one year in the pre-pandemic period (e.g., Belgrade men 2015) to almost three years during the pandemic (e.g., Belgrade men in 2021). Gains were systematically larger for men than for women and more pronounced in Vojvodina than in Belgrade, reflecting higher demographic vulnerability. Under the adjusted framework (IDEadj–OBS), values were also uniformly positive and, in most cases, slightly exceeded those obtained with IDE, particularly during the pandemic (e.g., Vojvodina men in 2021 gained 3.03 years under IDEadj compared with 2.39 under IDE). Direct comparison (IDEadj–IDE) shows that the adjustment generally increased seasonal gains, with the largest differences again observed among men in Vojvodina during the pandemic (up to +0.64 years). For women, discrepancies were smaller and in a few pre-pandemic years and 2023 slightly negative (e.g., Belgrade 2019; Vojvodina 2016). Overall, IDEadj produced larger and more internally consistent gains, underscoring its greater sensitivity to age composition and its methodological advantage over the unadjusted approach.

Figure 3: Residuals of IDE and IDEadj mortality rates relative to observed mortality (Belgrade, men, 2023)

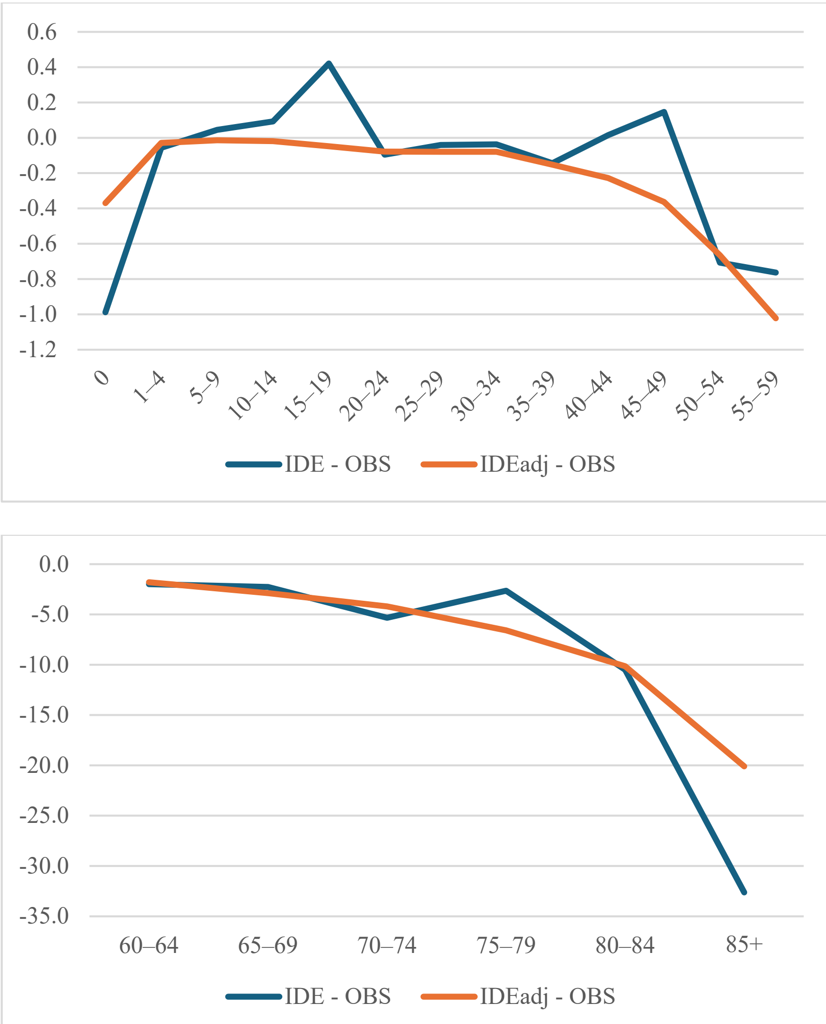

Table 1: Life expectancy at birth (e_0) under observed, IDE, and IDEadj scenarios, by sex, Belgrade and Vojvodina 2015–2023

	OBS_e_0	IDE_e_0	IDEadj_e_0	1	2	3	OBS_e_0	IDE_e_0	IDEadj_e_0	1	2	3
	Belgrade - male						Belgrade - female					
2015	73.86	74.74	74.83	0.88	0.96	0.09	78.85	79.81	79.95	0.96	1.11	0.14
2016	74.38	75.25	75.66	0.87	1.28	0.41	79.26	80.17	80.76	0.91	1.50	0.59
2017	74.17	75.56	75.58	1.39	1.41	0.02	79.02	80.22	80.49	1.19	1.47	0.27
2018	74.33	75.63	75.85	1.30	1.52	0.22	79.31	80.51	80.54	1.20	1.23	0.03
2019	74.56	75.26	75.47	0.71	0.91	0.20	79.42	80.39	80.38	0.97	0.96	–0.01
2020	72.42	74.44	74.85	2.01	2.43	0.41	78.41	80.21	80.55	1.80	2.14	0.34
2021	70.79	73.74	74.14	2.95	3.35	0.40	76.75	79.57	79.38	2.81	2.62	–0.19
2022	73.71	75.10	75.48	1.39	1.77	0.39	78.73	80.14	80.34	1.41	1.61	0.20
2023	74.58	75.60	75.84	1.02	1.25	0.23	79.47	80.61	80.45	1.14	0.98	–0.16
	Vojvodina - male						Vojvodina – female					
2015	71.46	72.74	72.87	1.28	1.41	0.13	77.15	78.56	78.60	1.41	1.46	0.05
2016	71.88	72.68	73.09	0.80	1.21	0.41	77.49	79.05	78.97	1.56	1.48	–0.08
2017	71.97	73.23	73.62	1.26	1.65	0.39	77.47	78.84	78.99	1.37	1.52	0.15
2018	72.42	73.22	73.44	0.81	1.02	0.21	77.81	79.36	79.40	1.55	1.60	0.04
2019	72.20	73.22	73.44	1.01	1.24	0.22	78.12	79.16	79.47	1.04	1.35	0.31
2020	71.01	73.53	73.65	2.52	2.64	0.12	77.07	78.77	79.23	1.70	2.16	0.46
2021	69.63	72.02	72.66	2.39	3.03	0.64	75.62	78.07	78.27	2.45	2.66	0.21
2022	71.66	73.02	73.48	1.36	1.81	0.46	77.09	78.16	78.50	1.08	1.42	0.34
2023	72.86	74.18	74.52	1.32	1.66	0.34	78.06	79.36	79.26	1.30	1.20	–0.10

Note: 1: IDE_e_0 - OBS_e_0; 2: IDEadj_e_0 - OBS_e_0; 3: IDEadj_e_0 - IDE_e_0.

4. Discussion and conclusion

Our results confirm the robustness of the framework while also highlighting its limitations. As expected, IDE produced higher e_0 than observed mortality, reflecting the removal of seasonal stressors. Yet age-specific inconsistencies emerged: IDE mortality rates sometimes exceeded observed values for children and young adults, while among the elderly they dropped to unrealistically low levels relative to observed annual age-specific mortality. IDEadj corrected these distortions by redistributing seasonal deaths according to annual age patterns, reducing anomalies at younger and older ages and stabilizing results in middle adulthood. Although overall seasonal gains in e_0 were similar across methods, IDEadj provided more coherent and internally consistent estimates.

An alternative solution could define separate ideal mortality windows for each age group. However, this would produce non-overlapping seasonal periods across ages, precluding aggregation into a single, seasonally consistent counterfactual. Moreover, it would effectively remove the notion of seasonality from the framework, reducing it to a theoretical construct of “ideal” mortality detached from seasonal patterns. The IDEadj framework, in contrast, maintains seasonality as the organizing principle while correcting for demographic composition, which is essential for analytical measures such as life expectancy or cause-of-death decomposition. Conceptually, this means that IDEadj represents mortality in the absence of seasonal shocks while preserving the empirical annual age-risk pattern, creating a single, coherent counterfactual that remains interpretable in population-level metrics such as e_0. In contrast, defining age-specific ideal windows would fragment the counterfactual into multiple non-overlapping 'ideal seasons' that cannot be synthesised into a meaningful population mortality schedule.

In addition to introducing IDEadj as an age-structure correction to the original IDE framework, we propose two complementary methodological refinements. First, we recommend defining the ideal mortality window using consecutive months with the lowest mortality, rather than allowing non-adjacent periods. A continuous window better reflects the concept of seasonality as a coherent temporal phenomenon driven by climatic and epidemiological conditions, and avoids constructing an "ideal" scenario from temporally fragmented episodes that may not represent a plausible seasonal context. This choice strengthens the interpretability of the counterfactual as a realistic seasonal state rather than a statistical minimum. Second, we recommend using mid-year population estimates, calculated as the average of population counts at the beginning (1 January) and end (31 December) of the year. The original IDE implementation relies on population estimates at the beginning of the year, whereas mid-year denominators provide a more accurate approximation of annual exposure to mortality risk and are standard in demographic rate estimation. This choice reduces potential bias in years affected by short-term demographic shocks, such as natural disasters, armed conflict, or severe epidemics, which may alter population size within the year.

Some limitations remain: IDEadj assumes that the annual age distribution is an adequate reference, and small age groups are sensitive to random variation. Although Belgrade and Vojvodina together account for nearly half of Serbia's population, the findings may not be fully generalizable to the national level, as other parts of the country differ in both climatic conditions and demographic structure. Nevertheless, this study refines the seasonal mortality window framework, improving the validity of seasonal life expectancy estimates and strengthening its applicability in demographic and public health research.

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