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LATENT STRUCTURES AND RECOVERY PATHS: A COMPARATIVE STUDY OF BALTIC SOCIO-ECONOMIC TRENDS

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Abstract. This study investigates the post-COVID socio-economic recovery of the Baltic States – Estonia, Latvia, and Lithuania – through the lens of Principal Component Analysis (PCA). Using standardized data from 2019 to 2023, PCA is employed to extract latent dimensions underlying key economic and social indicators. The analysis reveals distinct structural profiles across the three countries, highlighting differences in resilience, adaptability, and policy effectiveness. Estonia demonstrates consistent macroeconomic stability and institutional strength, Lithuania shows dynamic but uneven growth, while Latvia exhibits gradual recovery marked by short-term volatility. By reducing multidimensional data into interpretable components, PCA enables a nuanced comparison of recovery trajectories and offers insights into the structural factors shaping regional development. The findings contribute to the understanding of post-crisis adjustment in small open economies and inform future policy design within the EU context.

Key words: Baltic States, post-COVID recovery, post-crisis development, economic policy, socio-economic indicators, Principal Component Analysis (PCA).

Introduction. The COVID-19 pandemic triggered an unprecedented global disruption, reshaping economic structures, social systems, and governance models across nations. For the Baltic States – Estonia, Latvia, and Lithuania – the crisis exposed existing vulnerabilities while simultaneously accelerating strategic shifts in digitalization, fiscal policy, and labour market reform. Despite their shared geographic and institutional context, the three countries exhibited markedly different responses and recovery trajectories, shaped by distinct policy choices and structural conditions.

This study investigates the post-pandemic socio-economic development of the Baltic States through a comparative lens, focusing on the period from 2020 to 2023. It examines how each country adapted to the crisis, implemented recovery measures, and navigated the challenges of inflation, unemployment, and demographic change. Particular attention is given to the role of EU integration, public debt dynamics, and the evolving labour market landscape.

Research aim: To conduct a comparative analysis of the socio-economic recovery trajectories of Estonia, Latvia, and Lithuania in the post-COVID period (2020–2023), using multidimensional and temporal methods to identify structural differences and policy-driven outcomes.

Research Objectives:

- To evaluate the impact of the COVID-19 pandemic on key macroeconomic and social indicators in the Baltic States.
- To apply Principal Component Analysis (PCA) for identifying latent factors influencing recovery.
- To compare national policy responses and their effectiveness in mitigating crisis effects.
- To formulate recommendations for enhancing resilience and convergence in small open economies.

– To compare current PCA-based findings with earlier results obtained using Dynamic Time Warping (DTW).

The scientific novelty of this research lies in its application of PCA to assess the structural dimensions of post-COVID recovery. PCA enables the identification of underlying patterns across a wide range of economic and social indicators, revealing differences in resilience, adaptability, and policy effectiveness among the Baltic States.

In addition, the study incorporates a comparative assessment with earlier findings based on DTW approach, previously used to analyse temporal convergence and divergence in recovery trajectories. This comparison highlights the complementary strengths of both approaches and helps refine interpretations of national development paths.

By applying PCA to a comprehensive dataset covering the years 2019-2023, the study contributes to a deeper understanding of how small open economies respond to systemic shocks and what structural factors influence their capacity for sustainable recovery. The findings have implications for regional policy design, particularly in the context of future crises and EU-wide convergence efforts.

1. The Baltic States and the Chronology of the COVID-19 Pandemic

Prior to joining the European Union in 2004, the Baltic States transitioned from centrally planned Soviet economies to market-based systems following their independence in 1991. This shift led to economic instability, high unemployment, and social unrest. EU accession marked a turning point, offering improved access to markets, investment, and financial resources.

Post-accession, all three countries experienced strong economic growth. Before joining, Latvia's gross domestic product (GDP) grew at 7.5% annually, Lithuania at 6.7%, and Estonia at 6.5%. These rates peaked around 2007 – Latvia reached 11.9% in 2006. Between 2004 and 2020, Lithuania's GDP averaged 3.5% growth annually, while Latvia and Estonia grew at roughly 3% (Eurostat, 2025).

However, EU membership and free movement led to significant emigration, with nearly 20% of citizens leaving during the post-accession period.

In late 2019, rising pneumonia cases from an unknown pathogen prompted the World Health Organization (WHO) to declare a global health emergency. On 1 March 2020, COVID-19 was officially classified as a pandemic, which unfolded in three waves:

First Wave (Dec 2019 – May 2020): This phase disrupted financial markets and threatened economic stability. Governments responded with spending cuts, tighter credit, and stimulus measures. Trade balances shifted – developing nations remained active, while developed economies slowed. Restrictions and reduced energy demand, especially from China, deepened the downturn (Gurkov, 2020).

Second Wave (June 2020 – Mar 2021): The economic impact persisted. Global GDP fell by 4.3% in 2020 – over twice the decline of the 2009 crisis. Developed economies shrank by 5.6%, developing ones by 2.5%. The United Nations (UN) reported rising inequality, disrupted trade, and stalled activity, with uneven national responses (UN, 2021).

Third Wave (Mar – Oct 2021): After a summer lull, infections surged again. Inflation and energy prices initially dropped, then reversed due to rising logistics costs and demand (Kunickij, 2021; Zettelmeyer et al., 2022).

Among the Baltic States, Lithuania had the highest infection and mortality rates, followed by Latvia and Estonia. Vaccination coverage mirrored this order. As shown in Table 1, the countries followed distinct pandemic trajectories, likely shaping their respective recovery paths.

As shown in Table 1, the Baltic states experienced divergent pandemic trajectories in terms of case numbers, mortality rates, and vaccination uptake, which likely influenced their subsequent economic and social recovery paths.

Table 1

Impact of the COVID-19 Pandemic on the Baltic States

Indicator	Latvia	Lithuania	Estonia
Total number of confirmed cases	221,795	414,817	199,251
Total number of deaths and % of confirmed cases	3,312 (1.49%)	5,971 (1.44%)	1,563 (0.78%)
Total number of recoveries	183,973	365,466	170,095
Cases per 1 million population	119,354	155,277	150,069
Deaths per 1 million population	1,782	2,235	1,177
Vaccination coverage (% of population with at least one dose)	63%	67%	60%

Source: compiled by the authors (based on data from Worldometers, 2021; Our World in Data, 2021).

2. Economic Development Trends in the Baltic States under the Impact of the COVID-19 Pandemic

According to Eurostat (Eurostat, 2025), the Baltic States and Northern European countries were among the least affected by the pandemic within the EU. In early 2020, while the EU economy contracted by 8.3%, Northern Europe declined by just 2.9%, and the Baltics by 3.1%. Unlike the 2008-2009 crisis, when they were severely impacted, this time their decline was mild. Latvia saw the largest drop, with GDP falling by 3.6% in 2020. Growth resumed across all three countries in 2021.

Lockdowns and restrictions imposed to curb the virus significantly affected tourism, hospitality, and entertainment sectors (Hansen, 2021). In Q1 2024, Latvia's GDP rose by 0.1% year-on-year, Lithuania by 2.9%, while Estonia's fell by 2.4%. Despite geopolitical tensions and weak Eurozone growth, Latvia and Lithuania posted quarterly gains of 0.9% and 0.8%, respectively. Estonia's decline of 0.5% is linked to higher household and corporate debt, making it more sensitive to interest rates. Nonetheless, improving business and consumer sentiment suggests a cyclical recovery may be underway.

The 2020 drop in per capita GDP stemmed from global pandemic-related factors. Governments implemented stabilisation measures, increasing public debt. Latvia's debt rose from 35.2% to 42.7% in 2020, reaching 43.6% by 2023. Lithuania reduced its debt from 46.2% to 38.3%, while Estonia maintained the lowest ratio (around 18-19%) due to conservative fiscal policy.

EU-wide, public spending rose to fund crisis programmes. In the Baltics, post-COVID expenditure focused on healthcare, household support, and infrastructure. The war in Ukraine also impacted the region, with migration boosting Estonia's and Lithuania's populations in 2022. This narrowed the GDP per capita gap with Latvia.

In 2023, GDP per capita reached €16,300 in Estonia, €15,100 in Lithuania, and €13,200 in Latvia. The most pronounced divergence was observed during the 2020-2021 period, plausibly attributable to the comparatively stringent lockdown measures implemented in Latvia. When assessed in current prices, Estonia's elevated wage levels and consumer price index contribute to a further widening of the economic disparity among the Baltic states.

Inflation initially fell during the pandemic, with deflation in Estonia, but surged in 2021 due to rising resource and transport costs. In 2022, inflation peaked: Estonia at 19.4%, Lithuania at 18.9%, Latvia at 17.2%. By 2023, rates in Latvia and Lithuania dropped by nearly 50%, though remained above the EU average. This was largely due to the base effect from falling energy prices. However, domestic prices continued rising, especially in services, where inflation exceeded 5% in Latvia and Lithuania. In early 2024, Latvian service prices rose over 3%. Despite expected declines in heating costs, inflation may rise again as the base effect fades.

During the COVID-19 pandemic, purchasing power parity (PPP) declined in Latvia and Estonia, while Lithuania experienced a notable increase. By 2023, Lithuania's real GDP, adjusted for PPP, reached 86% of the European Union average – surpassing Estonia (81%) and Latvia (71%). This development

positioned Lithuania as the leading economy among the Baltic states in terms of relative economic convergence with the EU.

The 2020 GDP decline also reflected reduced exports and labour input. Demand for Baltic exports fell, leading to job losses and higher unemployment – most notably in Lithuania. In 2021, Latvia's unemployment dropped to 7.6%, still the highest in the region. Estonia recorded the lowest rate (6.2%), followed by Lithuania (7.1%).

Despite modest growth, labour markets remain resilient. Unemployment neared historic lows but rose slightly in late 2023 and early 2024, especially in construction and manufacturing. The rise is mainly due to increased labour supply, driven by Ukrainian refugees and net migration. More individuals, especially women, are entering the workforce. High inflation has encouraged dual-income households, while falling birth rates reduced parental leave. Many women who left the workforce during the pandemic have returned. Nonetheless, demographic shifts (particularly the shrinking working-age population) pose ongoing challenges.

Low unemployment has driven wage growth: in Q1 2024, average wages rose by 11% in Latvia, 10.3% in Lithuania, and 8.8% in Estonia (Eurostat, 2025). However, in Latvia and Estonia, wages have lagged inflation since 2021 and are only now beginning to catch up.

The Baltic States face significant demographic challenges, including population decline due to low fertility and migration. These disparities – across population size, life expectancy, and migration – shape divergent social and economic policy outcomes. A comparative summary of key demographic indicators as of early 2023 is presented in Table 2.

Table 2

Demographic Indicators of Latvia, Estonia, and Lithuania (as of early 2023)

Indicator	Latvia	Estonia	Lithuania
Population (million)	1.8	1.3	2.7
Life expectancy at birth (years)	75.8	76.8	74.3
Population density (persons/km ²)	31.3	30.2	43.7
Fertility rate (children per woman)	1.53	1.44	1.56
Mortality rate (per 1,000 people)	14.6	12.1	14.1
Net migration rate (per 1,000 people)	−0.3	+0.6	−2.3

Source: compiled by the authors (based on data from the Statistical Yearbook of Latvia; Official Statistical Portal of Lithuania; Statistics Estonia).

Lithuania has the highest population and density among the Baltic States, while Estonia has the lowest. Estonia also shows the lowest mortality rate and the most positive net migration.

From 2007 to 2023, Estonia's population grew by 1.7%, while Latvia and Lithuania saw declines of 14.8% and 12.1%, respectively. If Latvia and Estonia had similar development levels in 2007 and experienced comparable growth, Latvia's GDP per capita today would exceed Estonia's by 15%, largely due to Latvia's sharper population decline. Until 2020, Latvia maintained steady economic growth, driven by stabilization policies and significant labour migration.

The most significant divergence in GDP per capita between Latvia and its Baltic neighbours occurred during the 2020–2021 period, likely reflecting the comparatively more restrictive COVID-19 containment measures implemented in Latvia. By 2023, GDP per capita stood at €16,300 in Estonia, €15,100 in Lithuania, and €13,200 in Latvia. When assessed in current prices, the disparity is further accentuated, driven in part by Estonia's higher wage levels and elevated consumer prices, particularly for goods included in inflation indices.

3. Trends in Social Policy Development in the Baltic States under the Influence of the COVID-19 Pandemic

In the post-COVID period, all three Baltic States saw a decline in social protection expenditures, mainly due to the termination of temporary support measures such as downtime benefits. This led to a notable drop in unemployment-related spending.

While the share of social protection in GDP remains a key metric, annual per capita spending offers a more nuanced view. In 2022, Latvia spent €3,600 per inhabitant, slightly below Lithuania (€3,800) and Estonia (€4,200). Over the year, Latvia's per capita spending rose by 5.8%, compared to 3.7% in Lithuania and 4.2% in Estonia. In 2023, Latvia remained behind its neighbours, with €3,700 per person versus €4,100 in Lithuania and €4,300 in Estonia. Growth rates were 4.1% in Latvia, 4.8% in Lithuania, and 2.2% in Estonia. At the EU level, Luxembourg led with €27,000 per capita, while Latvia ranked among the lowest, ahead only of Hungary, Bulgaria, and Romania (Eurostat, 2025).

Wages also increased across the region. In 2022, Lithuania had the highest minimum wage (€730), followed by Estonia (€654) and Latvia (€500). By 2023, these rose to €840, €725, and €620 respectively. Average wages followed a similar pattern, with Latvia consistently lagging (Pol'skiy Konsul'tant, 2025). EU-wide, disparities remain stark: Luxembourg tops the list (€2,638), while Bulgaria sits at the bottom (€551).

The pandemic deepened social inequality, especially for vulnerable groups. In 2023, the share of population at risk of poverty was 25.6% in Latvia, 24.3% in Lithuania, and 24.2% in Estonia – well above the EU average of 21.3%. The highest rates were recorded in Bulgaria, Romania, and Greece. Pensioners were particularly affected: 46.5% in Latvia, 39.2% in Lithuania, and 55.0% in Estonia lived below the poverty line. Among those aged 65+, the figures were even higher – 67.8% in Latvia, 57.6% in Lithuania, and 79.1% in Estonia – two to three times the EU average of 27.3% (Eurostat, 2025).

Taken together, these indicators do not yield a clear verdict on which Baltic State weathered the pandemic most effectively. Each faced distinct challenges in balancing economic recovery with social protection.

Against this backdrop, the recovery strategies of the Baltic States must be viewed within the broader EU post-pandemic policy framework (Aude M, 2025). Central to this is the Recovery Plan for Europe, launched under the NextGenerationEU initiative, which supports member states in building more resilient, digital, and sustainable economies. The plan emphasizes green investment, digital infrastructure, and social cohesion, while promoting fiscal discipline and long-term competitiveness (European Commission, 2025). The allocation of recovery funds and conditionality of national plans have shaped key reforms in Estonia, Latvia, and Lithuania – particularly in labour markets, health-care, and digital public services (Consilium, 2024).

4. Research Methodology

The comparative analysis of the socio-economic development of the Baltic States was conducted in several stages:

1. A review of the literature and relevant data has been undertaken to identify and process statistical indicators reflecting various aspects of socio-economic development in the selected regions.
2. The selection of an appropriate method is imperative for the purpose of comparing the social and economic policy of the Baltic States in the post-pandemic period.
3. A comparative analysis is undertaken to identify patterns of socio-economic development through the interrelation of multiple factors.

To achieve this, two complementary methods are applied: PCA and DTW. Their combination enables the assessment of both structural differences and the pace and nature of recovery over time.

– PCA is used to reduce the dimensionality of complex datasets and identify latent factors that shape socio-economic development. It aggregates diverse indicators into integrated components, simplifying interpretation and revealing key patterns across countries.

– DTW is employed to analyse the temporal trajectories of indicators, especially in the context of asynchronous recovery. It allows for the comparison of time series with differing rates of change, capturing similarities and divergences in dynamics.

The selection of indicators was guided by a thorough review of existing literature and statistical sources, with the aim of ensuring their accessibility, reliability, and relevance (McKinsey & Company,

2024). The final set comprises 21 indicators: 10 pertaining to economic policy and 11 to social policy (as presented in Table 3). These indicators span key domains of socio-economic governance, including social protection, employment, income distribution, poverty, healthcare, education, demographic trends, and macroeconomic performance (Tsaurkubule & Zhukovskaya, 2024).

Table 3

System of socio-economic policy indicators

Economic Policy Indicators	Social Policy Indicators
1. GDP per capita at PPS, % of the EU average (EU = 100%)	1. Social protection expenditures, % of GDP
2. Real GDP growth rate, %	2. Life expectancy at birth, years (average value)
3. Total government expenditures, % of GDP	3. Average monthly wage, EUR
4. Government debt, % of GDP	4. Minimum monthly wage, EUR
5. Shadow economy level, % of GDP	5. Minimum monthly wage as a percentage of the average monthly wage, %
6. Inflation (average annual growth rate), %	6. Income inequality (Gini coefficient), %
7. Employment rate, %	7. Proportion of population at risk of poverty, %
8. Unemployment rate, %	8. Proportion of residents living below the poverty line, %
9. Population, thousand people	9. Proportion of residents experiencing severe material and social deprivation, %
10. Emigration, thousand people	10. Proportion of pensioners at risk of poverty, %
	11. Proportion of pensioners (65+) at risk of poverty, %

This study extends the findings of the earlier research by Tsaurkubule & Zhukovskaya (2024), which employed the DTW method to explore similarities and differences in the development trajectories of the Baltic States. DTW enables the comparison of socio-economic development paths even when the timing and pace of change vary across countries. In that context, the method revealed the degree of synchrony or divergence among Estonia, Latvia, and Lithuania from 2020 to 2023.

The analytical process followed a structured sequence. First, data from 2019-2023 were collected and normalized to ensure comparability. PCA was then applied to identify latent dimensions of socio-economic development. The current PCA-based findings were compared with earlier results obtained DTW-based findings, which focused on the temporal alignment of recovery trajectories. The results were visualized and clustered to reveal patterns of divergence and convergence. Finally, the findings were interpreted to draw policy-relevant conclusions.

5. PCA of Economic and Social Policy Indicators in the Baltic States during the Post-COVID Period (2020–2023)

5.1. PCA of Economic Indicators

To assess the structural dynamics of macroeconomic development among the Baltic states – Lithuania, Latvia, and Estonia – Principal Component Analysis was applied to a set of economic indicators in 2020-2023 years (Tsaurkubule & Zhukovskaya, 2024).

The first two principal components (PC1 and PC2), together explaining 68,2% of the total variance, were selected for interpretation and visualisation. PC1 was interpreted as a composite indicator of *macroeconomic vulnerability*, while PC2 reflected a dimension of *economic prosperity coupled with government expenditure efficiency*.

In the social and economic sciences, it is accepted that if the first two components explain 60% or more, this already allows a meaningful interpretation of the data in the PC1-PC2 space. This is especially true when variables are partially correlated (and in economics this is almost always the case: GDP growth is correlated with investment, unemployment with inflation, etc.) (Hair et al, 2010).

In our case the first two principal components explain 68,2% of the total variation in the data or more 2/3 of the total information contained in the data, this is enough to visualise and analyse countries in a two-dimensional PC1 × PC2 space. The remaining ~32% are small variations, “noise”, less significant differences that can be omitted in the initial visual and comparative analyses.

Let's look at the detailed interpretation of the first and second Principal Components (PC1 and PC2) (see table 4). This will answer the question of which of these indicators made the greatest impact on each of the two principal components.

The first principal component (PC1) (explain approx. 40.8% of variance) captures a *latent dimension of macroeconomic and institutional vulnerability*. It is primarily driven by high positive loadings on government debt (+0.953), shadow economy (+0.751), unemployment (+0.740), and population/emigration indicators, alongside a strong negative loading on employment rate (-0.896). These patterns suggest that PC1 distinguishes between countries exhibiting signs of structural economic fragility – characterized by fiscal imbalances, weak labour markets, and informal economic activity – and those with relatively stable, well-functioning labour and fiscal systems. As such, PC1 can be interpreted as a composite index of economic instability and systemic inefficiency.

The second principal component (PC2) (explain approx. 27,4% of variance) can be interpreted as an *indicator of economic prosperity with limited government expenditure*. It is primarily characterized by a strong negative loading on total government expenditures (-0.967) and a high positive loading on GDP per capita at purchasing power standards (+0.787). This suggests that PC2 differentiates between countries with higher income levels and relatively lean public sectors, versus those with lower incomes and larger government spending relative to GDP. Additional positive contributions from population size, inflation, and emigration further indicate that PC2 may also reflect demographic capacity and growth-related pressures. Overall, PC2 captures a structural distinction between market-oriented, higher-income economies and more state-reliant, lower-income economies.

Table 4

**Interpretation of the First and Second Principal Components (PC1 and PC2)
of the economic indicators**

n	Indicator	PC1	PC2	Interpretation
1	GDP per capita at PPS (% of EU average)	-0.209	+0.787	↑ Prosperity and Fiscal Efficiency (PC2), ↓ Structural Vulnerability (PC1)
2	Real GDP growth rate (%)	+0.297	+0.214	↑ Economic Growth (both PCs, moderate influence)
3	Total government expenditures (% of GDP)	-0.038	-0.967	↓ Government Spending (PC2)
4	Government debt (% of GDP)	+0.953	-0.017	↑ Fiscal Burden / Vulnerability (PC1)
5	Shadow economy (% of GDP)	+0.751	+0.046	↑ Informal Economy and Structural Weakness (PC1)
6	Inflation (average annual growth rate, %)	-0.313	+0.479	↑ Inflationary Pressure and Prosperity (PC2), ↓ Stability (PC1)
7	Employment rate (%)	-0.896	+0.329	↑ Employment and Economic Stability (↓ Vulnerability) (PC1), moderate ↑ Prosperity (PC2)
8	Unemployment rate (%)	+0.740	-0.417	↑ Unemployment and Economic Strain (PC1), ↓ Prosperity (PC2)
9	Population (thousand people)	+0.761	+0.613	↑ Population Size, Demographic Pressure and Economic Activity (both PCs)
10	Emigration (thousand people)	+0.672	+0.495	↑ Emigration and Demographic Outflow (both PCs), indicating social and economic challenges

5.2. Country-Level Trajectories of Economic Policy Changes in PCA Space (2020-2023)

This section examines the structural evolution of economic indicators in Lithuania, Latvia, and Estonia from 2020 to 2023 through the lens of Principal Component Analysis (PCA). By projecting each country-year observation into a two-dimensional component space it is possible to trace the trajectory of macroeconomic transformation and policy dynamics across the post-pandemic period (see figure 1).

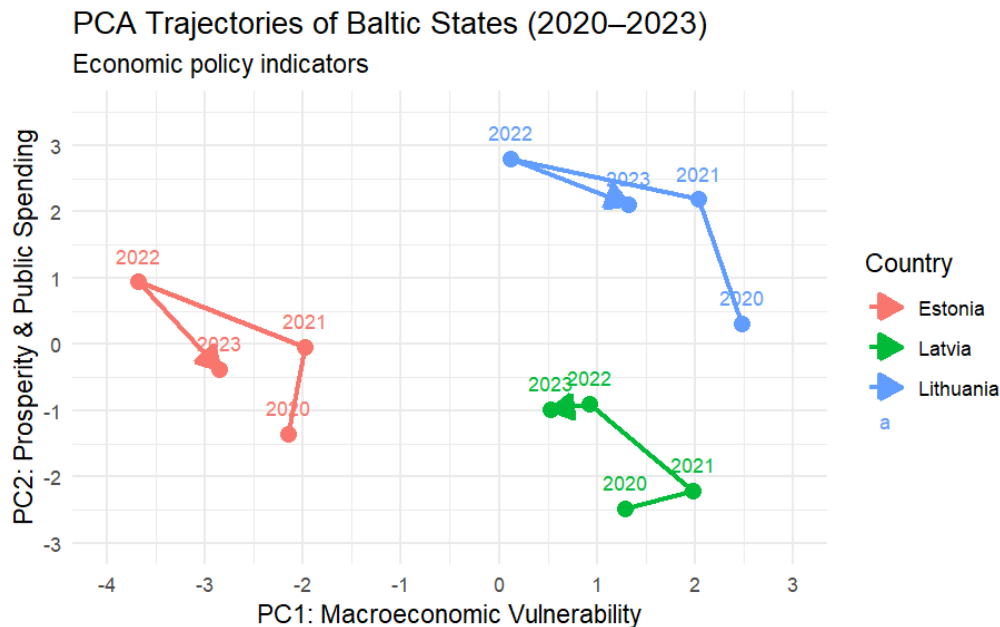


Fig. 1. Trajectories of changes of economic indicators of Baltic states in the two-dimensional PCA

Latvia's trajectory exhibits a gradual but consistent movement towards reduced macroeconomic vulnerability, as evidenced by a decline in PC1 values from 2020 (+1.29) to 2023 (+0.53). This likely reflects improvements in employment rates and moderate reductions in public debt and shadow economy size. In parallel, PC2 values increased markedly between 2020 (-2.48) and 2022 (-0.90), suggesting an improvement in relative prosperity, although the trajectory slightly reversed in 2023 (-0.98). This stagnation may reflect short-term inflationary pressures or renewed fiscal burden. Overall, Latvia demonstrates a steady structural improvement, albeit with some volatility in the final year.

Lithuania shows the most pronounced positive shift in the PC2 dimension, with values rising from +0.31 in 2020 to a peak of +2.80 in 2022, indicating significant economic convergence and improved performance in GDP per capita and employment levels. However, the PC2 value declined slightly in 2023 (+2.11), which may signal the onset of structural constraints or the impact of external shocks. In terms of vulnerability (PC1), Lithuania experienced a sharp decline in 2022 (from +2.04 in 2021 to +0.11), suggesting a substantial but possibly temporary reduction in fiscal and labour market stress. The rebound to +1.32 in 2023 may indicate the fragility of these gains. Overall, Lithuania's trajectory reveals rapid but uneven improvements, with a risk of reversal in the short term.

Estonia consistently occupies the lower-left quadrant of the PCA space, reflecting low macroeconomic vulnerability (PC1) and moderate to high economic prosperity (PC2). PC1 values remained strongly negative throughout the period (e.g., -2.15 in 2020, -2.86 in 2023), indicating persistent structural strength, particularly in terms of employment and fiscal discipline. PC2 values increased from -1.35 in 2020 to +0.94 in 2022, suggesting convergence towards a more prosperous profile. However, a decline to -0.38 in 2023 may point to emerging pressures, possibly associated with inflation, fiscal

policy shifts, or demographic challenges. Despite this, Estonia maintained the most favourable position among the Baltic countries throughout the period.

The trajectories of the three Baltic states reveal both commonalities and divergences. All countries demonstrated movement toward reduced vulnerability (lower PC1) between 2020 and 2022, though Latvia and Lithuania began to diverge in 2023. Estonia remained structurally stable, albeit with signs of pressure in the prosperity dimension (PC2). The multidimensional PCA space thus provides a compact and interpretable framework for tracing the evolution of economic conditions across countries and time.

5.3. PCA for social indicators (2020-2023)

A PCA was conducted on a set of eleven social indicators reflecting the income distribution, poverty risk, wage structure, welfare provision, and material well-being of populations in the Baltic states. The analysis focused on the first two principal components (PC1 and PC2), which together explain 74.4% of the total variation in the data or approx. The detailed interpretation of the PC1 and PC2 are given in the table 5.

The first principal component (PC1) explains 42.6% of the variance, *reflects a social inequality and vulnerability dimension, capturing systemic exclusion and the limited effectiveness of redistribution in alleviating poverty, especially among the elderly.*

Table 5

**Interpretation of the First and Second Principal Components (PC1 and PC2)
of the social indicators**

n	Indicator	PC1	PC2	Interpretation
1	Income inequality (Gini coefficient)	+0.90	0.00	↑ Inequality (PC1)
2	Severe material and social deprivation	+0.89	-0.21	↑ Deprivation (PC1)
3	Pensioners (65+) at risk of poverty	-0.90	-0.37	↓ Inclusion & Welfare (PC1)
4	Pensioners at risk of poverty (all ages)	-0.82	-0.31	↓ Inclusion (PC1)
5	Life expectancy	-0.76	+0.54	↑ Prosperity (PC2), ↓ Inequality (PC1)
6	Minimum wage / average wage	+0.77	+0.49	↑ Compression (PC1), ↑ Prosperity (PC2)
7	Population at risk of poverty	+0.34	-0.47	↑ Vulnerability (PC1), ↓ Prosperity (PC2)
8	Proportion living below poverty line	-0.21	-0.79	↓ Prosperity (PC2)
9	Social protection expenditures (% of GDP)	+0.49	-0.38	↑ Redistribution (PC1), ↓ Wage-Based Prosperity (PC2)
10	Minimum monthly wage	-0.02	+0.95	↑ Wage Prosperity (PC2)
11	Average monthly wage	-0.19	+0.90	↑ Wage Prosperity (PC2)

PC1 is characterized by strong positive loadings on indicators associated with social inequality and exclusion, such as the Gini coefficient (+0.90), the proportion of the population experiencing severe material and social deprivation (+0.89), and the share of minimum to average wages (+0.77). Additionally, it is positively associated with the risk of poverty (+0.34) and social protection expenditures (+0.49).

Negative loadings are observed for life expectancy at birth (-0.76) and particularly for poverty among pensioners (-0.82) and among those aged 65+ (-0.90), suggesting that lower PC1 values are associated with greater longevity and stronger protection of elderly populations. The pattern of loadings indicates that this component distinguishes between socially inclusive societies with effective welfare policies and those marked by structural poverty, inequality, and weak redistributive mechanisms.

The second principal component (PC2) explains 31.9% of variance, reflects absolute welfare via market incomes, identifying differences in wage levels and how effectively they reduce poverty.

PC2 is defined by strong positive associations with labour market income indicators, including the minimum monthly wage (+0.95), average monthly wage (+0.90), and life expectancy (+0.54). It is negatively associated with the proportion of residents living below the poverty line (-0.79), the population at risk of poverty (-0.47), and social protection expenditures (-0.38).

This component contrasts high-income, low-poverty systems – where wage levels are sufficient to ensure well-being – with contexts in which public transfers play a more prominent role, but wage-based welfare is weak. Unlike PC1, the Gini coefficient has a zero loading on PC2, indicating that relative income distribution is not a primary driver of this dimension. Rather, it reflects absolute income levels and their capacity to reduce poverty independent of formal redistribution mechanisms.

Together, these two axes provide a coherent framework for evaluating social policy trade-offs across countries and over time: some countries may reduce poverty primarily through public transfers (low PC1), while others rely on wage growth and labour market strength (high PC2).

5.4. Country-Level Trajectories of Social Development in PCA Space (2020-2023)

To examine the temporal evolution of social policy outcomes in the Baltic states, country-year observations were projected into a two-dimensional principal component space derived from eleven social indicators. The first component (PC1) captures a social inequality and structural vulnerability dimension, while the second component (PC2) reflects wage-driven prosperity and poverty avoidance. Together, these axes allow for a compact representation of each country's social development profile over time (see figure 2).

Latvia begins the observation period in 2020 with moderately high PC1 (+0.37) and the lowest PC2 value among the three countries (-2.96), indicating a combination of elevated inequality and low wage-based welfare. Over the four-year span, PC1 increases to a peak in 2021 (+1.15), suggesting a temporary deterioration in distributional outcomes, before gradually declining to +0.67 in 2023, signalling some improvement in structural inclusiveness.

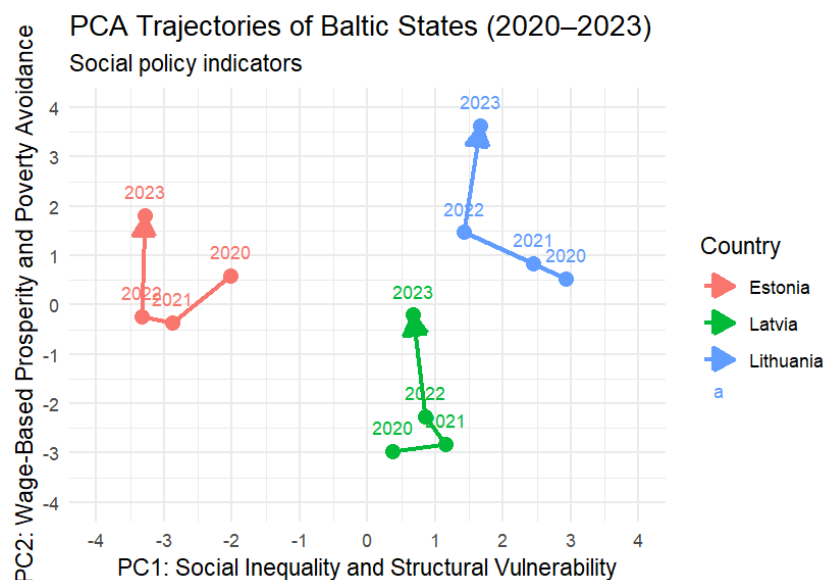


Fig. 2. Trajectories of changes of social indicators of Baltic states in the two-dimensional PCA

More notably, PC2 values rise significantly from -2.96 in 2020 to -0.21 in 2023, indicating a marked improvement in labour market-related welfare. This likely reflects rising wages and a reduction in poverty rates, consistent with a shift toward a more inclusive, wage-driven welfare model. However, Latvia remains in the quadrant associated with persistently moderate inequality and still-developing prosperity.

Lithuania starts in 2020 with the highest PC1 score (+2.93) among the Baltic states, reflecting pronounced social inequality, material deprivation, and elevated poverty risk, especially among vulnerable groups. Over time, PC1 decreases steadily to +1.66 in 2023, suggesting an improving distributional profile, albeit with continued structural vulnerabilities.

Simultaneously, Lithuania exhibits a consistent and dramatic rise in PC2 scores: from +0.53 in 2020 to +3.63 in 2023, indicating the most significant growth in wage-based prosperity of all three countries. This reflects both rising nominal wages and a declining proportion of the population living below the poverty line. By 2023, Lithuania positions itself as the regional leader in wage-based social well-being, despite lingering inequality.

Estonia presents an inverted trajectory compared to Lithuania. Beginning in 2020 with the lowest PC1 score (-2.02), Estonia consistently occupies the most egalitarian and socially inclusive position throughout the entire period, reaching -3.29 in 2023. This reflects strong protection of vulnerable populations, lower inequality, and robust life expectancy indicators.

However, Estonia's movement along PC2 is more modest and non-linear. After a slight dip from +0.59 in 2020 to -0.36 in 2021, PC2 values recover to +1.81 by 2023. This indicates delayed but eventual improvements in wage levels and poverty reduction, albeit less dramatic than those observed in Lithuania. Estonia remains in the low-inequality quadrant, but with a gradual shift toward greater wage prosperity.

In the PC1-PC2 space, Lithuania's trajectory reflects the most dynamic transformation, combining economic growth with expanding social protection through wage channels. Estonia maintains structural equality, slowly converging with Lithuania in prosperity. Latvia, though improving, still trails both neighbours, with more limited gains in inclusion and wages.

5.5. Alignment with Prior DTW-Based Research

This study builds on the findings of Tsaurkubule & Zhukovskaya (2024), who used DTW to explore convergence and divergence in the socio-economic trajectories of the Baltic States (2020–2023). While DTW captures temporal synchronicity, the Principal Component Analysis (PCA) applied here reveals latent structural patterns across economic and social indicators. Although the two methods yield broadly compatible results, several clarifications are needed.

- Latvia: DTW suggests stability, but PCA indicates a gradual yet volatile trajectory, with short-term reversals in 2023. Interpretation revised: Latvia shows structural improvement with intermittent fluctuations.

- Lithuania: Both methods confirm dynamic growth in 2022 followed by a mild retreat in 2023, consistent with reactive macroeconomic shifts.

- Estonia: DTW implies high variability, whereas PCA shows structural resilience and low vulnerability, with only moderate fluctuations in prosperity indicators.

Overall, the previously obtained (DTW) findings are confirmed and expanded by the results of the current (PCA) study.

Conclusion

The COVID-19 pandemic significantly reshaped the socio-economic landscape of the Baltic States -Estonia, Latvia, and Lithuania – exposing structural vulnerabilities while also accelerating digitalization, institutional reform, and green transformation. Each country faced distinct challenges and adopted varied crisis mitigation strategies, resulting in divergent recovery trajectories. Latvia experienced the deepest contraction and slowest rebound, while Lithuania and Estonia demonstrated more dynamic and resilient responses.

In the short term, the pandemic intensified existing issues such as income inequality, demographic pressure, and labour market fragility. Yet it also prompted innovation and policy shifts aimed at strengthening social protection and economic resilience. By 2023, the Baltic States had achieved moderate recovery, with stabilizing macroeconomic indicators and rising wages, though inflationary

pressures and household debt continued to shape financial behaviour – particularly in Latvia and Estonia.

This study offers a novel analytical contribution by integrating PCA and DTW to assess both the structural and temporal dimensions of post-pandemic recovery. PCA revealed latent factors such as macroeconomic vulnerability and welfare capacity, while DTW captured the synchronicity and divergence in recovery trajectories. The combination of these methods enabled a more nuanced understanding of how policy choices and institutional capacity influenced national outcomes. Data processing and visualization were conducted using the R programming language.

Findings show that Estonia maintained structural stability, Lithuania leveraged wage-driven growth despite inequality, and Latvia followed a more volatile path. These differences underscore the importance of adaptive governance, targeted investment, and EU-aligned recovery strategies. The dual-method approach presented here provides a replicable framework for evaluating crisis recovery in small open economies facing rapid transformation and uncertainty.

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