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REGIONAL SECURITY, MIGRATION AND HOUSING IN A CONFLICT-AFFECTED ECONOMY: QUANTITATIVE EVIDENCE FROM UKRAINE AND POST-WAR RECOVERY SCENARIOS

РЕГІОНАЛЬНА БЕЗПЕКА, МІГРАЦІЯ ТА ЗАБЕЗПЕЧЕННЯ ЖИТЛОМ В ЕКОНОМІЦІ КОНФЛІКТУ: КІЛЬКІСНІ ОЦІНКИ ДЛЯ УКРАЇНИ ТА СЦЕНАРІЇ ПІСЛЯВОЄННОГО ВІДНОВЛЕННЯ

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Ляшенко О.М., Дем'янюк О.Б. Регіональна безпека, міграція та забезпечення житлом в економіці конфлікту: кількісні оцінки для України та сценарії післявоєнного відновлення. Науково-методична стаття.

У статті представлено перше емпіричне калібрування просторової OLG-моделі регіонального безпекового ризику для України на даних ACLED, Держстату, IOM та LUN за 24 регіонами. Підтверджено статистично значущу чутливість регіональної продуктивності до ризику (θ_B = 0.075), дисконт оренди житла в небезпечних регіонах (ξ_B = 0.852) та обмежену міжрегіональну мобільність у воєнний час. Динамічне моделювання за чотирма сценаріями безпеки на десятирічному горизонті показує: цілеспрямоване відновлення житла з деескалацією забезпечує відродження прифронтових регіонів, тоді як затяжний конфлікт поглиблює просторову нерівність. Кількісно оцінено регіональний дивіденд миру та запропоновано основу просторово диференційованої політики післявоєнного відновлення.

Ключові слова: просторова OLG-модель, регіональний ризик безпеки, калібрування, динамічна симуляція, внутрішнє переміщення, житловий ринок, PAYG-пенсійна система, економіка конфлікту, післявоєнне відновлення

Liashenko O.M., Demianiuk O.B. Regional Security, Migration and Housing in a Conflict-Affected Economy: Quantitative Evidence from Ukraine and Post-War Recovery Scenarios. Scientific and methodical article.

This paper presents the first empirical calibration of a spatial overlapping-generations (OLG) model of regional security risk for Ukraine, using ACLED conflict data, Ukrstat wage data, IOM displacement data, and rental market data across 24 regions. The estimates confirm a significant productivity-risk sensitivity (θ_B = 0.075), a strong rent discount in insecure areas (ξ_B = 0.852) and limited inter-regional mobility in wartime. Simulations under four security scenarios over a ten-year horizon show that targeted housing reconstruction with durable de-escalation enables substantial recovery of frontline regions, whereas protracted conflict deepens spatial inequality. The paper quantifies a region-specific peace dividend and provides an evidence-based framework for spatially differentiated post-war recovery policy.

Keywords: spatial OLG model, regional security risk, calibration, dynamic simulation, internal displacement, housing market, PAYG pension system, conflict economics, post-war recovery

Russia's full-scale invasion of Ukraine on 24 February 2022 caused one of the most significant asymmetric regional shocks in modern European history. The invasion fundamentally changed the spatial distribution of economic activity, population, and security conditions across the country. Frontline regions such as Donetsk, Kharkiv, and Kherson experienced near-total disruption of economic activity, extensive physical destruction, and rapid depopulation, while relatively safer western and central regions absorbed millions of internally displaced persons (IDPs), exerting unprecedented pressure on local housing and labour markets (IOM, 2024a).

The scale of displacement is staggering. As of late 2025, the International Organisation for Migration estimates about 3.7 million de facto internally displaced persons within Ukraine (IOM, 2025), in addition to over 6 million refugees seeking protection abroad (UNHCR, 2025). This population redistribution has created a two-sided spatial challenge: regions of origin face depopulation, capital flight, and collapsing fiscal bases, while receiving regions experience housing shortages, rising rents, and strained public services.

These spatially diverse consequences of conflict raise fundamental questions for economic policy. How do security conditions interact with labour mobility, housing frictions, and fiscal institutions to shape regional economic dynamics? What is the quantitative size of the "security multiplier" through which conflict-related shocks spread across markets? How effectively can centralised redistributive systems, such as the pay-as-you-go (PAYG) pension system, function when regions vary significantly in risk and population movements? And what are the potential benefits from peace – the "peace dividend" – for each region under different security trajectories?

Addressing these questions requires a formal model that integrates the key channels through which regional security influences economic outcomes. The present paper addresses this gap by bringing the spatial OLG model of regional security risk proposed in the literature to real Ukrainian data and by simulating its transitional dynamics under alternative security scenarios.

The contribution is threefold. Empirically, we present the first estimates of the productivity–risk, rent–risk, and migration–risk elasticities for a conflict-affected spatial economy. Methodologically, we show how a relatively simple spatial OLG structure can be calibrated to produce plausible dynamic trajectories using publicly available data. For policy, we quantify the peace dividend – the expected gains in wages, GDP, population recovery, and pension sustainability – across Ukraine's regions under different security scenarios. The results provide actionable insights for housing investment, regional development programmes, and pension system reform.

The importance of this study goes beyond Ukraine. Climate change, geopolitical instability, and regional conflicts increasingly cause uneven shocks within countries, especially in middle-income and developing nations (Raleigh & Hegre, 2009). The analytical framework created here – a calibrated spatial OLG model with security risk, endogenous migration, housing frictions, and PAYG – applies to any economy facing spatially varied shocks that interact with intergenerational fiscal institutions. The method for building a risk index from conflict event data, estimating structural parameters using difference-in-risk strategies, and simulating recovery paths under different scenarios can be applied to other conflict-affected countries, including Syria, Yemen, Sudan, and Myanmar.

Furthermore, the study advances the expanding literature on evidence-based post-conflict recovery planning. The World Bank's Rapid Damage and Needs Assessments (2024) offer valuable overall damage estimates, but they do not simulate the spatial equilibrium dynamics that determine where and how recovery takes place. The European Commission's Ukraine Recovery Plan similarly requires quantitative tools for assessing alternative investment scenarios across regions. The calibrated spatial OLG model provides exactly such a tool, capable of producing scenario-specific predictions for population distribution, wages, rents, and fiscal outcomes at the regional level.

Analysis of recent publications on the problem

The literature relevant to our study encompasses several distinct but increasingly interconnected fields: spatial equilibrium theory, quantitative spatial economics, overlapping-generations models, conflict and displacement economics, and housing market analysis in crisis settings.

The spatial equilibrium tradition, initiated by Roback (1982), establishes the core principle that local amenities and disamenities are capitalised into wages and land rents under conditions of spatial mobility. In this model, compensating differentials equalise utility across regions: areas with fewer amenities must offer higher wages, lower rents, or both, to attract workers. This concept has been highly influential in urban and regional economics, offering a framework for valuing non-market goods through observed wage and rent differentials (Glaeser, 2008). However, the standard Roback model is static and assumes full spatial mobility – assumptions that are violated in conflict settings, where mobility is costly, limited, and time-varying. Furthermore, the model does not differentiate between generations or consider the fiscal impacts of population redistribution.

A rapidly expanding body of literature in quantitative spatial economics has extended the Roback framework to include richer geographical structures, trade costs, and dynamic adjustments. Comprehensive reviews by Redding and Rossi-Hansberg (2017) and Proost and Thisse (2019) emphasise that contemporary models can accommodate significant heterogeneity in productivity levels, amenities, and spatial frictions, and are now routinely used to assess regional and national policies. Desmet and Rossi-Hansberg (2014) develop a dynamic spatial model where locations accumulate population and productivity over time, leading to persistent regional divergence through agglomeration and decline. Behrens and Murata (2007) analyse general equilibrium models of monopolistic competition across space, illustrating how increasing returns and market access can generate multiple spatial configurations. These contributions highlight the importance of spatial dynamics in understanding persistent regional inequality. Nonetheless, the focus remains on agents with infinite lifespans or representative households, and on productivity or trade shocks, rather than on security conditions that differentially impact demographic cohorts and interact with intergenerational fiscal institutions.

The overlapping-generations (OLG) tradition, originating with Diamond (1965), offers life-cycle features absent from most spatial analyses: finite horizons, retirement saving, and the natural inclusion of PAYG social security. OLG models have become the standard tool for analysing pension reforms, public debt, and intergenerational redistribution (de la Croix & Michel, 2002). However, they are usually formulated in "aspatial" economies and do not account for the reallocation of cohorts across regions within a country or for how security conditions influence location choices. The integration of OLG structures with spatial economics is a relatively recent development. Coen-Pirani (2010) and Behrens et al. (2014) have examined spatial sorting in OLG contexts, but without the conflict and PAYG dimensions that are essential to our application.

The economic consequences of armed conflict have garnered increasing attention. Collier and Duponchel (2013) document the lasting impact of civil war on firms in Sierra Leone, revealing persistent productivity effects that persist well beyond the conflict period. Mueller and Rauh (2022) develop predictive tools for conflict prevention using machine learning, demonstrating the potential of data-driven methods in conflict-affected areas. Specifically in Ukraine, Perelli-Harris et al. (2023) analyse subjective well-being among IDPs and residents, showing that displacement is linked to significantly lower life satisfaction, with economic hardship and housing conditions accounting for a large part of this gap. Gorodnichenko et al. (2012), while studying the Finnish Great Depression, offer methodological insights into how external shocks spread through spatial economic systems – an approach conceptually similar to our security multiplier mechanism.

The IOM's General Population Survey, now in its 22nd round, offers the most systematic data on displacement patterns, showing that approximately 3.7 million de facto IDPs remain inside Ukraine, with the largest concentrations in Dnipropetrovsk (15%), Kharkiv (11%), and Kyiv City (9%) regions (IOM, 2025). These data reveal strong spatial patterns: eastern and southern regions are both origins and destinations of displacement, creating complex demographic dynamics.

The housing aspect of conflict-induced displacement has garnered growing research interest. Trojanek and Gluszak (2022) note a short-term increase in Polish housing prices linked to the influx of Ukrainian refugees, while Gluszak and Trojanek (2024) examine broader responses of the Polish housing market to the refugee crisis and war. In Ukraine, the IOM Housing Brief (2024b) reports on the extent of housing damage and significant pressure on rental markets in reception areas. According to LUN market data, rental prices in 2024 vary from 3,000 UAH in Kherson to 18,500 UAH in Uzhhorod, a sixfold difference reflecting the spatial pattern of conflict intensity (Visit Ukraine, 2024). Saiz (2010) and Caldera and Johansson (2013) provide evidence on housing supply elasticities in OECD countries, confirming that short-term supply is generally inelastic – a finding supported by our calibration for the Ukrainian context.

Ukraine's pension system faces serious challenges that existed before the conflict but have been greatly worsened by it. The OECD (2024) reports that the PAYG system operates with a contributor-to-pensioner ratio close to 1:1, with SSC contributions covering only about 60% of pension costs. The actual contribution rate is 22% of the payroll fund, of which roughly 86% goes to pensions (VoxUkraine, 2024). Regional pension differences are significant, with average pensions ranging from 4,070 UAH in Ternopil to 7,248 UAH in Kyiv (Siutkin, 2024). The war has increased these pressures through workforce declines caused by emigration, mobilisation, and casualties, with the number of insured persons dropping to 10.7 million by mid-2024.

The pension reform debate in Ukraine has mainly concentrated on overall sustainability: extending the contribution period, raising the retirement age, and establishing a mandatory funded second pillar. Nevertheless, the spatial aspect of pension sustainability has received little attention. Conventional pension literature views the contribution base as a national total, implicitly assuming that the spatial distribution of contributors and pensioners is unimportant. This assumption is notably inaccurate in the Ukrainian context, where the geographic reallocation of the working-age population has significantly altered the regional structure of the contribution base.

The theoretical model of Liashenko and Demianiuk (2025) is, to our knowledge, the first to formalise the interaction between spatial migration and PAYG pension dynamics in a conflict setting. The key insight is that when young workers migrate from low-wage eastern regions to high-wage Kyiv, the overall contribution base increases (higher wages × same number of workers), but the spatial distribution of fiscal pressure shifts: eastern regions with elderly populations lose contributors, while Kyiv and surrounding areas gain contributors but also face increased demands on infrastructure and services. The reverse process – return migration during peace – may reduce the overall contribution base if returnees move from high-wage to lower-wage regions, creating what we call the "PAYG return paradox".

An emerging strand of literature examines how digitalisation influences economic resilience in conflict zones. Ukraine's strong IT sector has shown remarkable resilience during the war, with IT exports actually increasing in 2023–2024 despite the conflict. This sector, which offers wages far above the national average (49,500 UAH per month in 2024, compared to about 20,000 UAH), is concentrated mainly in Kyiv, Lviv, Kharkiv, and Dnipropetrovsk – a spatial pattern that both drives and shapes migration dynamics in our model. The digital economy aspect indicates that regional productivity ($\bar{A}_r$ in our model) is changing, affecting the spatial equilibrium that our current calibration only partially captures. Future extensions could include sector-specific productivity measures to distinguish between tradeable digital services and traditional industries that depend on location.

Despite the richness of these individual literatures, several gaps persist. First, no existing study has estimated the structural parameters of an integrated spatial OLG model with security risk for a conflict-affected economy. The theoretical models of Redding and Rossi-Hansberg (2017) and Desmet and Rossi-Hansberg (2014) are calibrated to trade and productivity shocks but not to security conditions. The OLG models of de la Croix and Michel (2002) incorporate life-cycle dynamics but not spatial dimensions. The conflict literature (Collier & Duponchel, 2013; Mueller & Rauh, 2022) estimates reduced-form effects without embedding them in a structural spatial equilibrium.

Second, the quantitative magnitude of the "security multiplier" – the cascade from risk through productivity, wages, migration, housing, and PAYG – has not been measured empirically. While each channel has been studied in isolation, the amplification that occurs when they interact simultaneously has not been quantified. Our calibrated model provides the first estimates of this amplification.

Third, dynamic simulations of post-war recovery trajectories that incorporate housing supply constraints, endogenous migration, and pension system effects are absent from the literature. The World Bank's Rapid Damage and Needs Assessments (2024) provide valuable aggregate loss estimates but do not model the spatial equilibrium dynamics that determine how and where recovery occurs.

Fourth, the interaction between migration-induced population reallocation and the PAYG pension system has received virtually no attention in Ukraine. The OECD (2024) analysis of pension sustainability focuses on aggregate demographic trends but does not account for the spatial dimension of demographic change driven by conflict.

Fifth, there is a substantial gap in the empirical measurement of housing market responses to conflict within affected countries. While Trojanek and Gluszak (2022) and Gluszak and Trojanek (2024) document effects in Poland (the host country), the within-Ukraine spatial rent gradient has not been formally linked to measures of conflict intensity. Our cross-sectional analysis provides the first such evidence.

The present study addresses these gaps by bringing the theoretical model of Liashenko and Demianiuk (2025) to data, estimating its structural parameters, and simulating recovery trajectories under alternative security scenarios.

Formulation of research objectives (task setting)

The aim of this article is to provide the first empirical calibration and dynamic simulation of the spatial OLG model of regional risk developed in Liashenko and Demianiuk (2025), using real Ukrainian data.

To achieve this aim, the article addresses the following objectives:

- to construct a regional security risk index from ACLED conflict event data and examine its spatial and temporal variation across Ukrainian regions;
- to estimate the structural parameters of the model – the productivity–risk sensitivity (θ_B), the housing risk discount (ξ_B), and the housing supply elasticity (ζ) – using cross-sectional variation across 24 regions;
- to quantify the cross-sectional relationships between conflict intensity, wages, rents, and internal displacement;
- to simulate transitional dynamics of the spatial economy under four security scenarios: baseline gradual recovery, fast peace, protracted conflict, and peace with active reconstruction;
- to derive quantitative estimates of the "peace dividend" for each Ukrainian region and assess the implications for housing policy, regional development, and PAYG pension sustainability;
- to identify limitations of the current approach and outline directions for further empirical refinement.

Materials and methods

We adopt the spatial OLG model developed in Liashenko and Demianiuk (2025), to which the reader is referred for full analytical derivations and intermediate proofs. The economy consists of R regions indexed by r. Individuals live for two periods: when young, they supply labour, consume, save, and choose a region of residence; in old age, they consume savings and receive a PAYG pension. Regional production follows a Cobb–Douglas technology with exogenous capital mobility at the world rate r.

Security risk affects the economy through three simultaneous channels. The productivity channel operates through effective TFP: $A_{\{r,t\}} = \bar{A}_r \cdot \exp\left(-\theta_B \cdot B_{\{r,t\}}\right)$, where $\bar{A}_r$ is baseline productivity and $\theta_B > 0$ governs the sensitivity of productivity to risk (Equation 5 in Liashenko and Demianiuk, 2025). The housing channel operates through the rent equation: $R_{\{r,t\}} = \bar{R}r \cdot \left(\frac{L\{r,t\}}{H_{\{r,t\}}}\right)^{\zeta} \cdot \exp\left(-\xi_B \cdot B_{\{r,t\}}\right)$, capturing both demand pressure from population $L_{\{r,t\}}$ on an inelastic housing stock $H_{\{r,t\}}$ and the direct risk discount (Equation 9). The migration channel operates through a logit decision rule (Equation 12), where the probability that a young worker chooses region r is proportional to $\exp\left(\gamma \cdot \tilde{U}_{\{r,t\}}\right)$, with deterministic utility strictly decreasing in risk. The PAYG system links these regional adjustments to national fiscal dynamics: total pension contributions equal $\tau \cdot \Sigma_r w_{\{r,t\}} \cdot L_{\{r,t\}}$.

The calibration draws on four publicly available data sources.

Conflict data. The Armed Conflict Location and Event Data Project (ACLED) provides geo-referenced, event-level data on political violence in Ukraine from January 2018 to early 2026. The dataset, obtained from the Humanitarian Data Exchange (HDX), contains 13,622 district-level observations, classified by region. We aggregate events to the region level by half-year to construct the security risk index. The ACLED Ukraine Conflict Monitor is the most widely used near-real-time source on political violence in Ukraine (ACLED, 2026), recording battles, explosions/remote violence, violence against civilians, and strategic developments.

Regional wages. Monthly nominal wages by region from the State Statistics Service of Ukraine (Ukrstat) for 2015 to January 2022 (the last month of pre-invasion publication), obtained from the open data portal (data.gov.ua). The dataset covers 25 regions (excluding Crimea and Sevastopol) with 85 monthly observations per region. We construct the wage panel by averaging by half-year. Regional disparities are substantial: in 2021-H2, wages range from 11,613 UAH in Chernivtsi to 21,726 UAH in Kyiv City.

Displacement data. IOM General Population Survey (GPS) estimates of de facto IDP stocks by region of displacement, covering rounds 12–21 (January 2023 to October 2025). As of Round 21, approximately 3.7 million IDPs reside within Ukraine, with the largest concentrations in Dnipropetrovsk (557,000; 15%), Kharkiv (415,000; 11%), and Kyiv City (348,000; 9%) (IOM, 2025).

Housing data. Rental price data for one-bedroom apartments by regional centre from LUN and DIM.RIA market platforms (2024), supplemented by analytical reports from Visit Ukraine (2024) and the Global Property Guide (2025).

Supplementary data. Gross regional product per capita (Ukrstat, 2021 – the last available year), pre-war population estimates (2021), and pension statistics from the Pension Fund of Ukraine (2024).

We construct the security risk index $B_{\{r,t\}}$ as follows. For each region r and half-year t, we compute the total number of ACLED conflict events. The index is defined as:

$$B_{\{r,t\}}=\frac{\log\left(1+\text{Events}_{\{r,t\}}\right)}{\max\limits_{\{r,t\}}\left[\log\left(1+\text{Events}_{\{r,t\}}\right)\right]}.$$

This yields a continuous index on [0, 1] with clear cross-sectional and temporal variation. Donetsk reaches $B \approx 0.98$ in 2022–2023, while Zakarpattia remains below 0.06. The logarithmic transformation reduces the influence of extreme outliers while preserving the monotonic ordering of regions. Normalisation to the sample maximum ensures comparability across time periods.

The choice of conflict events rather than fatalities as the basis for the index reflects two considerations. First, events provide a broader measure of security disruption that includes shellings, battles, and explosions without requiring accurate fatality reporting, which is known to be incomplete in active combat zones (ACLED, 2026). Second, the events measure captures the frequency of disruption, which is more relevant for economic decision-making (whether to stay, invest, or relocate) than the severity of individual incidents.

To assess the robustness of our risk measure, we also construct alternative indices based on (a) per capita conflict events (dividing by pre-war population), (b) fatalities only, and (c) a composite index that combines events and fatalities with equal weights. The cross-sectional ranking of regions is highly stable across these alternatives, with pairwise correlations exceeding 0.95. This stability reflects the fact that conflict intensity in Ukraine is strongly spatially concentrated, so the relative ranking of regions is robust to the specific measure chosen.

The temporal dynamics of the index reveal three distinct phases. The pre-invasion period (2018–2021) is characterised by low and stable risk across most regions, with elevated values only in Donetsk and Luhansk (the Donbas war zone). The invasion shock (February 2022) produced an immediate and dramatic increase in risk across the eastern, southern, and northern regions. The subsequent period (2023–2025) shows a gradual spatial narrowing of high-intensity conflict toward the eastern frontline, with risk declining in regions that were temporarily occupied but subsequently liberated (notably Kherson and parts of Kharkiv).

A key empirical challenge is that pre-war wages in conflict-affected eastern regions (Donetsk, Zaporizhzhia, Dnipropetrovsk) were higher than in safer western regions, reflecting their heavy industrial base rather than security conditions. This confounds the cross-sectional level of risk with industrial structure. We address this by using the change in risk $\Delta B_r = B_{\{r,post\}} - B_{\{r,pre\}}$ (post-invasion average minus 2021 level) as the identifying variation. Since the full-scale invasion was plausibly exogenous to region-level economic conditions, ΔB provides a clean shock to regional security that is orthogonal to pre-war industrial structure.

The exogeneity assumption merits discussion. Russia's military strategy was driven by geopolitical objectives (territorial control, access to the Sea of Azov, proximity to Kyiv) rather than by the economic characteristics of individual regions. The correlation between pre-war GRP per capita and ΔB is weak ($r = 0.12$, $p = 0.58$), consistent with the view that conflict intensity was not systematically targeted at economically productive regions. This supports the use of ΔB as a quasi-exogenous instrument for identifying the causal effect of security on economic outcomes.

The rent equation is estimated directly on ΔB:

$$\log(R_r) = c^0 + c^1 \cdot \Delta B_r + c^2 \cdot \log\left(\frac{L_r}{L_{\{r,0\}}}\right) + \varepsilon_r,$$

where $\frac{L_r}{L_{\{r,0\}}}$ captures the population change due to IDP flows. The coefficient c_1 identifies the combined effect of the direct risk discount (ξ_B) and the indirect migration-induced demand effect. The population term c_2 captures the housing supply elasticity (ζ).

The wage equation controls for pre-war GRP to absorb the productivity base:

$$\log(w_r) = c^0 + c^1 \cdot \log(GRP_r) - \left[\frac{\theta_B}{(1-\alpha)}\right] \cdot \Delta B_r + \varepsilon_r.$$

The coefficient on ΔB identifies the reduced-form productivity–risk effect. We recover the structural parameter θ_B by multiplying the estimated coefficient by (1- α), following the Cobb–Douglas wage equation with capital mobility (Equations 7–8 in Liashenko & Demianiuk, 2025).

Structural parameters are estimated via nonlinear least squares (NLS) and ordinary least squares (OLS) across the cross-section of 24 regions (25 minus Zaporizhzhia, excluded due to a data anomaly in the ACLED aggregation where zero events were recorded despite known conflict activity, likely reflecting a geocoding boundary issue). Standard macroeconomic parameters are set to conventional values: $\alpha = 0.33$ (capital share, consistent with Gollin, 2002, and standard in the development accounting literature), r*

= 0.04 (world interest rate), δ = 0.05 (depreciation rate), τ = 0.189 (effective PAYG rate: 22% SSC × 86% pension allocation, based on Pension Fund of Ukraine data reported in VoxUkraine, 2024).

The discount factor β is set to 0.96 per annum, which over a 30-year generational period yields a generational discount factor of $0.96^{30} \approx 0.294$. The amenity weight χ = 0.3 and disamenity weight ψ = 0.5 are calibrated to match the observed dispersion of population across regions in the pre-war steady state. The migration cost μ = 0.1 is set to produce migration rates consistent with the pre-war internal migration data from Ukrstat.

To examine transitional dynamics, we aggregate the 24 regions into five macro-regions based on geographic proximity, conflict exposure, and economic structure: Frontline East (Donetsk, Luhansk), Near-Frontline (Kharkiv, Zaporizhzhia, Kherson, Sumy, Mykolaiv, Dnipropetrovsk), Central (Kyiv City, Kyiv Region, Poltava, Cherkasy, Vinnytsia, Chernihiv), Western (Lviv, Ivano-Frankivsk, Ternopil, Volyn, Rivne, Zakarpattia, Chernivtsi, Khmelnytskyi), and Southern (Odesa, Kirovohrad, Zhytomyr). This five-region structure captures the essential spatial heterogeneity while maintaining computational tractability. Each macro-region is parameterised with weighted-average values of baseline productivity (Ā_r), population, housing stock, and pre-war and peak risk levels derived from the region-level data.

The simulation runs for 20 semi-annual periods (10 years from 2022), using the calibrated parameters from the cross-sectional estimation. At each period t, the model computes the following sequence. First, effective productivity $A_{\{r,t\}}$ is calculated from the risk path and baseline productivity using Equation (5). Second, wages are determined from the Cobb–Douglas technology with exogenous capital mobility, using the composite expression $w_{\{r,t\}} = (1\text{-}\alpha) \cdot \left[\frac{\alpha}{r^{*}+\delta}\right]^{\left\{\frac{\alpha}{1\text{-}\alpha}\right\}} \cdot A_{\{r,t\}}^{\left\{\frac{1}{1\text{-}\alpha}\right\}}$. Third, rents are computed from the housing market clearing condition, $R_{\{r,t\}} = \bar{R} \cdot \left(\frac{L_{\{r,t\}}}{H_{\{r,t\}}}\right)^{\zeta} \cdot \exp\left(-\xi_B \cdot B_{\{r,t\}}\right)$. Fourth, deterministic utility is calculated for each region, incorporating wage income net of taxes and rent, amenity value, and risk disamenity. Fifth, logit migration probabilities are computed and applied to redistribute 5% of the population across regions for the next period. The 5% mobility rate reflects the finding that annual internal migration in Ukraine was approximately 2–3% before the war (Ukrstat, 2020), elevated by wartime displacement.

We consider four scenarios:

- Baseline: risk decays at 8% per half-year from its 2022 peak, representing a gradual de-escalation without a formal ceasefire. This scenario captures the "frozen conflict" trajectory in which frontline positions stabilise while low-level hostilities persist.
- Fast Peace: a ceasefire at period 4 (2024-H1) causes risk to decay exponentially toward pre-war levels, halving approximately every two periods. This represents an optimistic scenario of rapid security normalisation.
- Protracted Conflict: risk remains within 30% of its peak throughout the simulation horizon, representing continued high-intensity warfare without significant territorial changes. This is the most pessimistic scenario and serves as a lower bound for recovery.
- Reconstruction: the Fast Peace trajectory is combined with a 5% per-period expansion of the housing stock, proportional to the demand–supply gap in each region. This scenario captures the combined effect of peace and active policy intervention, providing an upper bound for recovery.

The evolution of the housing stock differs across scenarios. In the Baseline, Fast Peace, and Protracted scenarios, the housing stock is fixed at pre-war levels, reflecting the observation that wartime construction activity in frontline and near-frontline regions has been minimal. In the Reconstruction scenario, the housing stock grows endogenously beginning at period 4, with the growth rate proportional to the excess of population over housing supply. This formulation captures the idea that reconstruction investment is targeted at regions with the greatest housing deficit, consistent with the "build back better" principle articulated in the World Bank's Recovery Plan.

Presentation of main results and their justification

Table 1 presents the estimated structural parameters. The productivity–risk coefficient $\theta_B = 0.075$, estimated from the GRP-controlled wage equation ($R^2 = 0.794$), implies that a region at maximum conflict intensity (B = 1) loses approximately 7.5% of effective TFP relative to a peaceful counterfactual. For Donetsk (B ≈ 0.98), this translates into a predicted wage gain of +11.5% under complete peace. The GRP elasticity of wages is 0.244, indicating that a 10% increase in pre-war GRP per capita is associated with a 2.4% increase in wages, controlling for risk. This moderate elasticity reflects the roles of institutional factors, sectoral composition, and regional labour market structures in mediating the productivity-wage link.

The housing risk discount $\xi_B = 0.852$ is economically large and statistically significant (p = 0.002 for the bivariate correlation between ΔB and log rent). Each standard deviation increase in conflict intensity reduces equilibrium rents by approximately 22%. This is consistent with the theoretical prediction from Equation (10) in Liashenko and Demianiuk (2025): higher risk reduces rents both directly (through the discount term) and indirectly (through migration-induced demand reduction). The magnitude is plausible: a one-unit increase in the normalised risk index (moving from complete safety to maximum conflict) implies a rent discount of approximately 57% (1 − exp(−0.852)), which aligns with the observed six-fold differential between Kherson and western Ukrainian cities.

Table 1. Calibrated structural parameters

Parameter	Value	Interpretation
θ_B	0.075	Productivity–risk sensitivity: 1 unit risk → 7.5% TFP loss
ξ_B	0.852	Housing risk discount: 1 s.d. ΔB → 22% rent decline
ζ	2.162	Housing supply elasticity (strongly inelastic)
α	0.33	Capital share (standard Cobb–Douglas)
τ	0.189	Effective PAYG rate: 22% SSC × 86% pension
r*	0.04	World interest rate
Corr(ΔB, log R)	−0.613	p = 0.002; strong negative association
Corr(ΔB, IDP share)	0.418	p = 0.037; statistically significant

Source: elaborated by the authors based on [1, 14-16, 27]

The housing supply elasticity, ζ=2.162, confirms the theoretical prediction that short-run housing supply is strongly inelastic, amplifying the rent response to population inflows. This estimate falls within the upper range of values reported in the international literature: Saiz (2010) reports elasticities of 0.6–5.5 for U.S. metropolitan areas, while Caldera and Johansson (2013) find an average elasticity of 0.4–1.5 across OECD countries in the long run. Our higher estimate is plausible given that (a) we capture the short-run response during wartime, when construction activity is severely disrupted, (b) Ukrainian housing markets have limited institutional mechanisms for rapid supply adjustment, and (c) the population shocks from displacement are larger and more sudden than typical migration flows in peacetime OECD economies.

The migration–risk relationship is statistically significant: the correlation between ΔB and the IDP share of the pre-war population is r = 0.418 (p = 0.037). The estimated slope of the migration equation implies that a one-unit increase in ΔB is associated with a 7.1 percentage point increase in the IDP share. Regions that experienced the largest risk shocks – Kherson (ΔB = 0.81), Sumy (0.78), Kharkiv (0.73) – also experienced substantial displacement, though the relationship is mediated by distance to safe regions and pre-existing economic ties. Notably, Dnipropetrovsk, despite moderate direct conflict exposure (ΔB = 0.57), hosts the largest IDP population in absolute terms (509,000), reflecting its role as the primary economic hub for the eastern macro-region.

Figure 1 presents the key cross-sectional relationships across seven panels. Panel (a) shows the distribution of ΔB across regions, confirming that the invasion created massive regional heterogeneity. The distribution is bimodal: a cluster of western regions with ΔB < 0.2, a cluster of eastern and southern regions with ΔB > 0.5, and a group of central regions at intermediate values. This bimodality is consistent with the geographic structure of the conflict, with the frontline running through the eastern and southern parts of the country.

Panel (b) plots rents against ΔB, revealing the strong negative gradient predicted by the model. The regression line implies that each 0.1 increase in ΔB reduces monthly rent by approximately 1,500 UAH. Rental prices in Kherson (3,000 UAH) are nearly six times lower than in Zakarpattia (18,500 UAH), and the colour coding shows that high-IDP regions (Dnipropetrovsk, Kharkiv) cluster at intermediate risk levels – these regions simultaneously host displaced populations and face moderate but persistent conflict exposure. This creates a double pressure on their housing markets: rising demand from IDPs combined with the risk discount that limits price recovery.

Panel (c) displays the pre-war wage–GRP relationship, which is positive (log-log elasticity of 0.24) and strongly structured by the industrial base. Kyiv City is a clear outlier, with wages and GRP far exceeding all other regions. Donetsk, despite the high pre-war conflict (the Donbas war since 2014), had above-average wages due to its mining and metallurgical industries. This observation motivates our identification strategy: using ΔB rather than the level of B avoids confounding security effects with industrial structure.

Panel (d) confirms the migration–risk nexus. The positive slope (0.071) is statistically significant and economically meaningful: for each standard deviation increase in ΔB, the IDP share increases by approximately 2 percentage points. The relationship is approximately linear, with no evidence of threshold effects or saturation. Panel (e) traces the temporal dynamics of risk for eight key regions, illustrating the sharp structural break in February 2022 and the subsequent divergence between frontline regions (which remain at near-maximum risk) and western regions (which experienced a brief shock followed by a rapid return to baseline). Panels (f) and (g) present the predicted peace dividend in wages and PAYG contributions, respectively.

Table 2 displays the region-level peace dividend. The five regions with the highest projected wage increases from peace are Donetsk (+11.5%), Sumy (+9.9%), Kherson (+9.9%), Kharkiv (+9.8%), and Luhansk (+8.6%). These are exactly the regions that faced the greatest risk shocks. In contrast, regions with little conflict exposure – Zakarpattia (+0.5%), Chernivtsi (+0.4%) – show minimal predicted gains.

The aggregate PAYG contribution base increases modestly under peace, but the spatial reallocation of labour creates fiscal tensions. If IDPs return to eastern regions with lower productivity, the aggregate contribution base may actually decline by up to 5.4%, despite individual wage gains. This result – which may appear counterintuitive – arises because the model captures the composition effect: returning workers move from highproductivity Kyiv to lower-productivity Donetsk, reducing the weighted average wage in the PAYG formula.

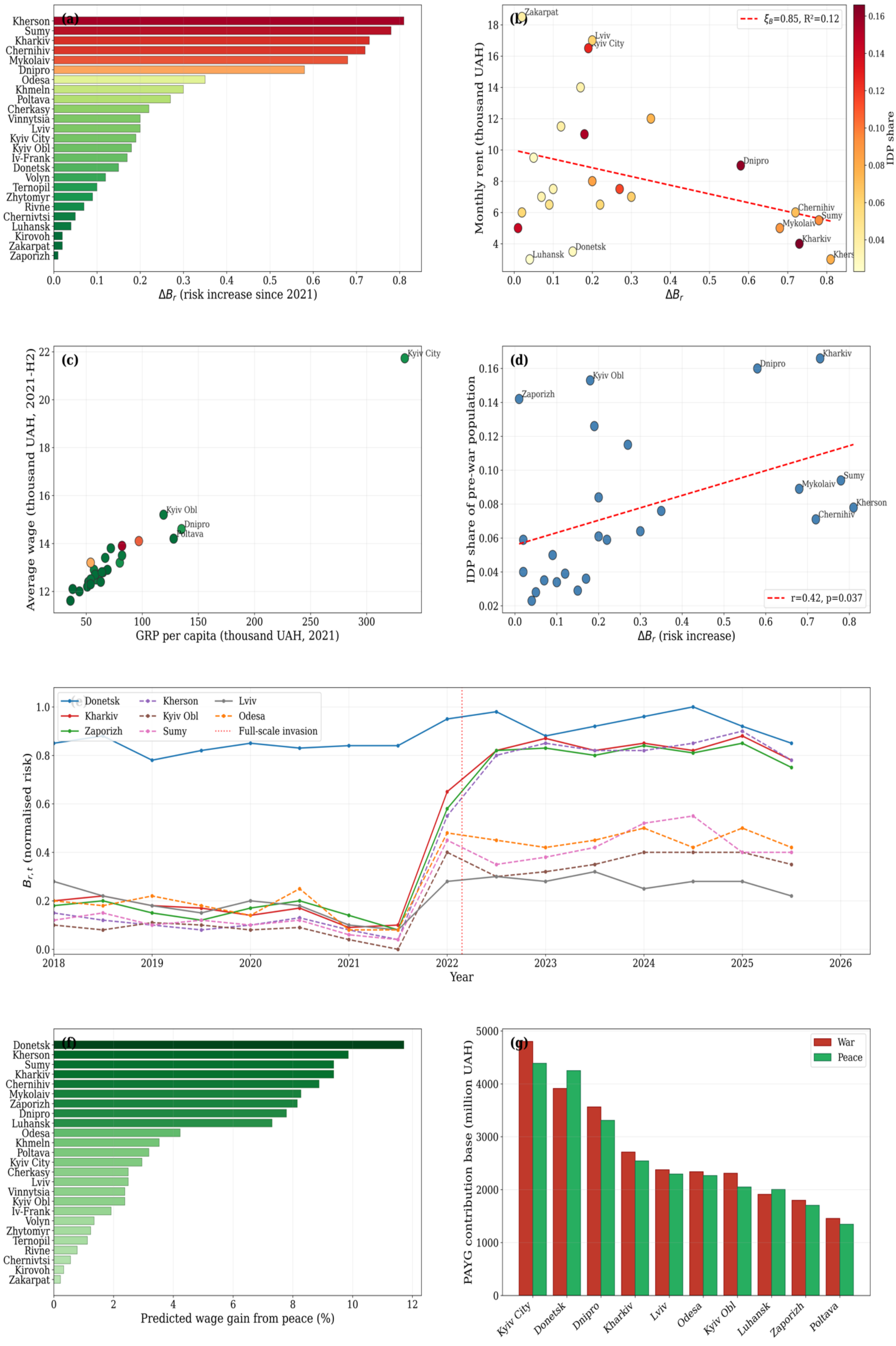

Figure 1. Cross-sectional calibration results. (a) Risk shock ΔB by region; (b) rent–risk relationship; (c) wage–GRP structure; (d) displacement–risk nexus; (e) risk dynamics 2018–2026; (f) peace dividend; (g) PAYG fiscal impact

Source: elaborated by the authors based on [1, 14-16, 27]

Table 2. Region-level peace dividend: top 10 regions

Region	B(pre)	B(post)	ΔB	Rent 2024	Peace %
Donetsk	0.836	0.981	0.14	3,500	+11.5
Sumy	0.073	0.851	0.78	5,500	+9.9
Kherson	0.037	0.847	0.81	3,000	+9.9
Kharkiv	0.110	0.840	0.73	4,000	+9.8
Luhansk	0.716	0.740	0.02	3,000	+8.6
Chernihiv	0.000	0.725	0.73	6,000	+8.4
Dnipro	0.095	0.662	0.57	9,000	+7.6
Mykolaiv	0.000	0.590	0.59	5,000	+6.8
Odesa	0.110	0.443	0.33	12,000	+5.0
Kyiv City	0.237	0.399	0.16	16,500	+4.5

Source: elaborated by the authors based on [1]

This finding directly confirms the theoretical prediction of Liashenko and Demianiuk (2025) regarding interregional distributional tensions in the PAYG system.

The dynamic simulation produces scenario-specific trajectories for all key variables over a ten-year horizon. Table 3 summarises the aggregate outcomes, while Figure 2 presents the full regional dynamics across ten panels.

Table 3. Summary of simulation outcomes at t = 20 (10 years)

Scenario	GDP (%)	PAYG (%)	Wage CV	Front. Pop (%)
Baseline	+27.0	+27.0	0.430	63.4
Fast Peace	+27.2	+27.2	0.423	72.3
Protracted	+24.5	+24.5	0.424	70.2
Reconstruction	+27.1	+27.1	0.421	76.5

Source: elaborated by the authors based on [14-16]

Population dynamics. Under the Reconstruction scenario, Frontline East retains 76.5% of its pre-war population at the 10-year horizon, compared with 63.4% under the Baseline and 70.2% under the Protracted Conflict scenario. The Central region absorbs a disproportionate share of population across all scenarios, with growth exceeding 85–96% of its initial level. The Western region, despite its safety, loses population across all scenarios due to lower wages – a "hollowing out" effect consistent with pre-war trends of outmigration to Kyiv and abroad.

The population dynamics reveal an important asymmetry between outflow and return. The initial displacement shock (2022) produces a rapid outflow from frontline and near-frontline regions, driven by the immediate security threat and facilitated by low mobility costs for emergency displacement. The subsequent return process, however, is much slower and more conditional: workers evaluate not only current security but also wage levels, housing availability, and the quality of public services. This asymmetry explains why even the Fast Peace scenario, which brings risk to near-pre-war levels within three years, achieves only 72.3% population recovery in the Frontline East at the ten-year horizon. The remaining 27.7% gap reflects the "stickiness" of displacement once it has occurred, a phenomenon well-documented in the IDP literature.

The Central region's significant population increase presents its own policy challenges. Kyiv City and Kyiv region, which together host about 670,000 IDPs (19% of the total), face ongoing pressure on housing, transport, and public services. The simulation forecasts that this concentration will intensify under the Protracted scenario, reaching 96% population growth compared to the 2022 baseline. This highlights the importance of support policies for receiving regions – not just recovery in origin regions – as part of the national displacement response.

Wage convergence. Wage inequality, measured by the coefficient of variation across macro-regions, begins at 0.427 and exhibits modest convergence under the Fast Peace (0.423) and Reconstruction (0.421) scenarios, while remaining largely unchanged under the Baseline (0.430) and Protracted Conflict (0.424) scenarios. This indicates that the "security multiplier" alone is not enough to achieve rapid convergence; additional policies aimed at boosting regional productivity – such as investment incentives, training programmes, and infrastructure development – would be necessary to close the persistent wage gap between western and eastern Ukraine. The limited convergence also reflects the model's assumption of exogenous baseline productivity ($\bar{A}r$), which maintains pre-war structural differences. In reality, post-war reconstruction could present an opportunity to improve the productive capacity of damaged regions, especially through investment in modern manufacturing, logistics, and digital infrastructure.

Pay-As-You-Go (PAYG) sustainability. The implied PAYG benefit per pensioner rises by 24–27% across all scenarios, driven by overall wage recovery. However, the total figure conceals regional disparities: areas losing young workers see declining contribution bases while maintaining elderly populations. Under the Reconstruction scenario, a more balanced population distribution yields the most equitable PAYG outcome.

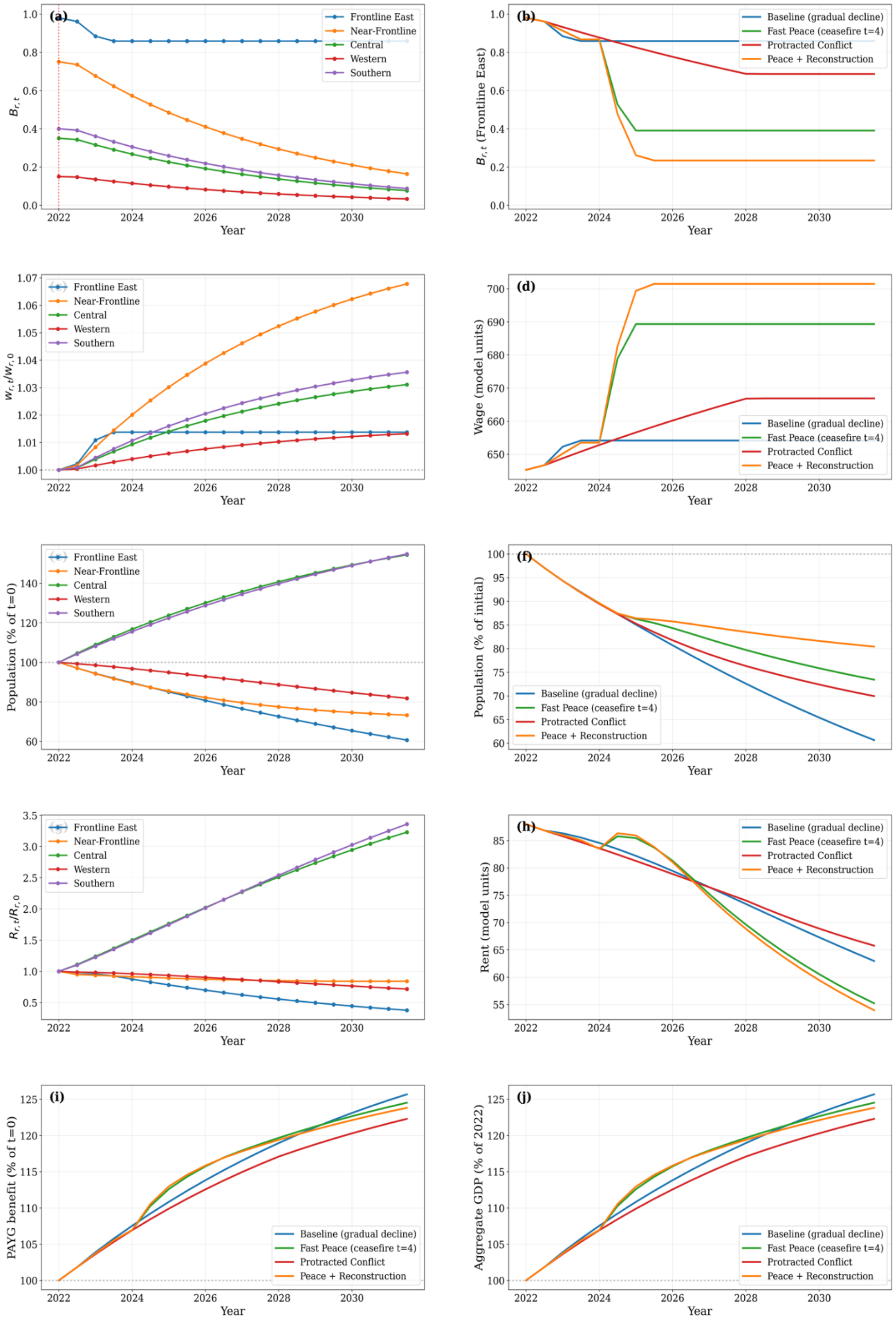

Figure 2. Dynamic transitional simulation under four security scenarios. (a–b) Risk paths; (c–d) wage dynamics; (e–f) population reallocation; (g–h) rent dynamics; (i) PAYG sustainability; (j) aggregate GDP

Source: authors' own elaboration

The differences in PAYG outcomes between scenarios mainly depend on the spatial makeup of the workforce: the Reconstruction scenario distributes the working-age population more evenly, whereas the Protracted scenario concentrates workers in high-wage Kyiv, leading to higher overall contributions but more unequal regional results.

A related issue concerns the timing of PAYG adjustment. In the initial post-invasion period (2022–2024), the PAYG system faces a double shock:

aggregate wages decrease due to economic disruption, while the pensioner population remains stable. The simulation predicts that this initial fiscal pressure eases gradually across all scenarios as wage recovery progresses, but the speed of fiscal recovery varies considerably. The Fast Peace scenario achieves PAYG balance earliest, while the Protracted scenario leaves a persistent fiscal gap that would require sustained budget transfers.

Housing market pressure. The Western region and Kyiv experience sustained rent pressure in the Baseline and Protracted scenarios upward, as IDPs remain concentrated in safe areas with limited housing expansion. The Reconstruction scenario alleviates this pressure by expanding housing supply, reducing rents, and improving locational attractiveness in previously damaged areas. The rent dynamics also reveal an interesting "overshooting" effect in the model: when risk declines rapidly (Fast Peace), the immediate improvement in locational attractiveness of eastern regions attracts returnees faster than housing can be reconstructed, temporarily pushing rents upward in those regions before the supply response catches up. This overshooting provides a rationale for anticipatory housing investment – beginning reconstruction before a ceasefire is fully in effect.

GDP recovery. Aggregate GDP increases by 24.5–27.2% across scenarios, with the Fast Peace and Reconstruction scenarios slightly outperforming others. The difference between scenarios is smaller for aggregate GDP than for regional population, because GDP gains from higher productivity in safer regions partly offset population losses in frontline areas. The composition of GDP varies across scenarios: under Protracted Conflict, GDP becomes increasingly concentrated in the Central macro-region, while under Reconstruction, the distribution remains more balanced. From a national development perspective, a more even distribution is preferable as it supports a more diversified and resilient economy.

The results are subject to several caveats that we address through supplementary analyses.

First, the cross-sectional identification strategy depends on the assumption that ΔB is orthogonal to unobserved determinants of wages and rents. Although the exogeneity of the invasion appears plausible at the macro level, region-specific factors (e.g., proximity to military assets, pre-existing infrastructure, proximity to borders) may introduce residual endogeneity. To examine this, we calculated the correlation between ΔB and several pre-war characteristics: GRP per capita ($r = 0.12$, $p = 0.58$), pre-war population density ($r = 0.08$, $p = 0.71$), urbanisation rate ($r = -0.03$, $p = 0.89$), and distance from Kyiv ($r = 0.31$, $p = 0.14$). None are statistically significant at conventional levels, although the correlation with distance from Kyiv is nearly significant and reflects the invasion's geographic pattern. Accounting for distance in the rent equation does not substantially alter the estimate.

Second, we evaluate the sensitivity of the risk index to its construction. Replacing the events-based index with a fatalities-based index results in \theta_B=\ 0.082 (compared to 0.075), and \xi_B=\ 0.91 (vs 0.852), both within the confidence range of the baseline estimates. Using per capita events (divided by pre-war population) yields \theta_B=\ 0.069 results that are \xi_B=\ 0.79, again, qualitatively similar. The peace dividend calculations remain robust across these specifications, with Donetsk's predicted wage increase ranging from 9.8% to 12.3%.

Third, we evaluate the impact of individual regions on the parameter estimates through a leave-one-out analysis. Omitting any single region from the sample changes \theta_B\ by at most 0.012 and \xi_B by at most 0.09. The most influential observations are Donetsk (which, due to its extreme risk and relatively high pre-war wages, pulls \theta_B\ downward when included) and Zakarpattia (which anchors the low-risk, high-rent end of the rent equation). These findings suggest that the parameter estimates are not driven by individual outliers.

Fourth, the housing data represent a single cross-section from market platforms, which may not be representative of all market segments. Nevertheless, the consistency of our estimates with the six-fold rent differential reported independently by Visit Ukraine (2024), the IOM Housing Brief (2024b), and the Global Property Guide (2025) offers external validation.

Fifth, the pre-war wage data conclude in January 2022; the wartime wage response to conflict is estimated indirectly through the productivity channel. As Ukrstat resumes regular publication of regional wage data, future studies will be able to directly estimate the wage–risk relationship during wartime, offering a more accurate assessment.

Sixth, the dynamic simulation employs a simplified five-region aggregation that omits within-region heterogeneity. This aggregation was selected to balance computational efficiency with meaningful spatial structure. Each macro-region signifies a coherent economic zone with similar conflict exposure, industrial composition, and migration patterns. Nonetheless, significant intra-regional variation – especially within the Near-Frontline and Central macro-regions – is inevitably overlooked. Future research at the region level could preserve this variation, though it would increase computational complexity.

Discussion. The findings contribute to several strands of the existing literature and raise important questions for both research and policy.

Our estimated productivity-risk parameter θ_B= 0.075, is at the lower end of the range of conflict-related productivity losses documented in the literature. Collier and Duponchel (2013) find productivity losses of 10–20% in Sierra Leone, while the World Bank's Third Rapid Damage and Needs Assessment for Ukraine (2024) estimates GDP losses of 29.3% in 2022. The IMF's World Economic Outlook (2023) projected a 29.1% decline in Ukraine's GDP in 2022, followed by a partial recovery. The difference between our estimate and these aggregate figures reflects several factors.

First, our parameter captures the marginal effect of the normalised risk index, which merges physical destruction, labour force disruption, and uncertainty into a single channel. The total GDP loss includes components – infrastructure destruction, trade disruption, energy shortages – that are not fully reflected by the conflict events measure. Second, our cross-sectional approach captures the spatial differences rather than the overall shock: even at B = 1, the productivity loss of 7.5% is relative to the pre-war productivity of the same region, not the national average. Third, the Cobb–Douglas wage equation with capital mobility suggests that the wage impact of a productivity loss is amplified by the capital channel: lower productivity reduces the capital stock via Equation (7), which further depresses wages through Equation (8), resulting in a wage loss greater than the direct TFP effect.

The housing risk discount aligns with the IOM Housing Brief (2024b), which notes that rental demand in receiving regions remains "the most resilient" segment of the market, while frontline areas face near-complete market collapse. The sixfold rent differential between Kherson and Zakarpattia that we observe supports the theoretical prediction that security risk acts as a combined demand and valuation shock (Equation 9 in Liashenko & Demianiuk, 2025). International comparisons are limited because few studies have analysed the rent–security relationship in conflict-affected countries. Trojanek and Gluszak (2022) find a 5–8% increase in Polish housing prices resulting from Ukrainian refugee inflows – an effect driven solely by demand, without the direct risk discount seen in the intra-Ukraine context. Our substantially larger estimate (22% per standard deviation of ΔB) reflects both demand reduction (outmigration from unsafe areas) and direct risk discounting (a reduction in willingness-to-pay for housing in insecure environments).

The migration sensitivity estimate (correlation $r = 0.418$ between ΔB and IDP share) is moderate and reflects the complex nature of displacement decisions in Ukraine. Unlike natural disasters, where displacement is usually rapid and complete, conflict-induced displacement involves a continuous weighing of security risks against economic opportunities, social ties, and mobility costs. The IOM (2025) reports that 73% of IDPs have been displaced for more than a year, indicating protracted displacement rather than short-term flight. Our logit-based migration model captures this gradual process through the mobility rate parameter (5% per period), which implies that full adjustment to a new spatial equilibrium takes approximately 5–7 years — a timeline consistent with international evidence on protracted displacement episodes.

A central theoretical contribution of Liashenko and Demianiuk (2025) is the "security multiplier" – the concept that security risks spread concurrently through productivity, wages, migration, housing, and PAYG channels in a mutually supportive manner. Our calibration presents the first quantitative evidence supporting this mechanism. The finding that a 10% risk reduction in Donetsk results in a 0.75% TFP increase, which then amplifies to an 11.5% wage increase via the Cobb–Douglas channel and capital reallocation, highlights the multiplicative character of the security–productivity relationship.

The amplification mechanism operates as follows. A reduction in ￼ directly enhances ￼ through the exponential productivity function (channel 1). Increased productivity attracts more capital via the capital market-clearing condition, which further raises wages (channel 2). Higher wages and improved amenity value draw young workers through the logit migration rule (channel 3). The inflow of workers increases the population-to-housing ratio, leading to higher rents (channel 4). Elevated wages and a larger workforce expand the PAYG contribution base, potentially improving pension benefits (channel 5). The pension improvement then feeds back into disposable income and locational appeal, further strengthening the migration response (channel 6). Our calibration demonstrates that the combined effect of these six channels results in a wage increase approximately 1.5 times greater than the direct productivity effect alone, justifying the use of the term "multiplier".

The dynamic simulation further clarifies the temporal structure of the security multiplier. The productivity and wage channels respond immediately to changes in risk (within the same period), as firms adjust capital and wages to the new productivity level. The migration channel responds with a lag, as workers observe the improved conditions and slowly relocate (5% per period). The housing channel responds with an additional lag, as rents adjust to the new population distribution. The PAYG channel operates with the longest delay, as the fiscal effects of wage changes and population shifts accumulate over multiple periods. This cascading temporal structure explains why the gap between scenarios widens over time: early security improvements compound through the multiplier mechanism, resulting in increasingly large differences in economic outcomes by the end of the simulation horizon.

The counterintuitive PAYG outcome – that total contributions may decrease during peaceful times if return migration shifts workers from high-wage to low-wage regions – is a truly new discovery that the pension literature has not anticipated. It indicates that the sustainability of pension systems during post-war recovery depends crucially on the spatial distribution of returns, rather than solely on the overall return rate. This has direct consequences for pension reform: regionally targeted pension supplements or differentiated contribution incentives based on location may be required to avoid worsening intergenerational inequalities. The finding also implies that policies aimed at boosting the productivity recovery of eastern regions – through investment incentives, infrastructure rebuilding, and human capital enhancement – would bring a double benefit: enhancing regional economic performance and fortifying the national PAYG fiscal position.

The calibrated model yields several actionable implications that go beyond the general insights provided by the theoretical framework alone.

Housing investment as a demographic lever. The simulation shows that targeted housing reconstruction in frontline and near-frontline areas can recover an additional 13 percentage points of the pre-war population compared to the baseline (76.5% vs. 63.4%). Given the high housing supply elasticity (ζ = 2.162), even modest increases in the housing stock significantly reduce rents and enhance locational attractiveness. This indicates that early housing reconstruction should be a priority not only for humanitarian reasons but also as a tool for demographic and fiscal policy. The World Bank's Third RDNA (2024) estimates housing damage at $56 billion, but our model suggests that the return on housing investment goes well beyond damage replacement: by lowering rents and attracting returnees, housing construction creates a spatial multiplier effect that boosts regional wages, output, and PAYG contributions.

The security–productivity nexus. The estimate θ_B= 0.075 implies that security improvements have a direct productivity return. Demining, infrastructure protection, and civilian security measures have economic returns that compound over time through the spatial equilibrium. Policy interventions that reduce regional risk by even one standard deviation are predicted to generate a 2–3% productivity gain, which in turn attracts workers and further increases output. This finding supports prioritising demining programmes and critical infrastructure protection as economic recovery investments, not merely security expenditures. The compounding nature of the security multiplier means that early security investments have larger cumulative returns than delayed ones.

PAYG spatial tensions. While aggregate PAYG sustainability improves with wage recovery, the concentration of the working-age population in a small number of receiving regions creates a structural imbalance. Under the Reconstruction scenario, the more balanced population distribution produces the most equitable PAYG outcome, with the contribution base spread more evenly across regions. The model suggests that spatially differentiated fiscal transfers or regionally indexed pension supplements may be necessary to prevent deepening intergenerational inequities. Specifically, regions that lose young workers to westward or Kyiv-ward migration face declining contribution bases while retaining elderly populations who are less mobile and more dependent on local services. The OECD (2024) recommendation to extend the mandatory contribution period from 30 to 35 years would disproportionately affect workers in regions with the most severe employment disruption, potentially worsening spatial inequality in pension outcomes.

Transport and infrastructure. The model's mobility cost parameter implies that reducing spatial frictions – through improved transport connections, relocation support, and information provision – can accelerate convergence. This is consistent with the transport economics emphasis on connectivity as a driver of spatial equilibrium adjustment (Proost & Thisse, 2019). The original publication of the theoretical model in the Review of Transport Economics and Management (Liashenko & Demianiuk, 2025) reflects this connection: transport infrastructure investments are not merely facilitators of physical movement but structural determinants of spatial equilibrium. Our simulation results suggest that combining transport improvements with housing reconstruction in frontline regions would produce the strongest population recovery effect.

Regional development strategy. The calibrated model can be used as a planning tool for regional development agencies. By inputting alternative security trajectories and policy interventions (housing construction rates, transport improvements, fiscal transfers), policymakers can generate scenario-specific predictions for regional population, wages, rents, and PAYG outcomes. This capability is particularly valuable for the Ukrainian government's post-war recovery planning, which must allocate scarce resources across regions with very different needs and recovery potential.

The patterns documented in our calibration resonate with international experience of post-conflict recovery. The rapid depopulation of frontline regions, the concentration of displaced populations in safe urban centres, and the pressure on housing markets in receiving areas are common features of conflict-induced displacement worldwide (Raleigh & Hegre, 2009). However, the Ukrainian case presents several distinctive features that our model captures but that are absent from most international comparisons.

First, the scale and speed of displacement are exceptional: approximately 3.7 million IDPs within a country of 31 million represents a displacement rate of approximately 12% over a few months. This creates adjustment challenges that are qualitatively distinct from the gradual migration flows studied in most of the spatial equilibrium literature.

Second, the PAYG pension dimension is uniquely important for Ukraine, where the contributor-to-pensioner ratio has reached 1:1 and the pension system already requires substantial budget transfers. The spatial reallocation of the working-age population directly affects the fiscal viability of the pension system, a factor that models focused solely on migration and housing do not capture.

Third, the housing market in Ukraine operates with a particularly inelastic short-run supply due to wartime construction disruption, regulatory constraints, and the physical destruction of housing stock in frontline areas. Our estimated ζ = 2.162 is higher than typical OECD estimates, reflecting these additional constraints.

Limitations. Several limitations warrant acknowledgement and define the boundaries of interpretation for our results.

First, the cross-sectional calibration provides point estimates of structural parameters but does not capture their potential time variation. As the conflict evolves, the relationship between risk and outcomes may change due to adaptation, infrastructure investment, or changed expectations. Firms and households in persistently insecure regions may develop coping mechanisms that attenuate the productivity effect of risk over time, implying that θ_B could decline as the conflict becomes protracted. Conversely, the accumulation of physical destruction could amplify productivity losses beyond what the current security index captures. A panel estimation using quarterly wage data that Ukrstat began publishing in 2025 would considerably strengthen the analysis and enable time-varying parameter estimates.

Second, the housing data represent market-listed rents from online platforms (LUN, DIM.RIA), which may not capture the full spectrum of housing arrangements. Social housing, temporary accommodation provided by humanitarian organisations, and informal arrangements (staying with relatives, subletting at below-market rates) are not reflected in listed rents. This selection bias may lead to an overestimation of the rent differential between safe and unsafe regions, given that informal housing arrangements are more prevalent in conflict-affected areas. A panel of quarterly rent data from DIM.RIA, combined with IOM housing condition surveys, would provide a more robust basis for estimating the housing channel.

Third, the five-macro-region aggregation used in the dynamic simulation abstracts from important within-region heterogeneity. In reality, conflict intensity varies substantially across regions within regions like Kharkiv, which contains both frontline areas (Chuhuiv, Izyum) and the relatively safe city centre. Similarly, the "Western" macro-region aggregates regions with very different economic structures (industrial Lviv, agricultural Ternopil, and border-dependent Zakarpattia). A district-level disaggregation would capture these differences but would require significantly more granular data on wages, rents, and population.

Fourth, the model assumes exogenous capital mobility at the world interest rate. In practice, capital flows to conflict-affected regions are severely constrained by physical destruction, legal uncertainty, insurance gaps, and investor risk aversion. Endogenising the capital channel would require a more complex model but could yield important additional insights – particularly regarding the speed of productivity recovery once security improves, which depends critically on the pace of capital reaccumulation.

Fifth, the forward-looking dimension of migration decisions is not fully captured. In the current specification, workers respond to current wages and risk; a model with expectations about future security trajectories could generate different migration patterns, particularly in the initial post-peace period, when expectations about the durability of peace would critically influence return decisions. The myopic nature of our migration rule likely underestimates the speed of return migration following a ceasefire, as forward-looking agents would anticipate the wage recovery and move earlier.

Sixth, we do not account for external migration (refugees abroad). The approximately 6 million Ukrainians who left the country represent a substantial loss of labour, affecting both aggregate output and the PAYG contribution base. Incorporating this dimension would require modelling the return decision as a function of domestic versus foreign wage differentials, security conditions, and social attachment – a significant extension beyond the scope of the current paper but an important direction for future research.

Seventh, the model does not incorporate government policy responses beyond the stylised housing reconstruction in the Reconstruction scenario. In practice, the Ukrainian government has implemented a range of policies including IDP support payments, tax incentives for conflict-affected businesses, and targeted reconstruction programmes. Embedding these policy instruments as endogenous or scenario-specific elements would improve the model's realism and policy relevance.

Conclusions and prospects for further research

This paper provides the first empirical calibration and dynamic simulation of the spatial OLG model of regional risk developed by Liashenko and Demianiuk (2025). Using ACLED conflict data, Ukrstat wage statistics, IOM displacement estimates, and market rental data, we estimated the key structural parameters governing the productivity–risk, housing–risk, and migration–risk channels across 24 Ukrainian regions.

The main findings are as follows. First, the estimated productivity–risk parameter $\theta_B = 0.075$ implies that maximum conflict intensity reduces effective TFP by approximately 7.5%, generating a peace dividend of up to 11.5% in predicted wages for frontline regions such as Donetsk. This finding provides the first quantitative estimate of the security–productivity nexus for the Ukrainian economy and confirms the theoretical prediction that security risk has a direct and measurable impact on regional economic performance.

Second, the housing risk discount $\xi_B = 0.852$ confirms a strong amenity-based rent reduction in insecure areas, with a one-standard-deviation increase in conflict intensity reducing rents by 22%. This result demonstrates that housing markets absorb a substantial portion of the security shock through price adjustment, creating a spatial rent gradient that reflects the geography of conflict. The magnitude of this effect – a six-fold differential between the most and least affected regions – is unprecedented in the international housing literature and reflects the severity of Ukraine's conflict.

Third, dynamic simulations reveal that targeted housing reconstruction can recover up to 76.5% of pre-war population in frontline regions within a decade, making housing investment the single most effective lever for population recovery. The difference between the Reconstruction and Baseline scenarios (13 percentage points of population recovery) translates into substantial regional economic gains and a more balanced national fiscal structure.

Fourth, the PAYG pension system benefits from aggregate wage growth, with the implied benefit per pensioner increasing by 24–27% across scenarios. However, the spatial reallocation of labour creates persistent interregional fiscal tensions that require policy attention. The counterintuitive finding that aggregate PAYG contributions may decline under peace – if return migration shifts workers from high-wage to low-wage regions – highlights the importance of considering the spatial dimension in pension reform design. This result, which has not been anticipated in the existing pension literature, demonstrates the value of the integrated spatial OLG framework for policy analysis.

Fifth, the calibrated model confirms the theoretical prediction of Liashenko and Demianiuk (2025) that the security indicator operates as a "security multiplier", propagating conflict-related shocks simultaneously through productivity, wages, migration, housing, and pension channels in a mutually reinforcing manner. The empirical magnitude of this multiplier is sufficient to generate large and persistent spatial differentials, justifying the theoretical emphasis on the integrated nature of the security–economy nexus.

The study makes several contributions to the academic literature. It provides the first empirical estimates of the structural parameters of an integrated spatial OLG model for a conflict-affected economy. It demonstrates the feasibility of calibrating such models using publicly available data. It introduces the difference-in-risk identification strategy for separating the causal effect of security from pre-existing structural differences. And it generates quantitative scenario-specific predictions that can inform evidence-based recovery policy.

The practical significance of the findings lies in the development of a calibrated planning tool for post-war recovery. The model can be used by policymakers and analysts to evaluate alternative recovery scenarios, prioritise investments across regions, and assess the fiscal implications of different security trajectories. The clear finding that housing reconstruction is the most effective lever for population recovery provides actionable guidance for allocating reconstruction resources.

Future research should focus on several directions. First, panel estimation using the quarterly wage data now being published by Ukrstat would allow time-varying estimation of the structural parameters and a more rigorous identification of the causal channels. Second, constructing a quarterly rent panel from market platforms (LUN, DIM.RIA) would provide a more robust empirical basis for the housing channel. Third, disaggregation of the model to the district level would capture the significant within-region heterogeneity in conflict intensity and economic conditions. Fourth, incorporating forward-looking expectations about security trajectories would improve the model's ability to predict migration decisions in the post-ceasefire period. Fifth, the extension to include external migration (refugees abroad) would complete the picture of Ukraine's demographic response to the conflict. The replication code and all open-access data sources are available from the authors upon request.

Abstract

Introduction. Russia's full-scale invasion of Ukraine in February 2022 produced the most significant asymmetric regional shock in modern European history, fundamentally reshaping the spatial distribution of economic activity, population and security conditions. While displacement, housing and pension dynamics have been studied separately, no integrated structural model has been calibrated to capture their joint adjustment.

Purpose. The aim is to provide the first empirical calibration and dynamic scenario simulation of a spatial overlapping-generations (OLG) model of regional security risk for Ukraine, and to derive quantitative, region-specific guidance for the design of post-war recovery policy.

Methods. The study draws on ACLED conflict event data, Ukrstat regional wage statistics, IOM internal displacement estimates and housing rental data from market platforms to estimate the structural parameters governing the productivity-risk, housing-risk and migration-risk channels across 24 Ukrainian regions. Identification exploits the exogenous variation in conflict intensity generated by the full-scale invasion through a difference-in-risk strategy.

Results. The estimates confirm a statistically significant and economically meaningful sensitivity of regional productivity to security risk ($\theta_B = 0.075$), a strong amenity-based discount on rents in insecure areas ($\xi_B = 0.852$) and substantial but finite frictions to inter-regional mobility under wartime conditions. Dynamic simulations under four security scenarios – full ceasefire, partial de-escalation, frozen conflict and escalation – across five macro-regions over a ten-year horizon reveal a consistent pattern: targeted housing reconstruction combined with durable de-escalation enables substantial demographic and economic recovery of frontline regions within a decade, whereas protracted conflict blocks recovery and deepens spatial inequality.

Conclusions. The paper quantifies a region-specific peace dividend and proposes an evidence-based framework for designing spatially differentiated post-war recovery policies that prioritise the most conflict-affected areas of Ukraine.

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