

Spatial Patterns of Population Ageing and Pension-Fiscal Pressure in the Liaoning Coastal Economic Belt

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Abstract: Using data from China's Seventh National Population Census and 2020 economic statistics, this study identifies the spatial configuration of older populations in Liaoning Province, assesses the match between ageing pressure and economic capacity across the coastal economic belt, and estimates fiscal resources released by delayed retirement. Older adults form a belt-like pattern with cohort heterogeneity: ages 60–64 concentrate along the coastal port-industrial corridor and development zones, whereas ages 65+ cluster in districts and industrial neighborhoods. Among six coastal prefecture-level cities, Dalian and Panjin have stronger capacity and lower pressure; Huludao, Dandong, and Jinzhou pair weaker economies with higher pressure; Yingkou is intermediate. Conservatively, pension outlays for ages 60–64 equal 5.54%, 5.53%, and 4.79% of local output in Huludao, Dandong, and Jinzhou. Delayed retirement could reduce spending by 35.663 billion yuan annually (178.315 billion over five years). Policy should prioritize employment support in high-pressure cities and redirect freed funds to industrial upgrading and public services in Dalian and Yingkou.

Keywords: Population ageing; Pension-fiscal pressure; Delayed retirement; Active ageing; Liaoning coastal economic belt

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1. Introduction

Against the dual backdrop of heightened global economic volatility and rapidly deepening population ageing, China has entered a critical stage in advancing an “active response to population ageing” and implementing delayed-retirement reforms^[1-2]. As a key spatial engine for revitalizing Northeast China, the Liaoning Coastal Economic Belt is confronting ageing constraints that are both earlier in onset and more severe in intensity than many other regions^[3]. This situation makes it imperative to precisely map the regional distribution of the older population and the geography of ageing-related pressure, while rigorously assessing the extent to which pension expenditures crowd out local economic resources and the potential development space that could be unlocked through delayed-retirement policy adjustments.

As a pioneer zone for industrial restructuring and upgrading in Northeast China, a front-runner in regional socio-economic development, and an emerging hub for open cooperation oriented toward Northeast Asia, the Liaoning Coastal Economic Belt constitutes a core spatial platform for advancing the revitalization of Northeast China. Yet, while it represents Liaoning's most densely concentrated locus of economic activity and its coastal growth pole, it is also among the most severely aged coastal regions nationwide. By the end of 2024, Liaoning Province had 12.95 million residents aged 60 and above, accounting for 31.2% of the provincial population, and a share of 21.9% aged 65 and above—substantially exceeding the national averages of 22.0% (60+) and 15.6% (65+) over the same period. In this sense, Liaoning has irreversibly entered a super-aged stage^[4].

Under the pressing circumstances of rapidly deepening population ageing, existing research has produced a series of studies on ageing. First, a body of work focuses on the spatial patterns of population ageing and the mechanisms through which they emerge^[5–8]. Such studies typically identify differences in the distribution of older populations from the provincial to the prefecture-level scale, and discuss how factors such as industrial structure, public-service provision, population mobility, and housing costs shape the spatial differentiation of ageing^[9–11]. However, most studies still concentrate on the population aged 65 and above, and seldom characterize populations near retirement age as an independent analytical object. Second, studies of spatial patterns have largely remained at the level of distributional description or associational explanation, and lack further efforts to translate spatial differences into questions of fiscal constraints and policy prioritization. The existing literature commonly uses indicators such as dependency ratios, the share of older adults, and per capita output to gauge the impacts of ageing on economic growth, labor supply, and fiscal pressure, emphasizing that population ageing affects long-run growth through declining labor supply, shifts in the saving-investment structure, and rising public expenditures^[12–13]; yet these effects are not linear and are highly contingent on institutional arrangements and labor-market responses^[14–15]. Nevertheless, the literature often measures the economic and demographic dimensions separately, without converting them into a unified and comparable metric. Moreover, it tends to emphasize correlations and trend-based judgments, while offering relatively few city-level, reproducible assessment frameworks that can be directly linked to specific policy instruments. Third, research has examined pension insurance fund sustainability and delayed-retirement reform, focusing on the effects of delayed retirement on the number of contributors, the number of beneficiaries, the fund's revenue-expenditure gap, and pressure for fiscal subsidies, and evaluating the reform's pressure-relief effects through scenario simulations or stochastic projections^[16–25]. However, most studies rely on national or provincial aggregates, making it difficult to reveal the heterogeneity of a single reform across cities arising from differences in demographic structure and economic foundations. At the same time, studies often treat fund revenues and expenditures as the endpoint, and rarely interpret reform effects as usable space within local macro-level resource allocation, thereby limiting the development of a closed-loop logic that proceeds from pressure identification to the prioritization of pilot implementation.

This study takes the Liaoning Coastal Economic Belt as the research focus and seeks to address three key issues. First, it aims to identify, under the context of population ageing, the ageing-related economic burden coefficient and the ageing-related economic carrying capacity of the Liaoning Coastal Economic Belt, and to examine how city-level economic scale and economic density shape a city's ability to absorb, buffer, and reallocate the pressures associated with the continued intensification of ageing. Second, it aims to diagnose regional pension-fiscal pressure by quantifying the intensity with which current urban economic resources are occupied—and the potential crowding-out effects that may arise—under the joint influence of elderly population structure and pension expenditures; it further evaluates the extent to which cities can maintain basic functions

under given fiscal constraints while preserving room for development-oriented spending. Third, it aims to identify the cities and priority areas that warrant urgent attention, and to determine the priority order of pilot cities in which delayed-retirement reform could be implemented. Centered on making population structure and urban economic foundations comparable through a consistent measurement approach, the study integrates ageing pressure, economic carrying capacity, and pension-expenditure constraints into a unified analytical framework. In doing so, it provides a complete analytical pathway for ageing coastal regions—from identifying spatial distributions, to estimating fiscal constraints, to establishing policy priorities—thereby adding region-specific evidence on the linkage between demographic-structural change and regional development constraints in coastal areas, and offering a replicable reference for identification and assessment in other ageing coastal regions.

2. Methods and data

2.1. Extraction of 100 m gridded older-population distribution data

The population-ageing data used in this study are derived from a nationwide 100 m-resolution gridded dataset of age-specific population densities based on China’s Seventh National Population Census. The dataset is constrained by township-level (the finest publicly available) age-group tabulations from the 2020 census, integrates multiple auxiliary geospatial covariates, and applies a random-forest model to generate spatial predictions. This process produces 100 m grid-cell population-density surfaces for the 60–64 and 65+ age groups. The researchers then clip and mask the 60–64 and 65+ gridded layers to the study area and conduct spatial statistics under a unified coordinate reference system. On the one hand, these data are used to depict the spatial patterns of clustering and dispersion of older populations across Liaoning Province and the Liaoning Coastal Economic Belt. On the other hand, the gridded population densities are aggregated to administrative units to obtain prefecture-level totals for the 60–64 and 65+ groups, thereby providing a consistent data basis for subsequent estimation of older-population density, the ageing-related economic burden coefficient, the economic carrying-capacity coefficient, and pension-fiscal pressure.

2.2. Ageing pressure and regional carrying capacity

To enable measurable and comparable scenario analysis, this study decomposes ageing-related constraints at the city level into two dimensions: pension-fiscal pressure and economic carrying capacity. The former emphasizes the intensity with which pension expenditures occupy urban economic resources, while the latter emphasizes the ability of city-wide economic scale and spatial economic density to absorb and buffer this pressure. In this study, an ageing-related economic burden coefficient (capturing the pressure dimension at the city level) and an older-population economic carrying-capacity coefficient (capturing the capacity dimension at the city level) are used to quantify ageing pressure and regional economic carrying capacity for the two age groups, 60–64 and 65 years and above.

Let the study unit be the i -th city in the Liaoning Coastal Economic Belt. Denote the administrative land area as $S_i(\text{km}^2)$, gross domestic product in 2020 as $GDP_i(\text{CNY } 100 \text{ million})$, the population aged 60–64 as N_i^{60-64} (persons), and the population aged 65+ as N_i^{65+} (persons). The authors first define regional economic density (economic output per unit area) as:

$$D_i^g = \frac{GDP_i}{S_i} (\text{CNY } 100 \text{ million}/\text{km}^2) \quad (1)$$

Next, age-specific older-population density (older-population size per unit area) is defined as:

$$D_i^{60-64} = \frac{N_i^{60-64}}{S_i} \text{ (person/km}^2\text{)}, D_i^{65+} = \frac{N_i^{65+}}{S_i} \text{ (person/km}^2\text{)} \quad (2)$$

Under this unified measurement basis, the authors construct the age-specific ageing-related economic burden coefficient, defined as the older-population density per unit of economic density. Substantively, it captures the older-population pressure per unit of GDP, facilitating cross-city comparison; a larger value indicates heavier ageing-related pressure:

$$B_i^{60-64} = \frac{D_i^{60-64}}{D_i^g} = \frac{N_i^{60-64}/S_i}{GDP_i/S_i} = \frac{N_i^{60-64}}{GDP_i}, B_i^{65+} = \frac{D_i^{65+}}{D_i^g} = \frac{N_i^{65+}/S_i}{GDP_i/S_i} = \frac{N_i^{65+}}{GDP_i} \quad (3)$$

Correspondingly, the authors construct the age-specific older-population economic carrying-capacity coefficient, defined as the economic density per unit of older-population density:

$$A_i^{60-64} = \frac{D_i^g}{D_i^{60-64}} = \frac{GDP_i/S_i}{N_i^{60-64}/S_i} = \frac{GDP_i}{N_i^{60-64}}, A_i^{65+} = \frac{D_i^g}{D_i^{65+}} = \frac{GDP_i/S_i}{N_i^{65+}/S_i} = \frac{GDP_i}{N_i^{65+}} \quad (4)$$

Here, A_i^{60-64} and A_i^{65+} represent the ‘‘GDP scale per person aged 60–64 (or 65+)’’; a larger value implies that the economic base provides stronger support for the ageing pressure of the corresponding age group. In contrast, larger B_i^{60-64} and B_i^{65+} indicate heavier ageing-related pressure. The two sets of coefficients are reciprocal:

$$A_i^{60-64} = \frac{1}{B_i^{60-64}}, A_i^{65+} = \frac{1}{B_i^{65+}} \quad (5)$$

On this basis, to directly connect the pressure indicator for the 60–64 cohort with a pension-fiscal pressure measure, the authors introduce a proxy parameter for the per-capita pension payment level, P_i (CNY/person·year), together with an effective conversion coefficient $\theta \in (0,1]$ (which jointly captures the share of the 60–64 population entering the beneficiary pool and the discrepancy between the benefit-calculation base and the actually paid level). Both the 60–64 population size N_i^{60-64} and prefecture-level GDP are taken from official 2020 statistics. The pension benefit-calculation base P_i follows the policy issued by the Liaoning Provincial Department of Human Resources and Social Security and the Liaoning Provincial Department of Finance: for Dalian, the basic pension benefit-calculation base under enterprise employees’ basic pension insurance is 92,147 CNY/person·year, whereas the other five cities uniformly adopt the provincial base of 72,686 CNY/person·year. For parameterization, θ is varied from 0.1 to 1.0 in increments of 0.1 to conduct scenario calculations, thereby systematically reflecting deviations induced by differences between the benefit-calculation base and the actual average pension level, the benefit-receipt share, and institutional heterogeneity. A smaller θ corresponds to a more conservative expenditure estimate, while $\theta=1$ represents the upper bound of pressure estimated using the benefit-calculation base, providing an upper-bound constraint for pension-fiscal pressure. Because the proxy expenditure $E_i(\theta)$ is linearly related to θ , the relative ordering of the cross-city pressure rate $PB_i(\theta)$ remains consistent across parameter settings; accordingly, the subsequent typology based on pressure intensity is robust.

On this basis, the marginal pressure of pension expenditures for the 60–64 age group on the GDP share can be expressed as:

$$PB_i^{60-64}(\theta) = \frac{\theta \cdot N_i^{60-64} \cdot P_i}{GDP_i \cdot 10^8} \times 100\% \quad (6)$$

Further incorporating the ageing-related economic burden coefficient defined above:

$$B_i^{60-64} = \frac{N_i^{60-64}}{GDP_i} \quad (7)$$

the pension-pressure measure can be simplified to:

$$PB_i^{60-64}(\theta) = \theta \cdot \left(\frac{P_i}{10^8} \times 100\% \right) \cdot B_i^{60-64} \quad (8)$$

This indicates that, given the pension-payment parameter P_i , the pension-fiscal pressure rate $PB_i^{60-64}(\theta)$ is strictly linearly related to the ageing-related economic burden coefficient B_i^{60-64} , which facilitates cross-city comparison and typological identification under alternative institutional scenarios.

3. Results

3.1. Spatial pattern of older-population distribution in Liaoning Province

Drawing on age-specific population data from the Seventh National Population Census, **Figure 1** illustrates, at 100 m resolution, the spatial clustering patterns and scale differences of the populations aged 60–64 and 65 and above in the Liaoning Coastal Economic Belt. Considering the spatial distribution of the younger-old (60–64) and older-old (65+) cohorts across Liaoning Province as a whole, both groups are generally concentrated along the old industrial corridor of central-southern Liaoning and the coastal port belt; together, the Shenyang-Anshan-Fushun-Benxi-Liaoyang axis and the six coastal cities of Dalian, Yingkou, Panjin, Jinzhou, Huludao, and Dandong form the two principal belts with the highest concentration of older populations. The key difference lies in the fact that high-value clusters of the 60–64 cohort are markedly more dispersed: in addition to high-density zones in old urban districts, relatively continuous hotspots also appear around various development zones, port-oriented industrial parks, and new-town clusters. By contrast, the 65+ population is more tightly concentrated in traditional central urban districts, old industrial neighborhoods, and historic street areas in county seats.

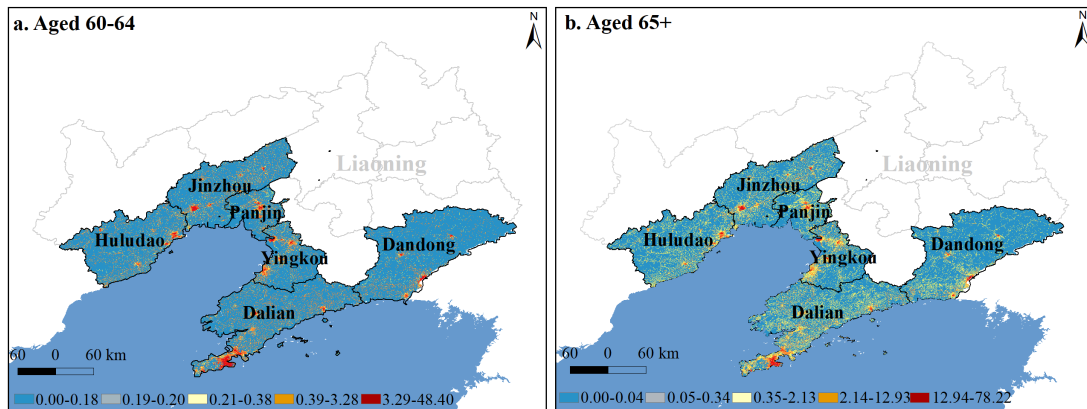


Figure 1. Spatial distribution of the older population in the Liaoning Coastal Economic Belt in 2020

Table 1 shows that, at the city level, the share of the population aged 60–64 ranges from 6.8% to 9.0%, while the share aged 65 and above ranges from 15% to 20%, exhibiting a clear structural profile. Dandong and Jinzhou record markedly higher ageing levels (population aged 60 and above) of 29.01% and 28.57%, respectively, than Dalian, Panjin, Huludao, and Yingkou, indicating that the border city in eastern Liaoning and the old industrial city in western Liaoning have entered a stage of deep ageing. This reflects two concurrent processes. On the one hand, early mining, manufacturing, and port-related industries had largely completed their industrial accumulation in the last century, leaving a substantial cohort of middle-aged and older workers. On the other hand, over the

past decade, the outward relocation of manufacturing, intensified port competition, and shrinking employment opportunities have driven a sustained out-migration of young and prime-age workers to the provincial capital, Dalian, and other provinces, thereby increasing the proportion of older residents. In contrast, Panjin exhibits a comparatively lower ageing level (22.22%), which partly indicates that the Liaohe Oilfield and the petrochemical sector continue to attract working-age labor, and partly suggests that its urbanization started relatively later, such that the peak of ageing has not yet fully materialized.

Table 1. Basic characteristics of the older population in the six coastal cities of Liaoning Province

City	Aged 60–64		Aged 65+		Population ageing level (aged 60+)
	Total population	Population share (%)	Total population	Population share (%)	
Dalian	576281	7.73	1239431	16.63	24.37%
Huludao	195703	8.04	423545	17.40	25.44%
Panjin	94546	6.80	214185	15.41	22.22%
Dandong	197797	9.04	437020	19.97	29.01%
Jinzhou	235581	8.71	536960	19.86	28.57%
Yingkou	181260	7.78	402005	17.26	25.05%

The results reveal that the spatial distribution of the older population overlaps to a very high degree with old industrial areas, traditional agricultural zones, and less-developed port cities, while being misaligned with emerging ports, industrial platforms, and service-sector clusters. This implies that the areas with the highest demand for elderly care are often those where the economic carrying capacity is relatively weak. For regional development, this is both a source of risk and a potential breakthrough point: if resources continue to be allocated on the basis of average indicators at the administrative-unit level, it is easy for population ageing to accelerate in peripheral counties and county-level cities; by contrast, if these differences in the spatial distribution of older populations are taken as a basis for restructuring spatial functions, and elderly-oriented care, rehabilitation and wellness, integrated agriculture-culture-tourism industries, and localized everyday service sectors are developed around county-level cities and peripheral zones, while treating the 60–64 age group as a reusable older labour force and facilitating their shift from secondary-sector jobs into community governance, care services, and the broader elderly-care industry, and at the same time further enhancing the attractiveness of high-end services and innovation industries to young people in Dalian’s core area and the Jinpu New Area, then population ageing can instead become a new leverage point for economic transformation and silver-economy development along the Liaoning coastal belt.

3.2. Matching between population ageing and regional economic development in the Liaoning Coastal Economic Belt

The authors use the ratio of age-specific older-population density to regional economic density as the ageing-related economic burden coefficient for each age group, which serves to identify high-pressure areas; a larger value indicates heavier pressure. Conversely, the authors use the ratio of regional economic density to age-specific older-population density as the older-population economic carrying-capacity coefficient, which characterizes a region’s capacity to support ageing; a larger value indicates stronger support. Against the backdrop of continued

deepening ageing, an internal spatial configuration is emerging within Liaoning’s coastal area, with Dalian and Panjin forming a “high-capacity-low-burden” core and Jinzhou-Huludao-Dandong constituting a “low-capacity-high-burden” periphery (**Table 2**). Overall, the six coastal cities of Liaoning exhibit a clear configuration in which Panjin-Dalian constitute the axis of a relatively robust ageing-support belt, Yingkou serves as an intermediate carrying-capacity zone, and Huludao at the western end, together with Dandong at the eastern end, plus Jinzhou, form the most vulnerable zone bearing the heaviest ageing burden.

Table 2. Economic carrying-capacity and economic burden coefficients of the older population in the six coastal cities of Liaoning Province

City	Economic carrying-capacity (older population) coefficient			Economic burden (ageing) coefficient		
	Aged 60–64	Aged 65+	Aged 60+	Aged 60–64	Aged 65+	Aged 60+
Dalian	122.00	56.72	38.72	0.0082	0.0176	0.0258
Huludao	39.37	18.19	12.44	0.0254	0.0550	0.0804
Panjin	137.88	60.86	42.22	0.0073	0.0164	0.0237
Dandong	39.40	17.83	12.28	0.0254	0.0561	0.0814
Jinzhou	45.51	19.97	13.88	0.0220	0.0501	0.0721
Yingkou	73.13	32.97	22.73	0.0137	0.0303	0.0440

Panjin and Dalian, as typical high-carrying-capacity-low-burden cities, have carrying-capacity coefficients for the population aged 60 and above of 42.22 and 38.72, respectively, with corresponding economic burden coefficients of only 0.0237 and 0.0258, clearly outperforming the average levels of the six coastal cities. This pattern is related to their higher GDP density and, to some extent, net in-migration, and indicates that their economic base is capable of absorbing the current fiscal and service pressures associated with population ageing while reserving buffer space for the forthcoming stage of more advanced ageing. Yingkou occupies an intermediate position, with a carrying-capacity coefficient of 22.73 and a burden coefficient of 0.0440, suggesting that its economic scale and industrial structure provide a certain degree of support for ageing, but that both its fiscal flexibility and the pace of industrial upgrading are evidently weaker than in Dalian and Panjin; if new growth drivers cannot be cultivated more rapidly, it is likely to evolve from a medium-burden to a high-burden city. Huludao, Dandong, and Jinzhou, by contrast, form a distinct high-pressure cluster: their carrying-capacity coefficients for the 60+ population are all in the range of 12–14, while their burden coefficients reach as high as 0.0721–0.0814, roughly three times those of Dalian and Panjin, making them typical low-carrying-capacity-high-burden cities.

By further comparing different age groups, the authors find that in Huludao, Dandong, and Jinzhou, the burden coefficients for the 60–64 age group have already reached 0.0220–0.0254, far exceeding those of Dalian and Panjin. This indicates that even at the “pre-elderly” stage (ages 60–64), these cities already exhibit relatively weak carrying capacity for populations approaching retirement age. This, in turn, implies that over the next decade, when this cohort of 60–64-year-olds fully transitions into the 65-and-above group, the ageing-related economic burden in these three cities will further increase sharply. By contrast, although Yingkou’s burden coefficient is higher than that of Dalian and Panjin, it retains a certain advantage in carrying capacity for the 60–64 age group, suggesting that there remains scope to partially buffer ageing shocks through moderate delayed retirement, the re-

utilization of older labor, and the development of the elderly-care service industry.

3.3. Pension-fiscal pressure and the scale of releasable funds under delayed retirement in the six coastal cities of Liaoning Province

Building on the preceding identification of the spatial pattern of population ageing across the six coastal cities of Liaoning, as well as the estimated ageing-related economic burden coefficients and economic carrying-capacity coefficients, the authors further introduce pension-fiscal pressure to translate population ageing—an inherently long-term, structural shock—into a macro-level constraint that is measurable, comparable, and suitable for policy-scenario analysis. Treating the 60–64 cohort as a near-threshold, pre-retirement age group, the authors construct a proxy for annual pension expenditures using the pension benefit-calculation base and the size of this cohort, and characterize the marginal intensity of pension-fiscal pressure by its share of GDP. The reduction in this pressure under delayed-retirement scenarios is then interpreted as the scale of releasable funds.

3.3.1. Identifying pension-fiscal pressure in the Liaoning Coastal Economic Belt

Under a conservative accounting approach, pension-fiscal pressure across the six coastal cities of Liaoning exhibits pronounced asynchrony: the pension-fiscal pressure rate does not vary linearly with economic scale, but instead concentrates at high levels in cities with medium-sized or relatively small economies. Taking as an example, the share of pension expenditures for the 60–64 cohort in GDP reaches 5.54%, 5.53%, and 4.79% in Huludao, Dandong, and Jinzhou, respectively—substantially higher than the corresponding levels in Dalian (2.27%), Yingkou (2.98%), and Panjin (1.58%). Even under conservative assumptions that do not overstate expenditure levels, pension-fiscal constraints have already generated considerable marginal resource occupation in some cities and display a clear inter-city gradient.

This asynchrony is not driven by differences in the benefit-calculation base; rather, it is determined to a greater extent by the relative relationship between the size of the near-retirement population and the city-level economic resource base. As shown in **Table 3**, under , Dalian’s pension expenditure scale amounts to 15.931 billion yuan, with a five-year cumulative total of 79.655 billion yuan, illustrating the magnitude of funds that delayed retirement could potentially release under conditions of a large population base and a high level of economic output. Yet its pressure rate is only 2.27%, indicating that for economically large cities, pension-fiscal constraints are manifested more as opportunities for expenditure-structure optimization and the reallocation of fiscal space toward development-oriented spending, rather than as a high-pressure constraint. By contrast, the annual releasable funds in Huludao, Dandong, and Jinzhou are 4.267 billion yuan, 4.313 billion yuan, and 5.137 billion yuan, respectively. Although these absolute magnitudes are smaller than Dalian’s, their pressure rates on a GDP basis are markedly higher, implying that under a relatively limited economic resource base, pension expenditures exert a more pronounced marginal crowding-out effect on macro-level resource allocation. Under the upper-bound scenario of , the pressure rates reach 18.46% in Huludao and 18.45% in Dandong, and 15.97% in Jinzhou, suggesting that under this upper-bound assumption, pension expenditures for a single age cohort alone could occupy close to one-fifth of city-level output—an order of magnitude sufficient to impose a structural constraint on the fiscal space available for development-oriented spending.

Table 3. Estimates of the 60–64 population and pension-fiscal pressure in the six coastal cities of Liaoning ($\theta=0.3$ and 1.0)

City	GDP (CNY 100 million)	E (0.3) (CNY 100 million)	PB (0.3) (%)	E (1) (CNY 100 million)	PB(1) (%)	Five-year cumulative expenditure reduction C (0.3) (CNY 100 million)
Dalian	7030.4	159.31	2.27	531.03	7.55	796.55
Huludao	770.4	42.67	5.54	142.25	18.46	213.35
Panjin	1303.6	20.62	1.58	68.72	5.27	103.10
Dandong	779.4	43.13	5.53	143.77	18.45	215.65
Jinzhou	1072.2	51.37	4.79	171.23	15.97	256.85
Yingkou	1325.5	39.53	2.98	131.75	9.94	197.65

3.3.2. Identification of pension-fiscal pressure and releasable funds under θ uncertainty

Tables 4–6 respectively report, for the six cities, the annual pension expenditure $E_i(\theta)$, the pension-fiscal pressure $PB_i(\theta)$, and the five-year cumulative releasable funds $C_i(\theta)$ under different values of $C_i(\theta)$. The results show that:

Dalian exhibits the largest annual and five-year cumulative releasable funds under all θ scenarios, yet its pension-fiscal pressure remains consistently at a moderate level. As θ increases from 0.1 to 1.0, Dalian’s $E(\theta)$ rises from 5.310 billion yuan to 53.103 billion yuan, and the five-year cumulative $C(\theta)$ increases from 26.550 billion yuan to 265.515 billion yuan; however, $PB(\theta)$ increases only from 0.76% to 7.55%. This indicates that Dalian’s cumulative releasable funds are driven primarily by a scale effect: given a large near-retirement population, delayed retirement can release a sizable amount of funds. Yet its pressure rate is not pronounced when measured relative to GDP, implying that the policy relevance for Dalian lies more in optimizing the expenditure structure and expanding fiscal space for development-oriented spending, rather than in alleviating a high-pressure constraint.

Huludao maintains high pension-fiscal pressure across all θ scenarios, and its constraint intensity is most pronounced under the maximum-pressure specification. Specifically, $PB(\theta)$ increases linearly from 1.85% ($\theta=0.1$) to 18.46% ($\theta=1.0$), reaching 5.54% already at $\theta=0.3$. Compared with Dalian, Huludao’s absolute pension-expenditure scale is smaller (4.267 billion yuan at $\theta=0.3$), but its pressure rate is significantly higher, indicating that its pension-fiscal constraint stems more from the relative occupation intensity of resources under a comparatively limited economic base. This pattern implies that Huludao is more sensitive to institutional adjustments: delayed retirement there manifests as a marked reduction in the pressure rate and a relatively larger scale of releasable funds.

Panjin maintains the lowest pension-fiscal pressure rate across the entire θ range, and the relative scale of its pension expenditures remains consistently low. Specifically, $PB(\theta)$ increases from 0.53% to 5.27%, and is only 1.58% at $\theta=0.3$, remaining the lowest among the six cities throughout. The annual $E(\theta)$ rises from 0.687 billion yuan to 6.872 billion yuan, while the five-year cumulative releasable funds increase from 3.435 billion yuan to 34.360 billion yuan. These results indicate that Panjin’s pension-fiscal pressure for the 60–64 cohort is relatively manageable and that the scope for releasable funds under delayed retirement is limited, making it less likely to generate a pronounced short-term pressure-reduction effect. Accordingly, policy in Panjin should not focus solely on the amount of pension expenditure that can be released through delayed retirement, but should place greater emphasis on the sustainability of its carrying capacity and the transmission of demographic-structural changes into medium- to long-term pressure.

Dandong exhibits a persistently high pressure-rate profile across the full θ range, and under the upper-bound (maximum-pressure) specification, its constraint intensity is almost identical to that of Huludao. Specifically, $PB(\theta)$ increases from 1.84% to 18.45%, reaching 5.53% at $\theta=0.3$, nearly the same magnitude as Huludao. At $\theta=0.3$, $E(\theta)$ amounts to 4.313 billion yuan, and the five-year cumulative releasable funds total 21.565 billion

yuan—moderate in absolute size, yet markedly high in relative intensity. These results indicate that Dandong’s pension-fiscal pressure is driven more by a high relative occupation of economic resources than by scale alone. Under the maximum-pressure specification, the pressure rate for a single age cohort exceeds 18%, implying a substantial squeeze on fiscal space; accordingly, the pressure relief brought by delayed retirement is likely to be more targeted in Dandong, with more direct policy effects.

Yingkou’s pressure rate falls within the upper-middle range, with pension expenditures occupying a median position in both scale and intensity. Specifically, $PB(\theta)$ increases from 0.99% to 9.94%, reaching 2.98% at $\theta=0.3$ —substantially higher than Panjin and Dalian, yet lower than Jinzhou, Dandong, and Huludao. At $\theta=0.3$, pension expenditures amount to 3.953 billion yuan, with a five-year cumulative total of 19.765 billion yuan. These results suggest that Yingkou faces neither an extremely high-pressure constraint nor a low-pressure situation; rather, the policy implication lies in using institutional adjustment to generate a meaningful scale of releasable funds, which can then support development-oriented spending needs such as industrial upgrading and improvements in public services.

Table 4. Annual pension expenditure for the 60–64 cohort in the six coastal cities of Liaoning, $E(\theta)$ (unit: CNY 100 million)

θ	Dalian	Huludao	Panjin	Dandong	Jinzhou	Yingkou
0.1	53.10	14.22	6.87	14.38	17.12	13.18
0.2	106.21	28.45	13.74	28.75	34.25	26.35
0.3	159.31	42.67	20.62	43.13	51.37	39.53
0.4	212.41	56.9	27.49	57.51	68.49	52.7
0.5	265.51	71.12	34.36	71.89	85.62	65.88
0.6	318.62	85.35	41.23	86.26	102.74	79.05
0.7	371.72	99.57	48.11	100.64	119.86	92.23
0.8	424.82	113.8	54.98	115.02	136.99	105.4
0.9	477.92	128.02	61.85	129.39	154.11	118.58
1	531.03	142.25	68.72	143.77	171.23	131.75

Table 5. Annual pension expenditure for the 60–64 cohort as a share of GDP in the six coastal cities of Liaoning, $PB(\theta)$ (unit: %)

θ	Dalian	Huludao	Panjin	Dandong	Jinzhou	Yingkou
0.1	0.76	1.85	1.60	1.84	1.60	0.99
0.2	1.51	3.69	3.19	3.69	3.19	1.99
0.3	2.27	5.54	4.79	5.53	4.79	2.98
0.4	3.02	7.39	6.39	7.38	6.39	3.98
0.5	3.78	9.23	7.99	9.22	7.99	4.97
0.6	4.53	11.08	9.58	11.07	9.58	5.96
0.7	5.29	12.92	11.18	12.91	11.18	6.96
0.8	6.04	14.77	12.78	14.76	12.78	7.95
0.9	6.80	16.62	14.37	16.60	14.37	8.95
1	7.55	18.46	15.97	18.45	15.97	9.94

Table 6. Five-year cumulative pension expenditure for the 60–64 cohort under delayed retirement in the six coastal cities of Liaoning, $C(\theta)$ (unit: CNY 100 million)

θ	Dalian	Huludao	Panjin	Dandong	Jinzhou	Yingkou
0.1	265.50	71.10	34.35	71.90	85.60	65.90
0.2	531.05	142.25	68.70	143.75	171.25	131.75
0.3	796.55	213.35	103.10	215.65	256.85	197.65
0.4	1062.05	284.50	137.45	287.55	342.45	263.50
0.5	1327.55	355.60	171.80	359.45	428.10	329.40
0.6	1593.10	426.75	206.15	431.30	513.70	395.25
0.7	1858.60	497.85	240.55	503.20	599.30	461.15
0.8	2124.10	569.00	274.90	575.10	684.95	527.00
0.9	2389.60	640.10	309.25	646.95	770.55	592.90
1	2655.15	711.25	343.60	71.90	856.15	658.75

At the regional scale, the aggregate pressure rate for the six cities increases linearly with θ , while the high-medium-low stratification of pressure across cities remains stable throughout the entire range. **Table 7** shows that the total pension expenditure $E_{sum}(\theta)$ rises from 11.887 billion yuan to 118.875 billion yuan, the corresponding aggregate pressure rate $PB_{sum}(\theta)$ increases from 0.97% to 9.68%, and the five-year cumulative releasable funds expand from 59.435 billion yuan to 594.375 billion yuan. Under the $\theta=0.3$ scenario, total pension expenditure is 35.663 billion yuan, corresponding to a pressure rate of 2.90%, with a five-year cumulative total of 178.315 billion yuan; under the maximum-pressure specification of $\theta=1.0$, the annual “buffer space” is 118.875 billion yuan, the pressure rate is 9.68%, and the five-year cumulative total reaches 594.375 billion yuan. Importantly, this linear increase in aggregate pressure does not alter the relative ordering across cities: Huludao, Dandong, and Jinzhou consistently remain in the high-pressure group, Panjin remains stably in the low-pressure group, and Dalian and Yingkou fall in the middle range. These results provide a robust quantitative basis for the subsequent city typology and indicate that parameter uncertainty primarily affects the magnitude of pressure levels, while having a limited influence on identifying the underlying pressure-gradient structure.

Table 7. Aggregate pension expenditure for the 60–64 cohort and cumulative releasable funds in the six coastal cities of Liaoning

θ	Total annual pension expenditure (CNY 100 million)	Total pension expenditure as a share of GDP (%)	Five-year cumulative releasable funds (CNY 100 million)
0.1	118.87	0.97	59.35
0.2	237.75	1.94	118.75
0.3	356.63	2.90	178.15
0.4	475.50	3.87	237.50
0.5	594.38	4.84	297.90
0.6	713.25	5.81	356.25
0.7	832.13	6.78	416.65
0.8	951.01	7.74	475.05
0.9	1069.87	8.71	534.35
1.0	1188.75	9.68	594.75

3.4. City-type identification based on ageing pressure and urban support capacity

Calculations over the full range of θ reveal a stable stratified structure in both pension-fiscal pressure rates and the scale of releasable funds across the six cities, and this structure remains consistent under both conservative and maximum-pressure scenarios. It is therefore necessary to identify each city's structural position and pressure-shift characteristics within a two-dimensional framework defined by pension-fiscal pressure and economic carrying capacity.

City types are classified by taking the terciles of the pension-fiscal pressure rate $PB_i(0.3)$ under as $\theta=0.3$ the primary thresholds, and cross-tabulating these with the level of the “economic carrying-capacity coefficient” A_i for the 60–64 cohort. Let Q_{33} and Q_{67} denote the 33% and 67% quantiles of $PB_i(0.3)$ across the six cities. First, the authors order $PB_i(0.3)$ from smallest to largest as Panjin 1.58%, Dalian 2.27%, Yingkou 2.98%, Jinzhou 4.79%, Dandong 5.53%, and Huludao 5.54%. Using rank statistics with rounding, $Q_p = x_{(\text{round}(p \cdot n))}$, the authors obtain $Q_{33} = x_{(\text{round}(0.33 \times 6))} = x_{(2)} = 2.27\%$ and $Q_{67} = x_{(\text{round}(0.67 \times 6))} = x_{(4)} = 4.79\%$. Second, the authors dichotomize A_i using the sample median: values above the median are defined as “high carrying capacity,” and otherwise as “medium-low carrying capacity.” For the six cities, the 60–64-based values are 122.00 for Dalian, 39.37 for Huludao, 137.88 for Panjin, 39.40 for Dandong, 45.51 for Jinzhou, and 73.13 for Yingkou. After ordering, the median is $\text{Median}(A) = 59.32$. Accordingly, Dalian, Panjin, and Yingkou are classified as high-carrying-capacity cities ($A_i \leq 59.32$), while Huludao, Dandong, and Jinzhou are classified as medium-low-carrying-capacity cities ($A_i > 59.32$). Finally, cross-classification proceeds as follows: when $PB_i(0.3) \geq Q_{67} (=4.79\%)$ and $A_i \leq 59.32$, the city is assigned to the high-pressure-sensitive type (Huludao: 5.54%, 39.37; Dandong: 5.53%, 39.40; Jinzhou: 4.79%, 45.51); when $Q_{33} (=2.27\%) \leq PB_i(0.3) < Q_{67} (=4.79\%)$ and $A_i > 59.32$, it is assigned to the medium-pressure, high-carrying-capacity type (Dalian: 2.27%, 122.00; Yingkou: 2.98%, 73.13); and when $PB_i(0.3) < Q_{33} (=2.27\%)$, it is assigned to the low-pressure, relatively stable type (Panjin: 1.58%, 137.88).

3.4.1. Huludao, Dandong, and Jinzhou as high-pressure-sensitive cities

Huludao, Dandong, and Jinzhou fall into the high-pressure group, where pressure rates remain persistently elevated, and the buffer space released through institutional adjustment has greater marginal significance. In terms of pension-fiscal pressure rates, under the $\theta=0.3$ scenario, the values of $PB_i(0.3)$ for the three cities are 5.54%, 5.53%, and 4.79%, respectively, all markedly higher than those of the medium-pressure and low-pressure cities. When θ rises to 1.0, their pressure rates increase to 15.97%–18.46%, implying that, under the maximum-pressure scenario, expenditures for a single age cohort alone can occupy close to or more than one-sixth of city-level GDP, indicating a clearly binding resource constraint. In terms of the cumulative scale of releasable funds, under $\theta=0.3$ the five-year cumulative releasable funds $C_i(0.3)$ for the three cities are 21.335 billion, 21.565 billion, and 25.685 billion yuan, respectively. Although these absolute amounts are not the largest, the associated pressure rates are high once matched against their economic resource base, indicating that the budget space released by institutional adjustment is more critical for these cities in a relative sense. For this type of city, the pressure reduction brought about by delayed-retirement scenarios should first be used to stabilize the basic expenditure structure and expand essential public-service provision, and only thereafter to enlarge development-oriented spending; otherwise, persistently high pressure will continue to crowd out fiscal allocation space and erode the capacity for long-term adjustment.

3.4.2. Dalian and Yingkou as medium-pressure, high-carrying-capacity cities

Dalian and Yingkou fall into the middle range of pension-fiscal pressure rates: their pressure rates are manageable,

yet scale effects are pronounced, making structural optimization and the expansion of development-oriented spending the central priorities. In terms of pressure rates, under $\theta=0.3$ the values of $PB(0.3)$ are 2.27% for Dalian and 2.98% for Yingkou; under the maximum-pressure scenario of $\theta=1.0$, they rise to 7.55% and 9.94%, respectively. Both remain below those of the high-pressure-sensitive cities, indicating that the intensity of their pension-fiscal constraints is relatively controllable. Under $\theta=0.3$, Dalian's annual pension expenditure $E(0.3)$ is 15.931 billion yuan, and its five-year cumulative releasable funds $C(0.3)$ reach 79.655 billion yuan—substantially higher than in other cities—reflecting a scale effect jointly driven by population size and economic output. Yingkou's annual $E(0.3)$ is 3.953 billion yuan, and its five-year cumulative total is 19.765 billion yuan, also indicating meaningful adjustment space. When combined with the economic carrying-capacity dimension, both cities have relatively large GDP and high economic-activity density, enabling them to absorb fiscal fluctuations under the same pressure rate. Accordingly, the policy implication for this type of city is more oriented toward budgetary rebalancing: by moderately reducing the crowding-out of development-oriented spending caused by the growth of pension expenditures, they can secure a stable resource base for industrial transformation, innovation investment, and improvements in the quality of public-service provision, thereby strengthening adjustability and intertemporal allocation capacity within the pension-fiscal subsystem.

3.4.3. Panjin as a low-pressure, relatively stable city

Panjin's pension-fiscal pressure rate has remained at a low level over the long term, with relatively weak short-term constraints, but its structural risk depends on the sustainability of its economic carrying capacity and the evolution of its population structure. Under $\theta=0.3$, $PB(0.3)=1.58\%$, the annual buffer space $E(0.3)$ is 2.062 billion yuan, and the five-year cumulative value $C(0.3)$ reaches 10.310 billion yuan; under the maximum-pressure scenario of $\theta=1.0$, $PB(1.0)=5.27\%$, still significantly lower than in the high-pressure-sensitive cities. These results indicate that Panjin has not yet developed a pronounced pension-fiscal constraint for the 60–64 age group, and that the scope for pressure reduction through delayed retirement is relatively limited. It should be emphasized that low pressure does not directly equate to long-term stability. At the current stage, Panjin's pressure level is shaped mainly by the relative relationship between population size and economic scale; once its economic carrying capacity declines or population ageing accelerates, the city may shift toward the medium-pressure zone within the two-dimensional framework. Therefore, for this type of city, policy priorities should focus on maintaining the stability of carrying capacity and improving the quality of economic density, including industrial-structure upgrading, employment absorption capacity, and the orientation of population flows, so as to prevent the current low-pressure advantage from being eroded by structural changes in the medium to long term.

4. Conclusions

Against the policy backdrop of rapidly deepening population ageing and the accelerated advancement of delayed-retirement reform, this study focuses on the spatial clustering of older populations in the Liaoning Coastal Economic Belt, the mismatch between ageing pressure and economic carrying capacity, and the constraints imposed by pension expenditures on city-level resource allocation. The main conclusions are as follows:

- (1) The older population in Liaoning Province exhibits a pronounced belt-like pattern of concentration, with clearly differentiated spatial forms across age groups. At the provincial scale, the 60–64 cohort expands in parallel with the coastal port belt and industrial development zones, whereas the 65-and-above cohort is

more concentrated in traditional central urban districts and old industrial neighborhoods. This manifests as a “diffusion-convergence” contrast within the same high-value belt. This pattern implies that hotspots of demand for elder-care services and public resources do not coincide with the main clusters of incremental industrial activity and fiscal revenue. Policy design should therefore prioritize the siting of elder-care facilities, primary health care, and community-based care in areas with high concentrations of the oldest age groups, while treating the 60–64 cohort as a redeployable labour force. Around development zones, port-adjacent industrial parks, and community service systems, more accessible, suitably matched positions and retraining programmes should be created for this group, in order to reduce the spatial mismatch between “high demand and low supply.”

- (2) A structural mismatch exists between ageing pressure and economic carrying capacity across the six coastal cities. Dalian and Panjin fall into the high-carrying-capacity-low-burden category; Huludao, Dandong, and Jinzhou fall into the low-carrying-capacity-high-burden category and remain at high levels across both age groups; and Yingkou occupies an intermediate tier. This result indicates that the critical constraint of ageing lies not in the absolute size of the older population, but in how much ageing pressure must be borne per unit of economic scale. Accordingly, at the provincial level, fiscal transfers, medical-care resources, and incremental public-service provision should be tilted toward low-carrying-capacity-high-burden cities, with industrial transformation and employment-structure optimization serving as the main levers for relieving ageing pressure. At the city level, expansion of elder-care services should proceed in parallel with efforts to enhance economic density, so as to avoid fiscal unsustainability caused by supply expansion alone.
- (3) The core change brought about by delayed retirement is how much pension expenditure can be reduced each year and how much fiscal space can be released from the budget; however, its marginal benefits are more concentrated in high-pressure cities. Under conservative estimates, the pressure rate—measured as pension expenditure for the 60–64 cohort as a share of GDP—reaches 5.54%, 5.53%, and 4.79% in Huludao, Dandong, and Jinzhou, respectively, significantly higher than in Dalian and Panjin. The six cities together can release about 35.663 billion yuan, or about 178.315 billion yuan cumulatively over five years, indicating that institutional adjustment yields stronger short-term pressure relief in high-pressure cities, whereas in large cities, it is reflected mainly as a larger absolute amount of fiscal space that can be reallocated. Accordingly, implementation should prioritize Huludao-Dandong-Jinzhou as the primary rollout zone for reform and employment-supporting measures, with the goal of rapidly reducing pressure rates and stabilizing basic public services. For cities such as Dalian and Yingkou, the key issue is not how much pension spending is reduced, but how the freed-up funds are used; these funds are better prioritized for industrial upgrading, improvements in public services, and risk governance. At the same time, it is necessary to proactively optimize contribution participation and collection mechanisms for re-employment, so that the additional funds generated by re-employment can, in a sustained and stable manner, fill the gap created by expenditure reduction.

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