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Modelling cross-border risks in China's new industrial chain along the Belt and Road: Integrating ageing-driven demand dynamics and logistics resilience synergies

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Abstract. The purpose of the research was to model cross-border risks within China's new industrial chain along the Belt and Road Initiative (BRI), integrating the dynamics of ageing-driven demand and logistics resilience synergies. The research problem addressed in this study is the insufficient understanding of how demographic changes, particularly population ageing, interact with climate and economic factors to influence logistics resilience and cross-border risks in BRI countries. The research niche of this article is the limited crosscountry empirical evidence integrating these demographic, climate, and economic drivers within one crossborder logistics risk framework. The study tested the hypothesis that demographic ageing, together with economic and environmental risk factors, significantly explains variation in logistics performance and crossborder risk exposure across BRI countries. To achieve this, a combination of quantitative modelling and systemic analysis was employed, focusing on the interactions between ageing populations and evolving demand structures, while also considering logistics networks' capacity to withstand shocks.

Findings indicate substantial heterogeneity across BRI countries; regression models identify economic decline and greenhouse gas emissions as key contributors to crossborder risk, while ageing does not show a uniformly negative effect on logistics performance. The results emphasize the need for enhanced resilience in logistics systems and greater attention to demographic factors in policy and infrastructure planning along the Belt and Road routes. The research concludes with policy recommendations aimed at fostering resilient and adaptive industrial systems to mitigate the risks posed by demographic changes and logistical challenges.
Keywords: ageing population, economic downturn, climate risks, public debt, logistics efficiency

Introduction

In the 21st century, demographic changes have become one of the most pressing issues influencing global economies, with population ageing emerging as a particularly significant challenge. While much attention has been devoted to the economic implications of ageing populations, its impact on the resilience of logistics systems remains underexplored. Population ageing not only affects labour markets but also alters demand structures, influencing supply chains' flexibility and efficiency. Understanding how ageing-driven demand dynamics and logistics resilience interact is crucial for assessing cross-border risks in the context of global trade, especially within large-scale initiatives like China's Belt and Road Initiative (BRI).

The dynamics of population ageing are not uniform across countries (Vazova et al., 2025; Kovalchuk et al., 2024). High-income nations, particularly in Europe and Asia, are expected to face more pronounced demographic challenges compared to low-income countries (Sveriges Riksbank, 2025). In this context, China's pivotal role in global logistics, particularly through its Belt and Road Initiative, adds a layer of complexity. The BRI, which spans more than 150 countries, aims to foster enhanced economic cooperation and infrastructure development. However, as noted by Akinci et al. (2023), this expansion is not without its risks. The initiative integrates regions with diverse socio-economic conditions, many of which are experiencing significant demographic shifts, particularly ageing populations. These shifts are likely to exacerbate existing logistical inefficiencies and increase cross-border risks.

The BRI presents a unique opportunity to explore the intersection of demographic changes, logistics resilience, and cross-border risks (Aidarbayev, Uderbayeva, 2020a; 2020b). As highlighted by A. Mukhtar et al. (2022), while the BRI has contributed significantly to infrastructure development, particularly in Central Asia and Eastern Europe, the demographic challenges in these regions could undermine the effectiveness of logistical systems. In countries with ageing populations, there is a growing concern about the reduced labour force and the subsequent impact on supply chain efficiency (Oklander et al., 2020; Tepavicharova et al., 2020). This issue is compounded by environmental factors, such as climate change, which further stress logistics networks, particularly in high-risk areas.

For instance, studies examining logistics performance and demographic shifts in European countries have found that regions with higher ageing populations are more susceptible to logistical bottlenecks, as the workforce shrinks and the demand for services becomes more complex. Countries like Latvia, Estonia, Greece, and Italy, which have high levels of ageing, also face the highest levels of logistical inefficiencies. According to Staniewska (2021), countries with robust logistics systems and high ageing rates are more likely to experience logistical strain, which exacerbates cross-border risks. Additionally, Jałowiec and Spychalski (2025) emphasize that the resilience of logistics systems in crisis situations depends not only on infrastructure but also on the adaptability of the workforce, which is increasingly challenged by demographic trends.

The Belt and Road Initiative, in its vast geographical scope, has made logistics networks even more complex, necessitating a deeper understanding of how demographic and economic factors impact cross-border logistics. As highlighted by Tsyrfa et al. (2024), the political and legal frameworks governing resource allocation and logistical management must adapt to the demographic realities in participating countries. This study aims to fill a significant gap in the existing literature by examining the intersection of ageing populations, economic factors, and logistics resilience, with a focus on cross-border risks within the BRI framework.

The research hypothesis posits that demographic factors, particularly population ageing, along with economic and environmental risks, significantly affect logistics resilience and increase cross-border risks. Countries with higher levels of ageing, economic instability, and environmental vulnerabilities are expected to experience greater inefficiencies in their logistics systems, which in turn will exacerbate the risks associated with cross-border trade. By focusing on a comprehensive set of 54 BRI countries, this study utilised cluster analysis, regression models, and cartographic analysis to assess the logistics resilience and demographic factors impacting cross-border risks.

The research objectives include: (1) conducting a cartographic analysis to map logistics resilience levels and ageing indicators across the BRI countries; (2) implementing cluster analysis to identify patterns in logistics performance and demographic factors; and (3) performing regression analysis to determine the impact of demographic, economic, and environmental factors on cross-border risks in these countries. Through this approach, the study seeks to offer a comprehensive framework for understanding the complexities of cross-border logistics within the BRI and provide actionable recommendations for policymakers to enhance the resilience of logistics systems, especially in regions facing significant demographic shifts.

Research methodology

For the purpose of the analysis, the study defined two main groups of indicators. The first group of indicators concerned the level of logistics resilience and was represented by the Logistics Performance Index (LPI) and its sub-indices (Bandaranayake et al., 2024). These indicators characterised the overall efficiency of logistics and its various components (infrastructure quality, delivery timeliness, customs clearance efficiency, etc.). The LPI and its sub-indices were selected because they provide a comprehensive measure of logistics efficiency across multiple dimensions that directly relate to cross-border risks. This choice was driven by the need to capture a holistic view of logistics performance in the context of the Belt and Road Initiative. Depending on the specific parameter, changes in logistics efficiency indicators could have indicated the level of relevant cross-border risks. Table 1 detailed what each LPI sub-index measured and what types of risks the levels might have reflected.

Table 1. Correlation of sub-indices LPI and key cross-border risks that the change may indicate

LPI subindex	What characterises	What risk does the index change reflect?
Customs Score	Customs clearance efficiency	Risk of delays and unpredictability when crossing the border, complications of customs procedures
Infrastructure Score	Infrastructure quality	Risk of disruption of supply continuity due to limited capacity or disruptions in logistics routes
International Shipments Score	Ease of processing and/or frequency of international shipments	Risk of limited access to foreign markets and difficulties in entering the international market
Logistics Competence Score	Quality of logistics services	Risk of improper cargo handling, loss or errors in the process of cross-border movement of goods
Tracking & Tracing Score	Ability to track shipments	Risk of loss of control, increased likelihood of fraud or theft of cargo
Timeliness Score	Timeliness of deliveries	Risk of breach of contract, fines, or loss of reputation due to late deliveries

Source: Summarised by the authors from World Bank (2024)

The second group of indicators covered internal macroeconomic factors that potentially affected the escalation of logistics risks, the level of which was represented in the study through LPI sub-indices (Noman, 2024). These included demographic, climatic, and economic factors such as: population aged over 65 (% of total population), healthcare expenditure per capita, government debt, economic decline index, greenhouse gas emissions, climate risk exposure, and climate change exposure. The selection of these indicators was justified by their relevance in understanding the broader socio-economic environment that influences logistics resilience. Demographic and economic factors, particularly the proportion of elderly population, were included due to their direct impact on demand structures, which in turn affect logistics systems. Climate-related factors were selected to assess how environmental risks contribute to logistics bottlenecks, especially in the context of global trade and cross-border operations. The share of the population aged 65 and over described the level of population ageing: this indicator influenced labour productivity and economic growth, and also stimulated demand driven by ageing. Healthcare expenditure per capita complemented the previous indicator and was indirectly associated with age-related demand. This connection could be explained by the fact that increasing healthcare costs responded to growing demand driven by ageing, especially in societies with a high proportion of elderly people. Government debt was an important indicator of a country's financial stability; furthermore, in the context of the Belt and Road Initiative, this indicator reflected the level of countries' dependence on external funding for infrastructure projects, particularly from China. The economic decline index was directly linked to logistics efficiency, as economic downturns implied a reduction in goods flows and investment, deterioration in logistics services, and a heightened likelihood of cross-border risks. Political risks also significantly affected logistics and customs efficiency due to increasing instability, corruption, conflict, and poor governance. Greenhouse gas emissions, climate risk, and climate change were particularly important in the context of global logistics development. Environmental challenges under increasingly stringent environmental standards – a modern requirement – could create additional barriers to cross-border trade.

All countries in the Belt and Road Initiative were initially included in the study's general sample. However, some countries were excluded from analysis due to a lack of required data. Accordingly, the inclusion criterion was participation in the Initiative, and the exclusion criterion was data unavailability for the selected indicators. As a result, the final sample included 54 countries that met the Belt and Road participation and data availability criteria. These were: China, Kyrgyz Republic, Argentina, Greece, Singapore, Italy, Austria, Bahrain, Costa Rica, Sri Lanka, Bolivia, Portugal, Cyprus, Zimbabwe, El Salvador, Ghana, Hungary, Ukraine, Slovenia, South Africa, Croatia, Albania, Philippines, Thailand, Rwanda, Nicaragua, Malaysia, Panama, Benin, Madagascar, Mali, Serbia, Malta, North Macedonia, Armenia, Poland, Honduras, Algeria, Romania, Cameroon, Latvia, Georgia, Guinea, Indonesia, Chile, Moldova, Peru, Bangladesh, Cambodia, Luxembourg, Saudi Arabia, Kazakhstan, Bulgaria, and Estonia. The study used official sources, particularly publications by international organisations and analytical reports (Green Finance & Development Center, 2025; World Bank, 2024; TheGlobalEconomy.com, 2024a; TheGlobalEconomy.com, 2024b; FM Global, 2024).

The research employed cartographic methods to visually present logistics resilience and population ageing in Belt and Road countries (Champahom et al., 2024). Cluster analysis was used to divide the countries into four clusters according to the levels of logistics resilience and population ageing. This was supplemented by statistical analysis to explore how demographic, climatic, and economic factors correlated with logistics and ageing. At this stage, arithmetic mean values were calculated for each cluster based on the following formula (1):

$$\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i, \quad (1)$$

where: $\overline{x}$ – the arithmetic mean value of the indicator within the cluster; – the value of the indicator for the i-th country; n is the number of countries in the cluster.

Both previously defined groups of indicators for the 54 studied countries were analysed using multivariate regression, where the LPI and its sub-indices were successively treated as dependent variables, and the demographic, climatic, and economic factors as independent variables. The use of these indicators as predictors made it possible to quantitatively demonstrate how certain factors generated or intensified cross-border risks. As a result, regression models for cross-border risks were developed, defined by the key risks the models could predict: customs inefficiency risk, infrastructure risk, trade flow disruption risk, supplier competence risk, cargo control loss risk, and delay risk. These models enabled the assessment of potential cross-border risks within the Belt and Road Initiative, taking into account the key demographic, climatic, and economic factors of participating countries.

Cartographic and cluster analysis of logistics resilience and population ageing in Belt and Road Initiative (BRI) countries

The LPI index by country and the share of the population aged 65 and over are key indicators of this study. These indicators make it possible to analyse how the synergy of sustainable logistics and population ageing – which alters demand structures – affects cross-border risks. Visualising the spatial distribution of LPI indicators across BRI participant countries enables a rapid identification of those with high or low levels of logistics resilience (Fig. 1).

The presented data on the LPI Score indicate significant disparities in the level of logistics efficiency among the Belt and Road Initiative (BRI) countries. This initially suggests differences in cross-border risk levels during international logistics operations involving these countries. Among the leaders in logistics resilience, with an LPI Score of 3.5 or higher, are countries such as Bahrain, Latvia, Thailand, Estonia, Luxembourg, Malaysia, Poland, China, Greece, Italy, South Africa, Austria, and Singapore. These countries have comparatively lower cross-border risk levels, and the logistics systems are sufficiently resilient to potential disruptions and challenges. Countries with a medium level of logistics resilience (LPI Score between 3.0 and 3.4) include Chile, Indonesia, Peru, North Macedonia, Panama, Bulgaria, Cyprus, Hungary, Romania, Croatia, Malta, the Philippines, Slovenia, Portugal, and Saudi

Arabia. Supply chains in these countries are generally stable, though these chains may face certain deficiencies, for example, in infrastructure or customs procedures. An LPI Score ranging from 2.1 to 2.9 was observed in countries such as Cameroon, Kyrgyzstan, Madagascar, Bolivia, Cambodia, Albania, Algeria, Armenia, Ghana, Guinea, Moldova, Nicaragua, Zimbabwe, Bangladesh, Mali, El Salvador, Georgia, Kazakhstan, Ukraine, Argentina, Rwanda, Serbia, Sri Lanka, Benin, Costa Rica, and Honduras. This indicates that logistics systems in these countries are underdeveloped, potentially resulting in higher cross-border risks. Figure 2 presents the performance of countries in terms of another key dimension of the study – the ageing population level.

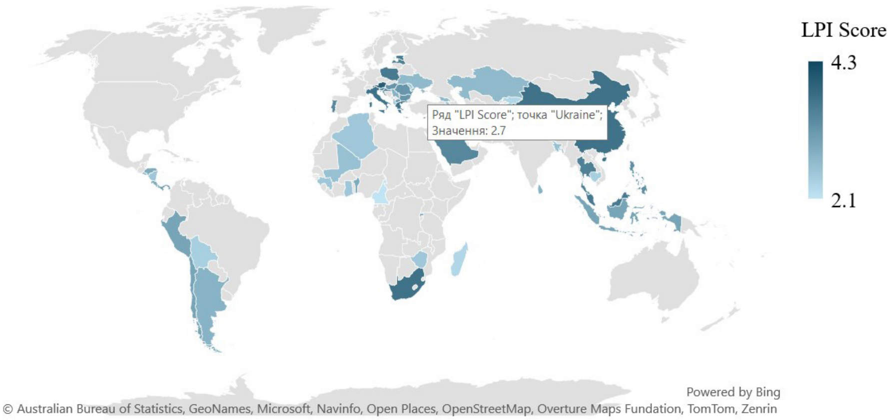

Fig. 1. LPI Score by Belt and Road Initiative countries

Source: Constructed by the authors based on data Green Finance & Development Center (2025); World Bank (2024)

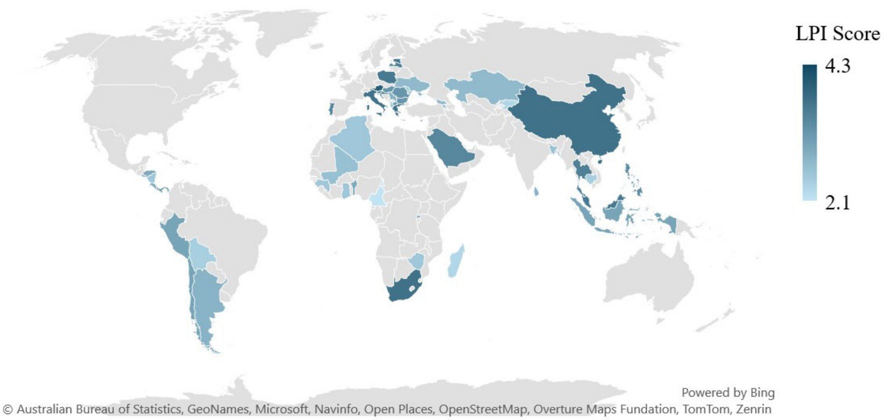

Fig. 2. Population aged 65 and above (% of total population) by Belt and Road Initiative countries

Source: Constructed by the authors based on data Green Finance & Development Center (2025); World Bank (2024)

As with the LPI Score, the proportion of the population aged 65 and over varied significantly across the Belt and Road Initiative countries. A number of countries exhibited a high level of ageing, with the population over 65 accounting for more than 20% of the total. This was mostly characteristic of European countries, including Italy, Portugal, Greece, Croatia, Serbia, Bulgaria, Slovenia, Latvia, Estonia, Hungary, and Austria. In these countries, medical and social services, health and care products, pharmaceuticals, and rehabilitation equipment made up a significant share of consumption. For instance, in Italy and Austria, substantial public spending was directed towards elderly care, with notable demand for personal medical equipment. A population share aged 65 and above ranging from 10% to 20% was observed in Romania, Poland, Ukraine, North Macedonia, Albania, Moldova, Georgia, Luxembourg, Thailand, Cyprus, China, Chile, Armenia, Singapore, Argentina, Sri Lanka, Costa Rica, and Malta. These countries had a mixed demand structure – while the demographic burden had not yet reached high levels, a general trend towards ageing was already evident. The lowest ageing levels (below 10%) were seen in countries such as Panama, Peru, Kazakhstan, El Salvador, Malaysia, Indonesia, South Africa, Algeria, Bangladesh, Cambodia, Bolivia, Kyrgyzstan, Nicaragua, the Philippines, Honduras, Rwanda, Bahrain, Ghana, Zimbabwe, Guinea, Madagascar, Benin, Saudi Arabia, Cameroon, and Mali. These countries were dominated by younger populations, so demand focused on products for children and youth, innovative technologies, education, leisure goods, and digital solutions. For example, Saudi Arabia was actively developing its digital technology, mobile services, and education markets due to the high proportion of youth and labour migrants.

Using k-means cluster analysis, the studied countries were grouped into four clusters, characterised as follows:

Cluster 1: High/medium logistics efficiency and high population ageing (Latvia, Estonia, Greece, Italy, Austria, Hungary, Bulgaria, Slovenia, Croatia, Portugal).

Cluster 2: High/medium logistics efficiency and medium ageing (Thailand, Luxembourg, Poland, Singapore, Chile, North Macedonia, Cyprus, Romania, Malta, China).

Cluster 3: Medium/low logistics efficiency and medium/low ageing (Armenia, Moldova, Albania, Georgia, Ukraine, Sri Lanka, Argentina, Costa Rica, Cameroon, Madagascar, Bolivia, Cambodia, Guinea, Zimbabwe, Ghana, Nicaragua, Algeria, Mali, Bangladesh, El Salvador, Kazakhstan, Rwanda, Benin, Honduras, Indonesia, Peru, Panama, the Philippines, Saudi Arabia, Kyrgyzstan).

Cluster 4: High logistics efficiency and low ageing (Bahrain, Malaysia, South Africa).

Among the studied countries, Serbia was not included in any cluster due to its atypical combination of logistics resilience and ageing. It had low logistics efficiency and high population ageing; a pattern not observed in any other country in the analysis.

Regression analysis of the impact of demographic, climate, and economic factors on cross-border risks in the Belt and Road Initiative countries

For each of the clusters formed in the previous section, the average values of indicators characterising climate, and economic factors were calculated using Formula 1, based on the countries within each cluster. The level of ageing – being a demographic indicator – had been used to form the clusters, so calculating its average values at this stage was considered inappropriate. As a result, a table was constructed, overlaid with a heatmap to better visualise and quickly identify the risk levels of each cluster across the studied factors (Table 2).

Table 2. Average values of indicators characterising climatic and economic factors within the formed clusters

	Government debt	Economic decline index	GHG Emissions	Climate Risk Exposure	Climate Change Exposure
Cluster 1: high/medium level of logistics efficiency and high level of population ageing	80.13	3.97	96.24565	88.71204	88.74169
Cluster 2: high/medium logistics efficiency and medium level of population ageing	62.91889	3.633333	95.87658	90.4017	91.54784
Cluster 3: medium/low logistical efficiency and medium/low population ageing	57.29655	5.910345	90.59548	76.95115	81.47055
Cluster 4: high level of logistical efficiency and low level of population ageing	71.93333	4.866667	83.15754	93.31244	93.51183

Note: red in the table corresponds to a higher level of risk, blue indicates a higher level of stability.

Source: Calculated by the authors based on Green Finance & Development Center (2025); World Bank (2024); TheGlobalEconomy.com (2024a); TheGlobalEconomy.com (2024b); FM Global (2024)

As shown in Table 2, countries with high logistics resilience combined with a high level of population ageing were characterised by high values of Government debt and GHG Emissions. These included developed countries, where ageing was the result of prolonged social development as well as high living standards and the provision of medical services. One factor contributing to the high level of government debt in these countries could have been the development of social programmes requiring funding. At the same time, well-developed logistics in such countries supported the economy but may have been a contributing factor to significant greenhouse gas emissions.

Countries with high logistics efficiency and a young population had high Climate Risk Exposure and Climate Change Exposure. This might have been the result of rapid economic growth, which was often accompanied by the intensive exploitation of natural resources, thereby worsening environmental indicators. Countries with high or medium logistics efficiency and a medium level of ageing typically showed rather high average values of GHG Emissions, Climate Risk Exposure, and Climate Change Exposure. This pattern was often observed in emerging economies, where significant production activity may have greatly increased environmental pressure. Countries with medium or low logistics efficiency and medium or low ageing levels demonstrated the best values for all indicators, except for the Economic Decline Index. A lower level of industrialisation reduced environmental pressure, although limited investment in logistics and the economy overall increased the risk of economic decline.

These results illustrated the complex nature of the relationship between logistics, population ageing, ageing-related demand, climate, and economic factors. This necessitated a deeper analysis in which demographic indicators were included as independent variables alongside climate and economic factors, with the aim of testing the assumption of the influence as drivers of cross-border risks. Graphical and cluster analysis revealed a high level of heterogeneity in the levels of logistics resilience and population ageing in the countries involved in the Belt and Road Initiative. Cluster analysis helped identify a certain pattern of dependency between logistics resilience, demographic structure, and climate, and economic factors, confirming the relevance of correlation and regression analysis to uncover hidden interrelations. The results of correlation analysis are presented below.

The results of the correlation analysis indicate the existence of a close statistical relationship between most of the indicators studied, which indicates the feasibility of further in-depth research, in particular using regression analysis. The regression analysis was conducted based on available data from 54 countries (Green Finance & Development Center, 2025; World Bank, 2024; TheGlobalEconomy.com, 2024a; TheGlobalEconomy.com, 2024b; FM Global, 2024), which were participants in the Belt and Road Initiative as defined by the methodology. No averaging or generalisation of indicators across countries was performed for the analysis – all calculations were based on actual data from individual countries. In other words, each observed unit (country) was considered individually in the dataset used for the regression model. Accordingly, all calculations presented in the tables were based on individual country indicators. Before each table, the correlation coefficient (R) and the adjusted coefficient of determination (Adjusted R-squared) were presented to characterise the overall model. It was also specified which variable served as the dependent one in the model, i.e., the variable whose value was explained by the influence of the independent variables in the respective regression model. The tables included the estimated regression coefficients for the independent variables, standard errors, and t-statistics for the independent variables included in the model. This allowed for the assessment of both the overall quality of the model and the statistical significance of individual predictors.

Table 3. Results of correlation analysis between the studied indicators

	Customs Score	Infrastructure Score	International Shipments Score	Logistics Competence and Quality Score	Timeliness Score	Tracking and Tracing Score	LPI Score
Population ages 65 and above (% of total population) 2023	0.44928122	0.460136	0.489564	0.52136135	0.486162	0.488924	0.49981976
Health spending per capita, 2021	0.69303335	0.651741	0.591594	0.68240464	0.533657	0.582493	0.66260369
Government debt, 2022	0.28733881	0.353247	0.316295	0.2924558	0.283998	0.290749	0.3303071
Economic decline index, 2024	0.70442327	-0.69295	-0.60053	-0.66890263	-0.62104	-0.59994	-0.68473733
Political Risk	0.61876886	0.643505	0.561531	0.65020379	0.506368	0.582193	0.6233226
GHG Emissions	0.39505951	0.395151	0.313665	0.39579974	0.276267	0.311168	0.35986619
Climate Risk Exposure	0.34373874	0.337104	0.139998	0.28878493	0.152429	0.30112	0.27230985
Climate Change Exposure	0.36364123	0.337789	0.120355	0.29711166	0.191436	0.347129	0.28850714

Source: Calculated by the authors based on Green Finance & Development Center (2025); World Bank (2024); TheGlobalEconomy.com (2024a); TheGlobalEconomy.com (2024b); FM Global (2024)

Table 4. Regression results for the general logistic risk model

	Coefficients	Standard Err	LCL	UCL	t Stat	p-value	H0 (5%)	VIF
Intercept	4.9018	0.8963	3.0943	6.7093	5.4692	2.1507E-6	Rejected	
Population ages 65 and above (% of total population)	0.0135	0.0077	-0.0020	0.0289	1.7587	0.0857	Accepted	1.8358
Health spending per capita	5.9125E-5	3.7822E-5	-1.7150E-5	0.0001	1.5632	0.1253	Accepted	2.1113
Government debt	0.0044	0.0014	0.0016	0.0072	3.1731	0.0028	Rejected	1.2396
Economic decline index	-0.1611	0.0364	-0.2345	-0.0877	-4.4274	6.4357E-5	Rejected	2.4327
Political Risk	0.0027	0.0041	-0.0055	0.0110	0.6690	0.5071	Accepted	3.1388
GHG Emissions	-0.0216	0.0103	-0.0423	-0.0009	-2.1077	0.0409	Rejected	2.2344
Climate Risk Exposure	-0.0036	0.0037	-0.0110	0.0039	-0.9666	0.3392	Accepted	3.4851
Climate Change Exposure	0.0064	0.0053	-0.0043	0.0170	1.2099	0.2329	Accepted	3.4496

Source: Calculated by the authors based on Green Finance & Development Center (2025); World Bank (2024); TheGlobalEconomy.com (2024a); TheGlobalEconomy.com (2024b); FM Global (2024)

These results illustrated the complex nature of the relationship between logistics, population ageing, ageing-related demand, climate, and economic factors. This necessitated a deeper analysis in which demographic indicators were included as independent variables alongside climate and economic factors, with the aim of testing the assumption of the influence as drivers of cross-border risks. Graphical and cluster analysis revealed a high level of heterogeneity in the levels of logistics resilience and population ageing in the countries involved in the Belt and Road Initiative. Cluster analysis helped identify a certain pattern of dependency between logistics resilience, demographic structure, and climate, and economic factors, confirming the relevance of correlation and regression analysis to uncover hidden interrelations. The results of correlation analysis are presented below.

The results of the correlation analysis indicate the existence of a close statistical relationship between most of the indicators studied, which indicates the feasibility of further in-depth research, in particular using regression analysis. The regression analysis was conducted based on available data from 54 countries (Green Finance & Development Center, 2025; World Bank, 2024; TheGlobalEconomy.com, 2024a; TheGlobalEconomy.com, 2024b; FM Global, 2024), which were participants in the Belt and Road Initiative as defined by the methodology. No averaging or generalisation of indicators across countries was performed for the analysis – all calculations were based on actual data from individual countries. In other words, each observed unit (country) was considered individually in the dataset used for the regression model. Accordingly, all calculations presented in the tables were based on individual country indicators. Before each table, the correlation coefficient (R) and the adjusted coefficient of determination (Adjusted R-squared) were presented to characterise the overall model. It was also specified which variable served as the dependent one in the model, i.e., the variable whose value was explained by the influence of the independent variables in the respective regression model. The tables included the estimated regression coefficients for the independent variables, standard errors, and t-statistics for the independent variables included in the model. This allowed for the assessment of both the overall quality of the model and the statistical significance of individual predictors.

At the first stage of the regression analysis, the dependent indicator was the overall LPI Score (Table 4), changes in which could indicate a general decline or improvement in logistics risks. The regression statistics demonstrated a high correlation between the model's variables (R=0.8360) and a fairly strong explanatory power of the model (Adjusted R-Squared=0.6430).

As can be seen from the results obtained, Government debt, Economic Decline Index, and GHG Emissions exerted a statistically significant influence on the LPI Score. The latter two indicators had an inverse effect, which may confirm acting as indicators of increasing cross-border risks and declining logistics efficiency.

In turn, Government debt had a positive effect on the LPI Score, meaning that rising debt was accompanied by an overall improvement in logistics. This may indicate the use of foreign funding for infrastructure development and other directions to improve the logistics system. At the same time, particularly within the framework of the Belt and Road Initiative, this could be accompanied by increased economic dependence on other countries, especially China.

The next stages of the regression analysis involved the successive use of LPI sub-indices as dependent variables and the same set of independent indicators. This allowed the identification of how exactly the analysed demographic, climate, and economic factors influenced specific cross-border risks. Table 5 presents the regression results for the customs inefficiency risk model (dependent variable – Customs Score). R in the model stood at 0.8348, and Adjusted R-Squared equalled 0.6404.

The effectiveness of customs was directly influenced by factors such as Health spending per capita and Government debt (Miniaci et al., 2014; Djeenalieva, 2024). With a statistically significant effect from Health spending per capita, the level of population ageing did not significantly affect customs-related risks. Therefore, in this case, it could be assumed that the identified dependencies were not related to demand driven by ageing. Rather, these dependencies were likely due to the fact that Health spending per capita closely correlated with GDP per capita and thus could indicate the general level of welfare in countries, which positively affected the management of public services, including customs. An inverse effect was exerted by the Economic Decline Index, which – as in the general logistics risk model – might increase cross-border risks and negatively affect customs efficiency (for example, through reduced investment or the issue of corruption, which may intensify during economic downturns). Table 6 presents the regression results for the infrastructure risk model (dependent variable – Infrastructure Score). R in the model stood at 0.8375, and Adjusted R-Squared equalled 0.6458.

The statistically significant variables in the infrastructure risk model were Government debt and the Economic Decline Index, the influence of the former being positive, and the latter negative. The results confirmed the fact that an increase in government debt may be accompanied by improvements in logistics – particularly infrastructure indicators – which could be the result of implementing international infrastructure projects under external financing conditions. In turn, economic decline indicated a reduction in infrastructure investment and a decrease in trade flows, which negatively affected logistics indicators and increased cross-border risks. Table 7 presents the regression results for the model of trade flow disruption risk (dependent variable – International Shipments Score). R in the model stood at 0.7660, while Adjusted R-Squared equalled 0.5098.

Table 5. Regression results for the customs inefficiency risk model

	Coefficients	Standard Err	LCL	UCL	t Stat	p-value	H0 (5%)
Intercept	3.8087	0.9359	1.9214	5.6961	4.0698	0.0002	Rejected
Population ages 65 and above (% of total population)	0.0050	0.0080	-0.0112	0.0211	0.6209	0.5379	Accepted
Health spending per capita	0.0001	0.0000	0.0000	0.0002	2.1718	0.0354	Rejected
Government debt	0.0039	0.0014	0.0009	0.0068	2.6731	0.0106	Rejected
Economic decline index	-0.1622	0.0380	-0.2388	-0.0856	-4.2692	0.0001	Rejected
Political Risk	0.0011	0.0043	-0.0075	0.0097	0.2510	0.8030	Accepted
GHG Emissions	-0.0126	0.0107	-0.0342	0.0090	-1.1743	0.2467	Accepted
Climate Risk Exposure	-0.0023	0.0038	-0.0101	0.0054	-0.6017	0.5505	Accepted
Climate Change Exposure	0.0081	0.0055	-0.0030	0.0192	1.4700	0.1488	Accepted

Source: Calculated by the authors based on Green Finance & Development Center (2025); World Bank (2024); TheGlobalEconomy.com (2024a); TheGlobalEconomy.com (2024b); FM Global (2024)

Table 6. Regression results for the infrastructure risk model

	Coefficients	**Standard Err**	**LCL**	**UCL**	**t Stat**	**p-value**	**H0 (5%)**
Intercept	4.2800	1.1750	1.9104	6.6496	3.6426	0.0007	Rejected
Population ages 65 and above (% of total population)	0.0078	0.0100	-0.0124	0.0281	0.7798	0.4398	Accepted
Health spending per capita	6.4852E-5	4.9584E-5	-3.5144E-5	0.0002	1.3079	0.1979	Accepted
Government debt	0.0065	0.0018	0.0028	0.0101	3.5685	0.0009	Rejected
Economic decline index	-0.2079	0.0477	-0.3041	-0.1117	-4.3584	8.0102E-5	Rejected
Political Risk	0.0042	0.0053	-0.0065	0.0150	0.7918	0.4328	Accepted
GHG Emissions	-0.0181	0.0135	-0.0452	0.0091	-1.3416	0.1868	Accepted
Climate Risk Exposure	-0.0010	0.0048	-0.0107	0.0087	-0.2102	0.8345	Accepted
Climate Change Exposure	0.0066	0.0069	-0.0074	0.0206	0.9544	0.3452	Accepted

Source: Calculated by the authors based on Green Finance & Development Center (2025); World Bank (2024); TheGlobalEconomy.com (2024a); TheGlobalEconomy.com (2024b); FM Global (2024)

Table 7. Regression results for the trade disruption risk model

	Coefficients	Standard Err	LCL	UCL	t Stat	p-value	H0 (5%)
Intercept	4.9863	0.9597	3.0510	6.9217	5.1960	5.3150E-6	Rejected
Population ages 65 and above (% of total population)	0.0166	0.0082	6.5151E-5	0.0331	2.0246	0.0491	Rejected
Health spending per capita	4.9880E-5	4.0497E-5	-3.1791E-5	0.0001	1.2317	0.2248	Accepted
Government debt	0.0039	0.0015	0.0009	0.0069	2.6180	0.0122	Rejected
Economic decline index	-0.1250	0.0390	-0.2036	-0.0465	-3.2094	0.0025	Rejected
Political Risk	0.0030	0.0044	-0.0058	0.0118	0.6775	0.5017	Accepted
GHG Emissions	-0.0197	0.0110	-0.0419	0.0024	-1.7956	0.0796	Accepted
Climate Risk Exposure	-0.0024	0.0039	-0.0103	0.0056	-0.6020	0.5503	Accepted
Climate Change Exposure	-0.0005	0.0057	-0.0119	0.0109	-0.0899	0.9287	Accepted

Source: Calculated by the authors based on Green Finance & Development Center (2025); World Bank (2024); TheGlobalEconomy.com (2024a); TheGlobalEconomy.com (2024b); FM Global (2024)

Table 8. Regression results for the supplier competence risk model

	Coefficients	Standard Err	LCL	UCL	t Stat	p-value	H0 (5%)
Intercept	4.4665	1.0380	2.3732	6.5599	4.3030	9.5424E-5	Rejected
Population ages 65 and above (% of total population)	0.0143	0.0089	-0.0036	0.0321	1.6103	0.1147	Accepted
Health spending per capita	8.1836E-5	4.3804E-5	-6.5035E-6	0.0002	1.8682	0.0686	Accepted
Government debt	0.0037	0.0016	0.0004	0.0069	2.2915	0.0269	Rejected
Economic decline index	-0.1418	0.0421	-0.2268	-0.0568	-3.3656	0.0016	Rejected
Political Risk	0.0047	0.0047	-0.0048	0.0142	1.0003	0.3228	Accepted
GHG Emissions	-0.0190	0.0119	-0.0430	0.0050	-1.5984	0.1173	Accepted
Climate Risk Exposure	-0.0025	0.0043	-0.0111	0.0061	-0.5947	0.5551	Accepted
Climate Change Exposure	0.0053	0.0061	-0.0071	0.0176	0.8626	0.3931	Accepted

Source: Calculated by the authors based on data (Green Finance & Development Center, 2025; World Bank, 2024; TheGlobalEconomy.com, 2024a; TheGlobalEconomy.com, 2024b; FM Global, 2024)

As in the previous models, Government debt exerted a positive influence, while the Economic Decline Index had a negative impact on the dependent indicator, which in this case was the International Shipments Score. However, in this model, alongside the aforementioned indicators, the variable Population ages 65 and above (% of total population) had a significant effect. This indicated that population ageing might directly affect the frequency, volume, and complexity of international shipments – particularly due to increased demand for imported medical goods, rehabilitation equipment, specialised products, durable goods, and household comfort improvements. Table 8 presents the regression results for the model of supplier competence risk (dependent variable – Logistics Competence Score). R in the model stood at 0.8175, and Adjusted R-Squared equalled 0.6066.

The Logistics Competence Score was also positively influenced by Government debt and negatively influenced by the Economic Decline Index. This indicated that these indicators were influential factors for the competence level of logistics providers – largely determined by the sufficiency of funding and investment opportunities. Table 9 presents the regression results for the model assessing the risk of losing control over cargo (dependent variable – Tracking & Tracing Score). R in the model equalled 0.7778, while Adjusted R-Squared stood at 0.5315.

In the model assessing the risk of losing control over cargo – where the Tracking & Tracing Score served as the dependent variable – four influential variables were identified. Alongside Government debt and the Economic Decline Index, whose impact direction was consistent with previous models, the Tracking & Tracing Score was directly influenced by Population ages 65 and above (% of total population) and inversely influenced by GHG Emissions. Population ageing may have increased the demand for accurate cargo tracking due to the need for timely and safe delivery of medical goods and equipment. The inverse relationship between greenhouse gas emissions and the dependent variable could be explained by the fact that in countries with high environmental standards, the delivery, and tracking processes may have slowed down due to stricter regulations. Table 10 presents the regression results for the model of delay risk (dependent variable – Timeliness Score). R in the model equalled 0.7716, while Adjusted R-Squared stood at 0.5201.

The risk of delays was positively influenced by the volume of Government debt and negatively influenced by the Economic Decline Index and GHG Emissions. As in the previous model, the inverse relationship with greenhouse gas emissions may have been the result of delays caused by the need to comply with strict environmental regulations. Thus, variables with an inverse relationship could be viewed as de-stimulators, while variables with a positive relationship – as stimulators of the logistics system's resilience to cross-border risks. Summarising the analysis conducted in the study, it could be noted that the key factors contributing to the increase in cross-border risks under the synergy of sustainable logistics and ageing-driven demand were economic decline and environmental issues due to greenhouse gas emissions.

Table 9. Regression results for the cargo loss risk model

	Coefficients	Standard Err	LCL	UCL	t Stat	p-value	H0 (5%)
Intercept	6.2824	1.0721	4.1202	8.4446	5.8597	5.8481E-7	Rejected
Population ages 65 and above (% of total population)	0.0244	0.0092	0.0059	0.0428	2.6606	0.0109	Rejected
Health spending per capita	1.6833E-5	4.5244E-5	-7.4411E-5	0.0001	0.3720	0.7117	Accepted
Government debt	0.0044	0.0017	0.0010	0.0077	2.6398	0.0115	Rejected
Economic decline index	-0.1980	0.0435	-0.2858	-0.1102	-4.5485	4.3731E-5	Rejected
Political Risk	6.8527E-5	0.0049	-0.0098	0.0099	0.0140	0.9889	Accepted
GHG Emissions	-0.0296	0.0123	-0.0544	-0.0049	-2.4121	0.0202	Rejected
Climate Risk Exposure	-0.0077	0.0044	-0.0165	0.0012	-1.7398	0.0890	Accepted
Climate Change Exposure	0.0090	0.0063	-0.0037	0.0218	1.4307	0.1597	Accepted

Source: Calculated by the authors based on Green Finance & Development Center (2025); World Bank (2024); TheGlobalEconomy.com (2024a); TheGlobalEconomy.com (2024b); FM Global (2024)

Table 10. Regression results for the delay risk model

	Coefficients	Standard Err	LCL	UCL	t Stat	p-value	H0 (5%)
Intercept	5.2699	1.1930	2.8640	7.6758	4.4173	6.6463E-5	Rejected
Population ages 65 and above (% of total population)	0.0191	0.0102	-0.0015	0.0396	1.8741	0.0677	Accepted
Health spending per capita	4.0816E-5	5.0345E-5	-6.0715E-5	0.0001	0.8107	0.4220	Accepted
Government debt	0.0040	0.0018	0.0003	0.0077	2.1792	0.0348	Rejected
Economic decline index	-0.1583	0.0484	-0.2559	-0.0606	-3.2676	0.0021	Rejected
Political Risk	0.0052	0.0054	-0.0057	0.0162	0.9636	0.3406	Accepted
GHG Emissions	-0.0311	0.0137	-0.0586	-0.0035	-2.2737	0.0280	Rejected
Climate Risk Exposure	-0.0056	0.0049	-0.0154	0.0043	-1.1347	0.2628	Accepted
Climate Change Exposure	0.0125	0.0070	-0.0017	0.0267	1.7808	0.0820	Accepted

Source: Calculated by the authors based on Green Finance & Development Center (2025); World Bank (2024); TheGlobalEconomy.com (2024a); TheGlobalEconomy.com (2024b); FM Global (2024)

Discussion

The research results demonstrated that economic decline and environmental issues were the key drivers of increased cross-border risks, while no negative impact of population ageing was identified. Moreover, ageing could act as a stimulating factor in developing certain aspects of logistics – for example, enhancing the efficiency of product tracking. At the same time, it should be considered that ageing was more prominent in high-income, developed countries, where its negative effects could be offset by general resilience and prosperity. Accordingly, as population ageing accelerates, the challenges it poses for economic systems overall (e.g., decreased productivity, economic slowdown, etc.) could trigger more far-reaching consequences affecting all sectors, including logistics.

M. Kallestrup-Lamb et al. (2024) and C.H. Jones and M. Dolsten (2024) identified a correlation between age-related demographic shifts and increasing demand for health-related products and care services. The study by N.J.O. Ogugua et al. (2024) examined the impact of population ageing on the sustainability of healthcare infrastructure systems, highlighting the need to adapt healthcare systems to the long-term consequences of ageing, particularly through policy intervention. The conclusions aligned with this study's findings on the need to account for the long-term implications of ageing, though the conclusions did not analyse ageing in relation to logistics system resilience. In the study by D. Parkhill (2022), ageing was considered a potential problem within the US Air Force logistics community. Like this study, LPI was used as a key logistics performance indicator, and the impact of employees' average age on LPI components was analysed. However, unlike this study – which did not confirm the assumption of a negative impact – D. Parkhill's research revealed certain adverse effects. The difference in results could be attributed to the varying research objects, highlighting the importance of considering local specifics when analysing demographic change.

Y. Zhang et al. (2022) noted the growing elderly population in China and defined it as a major social issue requiring appropriate resource distribution planning and supply management. However, the work focused on one country, while this study emphasised that population ageing is not only an internal social issue for specific countries but also a key international factor capable of influencing cross-border risk levels. A. Mahpour et al. (2023) analysed the impact of logistics, economic, and demographic indicators on maritime trade in various Asian countries. As in this author's study, LPI was used to measure logistics performance – though in A. Mahpour's work, it served as an independent variable. The findings showed that improvements in LPI led to increased trade flows. The study also concluded that population growth boosts trade, which aligns with this study's results on the connection between logistics, economic, and demographic factors. However, A. Mahpour et al.

used a slightly different analytical approach and indicator composition, applying total population figures instead of the ageing population indicator.

Earlier studies also provided limited insight into ageing's impact on logistics. Researchers mainly focused on other demographic factors, such as the growing need for skilled workers in logistics, requiring better training and knowledge (Klumpp et al., 2017; Kerimkhulle et al., 2023), or declining population numbers (Klumpp et al., 2014; Iskakova, Mukhamedjanov, 2022). Several studies examined risks generated during the circulation of goods and interactions between countries involved in the Belt and Road Initiative. L. Zhang and Z. Wang (2021) stressed that the expansion of international logistics, particularly under the Belt and Road Initiative, necessitated increased attention to logistics security. The authors noted that cross-border logistics security was influenced by political, economic, and other risks. In contrast to the work, this study found no empirical evidence of significant political risk impact on logistics. This study did, however, provide evidence of a significant and negative impact of economic risks – measured via economic decline – on logistics indicators. At the same time, increasing government debt – a potential sign of rising financial dependence – showed a positive effect on logistics indicators.

D. Chen et al. (2022) identified the main ways in which the Belt and Road Initiative affects transport and logistics, namely: policy changes, environmental changes, and direct impacts on transport and logistics. These dimensions were based on a literature review. Hence, the current study complements the results by providing empirical evidence that other important factors, including demographic ones, also affect logistics. The study by J. Li et al. (2021) underscored the importance of risk assessments for countries deciding whether to participate in the Belt and Road Initiative. The authors identified four risk dimensions, which partially corresponded to the framework applied in this study for selecting indicators for analysis. However, Li et al. did not consider environmental risks or assess the impact of these factors on logistics indicators.

W. Zhai (2023) concluded that China's foreign investment risks significantly influenced China's investment decisions – suggesting the country should carefully assess conditions in recipient nations. Overall, this conclusion aligned with this study's findings, although strong impact was confirmed only from economic, environmental, and demographic factors. X. Sun et al. (2021) focused on assessing risks in Belt and Road countries, distinguishing internal and external factors and proposing a methodology that can be applied to any country and any year. This was an advantage over the current study, which was based on an overall country-level assessment and did not provide a detailed individual risk assessment.

A number of studies, alongside risk factors, also identified key benefits of the Belt and Road Initiative for the logistics sector. X. Wang et al. (2021) listed benefits such as capacity expansion, integrated transport systems, route diversification for oil, and new transport formats. Y. Lu and J. Wolszczak-Derlacz (2025) found that the Belt and Road Initiative positively correlated with international trade and global value chains. Unlike those studies, the present research focused on risk assessment, so a promising area for future inquiry could be analysing how the identified risks might be balanced by the potential benefits of participation. Comparing the study's results with existing research confirmed that this work addressed an important but underexplored topic, offering new insights into the role of sustainable logistics and ageing-related demand in shaping cross-border risks and ensuring overall logistics performance.

Conclusions

This study analysed logistics performance levels in Belt and Road Initiative (BRI) countries. The findings indicated substantial disparities in logistics performance and population ageing across BRI countries – both of which should be considered in cross-border activities. Cluster analysis was applied using logistics performance and ageing indicators, identifying four clusters: high/medium logistics performance with high population ageing; high/medium logistics performance with medium ageing; medium/low logistics performance with medium/low ageing; high logistics performance with low ageing. For each cluster, average values were calculated for indicators reflecting domestic macroeconomic factors potentially affecting cross--border risks. These included climate and economic factors generating associated risks. The results revealed that the highest risks based on Government debt (80.13), and GHG Emissions (96.25) were typical for countries with high/medium logistics performance and high ageing (e.g., Latvia, Estonia, Greece, Italy, Austria, Hungary, Bulgaria, Slovenia, Croatia, Portugal). The highest environmental risks (Climate Risk Exposure and Climate Change Exposure: 93.31 and 93.51 respectively) were observed in countries with high logistics performance and low ageing, such as Bahrain, Malaysia, and South Africa. These findings highlighted the complex interrelation between logistics, ageing, ageing-driven demand, climate, and economic factors.

Further regression model analysis, reflecting the relationship between risk factors and components of logistics performance in the cross-border context, confirmed that economic decline and environmental issues from GHG emissions were the key contributors to cross-border risk under the synergy of sustainable logistics and ageing-related demand. Rising government debt and the proportion of people aged 65+ were positively associated with logistics performance – potentially indicating the important role of the state in financing infrastructure projects that support logistics. Future research could assess the adaptability of logistics infrastructure to demographic change by quantitatively evaluating the capacity of logistics systems to respond effectively to the growing elderly population and the resulting demand changes.

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