Estimating the economic burden of lower respiratory infections in China from 2020 to 2040: a health-augmented macroeconomic modelling study

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The Lancet Regional Health - Western Pacific 2026;69: 101855

Published Online xxx

https://doi.org/10.1016/j.lanwpc.2026.101855

Summary

Background Lower respiratory infections (LRI) are a major cause of mortality in China, yet there is a striking lack of nationally representative studies and comprehensive evaluations of their long-term economic impact. This study aimed to quantify the long-term economic burden of LRI across China's 31 provinces and regions, and to assess the spatial distribution.

Methods We used an improved health-augmented macroeconomic model (HMM) to estimate the economic burden of LRI in mainland China from 2020 to 2040. The model captures the burden via two channels: (1) the impact of LRI-related mortality and morbidity on labor supply, and (2) the effect of treatment costs on physical capital accumulation. Data were sourced from the China Provincial Burden of Disease Study 2023, the Global Burden of Antimicrobial Resistance Study, and other publicly available literature.

Findings From 2020 to 2040, LRI are projected to impose a cumulative economic loss of CNY 363 billion (95% UI: 216–710). Marked regional disparities were observed: Guangdong incurred the highest absolute burden (CNY 35.6 billion); Guizhou reported the largest economic losses relative to 61‰ GDP; and per capita losses were greatest in Southwest China. Although East and Southwest China bore the largest overall losses, the disease burden was disproportionately concentrated in Southwest China, which accounted for 33.6% of DALYs but only 23.2% of the total economic loss. Middle-income regions experienced the highest total losses (CNY 174 billion), while per capita losses were most pronounced in low-income areas (CNY 426). Notably, the share of treatment-related costs increased with decreasing income levels, ranging from 21% in Northwest China to just 2% in East China.

Interpretation The economic burden of LRI in China is substantial and regionally inequitable, underscoring the substantial economic returns to targeted LRI prevention and control—particularly in under-resourced regions. Far from being a fiscal liability, such investments offer meaningful long-term economic returns and are essential to advancing health and economic equity nationwide.

Funding The study was supported by Horizon Europe (HORIZON-MSCA-2021-SE-01; project number 101086139-PoPMeD-SuSDeV), and Ministry of Science and Technology of the People's Republic of China (project number 2023ZD0506000).

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Keywords: Lower respiratory infections; Health-augmented macroeconomic modelling; Economic burden

Research in context

Evidence before this study

LRI is a common and deadly infectious disease, particularly affecting children and older adults. Previous studies in China have estimated the economic burden of LRI among specific subpopulations, such as hospitalized children, or at the provincial level. However, these studies were often restricted in scope and did not assess the broader economic impact of LRI on national productivity. Due to substantial regional variation in disease burden and healthcare resource availability, extrapolating findings from localized settings to the national level remains challenging. Traditional estimation methods underestimate the economic system's ability to "self-repair" through equilibrium adjustments and to change dynamically in response to shocks. Therefore, they cannot fully assess the long-term impact of LRI on the economy. We searched PubMed using the terms ("lower respiratory infection*"[Title/Abstract] OR "LRI"[Title/Abstract] OR "Lower Respiratory Tract Infections"[MeSH] OR "pneumonia"[MeSH] OR "bronchiolitis"[MeSH]) AND ("China"[MeSH] OR "China"[Title/Abstract]) AND ("costs and cost analysis"[MeSH] OR "health care costs"[MeSH] OR "economics"[MeSH] OR cost*[Title/Abstract] OR expense*[Title/Abstract] OR expenditure*[Title/Abstract] OR "financial burden"[Title/Abstract] OR "treatment cost*"[Title/Abstract] OR "medical cost*"[Title/Abstract] OR "hospitalization cost*"[Title/Abstract]) NOT ("COVID-19"[MeSH] OR "SARS-CoV-2"[MeSH] OR "coronavirus"[Title/Abstract]) with no language restrictions, for articles published from Jan 1, 1990, to Aug 1, 2025. We did not identify any studies that comprehensively evaluated national-level trends in the health and economic burden of LRI across all age groups in China, nor any that quantified its economic impact on productivity losses.

Added value of this study

This study provides the first China nation-wide health-augmented macroeconomic modelling (HMM) to estimate LRI's economic burden, incorporating economic adjustment mechanisms and treatment-cost-induced capital effects to produce policy-relevant, subnational results. We applied the HMM across 31 provinces in mainland China to quantify the economic impact of LRI derived from health burdens, including disability-adjusted life years (DALYs). A key innovation of this study lies in the dynamic modeling of labor loss. Rather than assuming permanent reductions in productivity due to LRI-related illness or death, we incorporated labor market adjustments—such as replacement through new hires or capital substitution—providing a more realistic long-term estimation of economic losses. Moreover, the model accounts for demographic transitions and treatment costs over time, enabling a nuanced assessment of physical capital accumulation and resource allocation. Our findings reveal substantial regional disparities. Guangdong Province experienced the highest cumulative loss (¥35.6 billion), while Guizhou reported the highest proportional GDP loss (61‰). Nationally, LRI led to an estimated cumulative loss of 363 billion ¥ from 2020 to 2040, equivalent to 0.015% of total GDP. East and Southwest China endured the heaviest overall burden, yet Southwest China exhibited a striking mismatch between its disease burden (33.6% of DALYs) and its economic share (23.2%). Importantly, treatment-related costs represented a disproportionately large share of the total economic burden in less affluent areas—for instance, accounting for 21% of total losses in Northwest China compared to just 2% in East China. These findings underscore the unequal economic toll of LRI across China's diverse regions and income groups, offering critical evidence to inform targeted, equity-sensitive health and economic policy responses. Overall, these enhancements provide a more comprehensive and up-to-date understanding of the economic burden of LRI nationwide, incorporating the latest and most comprehensive data and considering the impact of both physical and human capital on the economic burden. This information will be invaluable to healthcare policymakers as they work to combat LRI and promote economic development.

Implications of all the available evidence

Our findings highlight the substantial and uneven economic burden of lower respiratory tract infections (LRI) in China, underscoring the urgent need for sustained policy attention. The distribution of this burden is shaped not only by epidemiological patterns but also by the country's evolving demographic profile and the effectiveness of future national strategies for LRI prevention—particularly those tailored to specific etiologies and modifiable risk factors. To mitigate this burden, policymakers must prioritize increased public health investment in middle-income and southwestern regions, where both absolute and per capita losses are highest. Equally critical is the implementation of targeted interventions for vulnerable populations, including expanded vaccination programs, strengthened pathogen surveillance systems, and rational antibiotic stewardship to curb overuse. Beyond the health sector, a broader economic development strategy is essential to enhance national productivity while safeguarding population health. A multisectoral approach that balances economic growth with equitable health outcomes will be key to reducing disparities and ensuring long-term resilience against respiratory disease threats across regions and socioeconomic groups.

Introduction

Lower respiratory tract infections (LRI) cause a significant global and Chinese health burden, with disproportionate impact among different regions. In 2021, LRI accounted for approximately 2.18 million deaths globally, corresponding to a mortality rate of 27.7 per 100,000 population, including 207,000 deaths in China alone.[1,2] Major risk factors including tobacco smoke exposure, ambient and household air pollution, and extreme temperatures,[3] continue to shape incidence and severity. In China, from 1990 to 2021, the proportion of disability-adjusted life years (DALYs) attributable to ambient particulate matter pollution increased steadily, while those linked to tobacco use rose from 19.06% to 26.53%.[4,5] In the post-COVID-19 era, reassessing the burden of non-COVID LRI in China is particularly crucial, given changes in respiratory infection patterns following the relaxation of non-pharmaceutical interventions.[6] Detailed trends in LRI cases, prevalence, mortality, and DALYs from 1990 to 2023 are shown in Supplementary Figs. S1 and S2; age-standardized incidence, prevalence, mortality, and disability-adjusted life expectancy across SDI (income) regions in China are shown in Supplementary Fig. S3; sex- and age-specific distributions of prevalence, incidence, death, and DALY rates across SDI regions in 2023 are shown in Supplementary Figs. S4–S7, and we could see the global burden of LRI from 1990 to 2023 reveals the etiological composition, age and sex distribution, and regional associations with social development level (SDI) in Supplementary Figs. S8–S10.

Global and national strategies—Strategic Advisory Group of Experts (SAGE) priorities,[7,8] the Immunization Agenda 2030,[9] and Healthy China 2030 —provide a policy frame, but inter-provincial disparities in exposure, health-system capacity, and incomes require evidence to target investments. Concurrently, the Global Health 2050 Commission proposed[10] reducing premature and preventable death (PPD) as a unifying long-term objective, arguing that progress across diverse health system goals tends to align with reductions in PPD. The Commission suggested that most countries could feasibly reduce national PPD by 50% by mid-century and identified a set of 15 priority conditions as concrete targets for achieving this goal. Notably, lower respiratory tract infections are included among the eight infectious and maternal conditions prioritized, reflecting their persistent contribution to mortality and morbidity despite substantial advances in prevention and treatment. For large, rapidly ageing countries such as China, assessing the future burden of lower respiratory infections within a mid-century time frame is particularly relevant for aligning health policy with global targets and national planning horizons.[10] Evaluating trends up to 2050 allows for the examination of long-term disease dynamics and their economic implications while maintaining reasonable predictive reliability, as uncertainty increases substantially over longer horizons. Against this background, quantifying the projected health and economic burden of lower respiratory infections through 2040–2050 provides policy-relevant evidence to inform strategic resource allocation and to assess progress towards global health goals centered on reducing preventable mortality.

LRI depress economic performance through two pathways—reductions in effective labor supply and lower physical-capital accumulation—so prevention is an investment with measurable returns.[11] Although previous studies have estimated hospitalization-related economic burdens of LRI among children or in specific provinces in China, few have provided a comprehensive national-level assessment of their economic impact, particularly regarding broader effects on economic productivity. For instance, the median hospitalization cost for children with viral community-acquired pneumonia was $907.38, calculated across 33 children's hospitals.[12] In another study on the economic burden of hospitalized patients with bronchiolitis and pneumonia, the average hospitalization cost and total cost of bronchiolitis patients obtained by direct and indirect methods were 4162 yuan and 5748 yuan, respectively, while the average hospitalization cost of pneumonia patients was 6096 yuan and 7783 yuan.[13] Additionally, in a central province of China, hospitalization records of 30,341 patients with chronic bronchitis from five urban general hospitals were used to estimate the substantial increase in medical expenses for patients with chronic bronchitis from 2015 to 2020. The proportion of treatment and nursing expenses continued to rise, with an average cumulative cost of 27,402 yuan.[14] Moreover, extrapolating existing findings to all LRI cases remains problematic due to variability in disease patterns and healthcare resource availability across regions.[15]

The HMM provides a robust framework for projecting disease burden and estimating both direct health and broader socioeconomic impacts by incorporating economic feedback mechanisms.[16] Direct health benefits stem from reduced mortality, morbidity, and treatment costs, while socioeconomic gains include increased labor force participation, enhanced savings and investment, and greater human capital accumulation—factors that collectively promote economic growth. Because prior Chinese studies were sub-population or province-specific and rarely linked LRI to aggregate productivity, we estimate national and provincial economic losses using a health-augmented macroeconomic model (HMM) from 2020 to 2040. We integrate Global burden of diseases (GBD) 2023 provincial health outcomes with demographic and economic projections to quantify losses under observed vs. counterfactual no-LRI scenarios, propagating uncertainty via Monte Carlo simulation. Reassessing LRI in the post-COVID period is timely, given shifts in respiratory epidemiology and care-seeking that may alter both health and economic trajectories. Our findings underscore that investments in prevention and control are not only health-promoting but also economically advantageous.

Methods

Study design and setting

This study provides the first comprehensive assessment of the health and economic burden of LRI across all 31 provincial-level administrative regions in mainland China, covering the period from 1990 to 2040. We aimed to quantify the economic impact of LRI by assessing both healthcare expenditures and productivity losses attributable to LRI-related morbidity and mortality. First, we identified the disease burden of LRI from GBD 2023,[15] in terms of mortality, morbidity and mean estimates of hospitalization costs. Second, we constructed economic projections for two scenarios: a status quo scenario and a counterfactual scenario. Third, we calculated the economic loss as the discounted (0%, 2%, 3%, 5%) cumulative difference in projected annual GDP between these two scenarios.

Data sources

We estimated the health burden of LRI in China from 1990 to 2023 using methods from the GBD 2023 Study. Our team provided national mortality data and collaborated with the GBD Cause of Death team to generate estimates of LRI-related deaths, YLLs, YLDs, and DALYs. Sex-specific estimates were obtained directly from the GBD database. For economic analysis, we assembled province-level data from 1990 to 2023 on population structure and education data,[17] as well as employment-to-population ratio, gross regional product, physical capital stock, saving rates, and health expenditure, drawing from official sources such as the China National Bureau of Statistics, the China Statistical Yearbook, the China Labor Statistical Yearbook, and the China Health Statistical Yearbook. The physical capital stock from 2000 to 2019 was constructed using the perpetual inventory method[18] based on data from the China Statistical Yearbook, with baseline capital stock and depreciation rates informed by the method of Shan et al.[19] Mean estimates of hospitalization costs for LRI were obtained from a national study expressed in 2024 CPI-adjusted prices and stratified treatment options for different etiologies.[20] All cost estimates were converted to constant 2024 Chinese Yuan (CNY) to facilitate comparability. For regional analyses, the 31 provincial-level administrative units were grouped into seven regions based on geographic location and Socio-Demographic Index (SDI) quantiles, following the classification proposed by Zhou et al.[21] A full description of data sources and outcome definitions is provided in Appendix A (Supplementary Figs. S15–S18).

Estimation and projection methods

GBD 2023 incorporates additional data sources and substantive methodological updates and explicit corrections for misclassification of COVID-19–related deaths compared with GBD 2021. The impact of COVID-19 on LRI mortality was addressed by applying a scalar to the LRI mortality envelope, informed by the estimated reductions in influenza and respiratory syncytial virus circulation during the pandemic period. In addition, GBD 2023 incorporates empirical cause-of-death data to directly inform LRI mortality estimates for recent years, including the pandemic years of 2020 and 2021, thereby improving the robustness and accuracy of the estimates. A more detailed explanation of each of the GBD methodologies and estimation processes has been published elsewhere.[22]

To project related mortality, YLLs, and YLDs from 2024 to 2040, we applied a Bayesian Age–Period–Cohort (BAPC) model,[23] which captures temporal trends and enables the incorporation of prior knowledge and uncertainty quantification. For model validation, we adopted a temporal split with a 2:1 ratio, using the first 23 years (1990–2012) for training and the subsequent 11 years (2013–2023) for testing. Predictive performance was assessed using root mean square error (RMSE) and mean absolute percentage error (MAPE). The final projections were generated using the complete dataset (1990–2023) to forecast LRI burden through 2040. For the projection of economic indicators—including GDP, saving rates, employment-to-population ratios, and health expenditure—we used Autoregressive Integrated Moving Average (ARIMA) models, which are well suited for short to medium term forecasting of time-series data without requiring exogenous predictors,[24] detailed model specifications and validation results are provided in Appendix B. All statistical analyses were conducted using the R software (version 4.2; R Foundation for Statistical Computing), Python (version 3.9) and Joinpoint Regression Program (version 4.9; National Cancer Institute) for data processing, analysis, and visualization.

Health-augmented macroeconomic model description

To quantify the economic burden of LRI, we employed an HMM that simulates GDP trajectories under two scenarios from 2020 to 2040: (1) a status quo scenario reflecting observed and projected trends in LRI-related health outcomes, and (2) a counterfactual scenario assuming the absence of all LRI-related mortality and morbidity. While the second scenario does not reflect a realistic policy objective, it serves as a theoretical benchmark to estimate the maximum potential economic loss attributable to LRI. The primary outcomes included annual and cumulative GDP losses attributable to LRI, as well as per capita cumulative GDP loss and the cumulative loss as a share of total GDP, each calculated as the difference between the status quo and counterfactual scenarios. Full technical specifications, and equations are detailed in Appendix C.

To propagate uncertainty through the economic model, we sampled key inputs from appropriate probability distributions based on their statistical properties. Mortality, YLLs, and YLDs were modeled using log-normal distributions, reflecting their non-negative and right-skewed nature, consistent with standard disease burden modeling practice. LRI treatment costs were modeled using a normal distribution. This probabilistic sampling strategy—repeated 1000 times under both scenarios—allowed us to rigorously quantify uncertainty in projected economic outcomes and represents a methodological advancement over previous studies relying on fixed-point inputs. All estimates were accompanied by 95% uncertainty intervals (UIs), derived from the 2.5th and 97.5th percentiles of 1000 simulation draws.

Sensitivity analyses

To assess the robustness of our estimates, we conducted sensitivity analyses in two domains. First, we varied key economic parameters—including the capital depreciation rate, returns to education, and returns to work experience—by drawing from uniform distributions ranging from 0.5 to 1.5 times their baseline values. Second, we applied alternative discount rates of 0%, 3% and 5%, in addition to the 2% baseline, to capture the influence of varying social time preferences. Each scenario was simulated using 1000 Monte Carlo draws under both the status quo and counterfactual conditions. Detailed results of these sensitivity analyses are provided in Supplementary Tables S1–S10.

Ethics approval

This study was based on secondary, aggregated data obtained from the Global Burden of Disease (GBD) study and other publicly available sources. No individual-level or identifiable personal data were used. Therefore, ethical approval and informed consent were not required for this study.

Role of the funding source

The funders had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit the manuscript for publication.

Results

Fig. 1 summarizes the 2040 projections and the average annual percent change (AAPC, 2020–2040). Across SDI strata, adults aged 50–69 years and those ≥70 years consistently bear higher incidence and prevalence than younger groups. In 2020, 2030, and 2040, age-specific incidence and mortality rates of lower respiratory infections increased progressively with age in both sexes, with consistently steeper age gradients observed among males than females (Supplementary Figs. S11 and S12). Notably, prevalence among the ≥70-year population increases most rapidly in low-middle SDI settings, while incidence shows sustained and pronounced year-on-year gains in high-middle SDI regions, indicating accelerating transmission or detection dynamics in more developed contexts. Spatially resolved projections (Supplementary Figs. S13 and S14) indicate that population aging and regional heterogeneity will amplify inequities in LRI burden across China. Residual diagnostic checks (Supplementary Fig. S19) confirmed the statistical adequacy of the ARIMA prediction results.

Figs. 2 and 3 present provincial-level variations in projected disability-adjusted life years (DALYs) and economic losses attributable to LRI from 2020 to 2040, ranked by projected economic burden, including total economic cost, cost as a percentage of gross domestic product (GDP), and per capita cost. Table 1 shows the total economic burden from 2020 to 2040 under the baseline scenario at discount rates of 3%, and Guangdong Province is projected to bear the highest economic burden, amounting to 35,585 million CNY (95% UI: 23,040–63,592), followed by Sichuan at 27,981 million CNY (95% UI: 15,222–59,598) and Guizhou at 25,958 million CNY (95% UI: 3157–59,477). The economic cost of LRI as a percentage of GDP ranged from 8‰ in Jiangsu (95% UI: 5–14), Shanghai (95% UI: 5–16), Henan (95% UI: 6–15), and Ningxia (95% UI: 6–12), to as high as 61‰ in Guizhou (95% UI: 31–140) — low- and middle-income regions with a high disease burden. Per capita estimates varied widely, from 90 CNY (95% UI: 59–161) in Henan Province to 768 CNY (95% UI: 545–1208) in Tibet. Other detailed estimates are presented by province at discount rates of 0% (Supplementary Table S1), 2% (Supplementary Table S2), 5% (Supplementary Table S3) and with different parameters (Supplementary Table S4). These tables include 95% uncertainty intervals (UI), derived from sensitivity analyses based on varying disease data inputs.

Figs. 3 and 4 illustrate that the economic burden demonstrates a clear upward trend over time, human capital constitutes the dominant component of the total economic burden, consistently accounting for a substantially larger proportion compared to physical capital throughout the entire study period. Both human and physical capital burdens maintain relatively stable proportions of GDP over time.

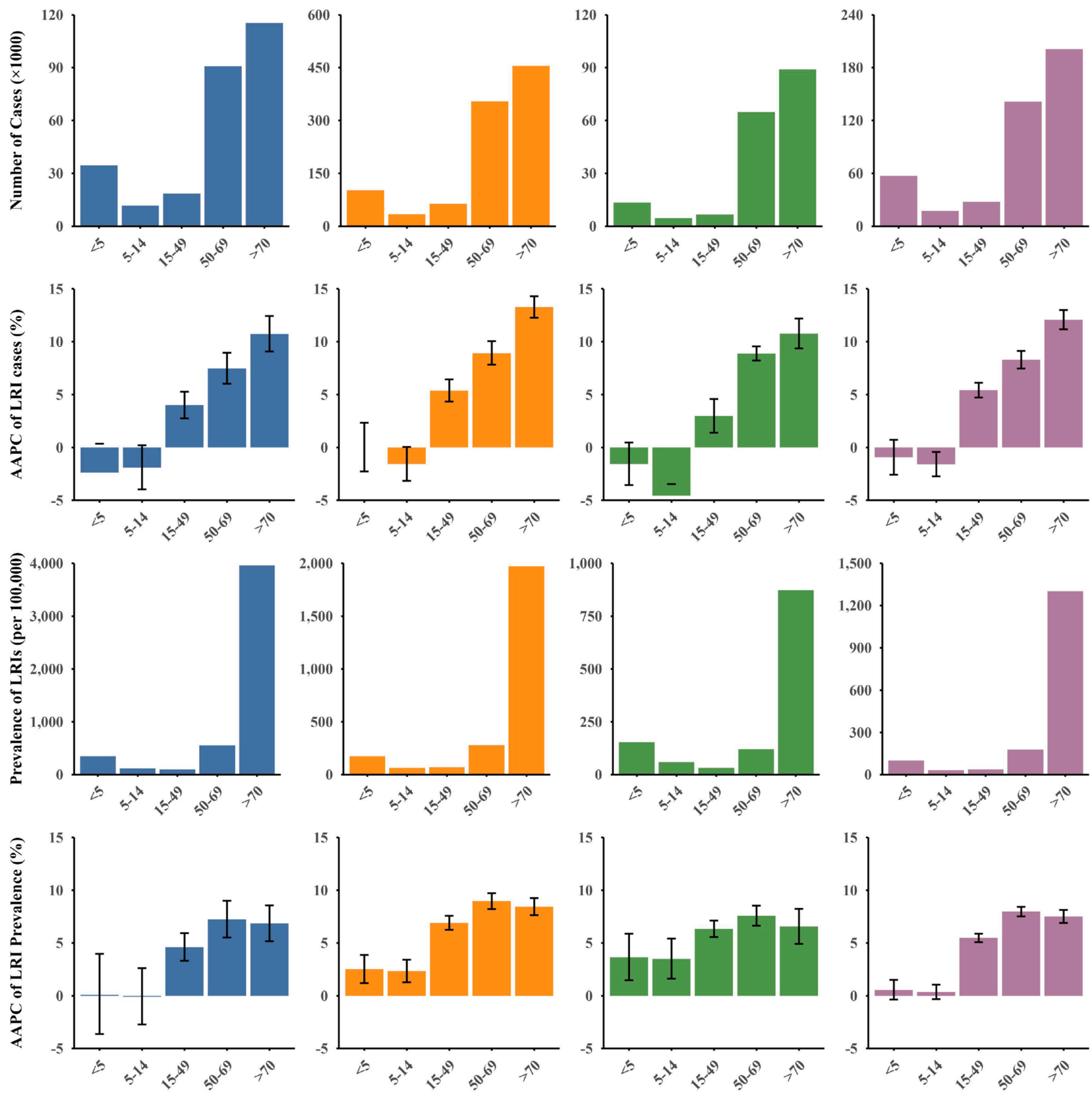

Fig. 1: **Burden of lower respiratory infections by age group and Socio-demographic Index (SDI) quintile.** From top to bottom, the panels represent four indicators: (A) projected number of cases in 2040, (B) average annual percentage change in cases from 2020 to 2040, (C) projected prevalence in 2040, and (D) average annual percentage change in prevalence from 2020 to 2040. From left to right, the bars represent SDI quintiles: low-middle SDI (blue), middle SDI (yellow), high-middle SDI (green), and high SDI (pink).

Table 2 presents aggregated economic estimates of the burden of LRI across Chinese regions and income groups. Nationally, LRI are projected to incur cumulative economic losses of 363 billion CNY (95% UI: 216–710) from 2020 to 2040, based on a 3% discount rate. Sensitivity analyses suggest that the cumulative economic burden was 275 billion CNY (95% UI: 167–524) under a 5% discount rate, and increased to 418 billion CNY (95% UI: 246–827) and 557 billion CNY (95% UI: 321–1125) under 2% and 0% discount rates, respectively. These estimates incorporate uncertainty from health outcomes, treatment costs, asset depreciation, discounting assumptions, returns to education, and work experience coefficients. We also provide detailed estimates by region at discount rates of 0% (Supplementary Table S5), 2% (Supplementary Table S6) and 5% (Supplementary Table S7), and with different parameters (Supplementary Table S8). In these regions, treatment-related physical capital losses account for 27% of the national economic burden from LRI, compared to 19% in middle-income, 18% in upper-middle-income, and just 13% in high-income

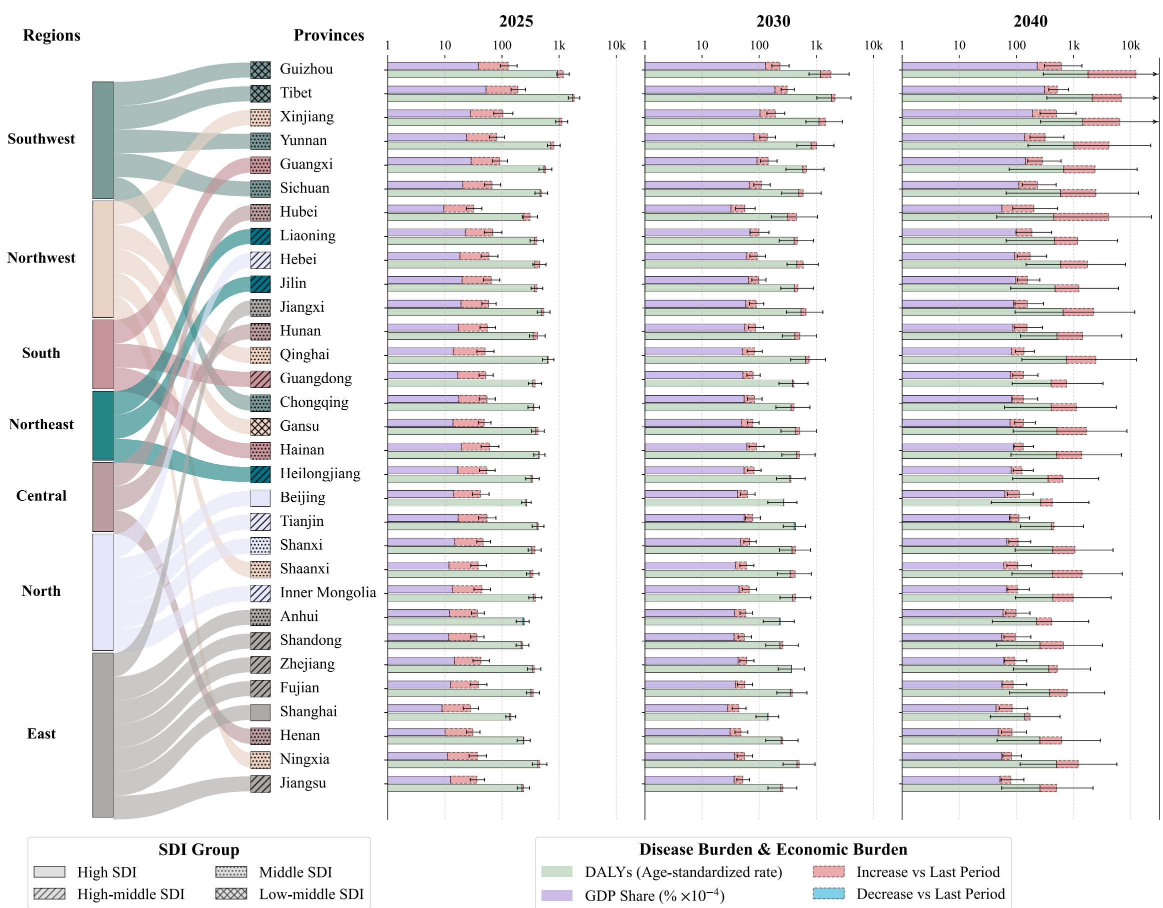

Fig. 2: **Projected DALYs and economic burden of LRI across 31 provinces in mainland China.** Note: The figure displays projected age-standardized DALYs rate and cost as a percentage of GDP, ranked by projected economic burden. Change bars indicate period-over-period differences (2025 vs. 2020, 2030 vs. 2025, 2040 vs. 2030).

regions shown in Supplementary Fig. S20. Across the seven regions, both human capital loss and physical capital loss showed sustained increases from 2020 to 2040, and the southern region consistently accounted for the largest absolute losses and the most rapid growth during the study period (Supplementary Fig. S21). The national burden of LRI is equivalent to 0.015% of China's cumulative GDP over the study period (95% UI: 0.009–0.029), or a per capita loss of 252 CNY (95% UI: 150–493). At the subnational level, the eastern and southwestern regions account for the largest absolute economic losses, followed by the southern region. However, when adjusted for population, the southwestern and northwestern regions exhibit the highest per capita losses. These two regions also bear the greatest proportional burden relative to national GDP, at approximately 0.05%. By 2040, the northeastern and southern regions are projected to rank second and third in terms of GDP share lost to LRI. Interestingly, the economic burden is not uniformly associated with regional income levels. Middle-income regions experience the highest absolute losses—174 billion CNY (95% UI: 98–360)—and substantial per capita losses of 247 CNY (95% UI: 140–510). In contrast, while total losses in low-income regions are relatively modest—32 billion CNY (95% UI: 17–69)—the per capita burden is substantially higher, at 426 CNY (95% UI: 231–922).

Table 3 highlights marked spatial heterogeneity in both the economic burden of disease and key health indicators across China's regions. The Southwest region, for instance, is projected to account for 9.26 million DALYs in 2040, with its share of the national burden increasing from 22.9% in 2020 to 33.5%. Despite this substantial health burden, its contribution to cumulative economic losses over 2020–2040 is estimated at 84 billion CNY (23.1%), while mortality from LRI in this region is expected to reach 30.8% of the national total. By contrast, the Eastern region will bear a dual burden of economic and health losses. With a consistently high prevalence rate (ranging from 29.4% to 34.0%), this region is expected to incur the

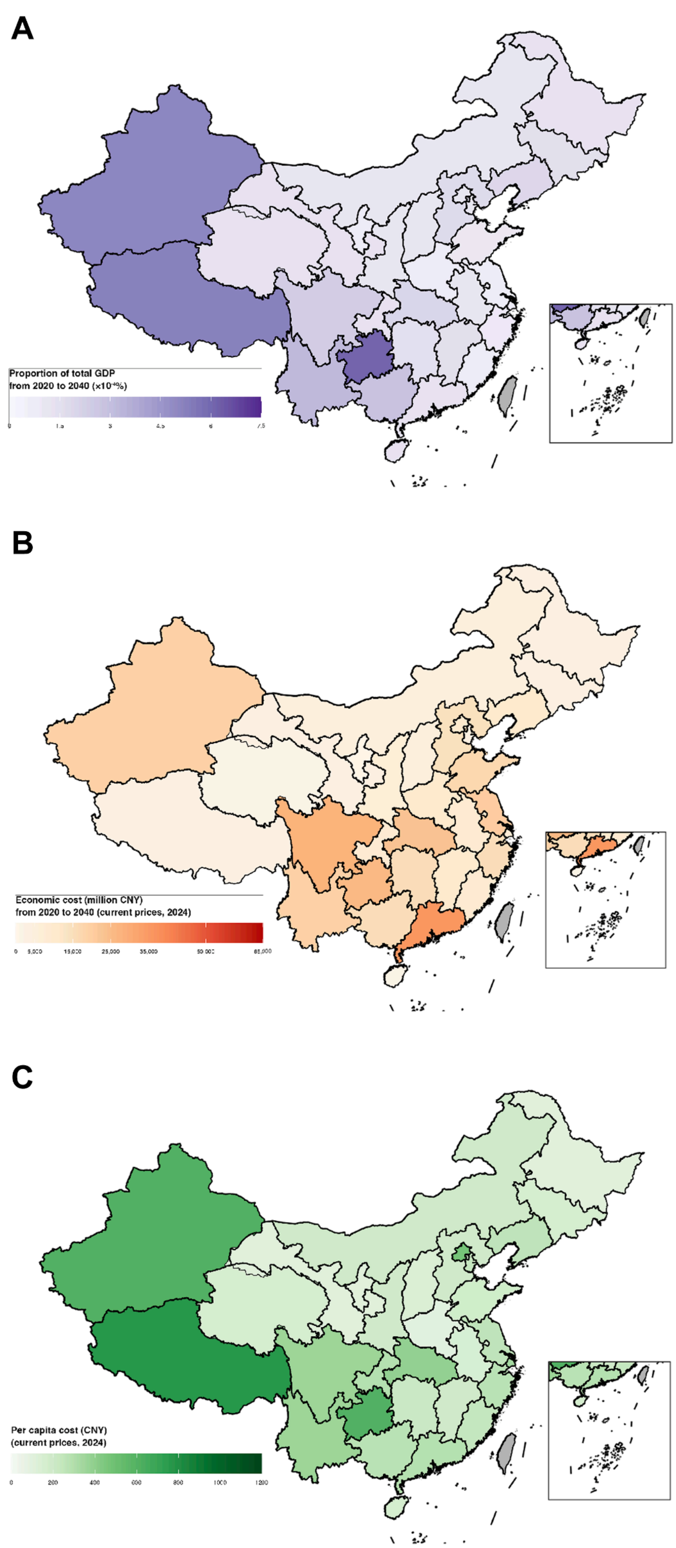

Fig. 3: **Economic cost, cost as a percentage of gross domestic product (GDP), and per capita cost of lower respiratory infections (LRI) in China from 2020 to 2040.** From top to bottom, panels A–C show: (A) total economic cost, (B) cost as a proportion of GDP, and (C) per capita cost. The darker the colour on the map, the higher the economic burden of LRI. Grey areas indicate countries with insufficient data.

highest total economic losses—89 billion CNY (24.6%)—and the greatest annual GDP loss, totaling 45,454 billion CNY (38.5%) over the study period. However, its share of DALYs remains relatively modest at 12.9%, indicating a disproportion between health outcomes and economic impact. Overall, while total DALYs are projected to increase across all income groups, the relative share will decline in high-income and upper-middle-income regions. In particular, the health burden in middle-income regions is expected to rise from 1.36 million DALYs (49.8%) in 2020 to 15.75 million DALYs (57.0%) by 2040. Collectively, lower-middle- and middle-income regions will account for approximately 75.3% of national DALYs by the end of the period.

A comparison of regional economic losses with disease burden and demographic data reveals a misalignment between economic burden, morbidity, and population size. For example, in 2040, the Southwest region is projected to experience 101,370 cases (10.1% of national cases) and 309,198 deaths (31.0%), despite representing only 14.1% of the national population (206 million), and will bear 23.1% (8.4 billion CNY) of national economic losses. In contrast, the Eastern region, home to 420 million people (29.0% of the population), will report 341,000 cases (34.0%) and 118,020 deaths (11.7%), incurring slightly higher economic losses of 8.9 billion CNY (24.6%). Region and income-specific economic losses under varying discount rates and different parameters are presented in Supplementary Tables S9–S12.

Discussion

Our HMM provides the first comprehensive assessment of the long-term economic burden of LRI in China. By integrating province-specific health outcomes, demographic dynamics, and macroeconomic projections, we quantify both cumulative economic losses from 2020 to 2040 and their pronounced spatial heterogeneity across China's 31 provinces. Unlike static cost-of-illness approaches, the model incorporates dynamic labor-market adjustments and capital accumulation, enabling evaluation of the long-term economic consequences of LRI-related morbidity and mortality. Interpretation of these findings should consider the restrictive case definition of LRI used in the GBD framework. In GBD 2023, fatal LRI are defined only when LRI is identified as the underlying cause of death, excluding common clinical presentations such as acute bronchitis[25] and infective exacerbations of chronic obstructive pulmonary disease.[25–27] In addition, pathogen attribution applies etiological proportions to LRI estimates, even though pathogen distribution models include cases in which LRI appears anywhere along the causal chain.[1,28,29] Therefore, both the health and economic impacts of LRI are likely underestimated and our

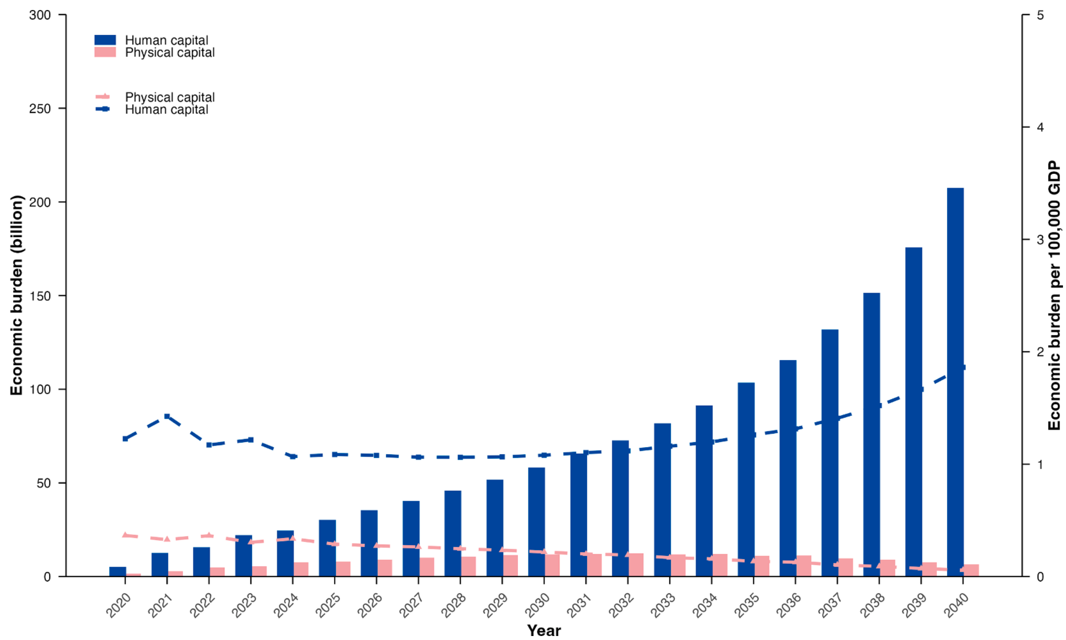

Fig. 4: **Distribution of national economic burden of physical and human capital and their share of GDP from 2020 to 2040.** The bars represent the human capital burden in purple and physical capital burden in blue, while the line shows the human capital proportion relative to GDP in purple and the physical capital proportion relative to GDP in blue.

results should be interpreted as conservative, lower-bound estimates rather than exhaustive quantifications of all clinically recognized LRI presentations.[30] Nevertheless, the standardized GBD framework provides harmonized estimates across age, sex, location, and time, ensuring internal consistency in the underlying epidemiological inputs that underpin our economic modelling and enabling robust comparisons of long-term trends and regional differences.[31]

Some studies[32] have tried to estimate the burden of LRI, and they used generalized additive regression models that integrated data from the National Influenza-like Illness Surveillance Network and meteorological sources to estimate influenza-attributable excess outpatient visits. In addition, a retrospective telephone survey of influenza-associated cases quantified societal costs, including direct medical, non-medical, and indirect costs. These cost estimates were validated against hospital accounts.[33] Other studies on population have found community-acquired pneumonia costs of outpatient and inpatient.[34] The difference is caused by methodological approaches (based on model-based excess-visit attribution or micro-costing), disease types, and age structure and regional disparities. None of these approaches provides a comprehensive analysis of the economic burden of LRI. The heterogeneous economic burden of our study arises from two primary pathways: losses in human capital and erosion of physical capital. High- and middle-income regions bear the largest share of the economic burden. In high-income regions, the labor force tends to possess higher levels of human capital—measured in terms of education and skills—meaning each DALYs lost results in greater depreciation of human capital. Conversely, low- and middle-income regions endure greater losses in physical capital, particularly due to higher out-of-pocket expenditures for medical care. Populations in upper-middle- and middle-income regions with pre-existing conditions are more likely to require hospitalization for LRI,[35] further increasing treatment-related costs. Environmental and behavioral risk factors compound these economic effects. Rapid urbanization is intensifying exposure to ambient and indoor air pollution—especially among children and older adults—exacerbating LRI risks and further constraining productivity.[36] Pollution-related illness may reduce labor supply through higher absenteeism and premature retirement,[37] limiting the effectiveness of fiscal incentives aimed at extending workforce participation. In addition, high-income countries such as France indicates that lower respiratory infections, particularly community-acquired pneumonia (CAP), are also associated with substantial healthcare-related economic costs at average costs ranged from €6495 for patients aged 18–46 years to €8166 for those aged 60–68 years, and €6045 for patients aged 80 years and older.[38] After conversion to Chinese yuan using contemporaneous exchange rates and adjustment to 2024 price levels based on the French consumer price index, these estimates correspond to approximately

Region	Province	Economic cost (million CNY, 2024)	Percentage of total GDP in 2020–2040 (× 10^{-3}%)	Per capita cost (CNY, 2024)
Central	Henan	9791 (6431–17489)	8 (6–15)	90 (59–161)
Central	Hubei	23,237 (9931–60755)	20 (9–53)	386 (165–1008)
Central	Hunan	15,511 (9443–29108)	15 (9–29)	218 (133–409)
East	Anhui	9270 (6130–16238)	10 (7–17)	144 (95–251)
East	Fujian	9525 (6096–16464)	9 (6–15)	234 (150–404)
East	Jiangsu	20,451 (13,761–34402)	8 (5–14)	258 (173–433)
East	Jiangxi	9976 (6083–19137)	15 (9–30)	197 (120–379)
East	Shandong	17,230 (10,887–32207)	10 (6–18)	177 (112–331)
East	Shanghai	7692 (4584–14448)	8 (5–16)	334 (199–628)
East	Zhejiang	15,232 (10,087–24619)	9 (6–15)	266 (176–431)
North	Beijing	9692 (5986–16957)	11 (7–20)	475 (293–831)
North	Hebei	14,783 (8804–28792)	17 (10–34)	189 (113–368)
North	Inner Mongolia	5080 (3410–8142)	11 (7–17)	199 (133–318)
North	Shanxi	5409 (3704–8967)	11 (7–18)	142 (97–236)
North	Tianjin	3608 (2472–5563)	11 (8–17)	241 (165–371)
Northeast	Heilongjiang	3708 (2599–5842)	13 (9–20)	107 (75–169)
Northeast	Jilin	4115 (2752–6766)	16 (10–26)	165 (110–271)
Northeast	Liaoning	10,734 (5653–23760)	19 (10–41)	260 (137–577)
Northwest	Gansu	3072 (2165–4991)	13 (9–21)	111 (78–180)
Northwest	Ningxia	870 (615–1307)	8 (6–12)	109 (77–163)
Northwest	Qinghai	1027 (723–1558)	14 (10–21)	162 (114–245)
Northwest	Shaanxi	7142 (4611–12364)	11 (7–18)	187 (121–324)
Northwest	Xinjiang	19,052 (9827–41822)	50 (26–111)	609 (314–1337)
South	Guangdong	35,585 (23,040–63592)	13 (9–24)	289 (187–516)
South	Guangxi	15,381 (8530–32711)	28 (16–60)	268 (149–571)
South	Hainan	1966 (1366–2986)	13 (9–20)	170 (118–258)
Southwest	Chongqing	8360 (5292–14826)	13 (8–24)	290 (183–514)
Southwest	Guizhou	25,958 (13,157–59477)	61 (31–140)	600 (304–1376)
Southwest	Sichuan	27,981 (15,222–59598)	23 (13–50)	362 (197–770)
Southwest	Tibet	2672 (1895–4202)	52 (37–82)	768 (545–1208)
Southwest	Yunnan	19,069 (10,398–40797)	32 (17–68)	364 (198–778)

GDP, gross domestic product; CNY¥, Chinese Yuan at constant 2024 prices.

Table 1: **Economic cost, the cost as a percentage of GDP in 2020–40, and per capita cost, by province and region with a discount rate of 3%.**

CNY 63,568 to CNY 79,923 per hospitalized episode. For severe CAP requiring admission to intensive care units, subsequent hospitalization costs within one year were estimated at €11,637, equivalent to approximately CNY 108,364 in 2024 prices, accounting for about 0.3–0.5 × 10^{-6}% of France's GDP.[39] Similar patterns have been observed in Canada, an analysis of CAP events between 2012 and 2014 estimated mean attributable costs of US$1595 per outpatient episode and US $12,576 per hospitalized episode, corresponding to approximately CNY 12,592 and CNY 99,282 in 2024 prices, respectively, and representing about 0.1–0.7 × 10^{-6}% of national GDP.[40] In the United Kingdom, the mean cost to the National Health Service for adult hospitalized CAP was estimated at £3,904, equivalent to approximately CNY 42,388 in 2024 prices, or about 0.2 × 10^{-6}% of GDP.[41] Although these estimates are not directly comparable with our macroeconomic projections, which capture productivity losses and capital accumulation effects over the long term, they illustrate that the per-episode healthcare costs of LRI in high-income countries are non-trivial.

However, monetary losses should not be equated with intrinsic health importance. Productivity-based economic valuations tend to assign higher monetary losses to wealthier regions, which may obscure underlying health needs if interpreted in isolation.[42–44] If policy prioritization were to rely predominantly on economic losses, resources could be unintentionally channeled towards more affluent provinces, where advantaged populations typically enjoy better health system capacity and greater access to advanced medical technologies, while disadvantaged populations face more substantial barriers to care, resulting in poorer accessibility and outcomes. Our results illustrate eastern region[45] with substantially higher resource density is projected to bear the largest absolute economic burden by 2040, but the southwest region exhibits a higher per capita economic cost (CNY 409) with a substantially greater epidemiological burden. Inequalities in the distribution of physicians and nurses across counties remain pronounced, with most inequality attributable to within-province disparities, and additional gaps between urban and rural areas. Such structural inequities may further amplify the disconnect between economic valuations and actual health needs across regions.[46] Therefore, guidance on implementation strategies[47] that achieve optimal returns on investment should therefore priorities improvements in patient care and population health while reducing per capita costs, consistent with the health system's triple aim. From a policy perspective,[48] assessments of an equitable healthcare system should explicitly consider three core principles: equal access to healthcare for individuals with equal need, equal utilization of healthcare services for individuals with equal need, and equity in health outcomes.

Regional patterns further highlight the uneven economic burden of LRI across China. While the Eastern and Southwestern regions together account for nearly half of the national economic burden, the underlying drivers differ substantially. In economically developed provinces in the east of Guangdong, high absolute economic losses are primarily driven by productivity losses associated with a large and highly productive workforce, resulting in comparatively lower relative losses and a smaller share of treatment-related costs. This pattern reflects higher labor productivity and greater capacity to absorb healthcare expenditures within overall economic output.[49] In contrast, in lower-income regions such as the Southwestern provinces, including Sichuan, treatment-related costs constitute a relatively larger share of the total economic burden. This pattern likely reflects several interacting factors. First, lower baseline productivity and economic output mechanically increase the relative contribution of direct medical costs to total losses.[50] Second, delayed care-seeking and limited access to high-quality primary healthcare may lead to higher disease severity at presentation,[51,52] increasing the likelihood of hospitalization and intensive treatment. Consistent with this, Sichuan exhibits disproportionately high DALY rates, indicating a heavier health burden relative to its economic capacity. Environmental exposures further compound these effects. The Southwestern region faces high levels of ambient and household air pollution, increasing population vulnerability to LRI and potentially raising treatment intensity and costs.[53] Similar dynamics are observed in Xinjiang in the Northwestern region, where elevated PM2·5 exposure and adverse climatic conditions contribute to increased LRI burden and associated healthcare utilisation.[54] In highly urbanized but economically heterogeneous regions such as the Pearl River Delta, dense population, air pollution, and high humidity may increase both the incidence of LRI and the demand for medical treatment,[55] although stronger health system capacity partially mitigates the relative economic impact.[56]

Group	Economic cost (billion CNY (constant prices, 2024)	Proportion of total GDP ($\times10^{-3}$%), 2020–2040	Per capita cost CNY (constant prices, 2024)
By region			
Central	49 (26–107)	15 (8–32)	202 (107–447)
East	89 (58–158)	9 (6–17)	217 (140–382)
North	39 (24–68)	13 (8–23)	218 (138–386)
Northeast	19 (11–36)	16 (10–32)	184 (109–361)
Northwest	31 (18–62)	21 (12–42)	279 (161–556)
South	53 (33–99)	16 (10–30)	276 (171–517)
Southwest	84 (46–179)	29 (16–62)	409 (224–871)
By income group			
High SDI	17 (11–31)	10 (6–18)	400 (243–723)
High-middle SDI	140 (90–250)	11 (7–20)	227 (145–405)
Middle SDI	174 (98–360)	18 (10–37)	247 (140–510)
Low-middle SDI	32 (17–69)	45 (24–97)	426 (231–922)
Total	363 (216–710)	15 (9–29)	252 (150–493)

Note: GDP = gross domestic product; CNY = Chinese yuan, constant 2024 prices.

Table 2: **Economic cost, cost as a percentage of GDP in 2020–2040, and per capita cost, by region and SDI group.**

Our findings provide important economic context for considering targeted investments in the prevention and control of lower respiratory infections. First, existing evidence suggests that the direct costs of pathogen identification are modest relative to the overall economic burden of LRI. For example, a multicenter study of 18,807 patients with community-acquired pneumonia between January 2009 and December 2020 reported routine viral testing at a cost of approximately RMB 40 per patient. Even when scaled nationally, such diagnostic expenditures represent a negligible fraction of the projected cumulative LRI-related economic loss, indicating that investments in improved pathogen surveillance and research infrastructure are economically reasonable.[57] Second, enhancing nationwide LRIs surveillance and primary healthcare systems would enable coordinated data sharing, early detection, and community-level management, reducing severe cases and productivity losses.[58] Third, advances in diagnostic technologies, including metagenomic and targeted next-generation sequencing (mNGS and tNGS), offer more precise pathogen detection and improved antibiotic stewardship. In China, the average cost of mNGS testing is approximately RMB 3000 per sample, underscoring the need for continued technological development, cost reduction, and supportive health policies to enable broader and more equitable implementation.[59,60] Vaccination remains among the most

Group	Economic cost (billion CNY, constant prices, 2024) (%)	Mortality number in 2020 (%)	Mortality number in 2040 (%)	DALYs in 2020, thousand (%)	DALYs in 2040, thousand (%)	Annual GDP 2020–40, 2024 in trillion CNY (national %)	Annual population 2020–40, millions (national %)
By regions							
Central	49 (13.3)	16,014 (11.7)	230,591 (23.0)	323 (11.8)	5107 (18.5)	15 (13.5)	239 (16.5)
East	89 (24.6)	37,504 (27.4)	118,020 (11.7)	651 (23.8)	3549 (12.8)	45 (38.5)	420 (28.9)
North	39 (10.6)	17,031 (12.5)	74,576 (7.4)	320 (11.7)	2364 (8.6)	14 (12.2)	180 (12.4)
Northeast	19 (5.1)	12,713 (9.3)	77,884 (7.8)	211 (7.7)	1745 (6.3)	5 (4.6)	108 (7.4)
Northwest	31 (8.6)	9007 (6.6)	88,986 (8.9)	241 (8.8)	3222 (11.7)	7 (5.9)	110 (7.6)
South	53 (14.6)	17,721 (13.0)	103,769 (10.3)	363 (13.9)	2369 (8.6)	16 (13.6)	188 (13.0)
Southwest	84 (23.1)	26,713 (19.5)	309,198 (30.8)	626 (22.9)	9263 (33.5)	14 (11.7)	206 (14.2)
By SDI							
High	17 (4.8)	3973 (2.9)	9800 (0.9)	57 (2.1)	221 (0.8)	8 (7.1)	46 (3.1)
High-middle	140 (38.6)	60,079 (43.9)	248,464 (24.7)	1070 (39.1)	6596 (23.8)	59 (50.5)	632 (43.6)
Middle	174 (47.9)	62,806 (45.9)	584,731 (58.3)	1362 (49.8)	15,754 (57.0)	46 (39.5)	701 (48.3)
Low-middle	32 (8.7)	9845 (7.2)	160,028 (15.9)	246 (9.0)	5049 (18.3)	3 (2.9)	72 (4.9)
Total	363 (100.00)	136,703 (100.0)	1,003,023 (100.0)	2735 (100.0)	27,619 (100.0)	12 (100.0)	1451 (100.0)

Note: GDP = gross domestic product; DALY = disability-adjusted life year; CNY = Chinese yuan (constant 2024 prices). Percentages in parentheses indicate the province's share of the national total for the same indicator and year. Mortality, 2020 (%) refers to the number of deaths in 2020 and the percentage of national deaths in that year. Mortality, 2040 (%) refers to the number of deaths in 2040 and the percentage of national deaths in that year. DALYs, 2020 (thousand, %) denote disability-adjusted life years in 2020 (in thousands) and their percentage of the national total. DALYs, 2040 (thousand, %) denote disability-adjusted life years in 2040 (in thousands) and their percentage of the national total. Annual GDP, 2020–2040 (billion CNY; national %) represents the average annual provincial GDP during 2020–2040, expressed in constant 2024 prices, and its percentage of the national average annual GDP. Annual population, 2020–2040 (million; national %) represents the average annual provincial population during 2020–2040 and its percentage of the national average annual population.

***Table 3:* Economic and lifetime disease costs measured in Mortality and Morbidity by region and SDI group.**

cost-effective preventive strategies. In this study, LRIs are projected to be associated with a cumulative economic loss of RMB 363 billion between 2020 and 2040—on the order of magnitude of 1000 times greater than annual vaccine procurement expenditures under China's National Immunization Program. Although vaccines such as Hib and pneumococcal conjugate vaccines are not yet universally included in the national program and coverage remains lower in less developed regions, this comparison highlights the potential economic relevance of expanding immunization coverage in the context of the substantial burden identified.[60]

This study has several limitations. First, the analysis relied on UEBMI inpatient data, which, while valuable, does not include rural residents or children under 15, and therefore may underestimate or overestimate the national burden of LRI despite extensive sensitivity analyses to test the robustness of our results. Second, several parameters, including labor force participation, educational attainment, saving rates, and the capital stock, were derived from projections based on official statistics. Although these are widely used and reliable sources, they inevitably introduce some uncertainty. Third, although the Global Burden of Disease (GBD) dataset provides the most comprehensive and internally standardized estimation framework available, it still depends on heterogeneous source data across countries and regions. Variations in diagnostic practices, surveillance intensity, case ascertainment, and reporting completeness may introduce uncertainty and affect the representativeness of estimates, especially in settings with limited data availability. In addition, the GBD data used in this study do not include information on gender identity and are not stratified by race or ethnicity for the Chinese population, which precluded analyses of gender-related and ethnic heterogeneity in the estimated burden.

Conclusion

This study provides a comprehensive assessment of the long-term economic burden of lower respiratory infections (LRI) in China across 31 provinces using a health-augmented macroeconomic modelling framework. Between 2020 and 2040, LRI are projected to be associated with a cumulative economic loss of 363 billion CNY, corresponding to an annualized loss of approximately 0.015% of GDP. The burden is unevenly distributed, with central and western provinces experiencing higher relative losses, while eastern provinces bear larger absolute losses due to differences in economic scale and human capital valuation. Importantly, these economic estimates should not be interpreted in isolation for policy prioritization, as higher monetary losses in more affluent provinces do not imply greater intrinsic health importance. Economic impacts should be considered alongside epidemiological burden and equity considerations. Although this analysis does not explicitly model future changes in specific risk factors or policy interventions, the findings highlight the macroeconomic relevance of LRI prevention and control. Future studies incorporating dynamic risk factor trajectories and explore alternative scenarios excluding or down-weighting pandemic years to further assess the sensitivity of long-term projections.

Contributors

SC, MGZ, YL, HXS, ZC, and KP conceptualized and designed the study. MGZ, BC, XHX, and YCZ acquired the data and supporting information. HXS and YL conducted the analyses, visualized and interpreted the data, and reviewed the literature. PY, DEB, MK, KP, and TWB contributed to the literature review and interpretation of the findings. YL, HXS, KP, and ZC drafted the manuscript, and ZC, HXS, KP, and SC critically revised it for important intellectual content. YL and HXS directly accessed and verified all the underlying data used in the study and had final responsibility for the decision to submit the manuscript for publication. SC, KP, MK, and DEB contributed methodology. All authors had full access to the data, contributed to the interpretation of the results, and approved the final version of the manuscript.

Data sharing statement

No individual-level data were used in this modelling study. Data from this modelling study are available with publication. The data are available to anyone who requests them for any non-commercial purposes. The data can be accessed by contacting SC (simiao.chen@uni-heidelberg.de), who will provide guidance on how to use and interpret the data.

Declaration of interests

We declare no competing interests.

Acknowledgements

The study was supported by National High Level Hospital Clinical Research Funding (Project Number BJ-2023-066) and Horizon Europe (HORIZON-MSCA-2021-SE-01; project number 101086139-PoPMeD-SuSDeV).

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lanwpc.2026.101855.

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