nature human behaviour

Article

https://doi.org/10.1038/s41562-026-02451-2

Economic burden of falls for 190 countries and territories from 2020 to 2050 based on health-augmented macroeconomic modelling

Received: 4 March 2025

Accepted: 17 March 2026

Published online: 20 April 2026

Check for updates

Jinxi Li[1,5], Ruxu Zhang[1,5], Qihua Song[1], Yanhong Gong[1], Simiao Chen[2,3,4] & Xiaoxv Yin[1]

Falls contribute to substantial and growing health losses worldwide, yet how they relate to economic output has not been quantified at the global level. Here we estimated the macroeconomic losses attributable to falls in 190 countries and territories for 2020–2050 using a health-augmented macroeconomic model capturing reduced labour supply from mortality and morbidity; heterogeneity in human capital by age, education and experience; and lower capital accumulation from treatment spending. Under the main specification, falls are projected to reduce global output by INT$3.939 trillion (95% uncertainty interval, 3.788–4.096), or 0.088% of the cumulative world gross domestic product. The largest absolute losses occur in the USA, followed by China and Germany. Low- and middle-income countries account for 74.8% of fall-related disability-adjusted life years but only 32.6% of the estimated economic loss, indicating a marked mismatch between health burden and monetized macroeconomic burden. The macroeconomic burden of falls is unevenly distributed globally, underscoring the need for stronger prevention efforts.

Falls present a serious global public health challenge. According to the Global Burden of Disease (GBD) Study, falls rank among the leading contributors to injury-related morbidity and mortality worldwide, disproportionately affecting vulnerable populations such as children, older adults and workers in high-risk occupations[1,2]. In 2021 alone, falls were associated with approximately 800,000 deaths and over 48 million disability-adjusted life years (DALYs)[2]. Among unintentional injuries, only road traffic injuries impose a greater disease burden[1]. Between 2000 and 2021, deaths from falls increased by 73%, compared with a 4% increase in deaths from all injuries combined[3].

The risks vary by age group. Children often suffer fractures and head injuries during play or sports. Older adults are more prone to falls due to declining physical function and chronic conditions. These may be complicated by hip fractures, traumatic brain injuries or even death[2]. Without effective prevention, these burdens are expected to grow as populations age and urbanization accelerates. Beyond their health impacts, falls impose a substantial economic toll, including reduced productivity, increased healthcare costs, labour losses and family caregiving expenses. Estimating the economic burden of falls enables policymakers to implement targeted interventions, allocate

[1]Department of Social Medicine and Health Management, School of Public Health, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China. [2]School of Population Medicine and Public Health, Chinese Academy of Medical Sciences & Peking Union Medical College, Beijing, China. [3]Heidelberg Institute of Global Health, Faculty of Medicine and University Hospital, Heidelberg University, Heidelberg, Germany. [4]State Key Laboratory of Respiratory Health and Multimorbidity, Beijing, China. [5]These authors contributed equally: Jinxi Li, Ruxu Zhang. e-mail: gongyanhong@hust.edu.cn; simiao.chen@uni-heidelberg.de; yxx@hust.edu.cn

resources efficiently and strengthen healthcare systems to address the growing prevalence of fall-related injuries.

Research on the costs of falls has largely been conducted in single countries or specific subpopulations. For example, the economic burden of informal caregiving related to falls among older adults in the USA has been estimated at about US$20 billion[4], and a systematic review in China reported wide variation in the cost per fall among older people[5]. However, these studies do not provide a global picture and often exclude other affected groups, including children and workers in high-risk jobs. In addition, most prior estimates rely on cost-of-illness methods that total direct and indirect costs but do not model how economies adjust to illness[6]. When workers are injured or die, firms may partly replace lost labour with other workers or capital; similarly, treatment spending can alter savings and investment. Ignoring these mechanisms may overstate the output losses attributable to falls. To address this issue, we build on the health-augmented macroeconomic framework developed in earlier work on cancer, chronic obstructive pulmonary disease and road injuries[6–8].

In this study, we adapt that framework to falls and estimate the macroeconomic burden associated with falls in 190 countries and territories from 2020 through 2050. By linking fall-related mortality, morbidity and treatment expenditure to labour supply and capital accumulation, we aim to provide a falls-specific assessment of long-run economic loss and its distribution across settings.

Results

Using the difference in projected gross domestic product (GDP) between the status quo and a counterfactual scenario without falls, our model estimates suggest a global output gap of INT$3.939 trillion (in 2017 international dollars) in scenarios incorporating falls (95% uncertainty interval, 3.788–4.096) during 2020–2050 under the 3% discount rate used in the main analysis. This corresponds to 0.088% (0.085–0.092) of the cumulative world GDP over the study period and to a per capita loss of INT$452 (434–472) (Table 1). Country-level totals and GDP shares are shown in Figs. 1 and 2.

Table 1 and Supplementary Figs. 3 and 4 present the results of the World Bank study for each region and country income group. Across World Bank regions, North America accounted for the greatest macroeconomic burden associated with falls and the highest per capita losses, followed by East Asia and the Pacific (Table 1 and Supplementary Fig. 3). North America also recorded the largest losses relative to output, equivalent to 0.209% of tax revenue (uncertainty interval, 0.209–0.209). The distribution of the economic burden of falls varied across country income groups, total GDP and per capita economic losses. High-income countries represented the largest portion of the global burden, with total economic losses of INT$2.654 trillion (95% uncertainty interval, 2.637–2.676) and losses per capita of INT$2,104 (2,091–2,122). In contrast, the estimated cost for low-income countries was INT$9 billion (7–11) in total and INT$10 (8–12) per capita. Subgroup analysis revealed that the 45–54 age group bore the highest economic burden, amounting to INT$1.350 trillion (1.315–1.396), with the burden among males exceeding that among females (Table 1). In the intermediate scenario analysis, we found that a 20% reduction in the burden of falls by 2050 is projected to be associated with global savings of INT$1.708 trillion (1.652–1.767).

In 2020, falls corresponded to 43.4 million DALYs worldwide. The economic losses are distributed very differently from the health burden. North America accounted for only 6.5% of global DALYs but 32.8% of the economic burden, whereas South Asia accounted for 27.2% of DALYs and only 4.9% of economic losses. More broadly, low- and middle-income countries represented 74.8% of global DALYs yet only 32.6% of the estimated macroeconomic burden (Table 2).

Supplementary Table 6 reports the economic burden estimates for 126 countries and areas with complete data, as well as for 64 countries with missing data. The former group represents 86.0% of the global population and 95.3% of the global GDP. The USA accounted for the largest economic burden of falls, followed by China and Germany. In terms of share of GDP, Saudi Arabia, the USA and Andorra accounted for the largest share (0.22% each). Iceland, the USA and Malta had the highest economic burden per capita.

Table 1 | Total macroeconomic burden, economic burden as a proportion of total GDP and per capita economic burden attributable to fall mortality and morbidity in 2020–2050 by World Bank region, by World Bank income group, by age group, by intermediate scenario and globally

	Economic loss, billions of 2017 INT$ (uncertainty interval[a])	Proportion of total GDP in 2020–2050, $\times10^{-3}$ % (uncertainty interval[a])	Per capita loss, 2017 INT$ (uncertainty interval[a])
By World Bank region			
North America	1,290 (1,288–1,292)	209 (209–209)	3,227 (3,223–3,232)
East Asia and Pacific	1,093 (1,000–1,180)	63 (58–68)	459 (420–496)
Europe and Central Asia	989 (979–1,001)	110 (109–111)	1,070 (1,059–1,083)
Middle East and North Africa	223 (213–236)	94 (90–100)	412 (393–437)
South Asia	192 (163–226)	33 (28–39)	89 (76–105)
Latin America and Caribbean	126 (124–129)	50 (49–51)	181 (178–185)
Sub-Saharan Africa	25 (21–31)	18 (14–21)	16 (13–19)
By World Bank country income group			
High income	2,654 (2,637–2,676)	159 (158–161)	2,104 (2,091–2,122)
Upper-middle income	961 (873–1,040)	53 (48–57)	338 (307–366)
Lower-middle income	314 (270–368)	34 (29–40)	85 (73–100)
Low income	9 (7–11)	19 (15–23)	10 (8–12)
By age group			
0–14	0 (0–1)	0 (0–0)	0 (0–1)
15–24	31 (29–40)	1 (1–1)	26 (24–34)
25–34	215 (196–244)	5 (4–5)	186 (168–209)
35–44	732(708–777)	17 (16–17)	727 (695–762)
45–54	1,350 (1,315–1,396)	30 (30–31)	1,520 (1,473–1,564)
55–65	1,328 (1,296–1,373)	30 (29–31)	1,947 (1,893–2,006)
65+	283 (273–295)	6 (6–7)	386 (370–400)
By sex group			
Male	2,892 (2,796–3,018)	65 (63–67)	332 (320–345)
Female	1,047 (1,019–1,101)	24 (23–25)	121 (117–126)
By intermediate scenario			
10%	1,659 (1,612–1,708)	38 (37–39)	193 (187–198)
20%	1,708 (1,652–1,767)	39 (37–40)	198 (192–205)
Global (190 countries and territories)	3,939 (3,788–4,096)	88 (85–92)	452 (434–470)

[a]Uncertainty intervals in parentheses are calculated on the basis of the lower and upper bounds of 95% uncertainty intervals for GBD 2021 mortality and morbidity data.

 https://doi.org/10.1038/s41562-026-02451-2

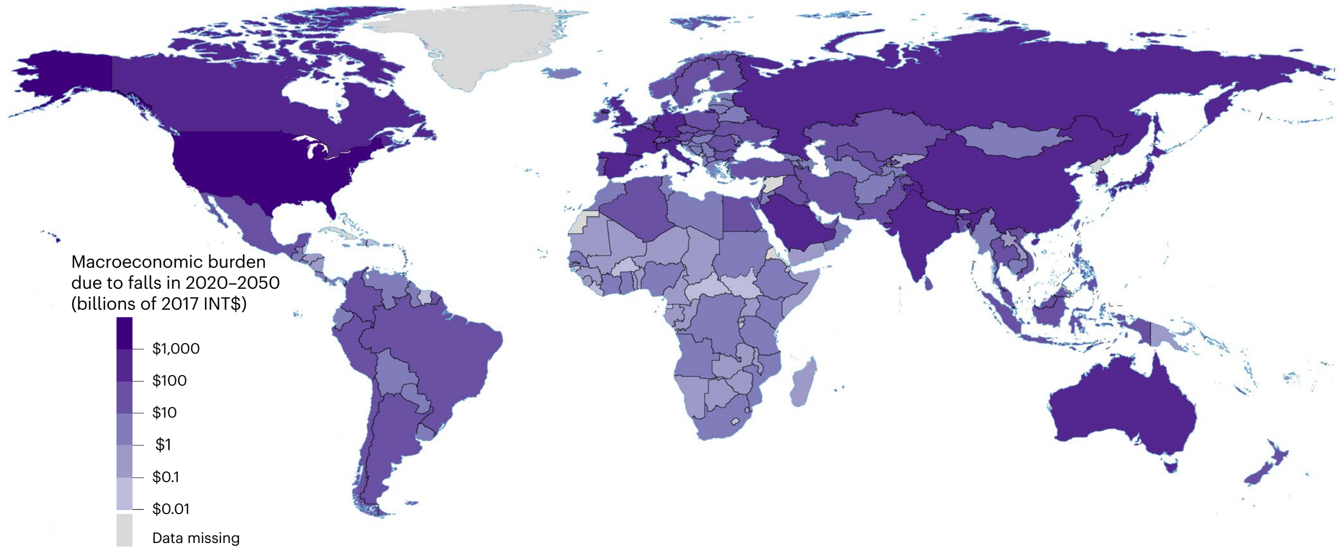

Fig. 1 | Macroeconomic burden due to falls from 2020 to 2050. The projected absolute macroeconomic burden attributable to falls for 190 countries and territories over 2020–2050, estimated using a health-augmented macroeconomic model. Burden is defined as the cumulative difference in GDP between a status quo scenario and a counterfactual scenario in which falls are eliminated at zero cost, reflecting losses in effective labour supply due to mortality and morbidity and the diversion of treatment-related resources from savings and investment. All estimates are reported in 2017 international dollars and are discounted at 3% in the main analysis. Countries are shaded according to total burden levels (darker shading indicates greater losses). Where applicable, territories or countries with insufficient inputs for the full model are indicated as having imputed estimates based on available data.

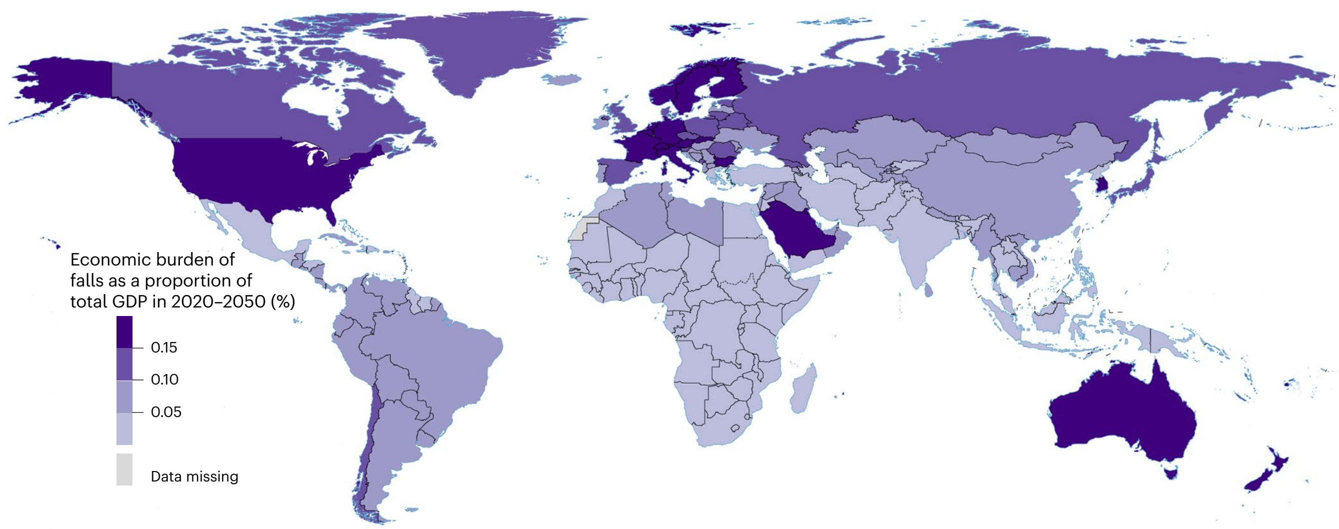

Fig. 2 | Economic burden of falls as a proportion of total GDP in 2020–2050. The projected macroeconomic burden attributable to falls expressed as a percentage of cumulative GDP over 2020–2050 for 190 countries and territories, based on the same health-augmented macroeconomic model. Relative burden estimates capture reductions in effective labour supply due to fall-related mortality and morbidity and reductions in physical capital accumulation via treatment-related resource diversion from savings and investment. Countries are shaded by burden category (darker shading indicates higher relative losses). Estimates are discounted at 3% in the main analysis and are comparable across countries because outputs are standardized to 2017 international dollars before GDP shares are calculated.

For sensitivity analyses, we evaluated the macroeconomic burden under different depreciation rates. When no discounting was applied, the estimate was INT$7.315 trillion (7.039–7.601). The corresponding estimates were INT$4.807 trillion (4.623–4.996) at a 2% discount rate and INT$2.704 trillion (2.599–2.813) at a 5% discount rate (Supplementary Tables 4, 5 and 7–10). Additionally, varying model parameters across a plausible range of 50–150% produced broadly similar results (Supplementary Table 11). These analyses did not

Table 2 | Comparison of macroeconomic burden and lifetime health burden of falls, by World Bank region and country income group

	Economic burden in 2020–2050, billions of 2017 INT$ (global %)	DALYs in 2020, millions (global %)	Total GDP in 2020, billions of 2017 INT$ (global %)	Population in 2020, millions (global %)
By World Bank region				
North America	1,290 (32.8%)	2.8 (6.5%)	21,665 (17.2%)	373 (4.8%)
East Asia and Pacific	1,093 (27.7%)	12.9 (29.7%)	41,097 (32.7%)	2,338 (30.3%)
Europe and Central Asia	989 (25.1%)	8.4 (19.4%)	30,855 (24.5%)	920 (11.9%)
Middle East and North Africa	223 (2.7%)	1.6 (3.7%)	7,431 (5.9%)	451 (5.8%)
South Asia	192 (4.9%)	11.8 (27.2%)	11,182 (8.9%)	1,872 (24.2%)
Latin America and Caribbean	126 (3.2%)	3.2 (7.4%)	9,273 (7.4%)	636 (8.2%)
Sub-Saharan Africa	25 (0.6%)	2.7 (6.2%)	4,188 (3.3%)	1,133 (14.7%)
By World Bank country income group				
High income	2,654 (67.4%)	10.9 (25.2%)	58,610 (46.7%)	1,232 (16%)
Upper-middle income	961 (24.4%)	14.8 (34.2%)	45,399 (36.2%)	2,760 (35.9%)
Lower-middle income	314 (8.0%)	15.9 (36.7%)	20,394 (16.2%)	3,095 (40.2%)
Low income	9 (0.2%)	1.7 (3.9%)	1,134 (0.9%)	608 (7.9%)
Global (190 countries and territories)	3,939 (100%)	43.4 (100%)	125,693 (100%)	7,724 (100%)

materially alter the estimates, supporting the robustness of the projected macroeconomic burden.

Discussion

This analysis applies a health-augmented macroeconomic model to quantify the long-run economic burden of falls in 190 countries and territories. After accounting for differences in education, work experience and treatment-related factors related to capital accumulation, we estimated cumulative global losses of about INT$4.0 trillion between 2020 and 2050. That scale of loss is larger than the 2021 GDP of Japan in constant 2017 international dollars, indicating that falls are not only a health problem but also a material constraint on economic performance.

A key finding is the pronounced disparity between the distribution of disease burden (measured in DALYs) and economic cost. Low- and middle-income countries account for 74.8% of fall-related DALYs and 84.0% of the global population, but only 32.6% of the estimated macroeconomic burden. High-income countries, by contrast, absorb a disproportionate share of economic losses. In our analysis, this divergence reflects fundamental differences in the key features of the model specification, including labour market structure, wage levels and healthcare spending. In the health-augmented macroeconomic framework, higher educational attainment and earnings in high-income countries imply higher economic value of productivity losses, while advanced medical care is associated with higher treatment expenditures. Together, these factors contribute to a substantially higher monetized burden per DALY in high-income settings, consistent with patterns observed in studies of road traffic injuries and chronic diseases[6–8].

Regionally, the burden is greatest in North America, followed by East Asia and the Pacific and Europe and Central Asia; together, these regions account for 85.6% of the global total. The comparatively large economic burden observed in these regions may partly reflect the presence of China and the USA. Within our modelling framework, the high economic burden estimated for China corresponds to its substantial health burden. In the USA, a typical high-income setting, the economic burden reflects large per capita human capital losses associated with relatively high levels of educational attainment. At the same time, substantial treatment expenditures are linked to lower levels of savings and investment, corresponding to slower accumulation of physical capital.

Our findings support greater investment in fall prevention. Because resources are limited, prevention strategies should be selected not only for effectiveness but also for value for money. Existing evidence points to three populations that warrant particular attention: older adults, children and adolescents, and workers exposed to occupational fall risks[2].

The macroeconomic burden attributed to older adults is smaller than their disease burden might suggest, potentially because labour-force participation declines at older ages and our model incorporates human capital and work to assess output. That does not lessen the public health importance of falls in later life, which are often associated with disability, loss of independence, poor quality of life and intensive healthcare use[9]. Evidence supports multifactorial prevention in this group, including exercise-based interventions, home hazard reduction, patient education and programmes that improve strength and balance[10,11]. Environmental safety also matters: safer housing, more accessible public spaces and age-friendly design can reduce exposure to fall risks[12].

Our results show a low economic burden of falls among children aged 0–14, as they are not part of the labour force and thus contribute little to current economic output. However, children are vulnerable to severe fall-related injuries, and preventive measures remain important to reduce harm and protect long-term health[2]. Since individuals aged 0–14 will eventually enter the workforce, injuries during this period may impair educational attainment and skill development, with lasting effects on future labour participation and human capital accumulation. Meta-analytic evidence supports interventions such as stair gates, avoidance of baby walkers and guardrails on upper floors to reduce the risk of falls[13]. The long-running New York City window-guard policy illustrates the potential impact of structural prevention: after mandatory window guards and reporting requirements were introduced, both falls and deaths from window falls dropped sharply over time[14].

Our study reveals that individuals aged 45–54 years bear the highest economic burden of falls. Several factors are relevant here: a large population base, high levels of accumulated human capital and a high prevalence of employment in physically demanding or high-risk occupations. Taken together, it is not surprising to see that falls in this age group are associated with substantial productivity losses and long-term economic outcomes. Despite often being overlooked in favour of older adults in fall prevention efforts, this working-age population warrants greater attention in public health and occupational safety policies to reduce both human and economic costs. Studies have been looking for risk-reducing strategies for workers in high-risk occupations. One study showed that the use of slip-resistant shoes in restaurants was

https://doi.org/10.1038/s41562-026-02451-2

associated with a 54% reduction in the reported rate of slipping[15]. In addition, the use of scaffolding that meets safety standards, as well as safer roofing, can reduce injuries to workers from falls. A study in Spain showed a 71% reduction in the incidence of worker falls in companies that had access to safe scaffolding through subsidy policies[16].

Our study has several limitations. First, we did not consider changes in workforce participation rates of household members who may be required to care for a person after a fall and therefore may have underestimated the economic burden of falls. Second, for 64 countries with missing data, we performed imputation using interpolation and projection based on available information. However, the countries with complete data included in this study cover more than 90% of the global population, so this does not substantially affect the results. Third, we used the USA to extrapolate health expenditures related to falls for all countries in this study, assuming that per capita treatment costs scale in proportion to per capita health expenditure; this may have influenced the estimates, although similar approaches have been adopted in previous studies. Finally, this study did not consider the costs associated with implementing fall prevention interventions, and future research should evaluate these costs to support informed policy decisions.

Conclusion

In summary, the global economic burden of falls is estimated at INT$3.939 trillion. The economic costs and health burden of falls are unevenly distributed among countries at different income levels. High-income countries bear the highest macroeconomic costs. However, low- and middle-income countries bear the majority of the human toll, highlighting the need for improvements on multiple fronts, including strengthening health systems and developing public health policies to reduce fall-related risk factors. Our study highlights the urgent need for greater investment globally to curb falls and their associated health and economic burdens.

Methods

We estimated the macroeconomic burden of falls using an adapted health-augmented macroeconomic model that has been described in earlier publications[6–8] and is summarized in Supplementary Information (pp. 1–4). Falls were defined according to the GBD falls category. In this framework, falls are linked to economic output through two main channels. First, in our model, fall-related morbidity and mortality reduce the effective labour supply: morbidity lowers productivity and increases absenteeism, whereas mortality reduces the number of people who can participate in production. Second, we also modelled expenditures on fall treatment to reduce savings and investment, thereby slowing the accumulation of physical capital. Households may finance these costs directly through out-of-pocket payments or indirectly through insurance premiums.

When estimating costs for 2020–2050, we followed Bloom et al.[17] and compared projected GDP under two scenarios: (1) total output Y_t in the status quo scenario without additional interventions to reduce mortality and morbidity from falls in year t, and (2) total output $\bar{Y}_t$ in the counterfactual scenario of eliminating falls at zero cost in year t. Using the macroeconomic production function, we projected economic outcomes through two channels: effective labour supply and physical capital accumulation. The macroeconomic burden of falls was defined as the cumulative difference in projected annual GDP between these two scenarios:

$$\Delta Y = \sum_{t=2020}^{2050} (\bar{Y}_t - Y_t)$$

Consider an economy in which time $t = 1, 2, \ldots, \infty$ evolves discretely. We considered the following production function for this economy:

$$Y_t = A_t K_t^{\alpha} H_t^{1-\alpha}$$

where Y_t is the aggregate output; A_t is the technological level at time t, which we assume evolves exogenously; K_t is the physical capital stock (that is, machines, factory buildings and so on); and H_t represents aggregate human capital. The parameter α is the elasticity of final output with respect to physical capital. Solow's framework, which underlies the original World Health Organization EPIC macroeconomic model[18], considers only physical capital and raw labour as production inputs[19]. By contrast, the aggregate production function also incorporates effective labour, including health, as an important determinant of output.

Physical capital evolves according to

$$K_{t+1} = (1-\delta)K_t + Y_t - C_t - TC_t = (1-\delta)K_t + \gamma_t Y_t,$$

where δ is the depreciation rate, γ is the saving rate, TC is the costs of ongoing treatment of falls and C is the amount of consumption. Note that the aggregate output Y_t is used for three purposes: (1) to pay treatment costs (hospitalization, medication and so on), (2) to consume the amount and (3) to save.

Individuals of age group a are endowed with $h_t^{(a)}$ units of human capital and supply $l_t^{(a)}$ units of labour from age 15 up to their retirement at age R; that is, for $a \in [15, R]$. Children younger than 15 and retirees older than R do not work. R varies by country and could correspond to a high age (for example, some people older than 80 could also be working). In the theoretical derivations, R indicates the upper bound of the summation. In our simulations, we used labour projections data from the International Labour Organization where positive values for the labour force exist for cohorts older than 65. Aggregate human capital in the production function is then defined as the sum over the age-specific effective labour supply of each age group:

$$H_t = \sum_{a=15}^{R} h_t^{(a)} l_t^{(a)} N_t^{(a)},$$

where $N_t^{(a)}$ denotes the number of individuals in age group a. Note that aggregate human capital increases with the number of working-age individuals who live in the economy (that is, with a higher $N_t = \sum_{a=15}^{R} N_t^{(a)}$), with individual human capital endowment (that is, with a higher $h_t^{(a)}$ for at least one a) and with labour supply (that is, with a higher $l_t^{(a)}$ for at least one a). This human capital function itself allows for the substitution of capital (machines or robots) for workers. In addition, if the disease predominantly affects one age group, then workers from other age groups can substitute.

We followed Mincer[20] and constructed the average human capital of the cohort aged a according to an exponential function of education and work experience:

$$h_t^{(a)} = \exp\left[\eta_1(\mathrm{ye}_t^{(a)}) + \eta_2(a - \mathrm{ye}_t^{(a)} - 5) + \eta_3(a - \mathrm{ye}_t^{(a)} - 5)^2\right],$$

where η_1 is the semi-elasticity of human capital with respect to average years of education as given by $\mathrm{ye}_t^{(a)}$, and η_2 and η_3 are the semi-elasticities of human capital with respect to experience of the workforce $(a - \mathrm{ye}_t^{(a)} - 5)$ and experience of the workforce squared $(a - \mathrm{ye}_t^{(a)} - 5)^2$, respectively. Here we assumed a school entry age of five years throughout.

Falls impede physical capital accumulation because savings finance part of the treatment costs. Physical capital accumulation in the counterfactual scenario can be written as

$$\bar{K}_{t+1} = \bar{\gamma}_t \bar{Y}_t + (1-\delta)\bar{K}_t,$$

$$\bar{\gamma}_t \bar{Y}_t = \bar{I}_t = \bar{Y}_t - \bar{C}_t = \gamma_t \bar{Y}_t + \chi TC_t.$$

where χ is the fraction of the treatment cost that is diverted to savings.

Falls are modelled into the accumulation of human capital via a smaller population and a lower labour participation rate. The evolution of the labour supply in the status quo scenario is given by

$$L_t^{(a)} = l_t^{(a)} N_t^{(a)} \text{ with } N_t^{(a)} = \left[1 - \sigma_{t-1}^{(a-1)}\right] N_{t-1}^{(a-1)},$$

where $\sigma_t^{(a)}$ is the overall mortality rate of age group a at time t. In this specification, mortality and morbidity reduce the effective labour supply. The reduction of the population size $N_t^{(a)}$ captures the mortality effect.

Let $\sigma_{r,t}^{(a)}$ denote the mortality rate of people in age group a due to falls, and let $\sigma_{-r,t}^{(a)}$ be the overall mortality rate due to causes other than falls; then we have

$$\left(1 - \sigma_t^{(a)}\right) = \left(1 - \sigma_{r,t}^{(a)}\right)\left(1 - \sigma_{-r,t}^{(a)}\right).$$

In the counterfactual scenario, in which we denote variables with an overbar, the size of the cohort aged a at time t ($\bar{N}_t^{(a)}$) evolves according to

$$\bar{N}_t^{(a)} = \left[1 - \sigma_{-r,t-1}^{(a-1)}\right] \bar{N}_{t-1}^{(a-1)}.$$

The loss of labour due to mortality then accumulates over the years according to

$$\bar{N}_t^{(a)} = N_t^{(a)} / \prod_{\tau=0}^{\min\{t,a\}-1} \left[1 - \sigma_{r,t-1-\tau}^{(a-1-\tau)}\right].$$

The reduction of the labour participation rate $l_t^{(a)}$ captures the morbidity effect because illness can reduce the labour supply through fewer working hours or complete withdrawal from the workforce. The labour participation rate in the counterfactual scenario $\bar{l}_t^{(a)}$ can be calculated as

$$\bar{l}_t^{(a)} \approx l_t^{(a)} / \prod_{\tau=0}^{\min\{t,a\}-1} \left[1 - p^{\tau} \sigma_{r,t-1-\tau}^{(a-1-\tau)} \xi^{(a-1-\tau)}\right],$$

where $\xi^{(a)}$ measures the size of the morbidity effect relative to the relevant mortality rate and where p^{τ} is the probability that a patient died from falls by time t.

Because the effect of morbidity is hard to estimate directly, we first defined

$$\xi^{(a)} = \frac{\text{loss of labour due to morbidity in age group } a}{\text{loss of labour due to mortality in age group } a}.$$

Next, we assumed that the following holds in any given year for each age group a:

$$\xi^{(a)} = \frac{\text{YLD}^{(a)}}{\text{YLL}^{(a)}},$$

where $\text{YLD}^{(a)}$ represents the years lived with falls and $\text{YLL}^{(a)}$ represents the years of life lost due to falls.

In sum, by reducing the prevalence of falls, the counterfactual scenario is associated with an increase in labour supply compared with the status quo scenario. We approximated the change in labour supply (at time t for age group a) by

$$\Delta L_t^{(a)} \approx l_t^{(a)} N_t^{(a)} \sum_{\tau=0}^{\min\{t,a\}-1} \sigma_{r,t-1-\tau}^{(a-1-\tau)} \left[1 + p^{\tau} \xi^{(a-1-\tau)}\right].$$

Data sources

As elaborated in prior work[21], this study relied on publicly available data (Supplementary Information pp. 5–8) and therefore did not meet the regulatory definition of human participant research, making it exempt from Institutional Review Board review under the Common Rule. Data on fall incidence, prevalence, mortality, years of life lost due to premature mortality and years lived with disability were obtained from GBD 2021 compiled by the Institute for Health Metrics and Evaluation[22]. Data on educational attainment, labour force participation, population and physical capital were obtained from the Barro-Lee Education Database[23], the International Labour Organization[24], the United Nations Department of Economic and Social Affairs[25] and the Penn World Table projections[26], respectively. Fall treatment costs were taken from Dieleman et al.[27]. GDP projections for the status quo scenario and savings rate data were drawn from the World Bank World Development Indicators database and the World Economic Outlook database[28–30]. Detailed definitions and data sources for all comparison metrics are provided in Supplementary Information (pp. 5–8). All economic burden estimates are reported in 2017 international dollars. Because most data sources use 2017 international dollars, all estimates are presented in the same unit. Purchasing power parity adjustment facilitates valid cross-country comparisons by accounting for differences in price levels[31].

We estimated the economic burden of falls for 190 countries and territories globally and presented the results separately by World Bank income groups (low income, lower-middle income, upper-middle income and high income) and by World Bank regional classifications (East Asia and Pacific, Europe and Central Asia, Latin America and Caribbean, Middle East and North Africa, North America, South Asia, and Sub-Saharan Africa). Of the 190 countries and territories, 126 had complete data, and their economic burden of falls was estimated directly using the health-augmented macroeconomic model; for the remaining 64 countries and territories, missing data were handled using linear projection methods applied in previous studies (Supplementary Tables 2 and 3). We performed a subgroup analysis stratified by sex, separately estimating the macroeconomic burden of falls for male and female subpopulations. We further conducted subgroup analyses by dividing the population into seven age groups: 0–14, 15–24, 25–34, 35–44, 45–54, 55–64 and ≥65 years. In addition, we present two intermediate scenarios in this study to simulate the impact of a gradual reduction in the burden of falls under different intervention scenarios (10% and 20% reductions by 2050, respectively).

Sensitivity analysis

Following prior studies[6–8,21], confidence intervals for the economic burden of falls were derived by varying mortality and morbidity rates within the lower and upper bounds of the 95% uncertainty intervals in the GBD data. We also reported estimates using a 3% discount rate in the main analysis, together with estimates based on discount rates of 0%, 2% and 5% in Supplementary Tables 4, 5 and 7–10. To assess the robustness of the results to parameter uncertainty, we conducted a semi-probabilistic sensitivity analysis in which key model parameters were sampled 200 times from uniform distributions spanning 50% to 150% of their baseline values. The resulting estimates were aggregated to generate overall uncertainty intervals, with 95% bounds calculated from the distribution of simulated outcomes. The analyses were conducted using R v.4.3.0[32].

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

All data used in this study are publicly available from existing repositories and databases. Detailed descriptions of the data sources, access links and processing procedures are provided in Methods. No new datasets were generated for this study. Source data are provided with this paper.

Code availability

All the code used for the descriptive tables and the analysis of the primary and safety end-points is publicly available via GitHub at https://github.com/Zhangruxu/Health-Augmented-Macroeconomic-Model.

References

1. GBD 2021 Demographics Collaborators. Global age–sex-specific mortality, life expectancy, and population estimates in 204 countries and territories and 811 subnational locations, 1950–2021, and the impact of the COVID-19 pandemic: a comprehensive demographic analysis for the Global Burden of Disease Study 2021. *Lancet* **403**, 1989–2056 (2024).
2. *Step Safely: Strategies for Preventing and Managing Falls Across the Life-Course* (WHO, 2021).
3. *Global Health Estimates: Life Expectancy and Leading Causes of Death and Disability* (WHO, accessed 10 September 2024); https://www.who.int/data/gho/data/themes/mortality-and-global-health-estimates
4. Joo, H., Wang, G., Yee, S. L., Zhang, P. & Sleet, D. Economic burden of informal caregiving associated with history of stroke and falls among older adults in the US. *Am. J. Prev. Med.* **53**, S197–S204 (2017).
5. Peng, K. et al. Incidence, risk factors and economic burden of fall-related injuries in older Chinese people: a systematic review. *Inj. Prev.* **25**, 4–12 (2019).
6. Chen, S. et al. Estimates and projections of the global economic cost of 29 cancers in 204 countries and territories from 2020 to 2050. *JAMA Oncol.* **9**, 465–472 (2023).
7. Chen, S. et al. The global economic burden of chronic obstructive pulmonary disease for 204 countries and territories in 2020–50: a health-augmented macroeconomic modelling study. *Lancet Glob. Health* **11**, 1183–1193 (2023).
8. Chen, S., Kuhn, M., Prettner, K. & Bloom, D. E. The global macroeconomic burden of road injuries: estimates and projections for 166 countries. *Lancet Planet. Health* **3**, E390–E398 (2019).
9. Lewis, S. R. et al. Population-based interventions for preventing falls and fall-related injuries in older people. *Cochrane Database Syst. Rev.* **1**, CD013789 (2024).
10. Gillespie, L. D. et al. Interventions for preventing falls in older people living in the community. *Cochrane Database Syst. Rev.* **2012**, CD007146 (2012).
11. Sherrington, C. et al. Exercise for preventing falls in older people living in the community. *Cochrane Database Syst. Rev.* **1**, CD012424 (2019).
12. Masud, T. & Morris, R. O. Epidemiology of falls. *Age Ageing* **30**, 3–7 (2001).
13. Kendrick, D. et al. Home safety education and provision of safety equipment for injury prevention. *Cochrane Database Syst. Rev.* **2012**, D5014 (2012) **Suppl. 4**.
14. Toprani, A., Robinson, M., Middleton, I. J., Hamade, A. & Merrill, T. New York City's window guard policy: four decades of success. *Inj. Prev.* **24**, i14–i18 (2018).
15. Rubio-Romero, J. C., Carrillo-Castrillo, J. A. & Gibb, A. Prevention of falls to a lower level: evaluation of an occupational health and safety intervention via subsidies for the replacement of scaffolding. *Int. J. Inj. Control Saf. Promot.* **22**, 16–23 (2015).
16. Verma, S. K. et al. A prospective study of floor surface, shoes, floor cleaning and slipping in US limited-service restaurant workers. *Occup. Environ. Med.* **68**, 279–285 (2011).
17. Bloom, D. E. et al. The economic burden of chronic diseases: estimates and projections for China, Japan, and South Korea. *J. Econ. Ageing* **17**, 100163 (2020).
18. Abegunde, D. & Stanciole, A. *An Estimation of the Economic Impact of Chronic Noncommunicable Disease in Selected Countries* (World Health Organization, 2006).
19. Solow, R. M. A contribution to the theory of economic growth. *Q. J. Econ.* **70**, 65–94 (1956).
20. Mincer, J. *Schooling, Experience, and Earnings* (Columbia Univ. Press, 1984).
21. Zhang, R. et al. The global economic burden of cirrhosis and other chronic liver diseases: a health-augmented macroeconomic modeling study. *Hepatol. Commun.* **10**, e0882 (2026).
22. *Global Burden of Disease Study 2021 (GBD 2021) Results* (Institute for Health Metrics and Evaluation, 2021); https://www.healthdata.org/
23. Barro, R. J. & Lee, J. W. A new data set of educational attainment in the world, 1950–2010. *J. Dev. Econ.* **104**, 184–198 (2013).
24. *Labour Force Participation Rate by Sex and Age* (International Labour Organization, accessed 10 September 2024); https://ilostat.ilo.org/topics/population-and-labour-force/
25. *World Population Prospects 2024: Department of Economic and Social Affairs Population Dynamics* (United Nations, accessed 10 September 2024); https://population.un.org/wpp/Download/Standard/CSV/
26. *Capital Stock at Current Purchasing Power Parities* (FRED Economic Data, accessed 10 September 2024); https://fred.stlouisfed.org/searchresults/?st=Capital%20stock%20at%20Current%20Purchasing%20Power%20Parities
27. Dieleman, J. L. et al. US health care spending by payer and health condition, 1996–2016. *J. Am. Med. Assoc.* **323**, 863–884 (2020).
28. *World Bank Database, GDP, PPP (Constant 2021 International $)* (World Bank, accessed 10 September 2024); https://data.worldbank.org/indicator/NY.GDP.MKTP.PP.KD
29. *World Bank Database, Gross Savings (% of GDP)* (World Bank, accessed 10 September 2024); https://data.worldbank.org/indicator/NY.GNS.ICTR.ZS
30. *World Economic Outlook Database* (International Monetary Fund, accessed 10 September 2024); https://www.imf.org/en/Publications/WEO/weo-database/2023/October
31. *Purchasing Power Parities and the Size of World Economies Results from the 2017 International Comparison Program* (World Bank Group, 2020); https://openknowledge.worldbank.org/server/api/core/bitstreams/d508f4dd-1075-579f-843d-cae5631a0a61/content
32. R v.4.3.0 (R Foundation for Statistical Computing, 2023).

Acknowledgements

Funding was provided by EU Horizon Europe (HORIZON-MSCA-2021-SE-01; project number 101086139-PoPMeD-SuSDeV) to S.C. The funders had no role in study design, data collection and analysis, decision to publish or preparation of the manuscript. We thank all authors and participants in the studies included in this study.

Author contributions

X.Y., J.L. and S.C. conceived of the study. J.L. and S.C. acquired the data and information. J.L. and R.Z. conducted the analyses, visualized and interpreted the data and reviewed the literature. X.Y., Q.S., Y.G. and R.Z. contributed to the literature review and the interpretation of the data. J.L. and S.C. wrote the article. R.Z. and J.L. revised the paper in response to reviewer comments. S.C. and X.Y. accessed and verified all the data, and they had final responsibility for the decision to submit the paper for publication. All authors had full access to all data used in the study and approved the final version.

Competing interests

The authors declare no competing interests.

https://doi.org/10.1038/s41562-026-02451-2

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s41562-026-02451-2.

Correspondence and requests for materials should be addressed to Yanhong Gong, Simiao Chen or Xiaoxv Yin.

Peer review information *Nature Human Behaviour* thanks David Bishai, Alexander Konnopka and the other, anonymous, reviewer(s) for their contribution to the peer review of this work. Peer reviewer reports are available.

nature portfolio

Corresponding author(s): Xiaoxv Yin and Simiao Chen

Last updated by author(s): Feb 24, 2026

Reporting Summary

Nature Portfolio wishes to improve the reproducibility of the work that we publish. This form provides structure for consistency and transparency in reporting. For further information on Nature Portfolio policies, see our Editorial Policies and the Editorial Policy Checklist.

Statistics

For all statistical analyses, confirm that the following items are present in the figure legend, table legend, main text, or Methods section.

n/a	Confirmed	
☒	☐	The exact sample size (*n*) for each experimental group/condition, given as a discrete number and unit of measurement
☒	☐	A statement on whether measurements were taken from distinct samples or whether the same sample was measured repeatedly
☒	☐	The statistical test(s) used AND whether they are one- or two-sided *Only common tests should be described solely by name; describe more complex techniques in the Methods section.*
☒	☐	A description of all covariates tested
☐	☒	A description of any assumptions or corrections, such as tests of normality and adjustment for multiple comparisons
☐	☒	A full description of the statistical parameters including central tendency (e.g. means) or other basic estimates (e.g. regression coefficient) AND variation (e.g. standard deviation) or associated estimates of uncertainty (e.g. confidence intervals)
☒	☐	For null hypothesis testing, the test statistic (e.g. *F*, *t*, *r*) with confidence intervals, effect sizes, degrees of freedom and *P* value noted *Give P values as exact values whenever suitable.*
☒	☐	For Bayesian analysis, information on the choice of priors and Markov chain Monte Carlo settings
☐	☒	For hierarchical and complex designs, identification of the appropriate level for tests and full reporting of outcomes
☐	☒	Estimates of effect sizes (e.g. Cohen's *d*, Pearson's *r*), indicating how they were calculated

Our web collection on statistics for biologists contains articles on many of the points above.

Software and code

Policy information about availability of computer code

Data collection	no software was used.The analysis of this study used publicly available summary data from international knowledge bases and previously published sources.
Data analysis	All the code used for the descriptive tables and the analysis of the primary and safety endpoints is publicly available at https://github.com/Zhangruxu/Health-Augmented-Macroeconomic-Model

For manuscripts utilizing custom algorithms or software that are central to the research but not yet described in published literature, software must be made available to editors and reviewers. We strongly encourage code deposition in a community repository (e.g. GitHub). See the Nature Portfolio guidelines for submitting code & software for further information.

Data

Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our policy

All input datasets are publicly available from the sources listed in supplementary 3. Country-level derived outputs underlying the figures and tables are provided in the Supplementary Tables. The corresponding authors hold the R (v4.3.0) code used for data cleaning, macroeconomic modeling, and figure/table generation,

April 2023

together with a minimal reproducible workflow; these materials are available from the corresponding authors upon reasonable request for academic, non-commercial purposes (contact: yxx@hust.edu.cn; zhangchichen@sina.com).

Research involving human participants, their data, or biological material

Policy information about studies with human participants or human data. See also policy information about sex, gender (identity/presentation), and sexual orientation and race, ethnicity and racism.

Reporting on sex and gender	The study uses publicly available,aggregated"age-sex-specific" data for labor force projections,education,and population. Sex is treated as a biological variable in the analysis. No individual-level data was collected.
Reporting on race, ethnicity, or other socially relevant groupings	The study does not use race or ethnicity for categorization. The primary groupings are geographical and economic.
Population characteristics	This study is a macroeconomic analysis using aggregated public data from 190 countries;it did not recruit human participants. Population characteristics are defined at an aggregate level,including data on demographics, mortality, morbidity, education, and labor force participation
Recruitment	NO participants were recruited for this study.
Ethics oversight	Ethics approval was not required. No individual-level human data were collected.

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☒ Behavioural & social sciences ☐ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	This is a quantitative, macroeconomic modeling study.
Research sample	The study uses aggregated, publicly available data for 190 countries and territories, Datasets, were sourced form the Global Burden of Disease GBD)2021 Study, the World Bank, and the International Labor Organization,among others.
Sampling strategy	The study did not use sampling.
Data collection	No new data was collected for this study.
Timing	The study projects the economic burden from 2020 to 2050.The authors accessed the various existing datasets used for the analysis between June 2017 and August 2022
Data exclusions	No data were excluded from the analyses.
Non-participation	not applicant
Randomization	Participants were not allocated to experimental groups.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☒	☐ Animals and other organisms
☐	☒ Clinical data
☒	☐ Dual use research of concern
☒	☐ Plants

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging

Clinical data

Policy information about clinical studies

All manuscripts should comply with the ICMJE guidelines for publication of clinical research and a completed CONSORT checklist must be included with all submissions.

Clinical trial registration	Not applicable.
Study protocol	Not applicable.
Data collection	This study did not involve primary data collection.
Outcomes	The primary outcome was the macroeconomic burden of falls,calculated as the cumulative difference in projected GDP between"status quo"scenario and a"counter factual" scenario over the period2020-2050.

Plants

Seed stocks	not applicant
Novel plant genotypes	not applicant
Authentication	not applicant