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ARTICLE

The impact of diabetes on productivity in China

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Abstract

Aims/hypothesis Diabetes increases the risk of premature death and reduces work productivity. We estimated the impact of diabetes in China in terms of mortality, years of life lost, and productivity-adjusted life years (PALYs) lost in the Chinese population.

Methods Life table modelling was used with simulated follow-up of those with diabetes in the Chinese population of working age (20–49 years in women and 20–59 years in men) until retirement age (50 years for women and 60 years for men). Data regarding the prevalence of diabetes, as well as excess mortality, labour force dropout and productivity loss attributable to diabetes, were taken from published sources. Models were constructed for the cohort with diabetes and repeated for the same cohort assuming that they had no diabetes. The differences in number of deaths, years of life lived and PALYs lived between the two models reflected the impact of diabetes. The WHO standard 3% annual discount rate was applied to years of life and PALYs lived.

Results In 2017, an estimated 56.4 million people of working age in China (7.1%) had diabetes. With simulated follow-up until retirement, those with diabetes were predicted to experience an estimated 4.1 million more deaths, the loss of an additional 22.7 million years of life (3.7%) and the loss of an additional 75.8 million PALYs (15.1%). This was equivalent to an average of 1.3 PALYs lost per person with diabetes. Based on gross domestic product (GDP) per full-time worker in 2017, the loss in PALYs equated to a total of Chinese ¥17.4 trillion (US$2.6 trillion) in lost GDP owing to reduced productivity, with an average of ¥307,925 (US$45,959) lost per person with diabetes.

Conclusions/interpretation Our study demonstrates the significant cumulative impact of diabetes on productivity across the working lifetime in the Chinese population, highlighting the potential economic benefits of diabetes prevention in the longer term.

Keywords Cost · Diabetes · Productivity

Abbreviations

GDP	Gross domestic product
ILO	International Labour Organization
OECD	Organisation for Economic Co-operation and Development
PALY	Productivity-adjusted life years
QALY	Quality-adjusted life years
UN	United Nations
WPP	World Population Prospects

Introduction

The People's Republic of China is the epicentre of the worldwide diabetes epidemic, with an estimated 114.4 million people with diabetes in 2017 [1]. This equates to one in four of people with diabetes worldwide living in China and follows a rapid increase in the prevalence of diabetes in China, from 0.7% in 1980, to 2.5% in 1994, 5.5% in 2000 and 10.9% in 2013 [2–5]. While the prevalence of diabetes is highest in older age groups, it continues to rise among younger people in China [6]. Furthermore, there is evidence to suggest Asian

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Research in context

What is already known about this subject?

- Diabetes and its complications can cause reduced workforce participation and productivity while at work
- Current estimates of the economic burden of diabetes in China are based on diabetes healthcare expenditure and do not incorporate diabetes-related productivity loss

What is the key question?

- What is the burden of diabetes in the Chinese population in terms of years of life lost and productivity-adjusted life years (PALYs) lost due to diabetes?

What are the new findings?

- Using a novel measure (PALYs), we demonstrated the significant cumulative productivity loss (15.1%) across the working lifetime of those with diabetes in China
- These productivity losses equated to a significant economic burden, highlighting the long-term economic consequences of diabetes in the Chinese population

How might this impact on clinical practice in the foreseeable future?

- Our findings indicate that diabetes has a significant cumulative impact on productivity across the working lifetime in the Chinese population, and studies such as this could provide an important theoretical benchmark against which funding for interventions can be assessed in terms of return on investment

populations develop symptoms at a younger age and experience greater severity of complications and risk of premature mortality, compared with Europid populations [7–9]. The burden of disease is potentially greater in younger populations owing to increased years lived with disease and higher risk of chronic complications [10].

Diabetes-related morbidity can lead to reduced workforce participation and productivity while at work, including more work days lost to ill health (absenteeism) and reduced efficiency at work (presenteeism) [11, 12]. The resulting loss of productivity can impose an economic burden on individuals, employers and governments through reduced earnings, tax revenue and gross domestic product (GDP) [13, 14]. In the USA, an estimated $89.9 billion was lost owing to diabetes-related productivity losses in 2017, including diabetes-related absenteeism ($3.3 billion), presenteeism ($26.9 billion), reduced labour force participation ($37.5 billion), and premature deaths attributed to diabetes ($19.9 billion) [13]. In China, this has been less well studied, but the IDF estimated that diabetes cost China approximately US$109.8 billion in 2017 [1]. However, these estimates were based on the 'direct' costs of diabetes relating to healthcare expenditure, and did not incorporate 'indirect' costs, including diabetes-related productivity losses. Estimates of productivity loss are important to capture the broader economic burden of diabetes and to inform the case for investment in its prevention and control [15]. In the present study, we sought to estimate the impact of diabetes on the Chinese population, both in terms of years of life lost and productivity-adjusted life years (PALYs) lost due to diabetes [16, 17].

Methods

Our analyses utilised multistate life table models [18], constructed for separate sex and age (in 5-year age groups) cohorts of the Chinese population aged 20 to 49 years in women and 20 to 59 years in men, with follow-up until 60 years in men and 50 years in women (retirement age) [19]. Official retirement age for female 'professionals' is 55 years (including medical personnel and other professions) and 50 years for all other female workers [19, 20]. However, owing to a lack of data regarding diabetes prevalence within professions, retirement age was conservatively assumed to be 50 years for all women.

Age-specific mortality rates, workforce statistics and measures of productivity were used to simulate the progression of these cohorts until death or retirement age, measuring cumulative years of life and PALYs lived. Data were derived from a combination of publicly available datasets and published sources, shown in electronic supplementary material (ESM) Table 1. First, the life table model estimated these variables for the working-age population who had diabetes. The cohort was then re-simulated with the hypothetical assumption that they did not have diabetes, with relevant changes to mortality rates, labour force rate and productivity indices (see below). The differences in total years of life lived and PALYs lived between the two cohorts reflected the impact of diabetes. The WHO standard 3% annual discount rate was applied to all years of life and PALYs lived [21].

Population and mortality rates The demographic profile of the cohort was derived from the 2017 China Statistical

Yearbook, stratified by sex and 5-year age groups [22]. Diabetes prevalence estimates from the 2017 IDF Diabetes Atlas were used to calculate the number of people with diabetes in the population by sex and age group [1]. Sex- and age-group-specific mortality data for 2017 were extrapolated from the 2010 census data using temporal trends in adult mortality rates for China from the United Nations (UN) World Population Prospects (WPP) [23, 24]. These were attributed to those with and without diabetes based on age- and sex-specific diabetes prevalence and the RR of all-cause mortality associated with diabetes in Chinese populations derived from a national prospective study of adults with diabetes (ESM Table 2) [25]. Mortality rates were obtained for 5-year age bands, and extrapolated using exponential functions to provide rates for age in single years (chosen for best fit, $R^2 = 0.96–0.99$), assuming that the rate for a 5-year age group applied to people in the midpoint of that age band. We projected temporal trends in population mortality risk across the model time horizon using average annual proportional reduction in adult mortality in China (1.0% per year) from the UN WPP forecast [24]. Annual age- and sex-specific mortality rates were applied to the model in yearly cycles with deaths assumed to have occurred at the midpoint of the year.

Labour force participation Sex- and age-specific labour force participation in China were drawn from International Labour Organization (ILO) estimates for 2017 [26]. Labour force participation was lowest in those aged 20–24 years in both men (69.4%) and women (65.0%) and highest in men aged 30–34 years (97.0%) and women aged 25–29 years (84.2%).

Productivity indices Diabetes-related productivity loss was characterised using two productivity indices: diabetes-related labour force dropout, which captures the shortfall in labour force participation in those with diabetes compared with those without diabetes, and a productivity index, which reflects the productivity of an individual as a proportion, ranging from 0 (entirely unproductive) to 1 (entirely productive), and captures impairment to productivity due to a health condition [16, 17]. These inputs were derived from estimates of absenteeism, presenteeism, and labour force participation in those with diabetes compared with those without diabetes [27]. Diabetes-related labour force dropout was expressed as labour force participation percentage shortfall and ranged from 7.0% in women and 5.2% in men with diabetes aged 20–29 years to 12.8% in women and 8.3% in men with diabetes over 40 years, respectively [27]. These relative reductions were applied to 2017 ILO sex- and age-group-specific population labour force participation rates to derive the labour force participation rates in those with and without diabetes. In the absence of data on the division of the labour force into full- and part-time employment by disease status, all employees were assumed to be in full-time employment. In the model, years of life lived by the cohort were multiplied by the labour force participation rate to calculate years lived in the labour force.

To estimate PALYs lived by the diabetes cohort, each year lived in the labour force by the cohort was multiplied by a productivity index derived from estimates of diabetes-related absenteeism and presenteeism [16, 17]. This is akin to multiplication of years of life lived by utilities to derive quality-adjusted life years (QALYs) [28]. Absenteeism was defined as the number of lost work days per year owing to diabetes and was expressed as a percentage of the total working days per year, while presenteeism was defined as self-assessed productivity loss while at work and expressed as a percentage of total productivity. Absenteeism was estimated to be 10.2 days per year in women and 1.9 days in men [27], which, as a proportion of the 245 maximum working days per year in China, represents a 4.1% and 0.8% reduction in productivity, respectively. The shortfall in productivity due to diabetes-associated presenteeism was 1.0% in women and 0.6% in men [27]. The available evidence did not allow for stratification of absenteeism and presenteeism estimates by age group. The combined productivity diabetes-related shortfall owing to absenteeism and presenteeism was thus assumed to be 5.1% in women (productivity index = 0.95) and 1.8% in men (productivity index = 0.98). The productivity index in those without diabetes was assumed to be 1.0.

Data on the GDP per worker were drawn from the 2018 Organisation for Economic Co-operation and Development (OECD) Compendium of Productivity Indicators, and in China in 2017, the figure was ¥179,486 (US$26,789) [29]. We assumed that the economic value of each PALY was equivalent to annual GDP per worker. We projected temporal trends in GDP across the model time horizon using the OECD long-term GDP forecasts [30].

Sensitivity and scenario analyses First, the individual contribution of absenteeism, presenteeism, labour force dropout and premature mortality to productivity loss were assessed. Second, deterministic sensitivity analyses were undertaken to assess the impact of uncertainty around diabetes-related mortality risk, productivity indices, and economic data inputs on the model and PALYs lost in those with diabetes in the Chinese population. These include: upper and lower uncertainty bounds around estimates of all-cause mortality risk associated with diabetes based on the upper and lower 95% CI around estimates of RR, respectively [25], and the upper and lower uncertainty bounds around productivity indices based on decreasing and increasing estimates of absenteeism, presenteeism, and labour force dropout by 25%, respectively [27]. Finally, scenario analyses were undertaken to explore other model assumptions and compared with the base case, including: varying population mortality risk, by doubling the average annual reduction in mortality risk from the UN WPP (1.0% per year) to a 2.0% reduction per year; and by removing the temporal trend and maintaining 2017 mortality risk across the model time horizon. Similarly, trends were varied in GDP per worker, by doubling the annual GDP growth rate from 3.2% per year (OECD forecast average annual GDP growth rate) to 6.4% per year; and by removing the temporal trend and maintaining 2017 GDP per worker estimates across the model time horizon [31]. To assess the impact of the assumption of the WHO standard annual discount rate of 3.0%, scenario analyses were performed in which the discount rate applied was 5.0% or 1.5% [22].

Results

The prevalence of diabetes in the Chinese working age population was 7.1% (9.6% in men and 4.7% in women), equating to 56.4 million people (41.4 million men and 15.1 million women) between 20 years and retirement age living with diabetes (Table 1).

Excess mortality and years of life lost to diabetes Until each cohort reached retirement age, there were an estimated 4.1 million more deaths in those with diabetes than in the same cohort assuming no diabetes (Table 2). We estimated that years of life lived by the current cohort of people living with diabetes in China would be reduced by an estimated 22.7 million years (3.7%) over their working lifetime, compared with the same cohort assuming no diabetes (Table 2). This equated to an average of 0.2 years of life lost per person with diabetes (0.5 in men and 0.1 in women) over the working lifetime.

Productivity-adjusted life years lost to diabetes Diabetes was estimated to reduce PALYs lived by the current cohort of people living with diabetes in China by 75.8 million PALYs (56.3 million in men and 19.5 million in women) over the working lifetime or by 15.1% (14.1% in men and 18.6% in women) (Table 3). This equated to 1.3 PALYs lost per person with diabetes (1.4 in men and 1.3 in women). Assuming a constant GDP per full-time worker of ¥179,486 (US$26,789), productivity lost to diabetes in China would be associated with a ¥17.4 trillion (US$2.6 trillion) loss in GDP. This is equivalent to an average GDP loss of ¥307,925 (US$45,959) per person with diabetes over the working lifetime.

Sensitivity and scenario analyses Figure 1 shows the contribution of the four causes of diabetes-related productivity loss considered in our models. Labour force dropout (62.1%) and mortality (24.7%) were the major contributors to productivity loss, followed by absenteeism (9.0%) and presenteeism (4.2%). Accordingly, the majority of costs associated with productivity losses were caused by diabetes-related labour force dropout (¥10.8 trillion, US$1.6 trillion) and mortality (¥4.2 trillion, US$640.8 billion), followed by absenteeism (¥1.6 trillion, US$232.9 billion) and presenteeism (¥728.4 billion, US$108.7 billion). The proportion of PALYs lost to diabetes-related mortality was higher in men (24.7%) than women (7.1%), while the proportion of PALYs lost to absenteeism was higher in women (21.1%) than in men (9.0%).

The model was sensitive to a number of inputs such as productivity indices, diabetes-related labour force dropout, and mortality risk, and model assumptions, including temporal trends in mortality risk and the annual discount rate (Table 4). Compared with the base case, at upper and lower

Table 1 The age- and sex-specific population and number of people living with diabetes in China in 2017

Five-year age group	Men			Women		
	Population [a]	Prevalence of diabetes (%) [b]	Number of men with diabetes	Population [a]	Prevalence of diabetes (%) [b]	Number of women with diabetes
20–24	49,362,747	2.1	1,047,558	45,076,346	1.1	495,924
25–29	64,710,828	3.4	2,200,168	62,636,763	1.8	1,155,245
30–34	52,681,251	5.2	2,758,241	51,989,896	3.0	1,550,205
35–39	48,947,934	7.7	3,750,163	47,150,411	4.6	2,179,783
40–44	57,659,007	10.6	6,094,422	55,446,671	6.8	3,793,198
45–49	63,466,389	13.7	8,696,194	61,392,324	9.6	5,912,172
50–54	59,041,717	16.7	9,863,741			
55–59	36,088,731	19.2	6,939,624			
Total	431,958,604	9.6	41,350,111	323,692,411	4.7	15,086,527

[a] Age- and sex-specific population estimates were based on the 2017 China Statistical Yearbook [22]

[b] Age- and sex-specific prevalence of diabetes based on estimates by age and sex from the 2017 International Diabetes Federation Diabetes Atlas (8th Edition) [1]. Number of men and women with diabetes calculated based on prevalence of diabetes but, due to rounding of data presented in this table, values may not precisely match

Table 2 Excess deaths and years of life lived in those with diabetes, and in the same cohort assuming no diabetes, over the working lifetime of the Chinese population simulated from life table modelling

Five-year age group	Deaths in cohort with diabetes	Deaths in 'diabetes cohort' assuming no diabetes	Excess deaths in diabetes cohort	Years of life lived in cohort with diabetes	Years of life lived in 'diabetes cohort' assuming no diabetes	Years of life lost (%)
Men						
20–24	233,673	93,055	140,618	23,068,663	24,137,075	1,068,412 (4.4)
25–29	491,025	199,620	291,405	44,595,058	46,819,697	2,224,639 (4.8)
30–34	606,503	252,329	354,174	50,479,125	53,125,434	2,646,309 (5.0)
35–39	794,274	338,998	455,276	60,347,927	63,562,440	3,214,513 (5.1)
40–44	1,199,885	526,579	673,306	82,915,298	87,189,008	4,273,710 (4.9)
45–49	1,497,072	676,916	820,156	93,781,293	98,110,211	4,328,918 (4.4)
50–54	1,366,637	639,541	727,096	74,209,042	76,935,304	2,726,262 (3.5)
55–59	501,187	241,477	259,710	25,645,750	26,133,906	488,156 (1.9)
Total	6,690,256	2,968,515	3,721,741	455,042,156	476,013,075	20,970,919 (4.4)
Women						
20–24	32,738	10,329	22,409	9,601,854	9,748,303	146,449 (1.5)
25–29	73,911	23,937	49,974	19,713,555	20,027,822	314,267 (1.6)
30–34	92,616	30,925	61,691	22,362,213	22,717,911	355,698 (1.6)
35–39	114,090	39,455	74,635	24,822,935	25,188,598	365,663 (1.5)
40–44	153,089	55,088	98,001	29,880,056	30,234,422	354,366 (1.2)
45–49	128,472	48,322	80,150	22,401,833	22,549,120	147,287 (0.7)
Total	594,916	208,056	386,860	128,782,446	130,466,176	1,683,730 (1.3)
Total	7,285,172	3,176,571	4,108,601	583,824,602	606,479,251	22,654,649 (3.7)

Calculation of years of life lived were modelled in life tables with a half cycle correction and were subject to an annual discount rate of 3%

uncertainty bounds of absenteeism and presenteeism estimates, PALYs lost to diabetes were reduced and increased by 3.1%, respectively; and by 15.6% at the upper and lower bounds of estimates of diabetes-related labour force dropout, respectively. Applying the upper and lower bounds of 95% CI around estimates of all-cause mortality risk associated with diabetes, PALYs lost were increased by 2.7% and decreased by 3.2%, respectively. In scenario analyses, doubling the annual reduction in population mortality risk to 2% reduced PALYs lost by 1.0%, while removing all temporal trends in population mortality risk increased PALYs lost by 1.2%. Doubling the annual GDP growth rate to 6.4% led to an increase in the estimate of GDP lost to ¥21.1 trillion (US$3.2 trillion), while removing all temporal trends in GDP decreased the estimate of GDP lost to ¥13.6 trillion (US$2.0 trillion). Finally, increasing the annual discount rate to 5% corresponded to a 14.5% reduction in PALYs lost, and a reduction in annual discount rate to 1.5% led to a 14.2% increase in PALYs lost (Table 4).

Discussion

Our study highlights the considerable impact of diabetes on the years of life lived and productivity in China. Among the working age Chinese population with diabetes followed to retirement age, diabetes was predicted to cause 4.1 million excess deaths, 22.7 million years of life lost and a 15.1% loss of PALYs, associated with a significant economic impact over the working lifetime.

Productivity losses accumulated from a combination of premature mortality and diabetes-related labour force dropout, absenteeism and presenteeism while at work. Over the working lifetime of the diabetes cohort, higher all-cause mortality risk in those with diabetes resulted in a 3.7% reduction in years of life lived; this was higher in men (4.4%) than women (1.3%). This is consistent with previous studies showing higher mortality risk in working age Chinese men than women [32]. Despite a lower prevalence of diabetes among younger age groups, the relative impact of diabetes on years of life lost was greater among younger people. This is consistent with the strong association between duration of diabetes and mortality risk, and evidence for high risk of diabetes complications and mortality among younger age groups in East Asian populations [8, 33, 34].

Our findings estimate that diabetes will cause a 15.1% reduction in the total number of PALYs lived by the current Chinese population with diabetes, or 1.3 PALYs per person, over a working lifetime. This was similar to the average number of PALYs lost per person with diabetes in a recent study in

Table 3 PALYs lived in those with diabetes, and in the same cohort assuming no diabetes, over the working lifetime of the Chinese population simulated from life table modelling

Five-year age group	PALYs lived in cohort with diabetes	PALYs lived in 'diabetes cohort' assuming no diabetes	PALYs lost (%)	PALYs lost per person with diabetes
Men				
20–24	18,174,785	20,808,177	2,633,392 (12.7)	2.5
25–29	36,552,611	41,998,670	5,446,059 (13.0)	2.5
30–34	41,785,698	48,233,987	6,448,289 (13.4)	2.3
35–39	49,109,290	56,983,885	7,874,595 (13.8)	2.1
40–44	64,612,176	75,376,378	10,764,202 (14.3)	1.8
45–49	68,090,522	79,840,754	11,750,232 (14.7)	1.4
50–54	48,713,250	57,417,480	8,704,230 (15.2)	0.9
55–59	14,684,793	17,354,773	2,669,980 (15.4)	0.4
Total	341,723,125	398,014,104	56,290,979 (14.1)	1.4
Women				
20–24	6,471,378	7,757,910	1,286,532 (16.6)	2.6
25–29	13,618,347	16,457,544	2,839,197 (17.3)	2.5
30–34	15,467,109	18,851,847	3,384,738 (18.0)	2.2
35–39	16,826,762	20,694,590	3,867,828 (18.7)	1.8
40–44	19,447,052	24,143,268	4,696,216 (19.5)	1.2
45–49	13,710,929	17,187,259	3,476,330 (20.2)	0.6
Total	85,541,577	105,092,418	19,550,841 (18.6)	1.3
Total	427,264,702	503,106,522	75,841,820 (15.1)	1.3

Calculation of PALYs were modelled in life tables and subject to an annual discount rate of 3%

Australia [16]. However, retirement age in China is 10 years and 20 years lower in men and women, respectively, than in Australia, and therefore people living with diabetes in China incurred similar productivity losses over a shorter timeframe, and in younger age groups. This is likely to be the result of higher mortality risk and labour force dropout in the Chinese population with diabetes compared with the Australian population with diabetes [16]. We further estimated that the lost productivity incurred a loss of ¥17.4 trillion (US$2.6 trillion) in GDP, demonstrating the significant economic impact of diabetes-related productivity losses. Furthermore, as our model did not take into account the considerable direct costs of diabetes (including diagnosis, treatment and care), this is likely to be a highly conservative estimate of economic impact. This is supported by recent ADA research which found that productivity losses only accounted for 27.5% of the total economic costs of diabetes in the USA in 2017, and a global study which reported that 34.7% of the total economic burden was due to productivity losses [13, 27]. These findings suggest that the wider economic burden of diabetes in China could be three to four times greater than our estimates.

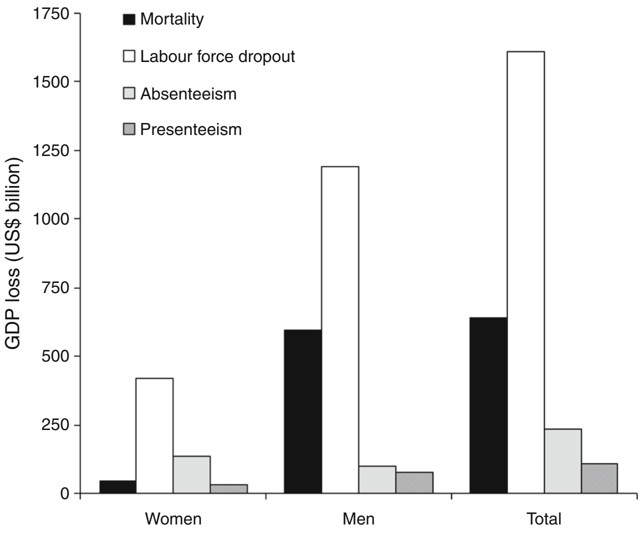

Fig. 1 Economic burden of productivity loss in those with diabetes owing to diabetes-related premature mortality, labour force dropout, absenteeism and presenteeism over the working lifetime in the Chinese population

The absolute number of PALYs lost over the working lifetime in our model was greater in men. This is because the prevalence of diabetes is higher in men than women and increased time at risk of diabetes-related productivity losses owing to the higher retirement age in men than women in China [20]. However, the relative reduction in productivity was greater in women with diabetes (18.6%) than men with diabetes (14.1%), and in all age groups driven by greater labour

Table 4 Sensitivity and scenario analyses to assess the impact of the uncertainties around productivity, mortality and economic data inputs on PALYs lost in those with diabetes in the Chinese population and the associated economic impact

Analysis	PALYs lost owing to diabetes	% change in PALYS lost compared with base case	GDP lost (US$ trillion)	GDP lost per person with diabetes (US$)
Base case	75,841,820		2.6	45,959
1. Productivity indices upper uncertainty bound [a]	78,197,619	+3.1	2.7	47,322
2. Productivity indices lower uncertainty bound [a]	73,486,021	−3.1	2.5	44,596
3. Labour force dropout upper uncertainty bound [b]	87,686,339	+15.6	3.0	52,994
4. Labour force dropout lower uncertainty bound [b]	63,997,300	−15.6	2.2	38,974
5. Upper uncertainty bound of all-cause mortality risk associated with diabetes [c]	77,894,655	+2.7	2.7	47,320
6. Lower uncertainty bound of all-cause mortality risk associated with diabetes [c]	73,396,102	−3.2	2.5	44,338
7. Temporal trend in population mortality risk is doubled to a 2% reduction per year [d]	75,057,463	−1.0	2.6	45,375
8. No temporal trend in population mortality risk [d]	76,718,554	+1.2	2.6	46,615
9. Annual GDP growth rate is doubled to 6.4% per year [e]			3.2	55,918
10. No temporal trend in GDP [e]			2.0	36,000
11. Annual discount rate increased to 5% [f]	64,838,665	−14.5	2.2	38,343
12. Annual discount rate reduced to 1.5% [f]	86,619,273	+14.2	3.0	53,597

[a] Sensitivity analysis 1 and 2 apply (1) a 25% increase and (2) a 25% reduction in absenteeism and presenteeism estimates, holding all other model inputs constant

[b] Sensitivity analysis 3 and 4 apply (3) a 25% increase and (4) a 25% reduction in diabetes-related labour force dropout estimates, holding all other model inputs constant

[c] Sensitivity analysis 5 and 6 apply (5) the upper bound of the 95% CI and (6) the lower bound of the 95% CI around the estimate of RR of all-cause mortality associated with diabetes, holding all other model inputs constant

[d] Scenario analysis 7 and 8 apply (7) double the annual reduction in mortality risk to 2% per year and (8) no temporal trend in population mortality risk, holding all other model inputs constant

[e] Sensitivity analysis 9 and 10 apply (9) double the annual growth rate in GDP to 6.4% per year and (10) no temporal trend in GDP across the model, holding all other model inputs constant. These sensitivity analyses do not affect the number of PALYs lived but do affect their assumed value and therefore the resulting GDP lost

[f] Sensitivity analysis 11 and 12 apply an annual discount rate (11) increased to 5% (in line with the WHO standard annual rate) and (12) reduced to 1.5%

force dropout and absenteeism in women with diabetes compared with men. This is reflected in the high proportion of productivity losses due to labour force dropout and absenteeism in women (66.6% and 21.1%, respectively) compared with men (60.7% and 5.0% respectively). There is a wealth of evidence for employment shortfall in people with diabetes compared with those without diabetes [13, 35, 36]. For example, diagnosis of diabetes in the USA was associated with approximately double the labour force participation shortfall and more days of work lost in women with diabetes compared with men with diabetes [37, 38].

We estimated an average GDP loss of ¥307,925 (US$45,959) per person with diabetes over the working lifetime. In theory, this amount could be spent per person in the current diabetes cohort in China to prevent diabetes as a break-even investment. However, this assumes 100% effectiveness of prevention. If an intervention was able to prevent 10% of diabetes, the break-even investment amount would be ¥30,793 (US$4596) per working age person. These figures are based on saved productivity alone and therefore likely to be a conservative estimate with savings from reduced direct costs of diabetes adding considerable economic benefit [15]. Future studies on diabetes prevention in Chinese populations that incorporate both direct and indirect costs of diabetes would more accurately characterise the potential cost benefit of these interventions.

Our study adds information to previous estimates by the IDF and others of the economic burden of diabetes, by quantifying these in terms of missed production opportunities, rather than health expenditure alone [1]. Another strength of our study was the use of contemporary sex-specific and age-group-specific estimates of diabetes prevalence, mortality risk, labour force participation and in-work productivity. Life table modelling allowed us to capture the impact of diabetes-related productivity losses across the working lifetime. We found that the majority of diabetes-related productivity losses were due to labour force dropout (62.1%) and premature mortality (24.7%) in those with diabetes. This suggests that increased labour force retention and improved diabetes treatment leading to reduced premature mortality in those with diabetes could reduce diabetes-related productivity losses in China. This highlights the trade-off between direct and indirect costs, where increased spending on direct costs may reduce indirect costs through productivity gains. In our analyses, we used PALYs to calculate productivity losses, and an advantage of this approach is that PALYs can be ascribed a financial value (GDP in our study) and net costs calculated.

Our study had several limitations that warrant mention. Data on the productivity effects of diabetes in Chinese populations were not available, and hence estimates from a multi-country meta-analysis of the effects of diabetes on absenteeism, presenteeism and labour force dropout were used instead, which may not have been generalisable to Chinese populations. Uncertainty around productivity indices was explored in sensitivity analyses; varying absenteeism and presenteeism by 25% had a small effect on estimates of PALYs lost (±3.1%), whereas the model was more sensitive to equivalent variation in labour force dropout (±15.6%). Our findings were based on modelled estimates from life tables which simulated the progress of the current cohort of people living with diabetes in China through to retirement, but we did not account for incident diabetes arising in the cohort, and hence would have underestimated the potential return on investment from prevention [15]. We also assumed that current projections in temporal trends in mortality rates and GDP growth held true across the model time horizon. However, in scenario analyses, the doubling and removal of the trend in population mortality rate affected the model output by <2%, although estimates of GDP lost were more sensitive to the equivalent changes in GDP growth rate. Other limitations of this study were that: (1) the contribution of comorbidities of diabetes (particularly obesity, and cardiovascular disease risk factors) to productivity loss could not be distinguished; (2) in the absence of available data, the assumption was made that those working were in full-time employment, and the impact of diabetes upon unpaid work was not included; and (3) diabetes might impact on GDP in ways other than through productivity losses [12, 14]. While these limitations may affect the accuracy of the estimate produced by our model, the overall conclusion of our study is unlikely to have changed.

Our findings highlight the significant productivity losses owing to diabetes in the current cohort of people living with diabetes in China. Given the considerable economic impact of these productivity losses, prevention of diabetes and of the complications of diabetes through adequate management of glucose levels should be considered an investment with potentially large economic benefits in the longer term. To inform relevant interventions and their potential social and economic returns on investment, further research is needed to describe the dynamic trade-off between the costs of prevention and treatment strategies and their net economic consequences, taking into account future productivity gains.

Data availability Data were derived from a combination of publicly available datasets and published sources (see ESM Table 1).

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Duality of interest The authors declare that there is no duality of interest associated with this manuscript.

Contribution statement TRH, DL and DJM conceived and designed the study and analyses. TRH, EZ, AJO, LC and ZA made substantial contributions to analysis and interpretation of data. All authors made substantial contributions to drafting the article and approved the final version. TRH and DL are the guarantors of this work and, as such, had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

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