Global Economic Burden of Diabetes in Adults: Projections From 2015 to 2030

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OBJECTIVE

Despite the importance of diabetes for global health, the future economic consequences of the disease remain opaque. We forecast the full global costs of diabetes in adults through the year 2030 and predict the economic consequences of diabetes if global targets under the Sustainable Development Goals (SDG) and World Health Organization Global Action Plan for the Prevention and Control of Noncommunicable Diseases 2013–2020 are met.

RESEARCH DESIGN AND METHODS

We modeled the absolute and gross domestic product (GDP)-relative economic burden of diabetes in individuals aged 20–79 years using epidemiological and demographic data, as well as recent GDP forecasts for 180 countries. We assumed three scenarios: prevalence and mortality *1*) increased only with urbanization and population aging (baseline scenario), *2*) increased in line with previous trends (past trends scenario), and *3*) achieved global targets (target scenario).

RESULTS

The absolute global economic burden will increase from U.S. $1.3 trillion (95% CI 1.3–1.4) in 2015 to $2.2 trillion (2.2–2.3) in the baseline, $2.5 trillion (2.4–2.6) in the past trends, and $2.1 trillion (2.1–2.2) in the target scenarios by 2030. This translates to an increase in costs as a share of global GDP from 1.8% (1.7–1.9) in 2015 to a maximum of 2.2% (2.1–2.2).

CONCLUSIONS

The global costs of diabetes and its consequences are large and will substantially increase by 2030. Even if countries meet international targets, the global economic burden will not decrease. Policy makers need to take urgent action to prepare health and social security systems to mitigate the effects of diabetes.

Diabetes is a major global health threat (1,2). Global prevalence has rapidly increased over the past four decades (3), and in 2015, diabetes was the 15th most important cause of years of life lost (4). Despite the World Health Organization (WHO) goal (5) to halt the increase in the prevalence of diabetes and the Sustainable Development Goal (SDG) (6) to reduce premature mortality from noncommunicable diseases (NCDs) by one-third by 2030, the outlook is not encouraging: recent estimates suggest that globally the number of people with diabetes between the ages of 20 and 79 years will increase from 415 million in 2015 (1 in 11 adults) to 642 million in 2040 (1 in 10 adults) even if age-specific prevalence remains constant (7).

Encouraging and planning responses to the increasing diabetes burden requires accurate information on future diabetes-related costs. The costs of diabetes include

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both direct costs from medical care as well as indirect costs incurred through loss of productivity or earnings, both of which are important contributors to the global economic burden (8). However, previous studies estimating the future costs of diabetes were limited to direct costs (9–14) or selected world regions or countries (15–21). Only one report (22) also considered indirect costs on the global level, but not all relevant cost components were covered. Notably, while the goal to stabilize diabetes prevalence and reduce mortality is highly ambitious given the past increase in age-standardized prevalence (3) and achievement of health-related SDGs has been shown to require large-scale public health investments (23), the implications of achieving diabetes-related targets for the future global economic burden of diabetes have never been studied. Moreover, it is unclear how diabetes-related costs will evolve if the world falls short of meeting these goals and diabetes prevalence and mortality continue to grow at past rates—which far outstrip those that would be predicted if rates rose in line with urbanization and aging only. This study fills this gap by juxtaposing these highly relevant scenarios and providing an assessment of the economic implications of the current global health agenda on diabetes. We include the complete range of direct and indirect cost components using well-verified parameters to estimate, for the first time, the full global economic burden of diabetes to the year 2030 under these possible scenarios.

RESEARCH DESIGN AND METHODS

This study builds on our recent estimates (8) of the total economic burden of diabetes from a societal perspective in 2015, based upon which we previously projected costs for sub-Saharan Africa (15). An overview of the main steps of our costing approach is provided in Fig. 1.

Economic Burden in 2015

Estimates for 2015 were initially based on prevalence and mortality data for 184 countries from the 7th edition of the International Diabetes Federation's (IDF) *Diabetes Atlas* (7,8). Four of these countries (Andorra, Dominica, the Marshall Islands, and Zimbabwe) were excluded, as input data for cost projections were unavailable. Rural and urban prevalence data and mortality rates by country were available for six age-groups (20–29, 30–39, 40–49, 50–59, 60–69, and 70–79 years), stratified by sex and individual's awareness of disease status; these stratifications were taken into account when deriving health expenditure and indirect costs for patients with diabetes. In a sensitivity analysis, we replaced IDF estimates with prevalence and mortality data from the 2015 Global Burden of Disease (GBD) Study (24). Priority was given to IDF-based estimates, as they distinguished, in contrast to the GBD data, between rural and urban location as well as between those who have been diagnosed with diabetes and those who remain undiagnosed. To harmonize both data sets, we truncated GBD data to the age range 20–79 years and collapsed 5-year age-groups into 10-year age-groups. The shares of individuals in rural versus urban areas as well as individuals with undiagnosed versus diagnosed diabetes were assumed to equal those in the IDF data. For both data sets, no distinction by diabetes type was possible, such that costs estimated in this article represent the joint burden from all diabetes types.

We defined the total economic burden of diabetes as the sum of excess health expenditure (direct costs) and the value of forgone production (indirect costs) due to diabetes and its complications. Direct costs were assessed using a three-step process (8). First, aggregate health expenditure (25) was assumed to follow an age distribution roughly similar to the distribution of mortality rates across age-groups. Second, we derived cost ratios between the patient-level expenditures for individuals with diabetes and individuals without diabetes from a previously conducted systematic review of studies comparing full health expenditure (i.e., at least outpatient care, inpatient care, and drug costs) for individuals with diabetes with that of sex- and age-matched control subjects. Third, we derived excess costs due to diabetes from the aggregate health expenditure data on the basis of the literature-derived cost ratios. Discussion of the methodology of the systematic review and the formula used in step 3 have previously been published (8).

In deriving cost ratios, we preferred studies making stratified comparisons (by age-group and, if possible, sex or rural vs. urban location) to capture heterogeneity. In low-and middle-income countries (LMICs), where stratification was not always reported, we also used studies that presented only age-standardized (rather than stratified) results to derive regional adjustment factors. As a result, we obtained cost ratios that varied not only between country income groups but also between world regions (Europe vs. rest of the world for high-income countries [HICs] and Middle East and North Africa vs. South Asia vs. rest of the world for LMICs). In LMICs, reliable data for the age-group 20–39 years were unavailable; we therefore assumed cost ratio estimates from the age-group 40–49 years for this age range. Lastly, adjustments were made to account for lower health expenditure in individuals who are unaware of their diabetes status. Cost ratios in HICs were further allowed to vary between sexes, while in LMICs they varied between rural and urban locations. Overall variation in cost ratios was small in HICs (cost ratios of 1.08–2.53 in individuals 50 years of age and older and 1.92–4.32 in those below the age of 50 years). In contrast, marked differences occurred in LMICs (cost ratios of 1.00–3.43 in rural areas and 1.14–6.44 in urban areas in those age 50 years and older and of 2.57–4.83 in rural areas and 4.82–9.07 in urban areas in individuals younger than 50 years old). A detailed overview of all cost ratios has previously been published (8).

Indirect costs were calculated as the sum of production losses of working-age individuals from labor force dropout, absenteeism, reduced productivity while working (presenteeism), and deaths before retirement (at age 65 years), evaluated at average annual or daily wages (8). Wage data were obtained from the Organization for Economic Co-operation and Development (OECD) or imputed based on data on gross domestic product (GDP) per worker and the share of labor income in total income (8). The rationale for focusing on the production side and not including government benefits payable to people with diabetes when calculating indirect costs was to avoid double counting, as government benefits only constitute a redistribution of added value (26). Similar to cost ratios, labor market assumptions were made based on findings from a systematic review of the available evidence from both HICs and LMICs (8). Accordingly, absenteeism due to diagnosed diabetes was estimated to vary between 1.9 and 4.3 excess days per year in HICs and from 1.9 to 10.2 days in LMICs,

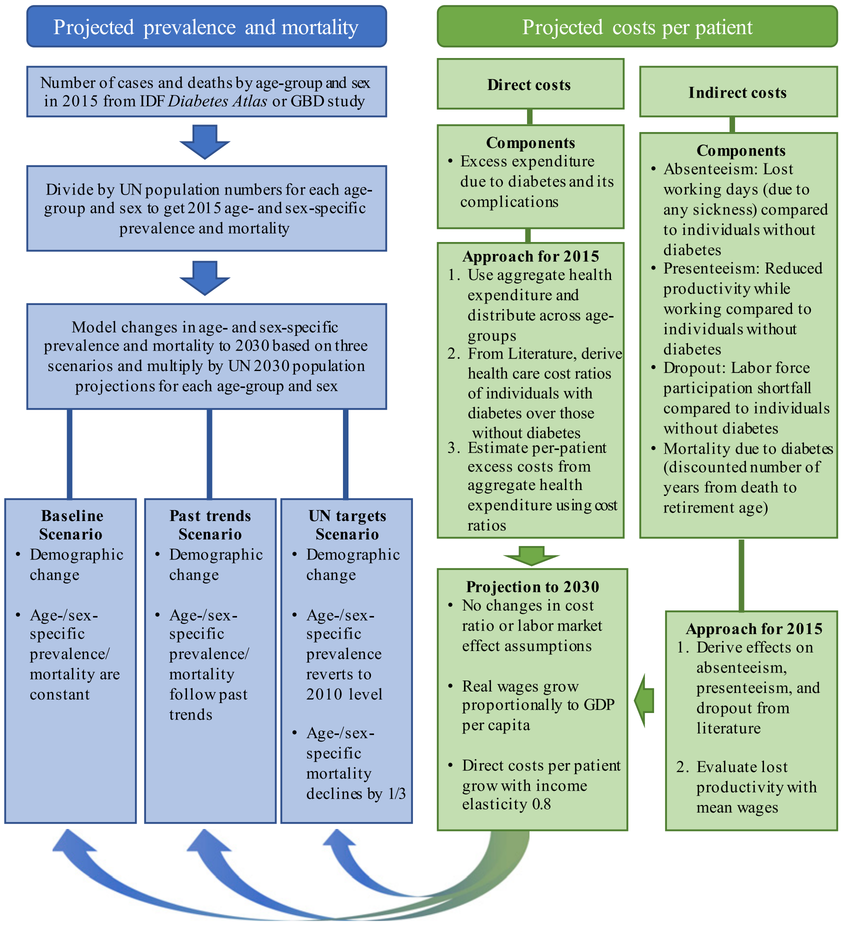

Figure 1—Summary of the main steps in the costing approach; we summarize the main components of the costing approach by conceptually dividing it into two interacting parts.

while the productivity shortfall due to presenteeism relative to individuals without diabetes was estimated to reach 0.3% in HICs and 0.6–1.0% in LMICs. Moreover, parameters for labor force participation shortfall compared with the labor force participation rate of individuals without diabetes were 12.6–25.2% in HICs and 1.1–17.4% in LMICs (8). Finally, in accordance with existing literature, we conservatively assumed no labor market effects for individuals with undiagnosed diabetes. A more detailed discussion of this costing approach has previously been published (8). Differences between cost estimates in this article and in our previous work (8) are the result of the exclusion of four countries for which projection input data were unavailable as well as the use of more recent data on wages (27), GDP (28), and size of labor force (28).

Prevalence and Mortality Scenarios

To account for changes in diabetes prevalence and mortality with age and rural versus urban living, we applied the medium fertility variant of the United Nations (UN) World Population Prospects (29) and the World Urbanization Prospects (30) to the 2015 prevalence and mortality data. We used three scenarios to simulate the evolution of age- and sex-specific diabetes prevalence and mortality rates. In a "baseline" scenario, and in line with previous studies (13,14,22), we assumed that changes in demography and urbanization are the only drivers of change. While arguably a conservative assumption, this provided the starting point for the analysis.

In our "past trends" scenario, we further estimated mean annual change rates in age- and sex-specific prevalence and mortality using data from the 2015 GBD Study (24) for the years 1990, 1995, 2000, 2005, 2010, and 2015. In order to reduce the influence of varying data availability over time, we grouped countries by World Bank income group classification—low-income countries, middle-income countries, and high-income countries—and world region—sub-Saharan Africa, East Asia and the Pacific, Europe and Central Asia, Latin America and the Caribbean, Middle East and North Africa, North America, as well as South Asia—and averaged mean annual change rates within each group. In a last step, we applied the resulting group-wise change rates to 2015 data to project the number of cases in 2030.

Finally, in our "target" scenario we investigated how costs would evolve if countries met SDG 3.4 (6) of a one-third reduction in premature mortality due to NCDs (here limited to diabetes) against a baseline in 2015, as well as the voluntary target to halt the rise (until the year 2025) in the age-standardized prevalence of diabetes against a baseline in 2010 as set out in the WHO Global Action Plan for the Prevention and Control of NCDs 2013–2020 (5). We incorporated these goals into our analysis by assuming that age-specific mortality rates will decrease by one-third from their 2015 levels and that age-specific prevalence will revert to that of 2010 by the year 2030. Note that while SDG 3.4 has been measured as a one-third reduction in the age-standardized mortality for the age-group 30–70 years (31), harmonizing with the IDF data necessitated an alteration of the age range to 20–65 years. Moreover, as age-standardized mortality rates are a population-weighted average of their age-specific counterparts, our approach to simultaneously change all age-specific mortality rates by one-third represents the most direct way of meeting the UN goal, but other "target scenarios" would be conceivable.

Costs Relative to Economic Development

To enable display of costs relative to GDP (to allow for larger economies being able to cope with higher absolute costs), we projected economic development until 2030 using OECD long-term GDP forecasts (32) for all OECD countries and the major transitioning economies of Brazil, China, India, Indonesia, Russia, and South Africa. For the remaining 141 countries, we used data from a recent study (33) that projected GDP by country based on an ensemble modeling approach. This approach generated a distribution of estimates for each country-year pair, and we always used mean estimates for each country in the year 2030 for the main analysis. We then performed three sensitivity analyses around GDP forecasts: First, we used mean GDP estimates from the ensemble modeling approach for all countries, instead of only those countries without OECD estimates. Second, we replaced mean estimates with the 2.5th percentiles from the estimated GDP distributions. And third, we used the 97.5th percentiles instead of means.

Real Wages and Income Elasticities

We assumed that growth in real wages is proportional to real GDP per capita growth, with future real GDP per capita calculated as the ratio of projected GDP to population. In our cost model, indirect costs grow proportionally with higher incomes as production losses were evaluated at real wages. In addition, direct costs per patient are likely to increase with higher incomes owing to greater demand for and access to care as well as increasing real wages of health staff. We assumed the income elasticity of diabetes-related health expenditure to be 0.8. While this assumption seems realistic given recent studies (34–37), we investigated the sensitivity of our results to changes in this assumption by also simulating future costs for alternative income elasticities in the range of 0.4–1.2.

CIs

For distinction of sampling error from assumptions made in this article, CIs reflect uncertainties in the prevalence and mortality data but do not incorporate additional uncertainties arising from cost ratios, labor market effects, and GDP projections. (See Supplementary Data for details.)

RESULTS

Main Results

Predicted population and diabetes prevalence and mortality, as well as cost estimates (in 2015 U.S. dollars) for 2015 and 2030 are presented in Table 1. (See Supplementary Tables 1 and 2 for country-level data.) By 2030, the 180 countries considered in this study will have reached a combined population of 8.39 billion and a total GDP of $115.30 trillion. In the baseline scenario, the global prevalence of diabetes is projected to increase from 8.8% (95% CI 8.4–9.5) in 2015 to 10.0% (9.5–10.7) in 2030 and the number of diabetes-related deaths from 3,148,325 (3,012,705–3,327,410) in 2015 to 4,180,852 (4,001,358–4,411,778) in 2030. The projected prevalence in the target scenario is 9.8% (9.4–10.5)—very close to the baseline scenario. However, the 33% reduction in age-group–specific mortality rates, which would be seen if SDG 3.4 were to be achieved, results in a substantially lower number of predicted deaths due to diabetes than in the baseline scenario (2,787,234 [95% CI 2,667,572–2,941,185]). In contrast, the past trends scenario exceeds the baseline scenario in both the number of deaths (4,565,690 [4,363,899–4,822,247]) and diabetes prevalence (11.8% [11.2–12.7]).

All scenarios suggest a large increase in absolute costs (expressed in 2015 U.S. dollars) from $1.32 trillion (95% CI 1.28–1.37) in 2015 to costs in 2030 of $2.12 trillion (2.06–2.20) under the target scenario, $2.25 trillion (2.18–2.34) under the baseline scenario, and $2.48 trillion (2.41–2.58) under the past trends scenario. When expressed as percentage of global GDP, total costs are predicted to change less markedly: from 1.8% (1.7–1.9) in 2015 to 1.8% (1.8–1.9) under the target, 1.9% (1.9–2.0) under the baseline, and 2.2% (2.1–2.2%) under the past trends scenarios in 2030. Across countries, we project on average an increase in costs relative to GDP from 1.4% (1.4–1.4) in 2015 to 1.5% (1.5–1.5) under target, 1.6% (1.6–1.7) under baseline, and 1.9% (1.8–1.9) under past trends scenarios in 2030, with the largest rise predicted for middle-income countries. Notably, high-cost countries are not concentrated in single world regions but widely dispersed around the globe (Fig. 2).

Regional Economic Burden

We present absolute and relative costs by world region in Fig. 3. North America exhibits the highest absolute costs in 2015 ($499.90 billion [95% CI 478.53–523.03]) and will continue to do so in 2030 in both the baseline ($702.35 billion [670.55–735.94]) and the target scenario ($685.97 billion [654.12–719.44]). Under the past trends scenario, East Asia and the Pacific region will become the largest contributor to global economic burden by 2030 (with $796.11 billion [756.97–881.03]). In contrast, while we predict substantial increases in sub-Saharan Africa, the region will remain the smallest contributor to the global economic burden in all scenarios with $36.42 (95% CI 27.1–50.88) to 52.05 billion (38.32–73.47) in 2030.

Despite its high absolute costs, North America is the only World Bank region that is projected to face a decline in costs relative to its economic capacity in all three scenarios. In fact, for most world regions we predict major increases in relative economic costs if past trends are to continue. This is particularly the case for Latin America and the Caribbean, where economic costs are projected to grow from 2.4% (95% CI 2.2–2.6) of regional GDP in 2015 to 3.4% (3.1–3.6) under the past trends scenario. Importantly, as shown by the numbers in parentheses depicted in Fig. 3, we do not predict any decreases in direct costs, such that the favorable development in North America is entirely driven by decreases in indirect costs relative to GDP.

Alternative Income Elasticities

As shown by Supplementary Fig. 1, the sensitivity of results to changes in elasticity assumptions is relatively low, with total costs in 2030 ranging between $1.91 and 2.24 trillion with income elasticity of only 0.4 instead of 0.8 and between $2.32 and 2.72 trillion with elasticity of 1.2.

Alternative GDP Projections

Supplementary Figs. 2, 3, and 4 show deviations in total absolute costs for the baseline, past trends, and target scenarios, respectively, with use of different GDP assumptions. Despite substantial differences in cost estimates for East Asia and the Pacific, global absolute costs in the baseline scenario do not change markedly when OECD forecasts are replaced by mean GDP projections (+4.3%). With lower- and upper-bound GDP estimates, costs decrease by 20.2% or increase by 28.8%, respectively. Results for the past trends and target scenarios are close to identical. With these uncertainties taken into consideration, the full global economic burden in 2030 would range between $1.79 trillion (2.0% of GDP) and 2.89 trillion (1.9% of GDP) in the baseline scenario, $1.98 trillion (2.2% of GDP) and 3.21 trillion (2.1% of GDP) in the past trends scenario, and $1.69 trillion (1.9% of GDP) and 2.72 trillion (1.8% of GDP) in the target scenario. Notably, the costs expressed as share of GDP are similar in all sensitivity tests, which suggests that the findings are robust to uncertainties in the GDP projections.

Alternative Prevalence Data

Lastly, using GBD data to project prevalence and mortality rates in 2030 (Supplementary

Table 1—Overview of key statistics and results of projection scenarios

	2015	Projection for 2030 Baseline scenario	Past trends scenario	Target scenario
Included countries	180	180	180	180
Population (billion)	7.25	8.39	8.39	8.39
Global GDP (trillion $)[a]	73.53	115.30	115.30	115.30
Prevalence, age-group 20–79 years (%)	8.8 (8.4–9.5)	10.0 (9.5–10.7)	11.8 (11.2–12.7)	9.8 (9.4–10.5)
Deaths in 1,000s, age-group 20–65 years	3,148 (3,013–3,327)	4,181 (4,001–4,412)	4,566 (4,364–4,822)	2,787 (2,668–2,941)
Total costs (trillion $)[a]	1.32 (1.28–1.37)	2.25 (2.18–2.34)	2.48 (2.41–2.58)	2.12 (2.06–2.20)
Direct costs (trillion $)[a]	0.86 (0.83–0.89)	1.51 (1.47–1.57)	1.70 (1.65–1.77)	1.50 (1.46–1.56)
Indirect costs (trillion $)[a]	0.46 (0.45–0.48)	0.73 (0.71–0.77)	0.78 (0.75–0.82)	0.61 (0.60–0.65)
Mortality (%)[b]	45.7	48.1	46.4	38.3
Dropout (%)[b]	48.3	45.8	47.1	54.5
Absenteeism (%)[b]	3.9	3.9	4.1	4.6
Presenteeism (%)[b]	2.1	2.3	2.4	2.7
Share indirect costs (%)[c]	35.0	32.7	31.3	29.0
Total costs/global GDP (%)	1.8 (1.7–1.9)	1.9 (1.9–2.0)	2.2 (2.1–2.2)	1.8 (1.8–1.9)
Mean (total costs/GDP) (%)	1.4 (1.4–1.4)	1.6 (1.6–1.7)	1.9 (1.8–1.9)	1.5 (1.5–1.5)
High-income countries only	1.2 (1.2–1.3)	1.3 (1.3–1.4)	1.4 (1.4–1.5)	1.3 (1.3–1.3)
Middle-income countries only	1.7 (1.6–1.7)	2.0 (1.9–2.1)	2.3 (2.3–2.4)	1.8 (1.8–1.9)
Low-income countries only	0.7 (0.6–0.8)	0.8 (0.8–1.0)	1.0 (0.9–1.1)	0.7 (0.7–0.8)

Data are presented as *n* unless indicated otherwise. Numbers in parentheses are 95% CI. [a]Absolute costs and GDP are expressed in terms of constant 2015 U.S. dollars. [b]The fraction of the respective indirect cost component in total indirect costs. 95% CI not shown. [c]The fraction of total costs allotted to indirect costs. 95% CI not shown.

Table 3), we find substantially lower global economic costs in all three scenarios compared with the main results: starting from $1.07 trillion (95% CI 1.04–1.09) in 2015, 2030 economic costs in the baseline scenario are forecasted to reach $1.81 trillion (1.77–1.86), $2.02 trillion (1.97–2.07) in the past trends scenario, and $1.78 trillion (1.74–1.83) in the target scenario. Interestingly, this is largely a consequence of lower mortality estimates in the GBD data, while direct costs remain very similar.

CONCLUSIONS

We estimate a substantial global economic burden of diabetes and its complications in 2030: more than $2.1 trillion in all scenarios considered in the analysis. Importantly, even if countries meet the SDG (6) of decreasing mortality from diabetes by one-third, and reduce age- and sex-specific prevalence to their 2010 levels (a key aim of the WHO NCD Global Action Plan [5]), the economic burden in 2030 will be 61% higher than in 2015. While this increase in absolute costs is countered by higher economic capacities, it is disappointing that even if SDG and WHO NCD Global Action Plan targets are met, global economic burden relative to GDP will not improve. If past trends continue, the economic burden of diabetes in 2030 will exceed 2015 levels by 88%, reaching 2.2% of global GDP (compared with only 1.8% in 2015). Owing to differential mortality estimates, costs in 2030 are lower when using GBD-based rather than IDF data for prevalence and mortality rates. Nevertheless, the projected increase in global costs remains similar and is a reason for concern.

With stratification of the global economic burden by world regions, North America and East Asia and the Pacific will be the largest contributors in absolute terms, while Latin America and the Caribbean are projected to face the highest burden relative to regional GDP in all three scenarios. Furthermore, North America is the only world region where relative costs decrease in all scenarios. It is worth noting that projections for direct and indirect costs follow different dynamics: whereas indirect costs only accrue from productivity losses caused by diabetes in working-age individuals, direct costs affect the whole age range of 20–79 years. Moreover, mortality projections are relevant for future indirect costs but not for direct costs. The favorable development of indirect costs in North America is a consequence of two factors: first, the demographic development will decrease the population share of those below the age of 65 years, and second, recent growth in age- and sex-specific prevalence was very modest, such that the past trends scenario does not predict substantial increases in this regard. This stands in stark contrast to Latin America and the Caribbean, where the past trends scenario predicts large increases in age-specific prevalence and, hence, costs, as illustrated by Fig. 2.

Our findings should provide a strong and urgent incentive for countries, international health organizations, and local public health agencies to take action to reduce the burden of diabetes and its complications. Although we have found that costs of diabetes in 2030 do not fall if global targets to reduce diabetes prevalence and mortality are met, it is imperative that actions are taken to reduce modifiable risk factors, for instance, obesity and physical inactivity, to ensure that costs do not rise even further. Unfortunately, it is well-known that the goal to stabilize diabetes prevalence and reduce mortality is highly ambitious given the past increases in age-standardized prevalence (3). Therefore, health and social security systems need to be prepared to cope with an increasing number of patients with the condition in order to mitigate the predicted economic burden and absorb adverse labor market effects.

While our results show the need for coordinated action, our study does have

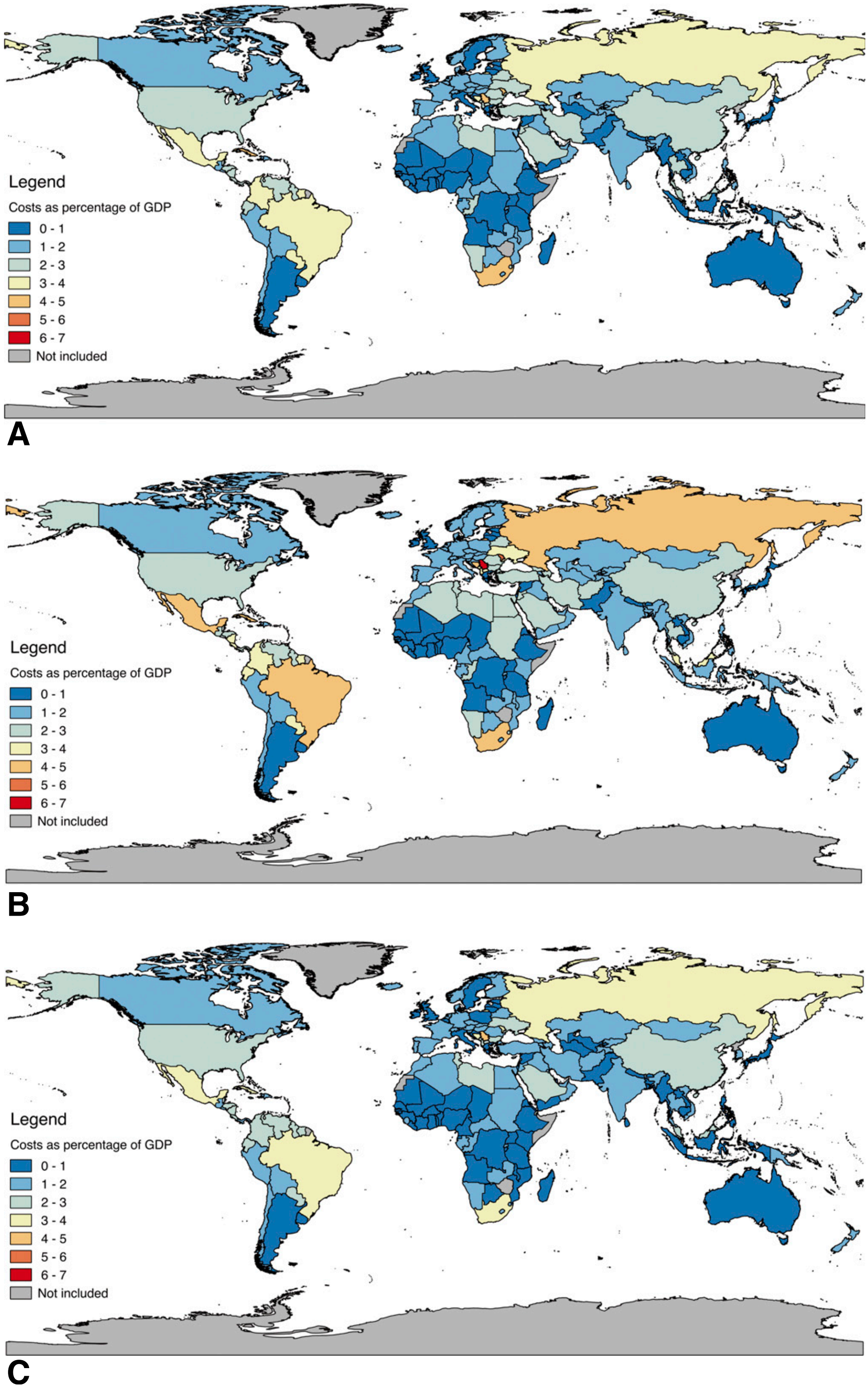

Figure 2—Global distribution of costs by country in 2030 (as determined by authors' calculations). Total costs as percentage of GDP for baseline scenario (*A*), past trends scenario (*B*), and target scenario (*C*).

limitations. In particular, our cost estimates do not factor in the costs of investments necessary to achieve UN targets. Given the large range of possible interventions and their uncertain benefits, such an analysis would necessarily be highly speculative. Nevertheless, the omission of such costs from our analysis does not detract from our aim, which was to provide an assessment of the potential benefits (in terms of averted cost of illness relative to the past trends scenario) of achieving the UN targets. Inherent and large uncertainties meant that we also did not allow for changes in labor market effects or cost

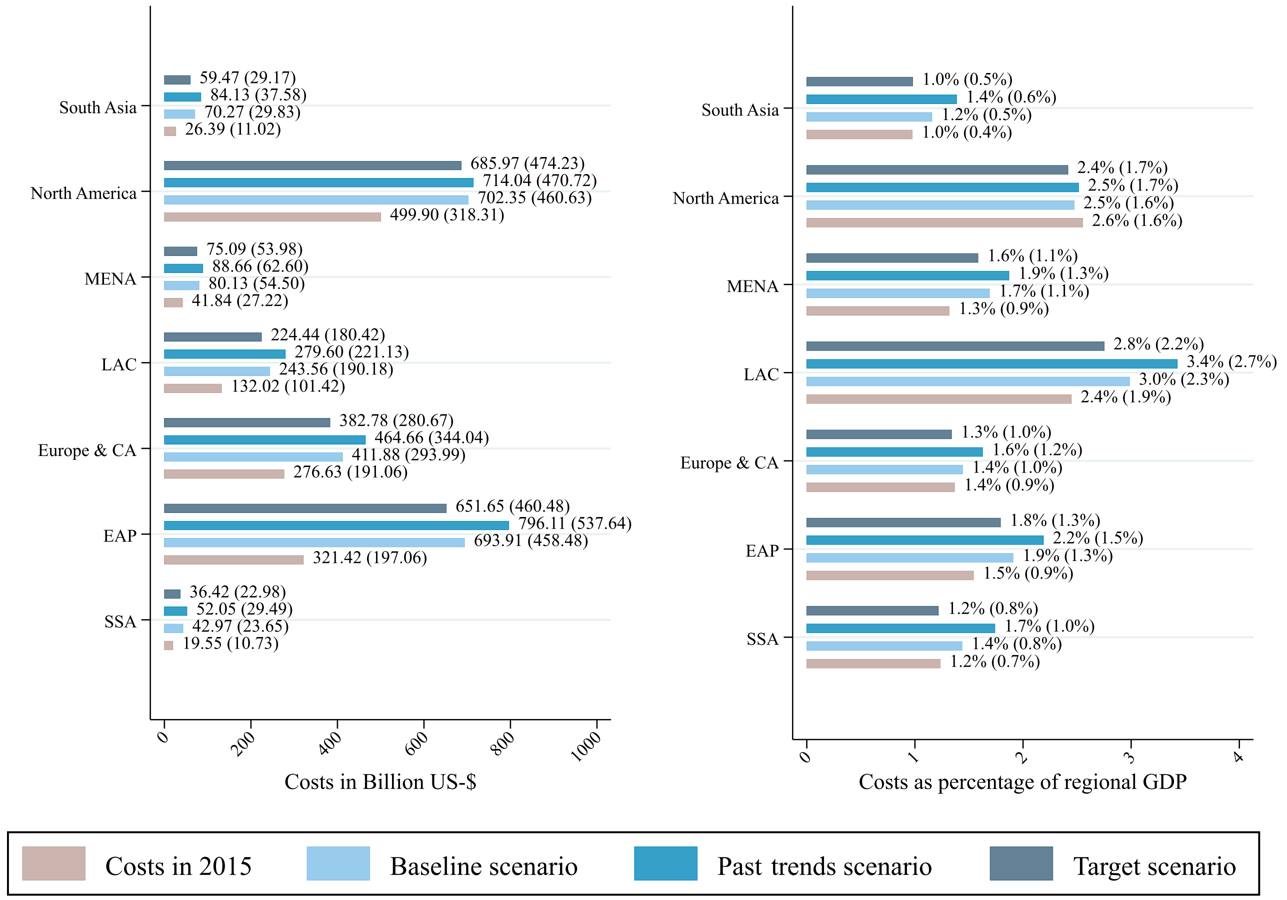

Figure 3—Regional economic burden: absolute and relative costs. Display of total absolute (2015 prices) and relative costs for different World Bank regions for the years 2015 and 2030. Numbers in parentheses are direct costs only. CA, Central Asia; EAP, East Asia and Pacific; LAC, Latin America and the Caribbean; MENA, Middle East and North Africa; SSA, sub-Saharan Africa.

ratios that could, for instance, result from the development of new drugs and therapies, reducing the rate of diabetes-induced complications. When, and at what costs, such improved treatment options would be introduced into routine care is highly uncertain, especially given that much of our analysis focuses on LMICs, where the majority of people with diabetes live and where these medications may remain relatively unavailable during the timeframe of this study. Another limitation of the present cost-of-illness approach is that real wages are assumed to only depend on GDP per capita. Moreover, we did not attempt to estimate which of the considered scenarios is the most likely one, as the future incidence of diabetes and mortality highly depend on the policy response to the growing diabetes epidemic.

Furthermore, for data quality reasons, this study focuses on the age range 20–79 years. While especially the omission of individuals older than 79 years will mean a slight underestimation of costs (relative to the full age range), the impact on the projection dynamics is negligible. First, according to UN population projections, increases in the share of individuals above the age of 79 years will be small until the year 2030: while in 2015, across the countries included in the analysis, on average 1.4% of men and 2.3% of women fell in that age-group, by 2030 their average share will grow to a mere 2.0% of men and 3.1% of women, respectively. Second, as indirect costs were only assumed to be caused by individuals with diabetes below the age of 65 years, the exclusion of individuals above the age of 79 years does not affect this major cost component.

Despite limitations, however, our analysis provides novel insights into the change in economic burden of diabetes if global targets are met relative to the continuation of past trends. A further important innovation is our use of cost ratios and labor market effect assumptions derived from studies conducted in both HICs and LMICs, whereas previous global projections only relied on estimates from HICs (14,22). While these studies use observational data and may not fully account for confounding or the full variation across countries, the sizable difference in cost ratios between HICs and LMICs, especially for patients below the age of 50 years, indicates that this distinction matters. A potential reason for the observed differences is that overall health care usage in the younger age-group may be particularly low in LMICs, such that essential diabetes treatments become more salient and, hence, lead to a greater ratio in health expenditure for individuals with diabetes to that for individuals without diabetes. In addition, larger cost ratios in urban versus rural areas may be a result of insufficient health care access for individuals with diabetes in rural areas. While these cost ratios seem reasonable, a limitation of their use is that evidence from LMICs is less plentiful than that from HICs, and further research in these areas is needed. Similarly, while the use of literature sources from both HICs and LMICs is an important step in increasing the reliability of assumptions on absenteeism, presenteeism, and labor force dropout, evidence from low-income settings is still limited and more data are needed to further understand the variation in labor markets across the globe.

We further improve upon previous cost projections by using recent input data, covering the full range of indirect cost components, and allowing economic burden to evolve with GDP per capita growth. As a result, expressed in 2010 U.S. dollars, our baseline scenario projections for the total economic burden in 2030 are more than twice as large as those by the World Economic Forum ($1.94 vs. $0.75 trillion) (22).

In summary, we find that by 2030, diabetes will likely pose an even larger burden to national health systems and economies than currently. Even if international targets are achieved, no decrease in costs relative to GDP can be expected, while absolute costs will continue to rise. Coordinated action is needed to prepare for this development.

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References

1. United Nations General Assembly. *Resolution Adopted by the General Assembly on 20 December 2006: World Diabetes Day*. Resolution no. A/RES/61/225. 2007
2. United Nations General Assembly. *Political Declaration of the High-Level Meeting of the General Assembly on the Prevention and Control of Non-Communicable Diseases*. Resolution no. A/RES/66/2. 2012
3. NCD Risk Factor Collaboration (NCD-RisC). Worldwide trends in diabetes since 1980: a pooled analysis of 751 population-based studies with 4.4 million participants. Lancet 2016;387:1513–1530
4. GBD 2015 Mortality and Causes of Death Collaborators. Global, regional, and national life expectancy, all-cause mortality, and cause-specific mortality for 249 causes of death, 1980-2015: a systematic analysis for the Global Burden of Disease Study 2015. Lancet 2016;388:1459–1544
5. World Health Organization. *Global Action Plan for the Prevention and Control of Noncommunicable Diseases: 2013–2020* [Internet], 2013. Geneva, World Health Org. Available from http://www.who.int/nmh/events/ncd_action_plan/en/. Accessed 14 June 2017
6. United Nations General Assembly. *Resolution Adopted by the General Assembly on 25 September 2015: Transforming Our World: The 2030 Agenda for Sustainable Development*. Resolution no. A/RES/70/1. 2015
7. International Diabetes Federation. *IDF Diabetes Atlas*. 7th ed. [Internet], 2015. Brussels, Belgium, International Diabetes Federation. Available from http://www.diabetesatlas.org. Accessed 9 March 2016
8. Bommer C, Heesemann E, Sagalova V, et al. The global economic burden of diabetes in adults aged 20-79 years: a cost-of-illness study. Lancet Diabetes Endocrinol 2017;5:423–430
9. Bagust A, Hopkinson PK, Maslove L, Currie CJ. The projected health care burden of type 2 diabetes in the UK from 2000 to 2060. Diabet Med 2002;19(Suppl. 4):1–5
10. Huang ES, Basu A, O'Grady M, Capretta JC. Projecting the future diabetes population size and related costs for the U.S. Diabetes Care 2009;32:2225–2229
11. Vos T, Goss J, Begg S, Mann N. *Projection of Health Care Expenditure by Disease: A Case Study From Australia*. Brisbane, Australia, School of Population Health, University of Queensland, 2007
12. Waldeyer R, Brinks R, Rathmann W, Giani G, Icks A. Projection of the burden of type 2 diabetes mellitus in Germany: a demographic modelling approach to estimate the direct medical excess costs from 2010 to 2040. Diabet Med 2013;30:999–1008
13. Ogurtsova K, da Rocha Fernandes JD, Huang Y, et al. IDF Diabetes Atlas: global estimates for the prevalence of diabetes for 2015 and 2040. Diabetes Res Clin Pract 2017;128:40–50
14. Zhang P, Zhang X, Brown J, et al. Global healthcare expenditure on diabetes for 2010 and 2030. Diabetes Res Clin Pract 2010;87:293–301
15. Atun R, Davies JI, Gale EAM, et al. Diabetes in sub-Saharan Africa: from clinical care to health policy. Lancet Diabetes Endocrinol 2017;5:622–667
16. Hex N, Bartlett C, Wright D, Taylor M, Varley D. Estimating the current and future costs of type 1 and type 2 diabetes in the UK, including direct health costs and indirect societal and productivity costs. Diabet Med 2012;29:855–862
17. Javanbakht M, Mashayekhi A, Baradaran HR, Haghdoost A, Afshin A. Projection of diabetes population size and associated economic burden through 2030 in Iran: evidence from micro-simulation Markov model and Bayesian meta-analysis. PLoS One 2015;10:e0132505
18. Png ME, Yoong J, Phan TP, Wee HL. Current and future economic burden of diabetes among working-age adults in Asia: conservative estimates for Singapore from 2010-2050. BMC Public Health 2016;16:153
19. Rowley WR, Bezold C. Creating public awareness: state 2025 diabetes forecasts. Popul Health Manag 2012;15:194–200
20. Rowley WR, Bezold C, Arikan Y, Byrne E, Krohe S. Diabetes 2030: insights from yesterday, today, and future trends. Popul Health Manag 2017;20:6–12
21. Bloom DE, Chen S, Kuhn M, McGovern ME, Oxley L, Prettner K. *The Economic Burden of Chronic Diseases: Estimates and Projections for China, Japan and South Korea*. Cambridge, MA, National Bureau of Economic Research, 2017 (National Bureau of Economic Research Working Paper no. 23601)
22. Bloom DE, Cafiero ET, Jané-Llopis E, et al. *The Global Economic Burden of Noncommunicable Diseases*. Geneva, World Economic Forum, 2011
23. Stenberg K, Hanssen O, Edejer TT, et al. Financing transformative health systems towards achievement of the health Sustainable Development Goals: a model for projected resource needs in 67 low-income and middle-income countries. Lancet Glob Health 2017;5:e875–e887
24. Global Burden of Disease Study 2015. *Global Burden of Disease Study 2015 (GBD 2015) Results* [Internet], 2016. Seattle, WA, Institute for Health Metrics and Evaluation. Available from http://ghdx.healthdata.org/gbd-results-tool. Accessed 14 May 2017
25. World Health Organization. *Global Health Expenditure Database* [Internet], 2015. Available from http://apps.who.int/nha/database/Select/Indicators/en. Accessed 1 October 2016
26. American Diabetes Association. Economic costs of diabetes in the U.S. in 2012. Diabetes Care 2013;36:1033–1046
27. Organisation for Economic Co-operation and Development. OECD.Stat [Internet], 2016. Available from http://stats.oecd.org/. Accessed 14 May 2017
28. The World Bank. *World Development Indicators* [Internet], 2016. Available from http://data.worldbank.org/data-catalog/world-development-indicators. Accessed 4 July 2017
29. United Nations, Department of Economic and Social Affairs, Population Division. *World Population Prospects: The 2015 Revision, DVD Edition*, 2015
30. United Nations, Department of Economic and Social Affairs, Population Division. *World Urbanization Prospects: The 2014 Revision, CD-ROM Edition* [Internet], 2014. Available from https://esa.un.org/unpd/wup/CD-ROM/WUP2014_XLS_CD_FILES/WUP2014-F02-Proportion_Urban.xls. Accessed 9 March 2016
31. GBD 2015 SDG Collaborators. Measuring the health-related Sustainable Development Goals in 188 countries: a baseline analysis from the Global Burden of Disease Study 2015. Lancet 2016;388:1813–1850
32. Organisation for Economic Co-operation and Development. GDP long-term forecast [Internet], 2017. Available from https://data.oecd.org/gdp/gdp-long-term-forecast.htm. Accessed 14 May 2017
33. Dieleman JL, Campbell M, Chapin A, et al.; Global Burden of Disease Health Financing Collaborator Network. Future and potential spending on health 2015-40: development assistance for health, and government, prepaid private, and out-of-pocket health spending in 184 countries. Lancet 2017;389:2005–2030
34. Abdullah SM, Siddiqua S, Huque R. Is health care a necessary or luxury product for Asian countries? An answer using panel approach. Health Econ Rev 2017;7:4
35. Baltagi BH, Moscone F. Health care expenditure and income in the OECD reconsidered: evidence from panel data. In *IZA Discussion Paper*. Bonn, Germany, Institute for the Study of Labor, 2010, p. 4851
36. Chakroun M. Health care expenditure and GDP: an international panel smooth transition approach. In *MPRA Paper*. Munich, Germany, University Library of Munich, 2009, p. 17493
37. Dreger C, Reimers H-E. Health care expenditures in OECD countries: a panel unit root and cointegration analysis. In *IZA Discussion Paper*, Bonn, Germany, Institute for the Study of Labor, 2010, p. 1469