Regional differences in the impact of diabetes on population health in the USA

Emma Zang [1], Scott M Lynch,[2] Jessica West[3]

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For numbered affiliations see end of article.

Correspondence to
Emma Zang, Department of Sociology, Yale University, New Haven, CT, USA; emma.zang@yale.edu

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ABSTRACT

Background To evaluate regional disparities in the influence of diabetes on population health, we examine life expectancies at age 50 between population with diabetes and healthy population and life quality among the population with diabetes among native-born Americans by birth region and current residence.

Methods Using data on a cohort of 17 686 native-born individuals from the Health and Retirement Survey (1998–2014), we applied a Bayesian multistate life table method to estimate life expectancies at age 50 between population with diabetes and healthy population by each birth/current region combination. We further estimate the proportion of life remaining without either chronic conditions or disabilities as a quality of life measure and the probabilities that one region is worse than the other in terms of different health outcomes.

Results At age 50, persons with diabetes (PWD) were expected to live on average 5.8–10.8 years less than their healthy equivalents across regions. Diabetes had the greatest influence on life expectancy (LE) for older adults who lived in the South at the time of interviews. PWD born in the South were more likely to have developed chronic conditions or disabilities and spent greater proportions of life with these two issues compared to other regions.

Conclusion Diabetes is a significant threat to LE and healthy LE in the USA, particularly for people born or living in the South.

Diabetes is a major cause of morbidity and mortality in the USA, and its prevalence has increased rapidly in the overall population over the past few decades driven, in part, by the obesity epidemic.[1] In 2015, approximately 9.4% (30.3 million) of Americans had diabetes, with that number nearly tripled (25.2%) for adults aged 65 or older.[2] The rise in diabetes may contribute to a decline in future life expectancy (LE).[3] While LE at birth in other developed countries has increased, US LE has declined, partly perhaps due to increases in cause-specific mortality caused by drug overdoses, alcohol abuse, suicides and diseases including hypertensive diseases and diabetes.[4] Large disparities exist in LEs between populations with and without diabetes in the USA,[5–7] indicating that the long-term rise in the prevalence of diabetes has major implications for longevity and health.

Previous studies primarily report LE by gender and race/ethnicity but neglect the impact of regional differences on health disparities. This omission has public health consequences. For example, establishing patterns of stroke in the American 'stroke belt' allowed for further study of disease aetiology and the development of targeted interventions.[8 9] Diabetes, like stroke, is influenced by cultural, behavioural and environmental factors interacting with genetic susceptibility and is geographically patterned: diagnosed diabetes prevalence is lowest in the Midwest and Northeast but highest in Southern and Appalachian states.[10 11] Despite evidence that diabetes is more prevalent in the South, little research considers the joint roles of birth and current regions in LE disparities. Theoretically, *birth region* provides a proxy for childhood exposures and possibly long-term exposures assuming individuals typically grow up in the region of birth, whereas *current region* measures current environment. The two concepts may combine in contributing to later life health outcomes.

Moreover, it is important to gauge the broader impact of diabetes via a more global measure of population health that considers both morbidity and mortality rather than any single health outcome. One approach is to estimate *health expectancy* (HE), which entails analysing both healthy and unhealthy years of life and defines health along numerous dimensions.[12] HE monitors population health by measuring both *quantity* and *quality* of life-years by adding a quality of life (QoL) aspect to LE.[12] Since older adults with diabetes often later develop chronic conditions[13] and disabilities[14] and persons with diabetes (PWD) with chronic conditions or disabilities typically have greater difficulties in self-care compared to individuals with only diabetes,[13] estimating LE without chronic conditions and disability among PWD is important.

The current study examines whether diabetes is equally consequential to health and survival across the USA. We first examine regional differences in LEs at age 50 between population with diabetes and healthy population, considering the joint role of birth and current regions. Second, we calculate the proportion of life remaining without either chronic conditions or disabilities (%XLE) among PWD. Finally, we estimate the probabilities that one region is worse than the others in terms of different health outcomes. Based on previous research, we hypothesise that (1) PWD will have shorter LEs compared to their healthy counterparts across all US regions and (2) Southern birth and residence will be associated with shorter LE and larger proportions of life spent with chronic conditions or disability for PWD.

METHODS

The Health and Retirement Survey (HRS) is a biennial, nationally representative, longitudinal panel survey of over 30 000 non-institutionalised

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US adults over age 50.[15] We restrict our sample (1998–2014) to individuals interviewed in 1998 or recruited to the survey in 2004 or 2010, individuals aged 50 or older and to one individual per household. We exclude individuals if they were dropped by the HRS in any later wave, did not live in the USA at one or more study waves, were foreign-born or were missing health information at the beginning or ending of transition intervals. Our final sample of 16 983 individuals contributes 80 146 person transition intervals (the 2-year period between waves).

Measures

The outcome variables are health transitions between study waves (transition intervals), where transitions are defined by combinations of health statuses at the beginning and end of a transition interval. Three health variables are included in these transitions. *Diabetes* is a self-reported diabetes diagnosis (no/yes, 'Has a doctor ever told you that you have diabetes or high blood sugar?'). Diabetes is associated with a higher risk of *chronic conditions* including heart disease (heart attack, coronary heart disease, angina, congestive heart failure or other heart problems), stroke, cancer (cancer or malignant tumour, excluding minor skin cancer) and lung disease (chronic lung disease, ie, chronic bronchitis or emphysema).[16–21] Dummy variables indicate whether participants have ever been told by a doctor that they had these conditions. *Activities of daily living (ADL) disability* is based on whether participants report difficulty with any one of the following (no/yes): dressing, bedding, bathing, toileting, walking or eating.

At the beginning of a transition interval, individuals may (1) be healthy, (2) have diabetes, (3) have at least one other chronic condition (heart disease, stroke, cancer or lung disease), (4) have at least one ADL, (5) have diabetes and at least one of the other chronic conditions, (6) have diabetes and ADLs, (7) have at least one of the other chronic conditions and ADLs, or (8) have diabetes, at least one other chronic condition, and at least one ADL. At the end of a transition interval, death is a possible outcome. These nine possible health statuses represent a 9-by-9 state space for possible transitions across transition intervals. Consistent with previous research,[5] we assume that some transitions are impossible: once diagnosed with diabetes or another chronic condition, individuals cannot return to a state without such a diagnosis. Figure 1 shows the state space and 44 transitions that are possible over a transition interval. Transition A to DC (being diabetic with at least one condition) has only 10 observations and is recoded to transition A to DCA (being diabetic with at least one condition and at least one ADL disability) for modelling purposes.

Our main predictor of interest of these transitions is region of birth and region of residence at time of interview. We measure US region in four categories: Northeast, Midwest, South and West.[22] Currently, there is no consensus about which geographic level (region, division, etc) to use to track health inequalities.[23] While regional analyses may mask heterogeneity across states/counties, such analyses minimise issues associated with classifying individuals who live/work in different states/counties and migration effects (individuals are half as likely to move between regions as between states in any given year[24]).

Additional covariates included are age (years), gender (male=1), race (dummy variables for Blacks and other races; White=reference), ethnicity (Hispanic=1), marital status (married=1), years of schooling and birth cohort (birth year minus 1900). See table 1 for descriptive statistics.

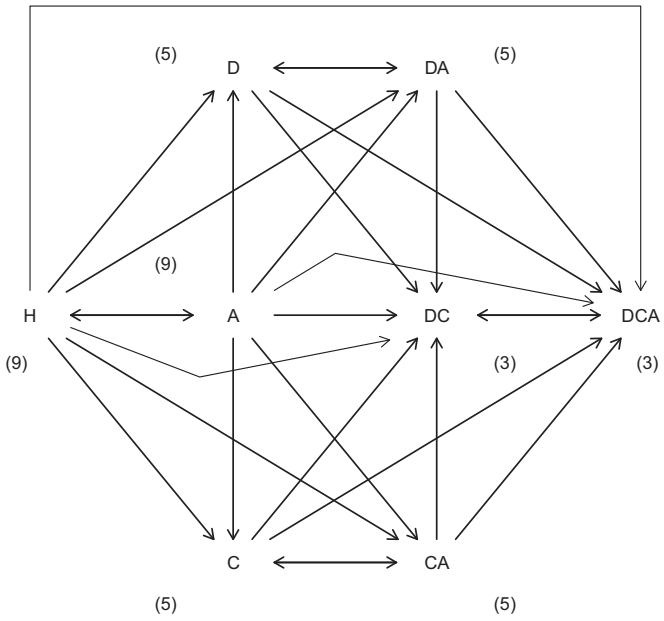


Figure 1 State space of interest.
States include (1) being healthy (H), (2) being diabetic (D), (3) having at least one chronic condition (C), (4) having at least one ADL disability (A), (5) being diabetic with at least one condition (DC), (6) being diabetic with at least one ADL disability (DA), (7) having at least one condition and one ADL disability (CA), (8) being diabetic with at least one condition and at least one ADL disability (DCA) and (9) death. Death is not shown but is allowed from all states. Retention is not shown but is allowed. The parenthetical numbers next to each state indicate how many transitions are possible from the given state.

Analysis

We adopt a Bayesian approach to produce multistate life tables (MSLT) and calculate regional disparities in LEs at age 50 between population with diabetes and healthy population.[25] The method involves (1) sampling parameters from a multinomial logit model predicting transitions with the covariates above, using Markov chain Monte Carlo methods (Gibbs sampling); (2) generating sets of age-specific transition probability matrices from the samples by applying the sampled model coefficients to a selected set of covariate values; (3) applying standard MSLT calculations to the sets of transition probability matrices and (4) summarising quantities of interest from the tables.

Our approach to generating MSLTs is a recent extension of the Bayesian method developed by Lynch and Brown in 2005, which uses Gibbs sampling to obtain parameter samples from a bivariate probit model for generating MSLTs for a very limited state space.[26] Since our state space is of much higher dimensionality, we use a newly developed Gibbs sampler that can handle high dimensionality.[27] We ran the Gibbs sampler twice, using randomly generated starting values and drew 2500 samples per run. The first 500 samples from each run were dropped as burn-in. Among the remaining 2000 samples from each chain, we kept every 4th draw to reduce autocorrelation in the samples, leaving 1000 posterior samples in total.[28]

Using each of the 1000 posterior samples, we calculated the 9-by-9 transition probability matrix at each even-number age from 50 to 110. We chose 50 as the starting age because diabetes prevalence is still low at this age.[29] We constructed life tables (LTs) for populations defined by each combination of birth and

Table 1 Descriptive statistics for covariates

Variable	Mean (SD) or percent
Birth cohort	35.3 (11.7)
Age	69.4 (10.7)
Male	44.4%
Race	
White (reference)	79.0%
Black	18.0%
Other race	3.0%
Hispanic	4.6%
Education	12.5 (3.0)
Married	52.1%
Birth region	
South (reference)	40.3%
Northeast	20.7%
Midwest	30.0%
West	9.0%
Current region	
South (reference)	41.4%
Northeast	15.3%
Midwest	26.1%
West	17.2%

Data come from 1998 to 2014 waves of the Health and Retirement Survey. Descriptive statistics include all n=80 146 transition intervals. Cohort is computed as birth year 1900.

current regions. All other covariates were set to their sample means, thereby controlling on regional differences in the composition of these covariates. Finally, we calculated interval estimates for LEs from the collection of 1000 LTs for each birth/current region combination. All analyses were conducted using R.

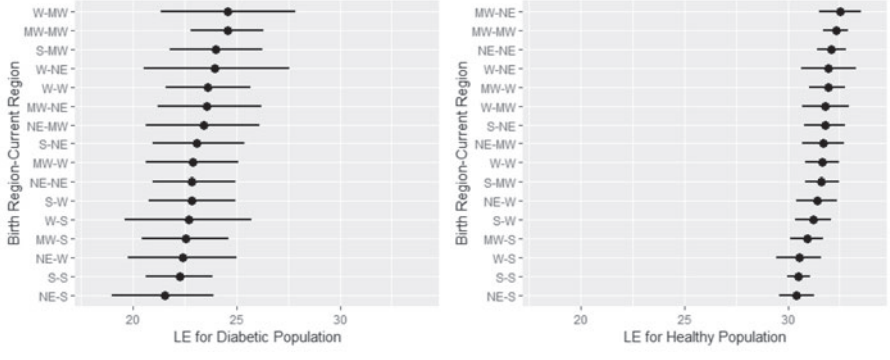
We conducted three sets of analyses. First, to assess regional disparities in LEs for adults with diabetes and healthy adults, we estimated total LE from diabetic status–based and healthy status–based LTs by birth/current region combination. In diabetic status–based LTs, the radix is set so that all synthetic cohort members are diabetic at age 50 (but without chronic conditions or ADLs). The radix for healthy status–based LTs is set so that all synthetic cohort members are healthy at age 50. Total LEs were calculated by summing LEs across all living states. Second, to examine the QoL among PWD, we estimated %XLE using diabetic status–based LTs. Individuals can acquire ADLs from diabetes without having other chronic conditions (eg, one can have diabetic neuropathy that manifests as an ADL without having a direct heart disease diagnosis) or they can have other chronic conditions without having ADLs. Research documents an inverse relationship between multimorbidity and QoL,[30 31] and so we consider having other chronic conditions or ADLs as reducing QoL. This QoL measure, %XLE, is calculated by the number of years spent with only diabetes (XLE) divided by total life expectancy (TLE) in the diabetic status–based LTs. Posterior means are reported with 84% credible intervals, following the precedent of the frequentist literature showing that under the assumption of roughly equal SEs, comparing multiple 84% intervals gives comparable results with a 5% level test.[32] Finally, to summarise our findings on regional disparities, we estimate the probabilities that one region is worse than other regions in health outcomes. We consider the following health outcomes: TLE, XLE, LE with diabetes and chronic conditions, LE with diabetes and ADLs, LE with all three health issues as well as the proportions of these LEs with regard to TLE.

RESULTS

Figure 2 compares LEs at age 50 for individuals with diabetes and healthy individuals, with 84% credible intervals (see online appendix tables 1–2 for full results of regional disparities in LEs for population with diabetes/healthy population). The mean LEs for PWD range from 21.5 to 24.6 years, whereas means for the healthy population range from 30.4 to 32.3 years (gap of 5.8–10.8 years). Comparing across regions, PWD currently living in the South live shorter lives, on average: among the five birth/current region combinations with the shortest mean LEs, four involve current Southern residence. Currently living in the South is similarly adverse for those who are healthy at age 50: among the five birth/current region combinations with the shortest mean LEs, four involve current Southern residence. In particular, persons born in the South or Northeast and currently living in the South tend to have the shortest LEs (estimated probability of 96%).

To examine HE across the region, we calculated %XLE for PWD at age 50 (figure 3). On average, people born in the South have the smallest proportions of life remaining without either other chronic conditions or ADLs. Among the five birth/current region combinations that have the smallest means, four involve Southern birth.

These results suggest that currently residing in the South is linked to shorter LEs for individuals with or without diabetes and Southern birth is linked to lower QoL for PWD. To quantify



(a) (b)

Figure 2 Regional differences in life expectancies at age 50 by diabetes status, with 84% credible intervals. (A) Life expectancies for population with diabetes. (B) Life expectancies for health population.
Regions include West (W), South (S), Northeast (NE) and Midwest (MW).

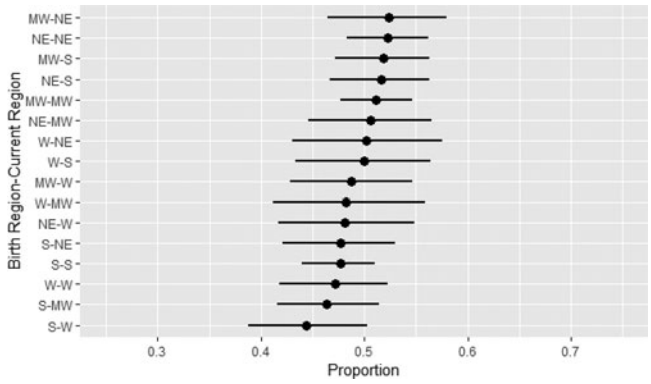


Figure 3 Regional differences in proportions of life remaining without either chronic conditions or activities of daily living at age 50 among population with diabetes, with 84% credible intervals.
Regions include West (W), South (S), Northeast (NE) and Midwest (MW).

these disparities, we estimate the posterior probabilities that Southern health outcomes are worse than those of other regions from diabetes status–based LTs (table 2). Three findings are particularly noteworthy. First, the probabilities of developing other chronic conditions and ADLs and spending greater proportions of life with these diseases for PWD born in the South versus other regions are at least 80%. Second, the probabilities of not having either other chronic conditions or ADLs and spending greater proportions of life without chronic conditions or ADLs for Southern-born PWD are at least 70%. Third, the probabilities of having a shorter LE for PWD currently living in the South are 79.2% compared to the Northeast, 93.4% compared to the Midwest and 66.2% compared to the West.

DISCUSSION

Comparing LEs between population with diabetes and healthy population can elucidate the impact of diabetes on population health. We hypothesised that diabetes would be associated with shorter LEs across all US regions and that Southern birth/current regions would be associated with shorter LEs and more time spent with chronic conditions/ADLs for PWD. Consistent with our first hypothesis, estimates showed that, at age 50, PWD could expect to live, on average, 5.8–10.8 years less than their healthy equivalents. These numbers are consistent with those estimated from the Framingham Heart Study, with the gaps equal to 8.2 (7.5) years for men (women).[33]

While the increased mortality associated with diabetes is well documented, a novel contribution of our study is the regional differences in LEs among PWD. Previous research in the USA reveals that diabetes is more prevalent in the South,[10] which our study confirmed. In terms of HE, research from the UK has shown that men (women) without diabetes at age 65 had 4.1 (5.1) years free of ADLs and instrumental ADLs compared to those with diabetes.[34] Consistent with our second hypothesis, diabetes had the greatest influence on both LE and HE for older adults who were born in or currently lived in the South. As such, Southerners with diabetes not only have a reduced LE but also spend more time living with disability or other chronic conditions. Moreover, it is important to distinguish between those of Southern birth versus those currently residing in the South. On the one hand, diabetes is influenced by cultural, behavioural and environmental factors, so Southern-born individuals may experience factors that influence their awareness of their diabetic status or need for treatment,[35] thus resulting in the worst QoL compared to other regions. On the other hand, people living in the South are less likely to access medical care[36] or have health insurance,[37] which may contribute to shorter LEs if Southerners do not seek treatment for diabetes.

Table 2 Estimated probabilities that health outcomes of Southerners are worse compared to those from other regions

	Birth region			Current region		
Measure	NE	MW	W	NE	MW	W
TLE (<)	0.356	0.599	0.618	0.792	0.934	0.662
XLE (<)	0.748	0.877	0.704	0.703	0.739	0.363
XCLE	0.794	0.629	0.543	0.517	0.156	0.301
XDLE	0.583	0.654	0.259	0.083	0.184	0.486
XCDLE	0.879	0.924	0.808	0.521	0.270	0.098
%XLE (<)	0.899	0.922	0.699	0.545	0.358	0.202
%XCLE	0.766	0.676	0.612	0.701	0.400	0.375
%XDLE	0.544	0.687	0.273	0.109	0.312	0.543
%XCDLE	0.860	0.947	0.851	0.671	0.553	0.141

Probabilities are estimated from diabetic status–based life tables. Regions include West (W), South (S), Northeast (NE) and Midwest (MW). Life expectancies include total life expectancy (TLE), life expectancy with only diabetes (XLE), life expectancy with diabetes and chronic conditions (XCLE), life expectancy with diabetes and ADLs (XDLE) and life expectancy with all three health issues (XCDLE). %XLE, %XCLE, %XDLE and %XCDLE are calculated using XLE divided by TLE, XCLE divided by TLE, XDLE divided by TLE and XCDLE divided by TLE, respectively. 'Worse' means shorter total life expectancy, shorter life expectancy with only diabetes, longer life expectancy with more than one disease and so on.

Limitations

First, because of the complexity of directly adjusting for the HRS complex sampling design in Bayesian models, we adopted a recommended approach to account for sample clustering and weighting.[38] Specifically, we controlled for race/ethnicity and region in our regression models, which accounts for the probability of inclusion and non-response due to these factors and helps with the potential consequences of not using HRS sample weights. In addition, compared to other studies using data from a cohort with a long follow-up period (eg, Framingham Heart Study), our sample is more nationally representative because considerable numbers of blacks and Hispanics are included. Since minorities have a higher risk of diabetes, ignoring them could underestimate the true public health burden of diabetes. Indeed, our analyses produced LE estimates that are consistent with national estimates, and our large sample size reduces the potential bias in SEs.

Second, due to data limitations, a common assumption made by most existing MSLT methods is that the data are complete and only one net transition can happen between successive observations for each individual. Two situations are consistent with this assumption: 1) a single transition between intervals that occurs at the midpoint, or 2) possibly repeated transitions between the starting and ending state that balance out to yield half the time in each state based on the linear assumption. Older adults are likely to experience fast chronic disease accumulation and multimorbidity development. Therefore, when the assumption is not met, our 2-year intervals could miss certain transitions. For example, PWD can develop ADLs shortly before death so that multiple transitions (ie, from D to DA and from DA to dead) happen in one interval. In this case, %XLE at age 50 can be

overestimated. However, because our focus is regional disparities, and it is plausible that this kind of situation has equal chances to happen across regions, our substantive conclusion on regional disparities should still hold.

Third, selective mortality before age 50 may lead to a higher probability of healthier individuals (eg, whites and people not living in the South) being included in the survey. In our model, we adjusted for major factors that may affect mid-life mortality (eg, birth cohort, educational attainment, race/ethnicity and marital status). Additionally, our analyses are descriptive and forecasting in nature rather than causal. The population of interest is the older population, which by default is conditional on living to age 50.

Finally, LT results are based on a hypothetical cohort: showing what would happen to a cohort if it was subjected for all of its life to the mortality conditions of the period covered. If there are dramatic changes after 2014, readers should be cautious when generalising this study's results.

Public health implications

Our results confirm that diabetes is a major US public health concern and show that the burden of diabetes varies by region of birth and current residence. On average, diabetes reduces LE by 5.8–10.8 years across regions. This is problematic because diabetes is often accompanied by chronic conditions and disabilities, which can impact both independent functioning and QoL.[13 14] Moreover, these numbers mean a significant burden to the US medical system during PWDs' dependent years,[39] and the burden will not be the same in local medical systems across regions. Future studies should monitor the gap in LEs between population with diabetes and healthy population.

The regional variations we identified are consistent with previous research indicating that diabetes is particularly prevalent in the South.[10 11] These geographic patterns could be due to multiple factors, including regional differences in socioeconomic conditions and diabetes care; region-specific programmes and policies; and regional, cultural and behavioural factors. Public policies are needed to develop targeted interventions to narrow the geographic inequality in the impact of diabetes on population health. Policies targeting both early-life interventions for Southern-born individuals and care for older adults living in the South are needed. To that end, estimates from this study can be used to inform public health initiatives and to help guide diabetes-related policies.

What is already known on this subject

- Previous research has demonstrated large disparities in life expectancies between populations with and without diabetes in the US. Despite evidence that diabetes is more prevalent in the South, little work has been done to consider the roles of birth and current regions jointly in these life expectancy disparities.

What this study adds

- At age 50, persons with diabetes were expected to live on average 5.8–10.8 years less than their healthy equivalents across regions. Diabetes had the greatest influence on life expectancy for older adults who lived in the South at the time of interview. Persons with diabetes born in the South were more likely to have a lower quality of life.

Author affiliations
[1]Department of Sociology, Yale University, New Haven, Connecticut, USA
[2]Department of Sociology, Duke University Population Research Institute, Center for the Study of Aging and Human Development, Duke University, Durham, North Carolina, USA
[3]Department of Sociology, Duke University, Durham, North Carolina, USA

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Twitter Emma Zag @DrEmmaZang and Jessica West @jswest.

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ORCID iD
Emma Zang http://orcid.org/0000-0002-5700-3179

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