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ORIGINAL PAPER

Are quality-adjusted medical prices declining for chronic disease? Evidence from diabetes care in four health systems

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Abstract
Improvements in medical treatment have contributed to rising health spending. Yet there is relatively little evidence on whether the spending increase is "worth it" in the sense of producing better health outcomes of commensurate value—a critical question for understanding productivity in the health sector and, as that sector grows, for deriving an accurate quality-adjusted price index for an entire economy. We analyze individual-level panel data on medical spending and health outcomes for 123,548 patients with type 2 diabetes in four health systems: Japan, The Netherlands, Hong Kong and Taiwan. Using a "cost-of-living" method that measures value based on improved survival, we find a positive net value of diabetes care: the value of improved survival outweighs the added costs of care in each of the four health systems. This finding is robust to accounting for selective survival, end-of-life spending, and a range of values for a life-year or fraction of benefits attributable to medical care. Since the estimates do not include the value from improved quality of life, they are conservative. We, therefore, conclude that the increase in medical spending for management of diabetes is offset by an increase in quality.

Keywords Productivity · Quality adjustment · Health expenditures · Medical spending · Net value

JEL Classification I10 · I18 · H51

Introduction

Medical spending has increased significantly in most economies in recent decades, challenging health system financing and prompting efforts to control cost growth. Improvements in medical treatment have clearly contributed to increases in medical spending, yet there is relatively little quantitative evidence on whether the rise in expenditure is "worth it" in terms of producing better health outcomes of commensurate value. Without such evidence, simply imposing cost controls may stifle life-saving innovations as much as reduce low-value care and "waste."

Consequently, understanding and enhancing the net value of medical spending is important for assessing and

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improving productivity in the growing service sectors of most economies. A few studies develop methods for quality adjustment of medical price indices [7]. As Dauda et al. [9] show in their recent study, "when properly adjusted for quality, declining prices from innovation are a prevalent feature of this sector" (p. 1).[1] Yet most studies to date focus on acute episodes of care, leaving little evidence on the net value of spending for the leading cause of morbidity and mortality—chronic disease. Furthermore, few studies focus on Europe, and none to date focus on Asia, the most populous region in the world.

Diabetes is an important chronic disease to study, given its growing prevalence, new treatment technologies, relatively complicated management, and life-long health implications. Eggleston et al. [12] found a positive net value of spending on diabetes management among a 613-patient Mayo Clinic sample in the US between 1997 and 2005: \$6931–\$10,911 for \$200,000 per life-year, or \$1050–\$2215 for \$100,000 per life-year gained. A follow-up study to the 1999–2009 period similarly found a small positive net value [13], implying that quality improvements roughly offset the increased treatment costs on average, or that the quality-adjusted unit cost of care was not increasing.

We apply a standardized methodology for estimating the net value of changes in medical spending, with population-specific risk prediction models to account for the over-prediction of cardiovascular events and death when western-based models are applied to Asian populations [27]. This method measures value using a "cost-of-living" approach that is analogous to a cost-effectiveness analysis comparing outcomes in the baseline and final periods, assigning a monetary value to life-years gained, and then subtracting the added costs of care [12]. An overview of the literature on quality adjustment of medical prices and the empirical precedents for this analysis is provided in Appendix.

Our study contributes to the literature in several ways. First, compared to previous studies, we assemble a larger dataset of patient-level panel data, linking medical spending to biomarkers for 123,548 individuals with type 2 diabetes over more than 642,000 person-years. Second, we explicitly compare results to see whether quality-adjusted price changes differ significantly across divergent health systems of the high-income world: a Bismarckian social insurance system (Japan); a hybrid system of regulated competition with mandatory insurance (The Netherlands); a Beveridge-style public system (Hong Kong); and a single-payer National Health Insurance system (Taiwan). Third, to adjust for quality changes appropriately, we use risk prediction models tailored to the population in each sample. Finally, as a robustness check, we develop methods to account for decedents and undertake several sensitivity analyses.

Our results suggest both strong similarities across the four systems as well as the importance of quality adjustment for understanding medical spending increases. Specifically, we find a positive net value of diabetes care, implying that the value of improved survival outweighs the added costs of care on average in each of the four health systems. For US \$100,000 value of a life-year, mean net value, standardized by age and sex, was \$646 for Japan, \$3669 in the Netherlands, \$3985 in Hong Kong, and \$10,717 for Taiwan. The net values remain positive if one assumes a value of \$50,000 per life-year gained (which is analogous to assuming only half of survival gains valued at \$100,000 were due to improved medical care). This conclusion would only be strengthened, of course, to the degree the newer medical treatment improves non-fatal outcomes or quality of life. Our finding that the quality-adjusted "cost of living" medical price index for managing diabetes has been declining across all four health systems is robust to various sensitivity analyses accounting for selective survival, end-of-life spending, change only in biomarkers, and a range of values for a life-year or percentage of survival benefits attributable to medical spending. We, therefore, conclude that the increase in medical spending for management of diabetes is offset by an increase in quality, as measured by a reduction in risk of all-cause mortality.

Data and methods

Data and institutional setting

This study draws on data from four health systems: three in Asia and one in Europe. Our sample includes 7432 Japanese patients with diabetes, linked to biomarkers from mandatory annual health check-ups between 2010 and 2014; 14,312 patients with diabetes from a general practitioner (GP) registry in the Netherlands, linked to medical claims for 2008–2011; administrative and clinical data for 90,891 patients treated for diabetes with publicly provided health services under the Hong Kong Hospital Authority between 2006 and 2014; and electronic medical records of 10,913 patients treated at a regional hospital in Taiwan from 2007 to 2013. Overall, with samples from four health systems spanning 2006–2014, we analyze individual-level panel data for 123,548 individuals with type 2 diabetes (5% of whom died during the study period) and more than 642,000 person-years of spending and outcomes. A more detailed description of the data and institutional setting in each of the four health systems follows.

[1] Hall [16] notes in her excellent review, "in general, the research literature shows adjusting for quality in the measurement of output in the medical sector to be quantitatively important".

Japan

Japan's social health insurance system provides universal coverage through insurance programs managed by employers for their employees, as well as insurance programs managed by municipalities (called National Health Insurance, NHI; see discussion in [30]). The benefit package and payment systems are uniform nationally. A mixed-ownership service delivery system provides accessible care. Diabetes constituted the third largest disease category in 2014, with a national prevalence rate of 7.7% that is increasing as the population ages; more than one-quarter of Japan's adult population may have pre-diabetes or diabetes [17, 19]. According to the International Diabetes Federation data for 2017, Japan's total healthcare expenditure on its 7.2 million people with confirmed diabetes aged 20–79 was the fifth highest in the world [19].

We study the net value of care for patients with type 2 diabetes in Japan between 2010 and 2014, using medical claims and risk factors from mandatory annual health check-ups among 7432 employed adults (aged 19–72) drawn from the database of employer health insurance claims provided by JMDC Inc (www.jmdc.co.jp/en). Individuals in our sample range from those newly diagnosed in 2009–2010 to those with duration of diagnosis over 30 years. The most reliably enforced mandatory health check-ups are for employees aged 40–74 working in large firms, such as the insured individuals in our dataset [19]. Since our data come from insurance plans managed by corporations, the insurer in this case is the employer. However, limitations on the proprietary data preclude linking any claims information to specific firms or measures of at-work productivity.

The Netherlands

Within the Dutch health care system, mandatory private insurance is financed by a mix of income-based, employer-paid, and privately paid premiums. Insurers are obliged to accept all individuals for insurance and receive a case-mix-based payment to avoid cherry picking [36]. Residents choose a health insurance policy with the insurer of their choice. The content of the basic insurance package is determined by the Minister of Health and consequently similar between insurers. Citizens may change their insurer on an annual basis, and about 6–8% of enrollees do so. In 2015, nearly 975 thousand persons aged 20–79 had diabetes in the Netherlands, which is a rate of 79 per 1000 [20]. Nearly 90% of this is type 2 diabetes, which is one of the three most prevalent chronic disorders. Ongoing aging and increases in the number of overweight people imply that the number of persons with diabetes will continue to rise. Primary care has been estimated to provide more than 80% of care for individuals with type 2 diabetes [29].

We investigate the net value of diabetes care in a Dutch primary care setting. Clinical data from a Dutch GP-registry, Zodiac, are linked to an all-payer claims dataset from Vektis Health Care Information Center, covering the period 2008–2011 [28]. This linked dataset is comprised of nearly 16,000 individuals aged 40–90 with type 2 diabetes and includes medical spending (limited to the mandatory insurance package and copayments) and diabetes-related outcomes including lab measurements. The difference between 2011 and 2008 complications risk is valued in monetary terms and predicted medical spending (in 2010€ and corrected for Elixhauser comorbidities, age and diabetes duration) is subtracted [29]. Risks are estimated using the UKPDS risk engine, as described below in the methods section.

Hong Kong

Hong Kong is the most developed among Chinese cities. Given its economic trends, lifestyle changes, and current stage of population aging, Hong Kong can arguably serve as a sentinel for the future of Mainland China. The majority (94%) of the population is ethnically Chinese, mostly second- or third-generation immigrants from the southern Chinese province of Guangdong. From 2006 to 2014, overall prevalence of diabetes standardized by age and sex in Hong Kong increased from 7.2 to 10.3% [26]. Age- and sex- adjusted incidence slightly declined from 10.0 per 1000 person-years in 2007 to 9.5 per 1000 person-years in 2014. The overall prevalence of pre-diabetes was 8.9% in 2014. The prevalence of diabetes and pre-diabetes is expected to further increase as the population ages.

Hong Kong has a dual-track public and private health care system. Public-sector services, provided by the Hospital Authority, account for the majority of inpatient care (90% of total bed days and 80% of admissions), 50% of specialist outpatient care, and 30% of first-contact outpatient services. Universal coverage is provided by the public-run system with the government subsidizing over 90% of funding. In our net value analyses, we use the Hospital Authority electronic health record data on people with diabetes treated in the public health care system, which includes socio-demographic information, clinical and laboratory records, health service utilization, and prescribed medications.

Taiwan

Taiwan's population of 23 million has enjoyed universal health coverage since 1995 under the single-payer National Health Insurance (NHI) program, which integrated three pre-existing social insurance schemes and extended coverage to the remaining uninsured. Taiwan NHI offers comprehensive benefit coverage of ambulatory and inpatient services, delivered by a mix of public and private providers within Taiwan's market-oriented health care delivery system. The prevalence of diabetes in Taiwanese adults (aged 18 and above) was estimated to be 12.4% in 2013–2015 [32]. Diabetes treatment cost accounted for 4.24% of total NHI expenditures, next to renal disease and diseases of oral cavity and salivary glands in 2017 [33].

Our analytical dataset, which includes detailed clinical indicators, medical expenditures (insurance payout and patient out-of-pocket payment) and sociodemographic information, includes individuals diagnosed with and treated for type 2 diabetes in the outpatient and/or inpatient departments of a large regional hospital in northern Taiwan from 2007 to 2013. These patients include participants and non-participants in a pay-for-performance program for diabetes management [3, 4, 6, 18]. A separate analysis focuses on comparing the net value of the P4P program with usual care [22]; this analysis uses the entire sample. The selection criteria were that an individual was either enrolled in the diabetes P4P program or had no fewer than three diabetes visits in a year in the baseline period.

Methods

We extend the methods developed by Eggleston et al. [12] to estimate the net value of spending on diabetes care. Because the health benefits of medical treatments often manifest over long periods, those methods require prediction of future outcomes based on biomarkers from individuals in each time period, linked to utilization and spending. We then assess the monetary value of the change in quality—proxied by predicted risks—between the baseline and final periods, net of change in spending. Importantly, estimating the net value requires risk prediction models appropriate to the characteristics of a given population.

Using patient biomarkers, we estimate 5-year risks of all-cause mortality.[2] Following the previous Mayo clinic study [12], we define "modifiable" risks by holding at the baseline value the patient's age, and (for the Japan, Netherlands, and Hong Kong samples) diabetes duration. For example, for a 60-year-old woman who in 2010 had been living with diabetes for 4 years, we calculated baseline predicted risk using age 60, duration 4 years, and other risk factors such as systolic blood pressure as measured in 2010. We then calculated her modifiable risk in 2014 using her 2014 blood pressure, HbA1c, and other risk factors, but assuming her age in 2014 was still 60 and duration of diagnosis was still 4 years. Our net value calculations are based on these modifiable risk estimates to isolate the change in quality that is plausibly attributable to clinical care (including advice from providers to stop smoking, healthy lifestyle, etc.), rather than the natural process of aging and number of years the patient has lived with diabetes.

Our primary endpoint is modifiable risk of all-cause mortality for the next 5-year period based on the appropriate risk model for each race and ethnicity. For survivors beyond the 5-year period, we assume remaining age- and sex-specific life expectancy based on the relevant 2010 life table.

We measure quality or value as the present discounted monetary value of any improved survival, holding age and duration of diagnosis constant at their baseline levels (the aforementioned "modifiable risk"). Net value subtracts the increase between the baseline and final periods in annual real modifiable spending per patient, as described below. Annual spending aggregates all health expenditure of the individuals diagnosed with diabetes, including out-of-pocket expenditures and spending on medications, without any attempt to disentangle diabetes-specific spending from non-diabetes spending.

Unlike the previous Mayo Clinic studies from the United States [12, 13], we focus on a lower value of a life-year that is consistent with the generally accepted cost-effectiveness thresholds used in the regions we study and in other health systems with similar living standards per capita. Thresholds in the range of USD $50,000–$100,000 per quality-adjusted life year have been used in all four health systems in multiple academic and policy-focused studies.[3]

Denoting the 5-year risk of all-cause mortality for individual j in period t as P_{jt}, we calculate the value of reductions in fatal risk as follows: assuming a 3% annual real discount rate applied halfway through each year and a value of one life-year ranging from $50,000 to $150,000, we estimate the present discounted value of remaining life for 2 time points: baseline and final observation periods. To do so, we approximate the predicted probability of death in the next 5 years by giving one-fifth of the predicted probability ($0.2\ P_{jt}$) to each of the first 5 years, and assume that all patients surviving beyond year 5 (with probability $1 - P_{jt}$) have the same age- and sex-specific remaining life expectancy as a general individual from the life table of that population.

For comparability across our four samples, we standardize by age and sex to the World Health Organization (WHO) World Standard Population (see Appendix Table 1). Throughout our analyses, 95% confidence intervals are bootstrapped using the percentile method with 1000 repetitions. We use each economy's GDP deflator as a measure of the

[2] One of our robustness checks also predicts the risk of major diabetes complications, using the Japanese sample and the Japan-specific risk prediction engine developed by Tanaka et al. [34].

[3] See examples and discussion in Baudot et al. [1]; Bertram et al. [2]; Fitria et al. [14]; Stadhouders et al. [31]; Tang et al. [35] (for Taiwan); and Woods et al. [41]. For Hong Kong, see Wong et al. [39, 40].

opportunity cost of the overall economy to adjust value and spending to constant 2010 PPP US dollars. Appendix Table 4 shows the net value results in 2019 Euro (converted at PPP to EU19 Euro) and 2019 PPP US dollars.

We estimate predicted spending for each patient in the baseline and final periods to smooth variation in individual observations of actual spending, as well as to calculate modifiable spending (holding age and duration of diabetes at baseline values). To account for differences in how risk factors affect spending, we estimate generalized linear models and assumed a log link and gamma distribution [23]. All medical and pharmaceutical spending is included in the dependent variables. The independent variables are age, sex, and indicator variables for the presence of Elixhauser comorbid conditions at baseline. For samples with duration of diabetes, duration (years with diagnosis) and an interaction term of age with duration are included. For samples lacking the duration of diabetes variable, age-squared is included. Using the estimated coefficients from the model, we predict total spending for each patient in the baseline and final periods, and then predict total spending while holding age (and duration of diagnosis) constant at their baseline values. The increase in predicted spending between the baseline and final periods is then compared with the value of health status improvement to calculate the net value of the additional spending.

Quality adjustment with health outcomes: risk prediction models

Measurement of health outcomes utilizes a risk prediction model suitable for estimating all-cause mortality in each of our samples. Population-specific risk models are preferable because they more accurately reflect the contribution of current clinical management of specific risk factors for that patient population. For example, using the UK Prospective Diabetes Study (UKPDS), as in the U.S.-based studies [12, 13], would not have been appropriate for all our samples, because the UKPDS over-predicts coronary heart disease (CHD) for Asian populations [27], for whom stroke risk is relatively high [15]. Other risk prediction models such the Risk Equations for complications of type 2 diabetes (RECODe) have also been calibrated for Western populations and demonstrated to be less accurate for East Asian populations [27]. Below we provide a brief overview; for more details on the risk factors used (Appendix Table 3) and on how each risk model was estimated, see Appendix.

Measurement of health outcomes for the Japan sample, including all-cause mortality, is based on an extension of the 5-year risk of developing major complications and mortality as predicted by the Japan Diabetes Complications Study/the Japanese Elderly Diabetes Intervention Trial risk engine (JJRE) [34]. The JJRE incorporates 11 risk factors to predict macro- and microvascular complications among Japanese patients with diabetes (without diabetes complications except mild retinopathy): sex, age, HbA_{1c}, years after diagnosis, body mass index (BMI), systolic blood pressure, non-high-density lipoprotein (HDL) cholesterol, albumin-to-creatinine ratio, atrial fibrillation, current smoker, and leisure-time physical activity. The model was developed from 1748 Japanese type 2 diabetic patients pooled from two clinical trials. Fortunately, Japan's mandatory annual health check-ups include a survey of various health behaviors including two questions that allow us to code leisure-time physical activity.

The Dutch sample applies the UKPDS risk engine. This model has been validated in the Dutch population and was shown to overpredict cardiovascular events [37]. The UKPDS risk engine is used to predict the risk of fatal CHD and cerebrovascular events and then added to calculate total risk of fatal events as an approximation of diabetes-specific mortality risk. Age-specific all-cause mortality risks are then added, after correcting for stroke and cardiovascular mortality, to avoid double counting. Risks of death from microvascular diabetes complications are considered negligible in comparison to these risks and ignored [29]. Variables required by the risk prediction model are taken from the linked datasets: mortality from VEKTIS data and comorbidities from coding available in ZODIAC.

Analyses for Hong Kong are based on risk prediction scores developed by Quan et al. [27] for ethnic Chinese individuals residing in high-income East Asia using data for 678,750 participants from Hong Kong, and validated with 386,425 participants from Singapore. The resulting HKU-SG risk score for mortality uses the following risk factors: age, duration of diabetes, gender, smoking, BMI, systolic and diastolic blood pressure, HbA1c, low-density lipoprotein (LDL) cholesterol and pre-existing conditions: atrial fibrillation, chronic kidney disease, ischemic heart disease and cerebrovascular disease (https://jquan.shinyapps.io/riskmodel/).

The Taiwan diabetes risk prediction model is constructed based on a sample of 18,202 type 2 diabetes patients treated in a large regional hospital in northeastern Taiwan from 2007 to 2013. The national death registry is linked to the data to identify mortality and construct an all-cause mortality risk prediction engine using eight risk factors in a Cox proportional hazard model: age, gender, history of cancer, history of hypertension, any use of anti-hyperlipidemic drugs, HbA1c, creatinine, and LDL/HDL ratio [6]. The Taiwan diabetes risk prediction model was internally validated based on the method in Chiu et al. [5].

Sensitivity analyses and robustness checks

We undertake several sensitivity analyses. First, we compare net value for different assumptions on the value of a life-year, both using each sample's own age–sex structure and when standardizing by age and sex. We also compute results for different age–sex groups relative to age 60–64 for each sample, and net value stratified by duration quintiles (for the samples with diabetes duration).

We further modify and extend our methods with several robustness checks. The first attempts to isolate the health gains plausibly caused by medical care by assuming that medical care directly impacts biomarkers, but that health behaviors (e.g., smoking, physical exercise) may change because of non-medical factors. Therefore, we re-estimate net value holding constant all risk factors other than biomarkers for the Japan and Hong Kong samples.[4] The Netherlands sample could not undertake this robustness check fully due to data limitations; and since the Taiwan risk prediction model already holds constant all factors other than biomarkers (e.g., medication use is recorded and held constant at baseline), the net value results already reflect this method of isolating the impact of medical care on quality change.

The second examines the impact of including avoided treatment spending for major complications of diabetes. Using the JMDC Inc. claims data, the Japan team finds people with a first stroke or development of CHD, and estimates associated expenditures in the incident year and incrementally for every subsequent year living with those complications. Then the present discounted value of avoided treatment spending is estimated based on reduction in the individual's modifiable predicted risks of CHD and stroke.

A third robustness check uses Cutler et al. [8]'s assumption that medical care accounts for half of health gains, with non-medical factors playing an equally important role in health improvement. We compare our main results about net value assuming $100,000 per life-year gained with those using half that value (i.e., $50,000 per life-year). Our main results prove robust to assuming that only half of survival gains were due to medical care.

Because the main results about net value are based on those who survive to the final period, we undertake a fourth robustness check to account for decedents symmetrically with survivors. This check is especially important for our samples from Hong Kong and Taiwan, which are much larger and older than the working-age population analyzed by Eggleston et al. [12]. As a result, medical care may be less effective at preventing mortality. The Netherlands sample excluded decedents.

To take account of selective survival and incorporate decedents and all their medical spending for the three samples with decedents, we estimate the net value of decedents, NV_D; this receives a weight in the overall net value that is proportional to the fraction of the baseline cohort that dies before the final period. NV_D is estimated in a different way from that of survivors, because it is based on cumulative spending and cumulative life-years, rather than subtracting baseline from final period values. To calculate NV_D, we add the value of a life-year for every year survived, net of spending. Since even a small value of a life-year (e.g., $25,000) is much larger than mean expenditures in any given year in our samples (no more than $5000), this method yields a much larger net value than our main specification based on change in modifiable risk and expenditures between the baseline and final years. The net value for survivors receives a weight in the overall net value that is proportional to the fraction of the baseline cohort that survives to the final period in each sample. For more details, see Appendix.

Results

Net value of diabetes care

Characteristics about the health systems and patient samples we analyze are provided in Table 1. All four represent high income, mostly urban settings, with some of the highest life expectancies in the world, marked population aging, and growing burden of chronic diseases such as diabetes. Average age ranged from 52 in the Japanese working-age sample to 67.8 years in the Netherlands sample, with all but the Japan sample including individuals into their 90s. Most are balanced by gender, except that only one in five in the Japanese sample is a woman. Co-morbidity profiles also vary, with a more complicated clinical profile (e.g., 14% with renal failure) among patients regularly cared for at the regional hospital in Taiwan. This heterogeneity not only enriches our study of how quality-adjusted spending differs across different populations in different health systems, but also presents challenges for comparisons. For net value, we focus on age- and sex-standardized results.

Baseline average annual medical spending per individual with diabetes, in 2010 US$, varied across the four health systems: $2526 in Japan (2010–2011), $5587 in the Netherlands (2008), $1135 in Hong Kong (2006–2008), and $2474 in Taiwan (2007–2009), see Table 2. The average increase in per-patient annual modifiable expenditures ranged from $108 more per year in the Netherlands between 2008 and 2011, to $896 more per year in Hong Kong between 2006–2008 and 2012–2014. These trends (see Appendix Fig. 1) illustrate the relentless pressure of increasing input costs and technological change in medical care, even when removing the impact of aging and longer duration for those living with diabetes.

The increase in medical expenditures was accompanied by decline in modifiable risk of all-cause mortality (Table 2).

[4] We are grateful to an anonymous reviewer for suggesting this robustness check.

Table 1 Characteristics of the four health systems and the four samples of adults with type 2 diabetes mellitus. Sources: authors' analyses of the four study samples; World Bank World Development Indicators

	Japan	The Netherlands	Hong Kong	Taiwan
Population, 2017, in millions	126.8	17.1	7.4	23.6
GDP per capita, 2016 USD PPP	$41,476	$51,320	$58,561	$50,400
Health expenditures per capita (2014 USD)	$3703	$5694	$2222	$1435
Data	JMDC Inc. medical insurance claims data for working-aged adults employed at large corporations, linked to annual health check-up data	Linked data from ZODIAC (routine data from primary care physicians) and VEKTIS (national claims data covering mandatory health care insurance)	Administrative dataset of all publicly provided health care services. Participants with complete data at baseline and final periods	Electronic medical records from one large regional hospital in northern Taiwan
Observations (*N* individuals)	7432	14,312	90,891	10,913
Survivors (*N*)	7077	14,312	86,344	9739
Decedents (*N*)	355	Were excluded	4547	1174
Baseline period [year(s)]	2010–2011	2008	2006–2008	2007–2009
Final period [year(s)]	2013–2014	2011	2012–2014	2011–2013
Baseline characteristics				
Age: mean, (min–max)	52.02 (20–74)	67.76 (40–92)	60.78 (15–101)	62.58 (19–99)
Female (share of sample)	0.205	0.51	0.526	0.507
BMI	25.49	27.18	25.6	NA
Systolic blood pressure	129.34	138.54	135.79	73.77% using antihypertensive
Diastolic blood pressure	73.9	NA	74.92	NA
HbA1c	6.73	6.68	7.58	7.38
Duration of DM, years	3.66	5.64	5.82	NA
Selected Elixhauser comorbidities (share of sample with each)				
Hypertension	0.38	0.14	0.36	0.54
Renal failure	0.01	0	0.04	0.14
Peripheral vascular disorders	0.06	0.13	0.04	0.02
Congestive heart failure	0.05	0.06	0.05	0.08
Cardiac arrhythmias	0.06	NA	0.1	0.05
Valvular disease	0.02	NA	0.01	0.04
Chronic pulmonary disease	0.11	NA	0.04	0.09
Hypothyroidism	0.01	0.01	0.01	0.02

NA not available

Table 2 Average change in spending and quality, as proxied by predicted mortality, holding age and duration constant

	Japan	The Netherlands	Hong Kong	Taiwan
Predicted expenditures (baseline) (a)	$2526	$5587	$1135	$2474
Predicted modifiable expenditures (final) (b)	$2813	$5695	$2029	$3055
Change in annual expenditures (b–a)	$286	$108	$894	$580
Percentage change, baseline to final	11.34%	1.93%	78.71%	23.46%
Predicted mortality (baseline) (c)	2.01%	7.40%	9.93%	17.47%
Predicted modifiable mortality (final) (d)	1.83%	7.20%	8.87%	17.25%
Change in modifiable mortality risk (d–c)	−0.18%	−0.20%	−1.06%	−0.23%
Percentage reduction in modifiable mortality risk, baseline to final	8.96%	2.70%	10.67%	1.32%

Spending is expressed in 2010 USD to reflect the time period of the data. For equivalents in 2019 Euro and 2019 USD, see Appendix Table 4. "Modifiable" refers to predictions of spending or mortality risk when the individual's age and duration of diagnosis are held constant at their values in the baseline period. Only other risk factors, such as control of blood sugar and blood pressure, differ. See text

The change in mean predicted modifiable mortality risk between baseline and final periods was negative (lower mortality) for all four samples, ranging in magnitude from one-fifth of a percentage point in the Netherlands and Taiwan to slightly more than a percentage point in Hong Kong. The percentage reduction in modifiable mortality risk was unsurprisingly largest in the sample with the longest panel of patients, Hong Kong, with a 10.67% reduction in age- and duration-constant risk of death. The percentage reductions in modifiable mortality risk were 8.96% in Japan, 2.70% in the Netherlands, and 1.32% in Taiwan.

Figure 1 shows the changes in mortality risk across age groups (in either age quintiles or 5- or 10-year groupings, depending on sample sizes) for each of the four systems. Across all age groups, modifiable mortality risk declined, with the largest absolute declines among the older individuals with larger absolute risk of death. These larger gains in modifiable risks among the oldest old may be driven not only by technological and behavioral change for better diabetes management, but also partially by selective survival. Our robustness check including decedents, described below, reveals that the overall pattern of improved outcomes is not driven entirely by selective survival. Indeed, accounting for decedents increases the magnitude of net value.

Because outcomes improved, quality-adjusted spending increases will be lower than unadjusted spending increases. The question remains, however, whether the net value of treatment spending was positive.

To answer whether the increase in spending associated with a commensurate or greater value of improved outcomes, Table 3 reports the mean net value for each health system, for a range of life-year values. For comparability, the net values reported in Table 3 are standardized to the WHO world standard population. This standardization places a higher weight on younger cohorts and thus lowers the net value relative to almost all the samples' own age–sex composition of individuals with diabetes (see Appendix). Nonetheless, the average standardized net value for all four systems is positive. If life-years are valued at $100,000 2010 USD, mean net value ranges from $646 for Japan, to over $10,000 for Taiwan, with the Netherlands and Hong Kong in a similar middle range at $3669 and $3985, respectively. The net values are lower but remain positive when assuming life-years are valued at $50,000, or, equivalently, assuming that half of survival gains valued at $100,000 per life-year were attributable to medical care. Table 3 also shows the confidence intervals; every estimate is statistically significantly greater than zero. In Appendix Table 4, we report the equivalent net values in 2019 Euro and 2019 USD; as shown, the main results continue to hold when expressed in PPP values beyond the time period of our study data.

Since the net value was positive, we conclude that the increase in medical spending for management of diabetes was offset by the value of improved quality, as measured by reduction in risk of all-cause mortality. Accordingly, the quality-adjusted "cost-of-living" medical price index for managing diabetes has been declining across all four health systems, to varying extents. These results are consistent with other studies estimating a modest positive net value for management of diabetes in the US using similar methods [12, 13] as well as contrasting methods [38].

Robustness checks

This finding of positive net value is robust to a range of robustness checks. Our method for estimating value is based on factors that change over the study period. Any factors which do not change over time, such as demographics and already acquired comorbidities, will not contribute to the estimated quality. However, secular trends in the nonmedical determinants of health could have an impact on changes in predicted risks, as well as any changes in lifestyle behavior that physicians recommend. To be conservative, we ignore the latter and focus only on change in biomarkers on the

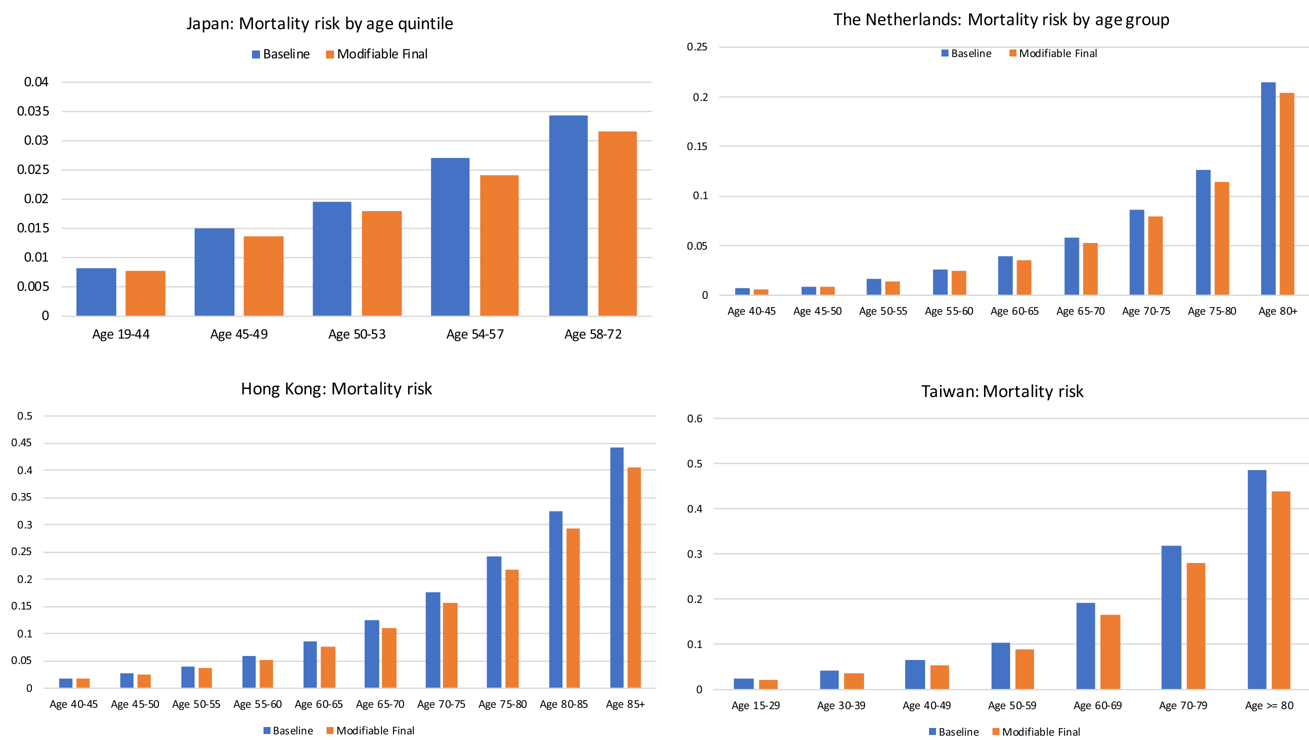

Fig. 1 Quality trends: change in modifiable mortality risk, by age category

Table 3 Mean net value of spending on diabetes management in four health systems, for a range of values of a life-year

Value of a life-year	Japan	The Netherlands	Hong Kong	Taiwan
$50,000	**$259**	**$1799**	**$1874**	**$5119**
Confidence interval	$220–$297	$1546–$2053	$1785–$1965	$4478–$5761
$100,000	**$646**	**$3669**	**$3985**	**$10,717**
Confidence interval	$570–$722	$3162–$4175	$3846–$4122	$9437–$11,996
$150,000	**$1018**	**$7407**	**$6096**	**$16,254**
Confidence interval	$901–$1135	$6649–$8167	$5909–$6268	$14,357–$18,151

Standardized by age and sex according to the WHO world standard population and expressed in 2010 USD to reflect the time period of the data

assumption that they most closely reflect medical treatment.[5] For the samples that include patients beyond the working ages, this robustness check yields consistent results of positive net value from medical care. In the Taiwanese sample, the net value estimates are identical and substantially positive since the risk model for Taiwan already holds constant all values except the biomarkers (HbA1c, HDL/LDL ratio, and serum creatinine). For the Hong Kong sample, the robustness check still yields positive net value: only allowing HbA1c, SBP, DBP, and LDL to change, with all other variables held constant, yields a net value of $1798 for $50,000 value of a life-year and $3895 for $100,000 value of a life-year. The net value is slightly lower when only allowing changes in HbA1c and LDL to contribute to measures of quality ($1435 and $3169 for $50,000 and $100,000 values of a life-year, respectively). Unfortunately, we were unable to re-estimate risks for this robustness check for the Netherlands sample, given the expiration of the IRB access to the patient-level data. However, the risk models used for the Dutch analyses contain only BMI and smoking as additional predictors next to biomarkers, age, gender and duration. Over the study period, smoking did not change, with a mean percentage of 15.7 in the cohort studied, and BMI decreased, arguably as a result of treatment and care, given the background trend of increasing obesity in the Netherlands in that period.

[5] We are grateful to an anonymous reviewer for suggesting this robustness check.

In general, younger cohorts experienced smaller average quality improvement as measured by reduced mortality risk. Thus, as expected (given that the Japanese sample of working-age adults had smallest net value), this robustness check holding constant everything except systolic blood pressure, HbA1c and cholesterol constant yields a small negative net value for Japan: spending increases exceeded the monetary value of quality improvement by $146.45 and $163.77, for $50,000 and $100,000 values of a life-year, respectively. This arises because there was negligible change in mortality risk from changes in those biomarkers, especially given the already small baseline risk, that is, for a working-age population with a low mortality rate, estimates of the value of medical care are sensitive to the inclusion or exclusion of health behaviors from the measure of net value, especially over a short period of follow-up such as we have in our sample. For non-elderly populations, inclusion of measures of morbidity and quality of life and/or longer follow-up periods are especially important for identifying the net value of current investments in chronic disease control. Further research into ways of capturing the value of medical care, separate from secular trends in health behaviors and other social and environmental factors, will be important for better understanding the productivity of healthcare.

In addition, because the primary net value results (Table 3) derive from biomarkers in the baseline and final periods for each individual, they cannot be estimated for those who died before the final period. To account for decedents, we calculated an alternative measure of net value based on spending and outcomes per year survived. To illustrate, consider the Hong Kong sample of 90,891 individuals with diabetes, with 5% decedents; cumulative spending of all decedents (including spending in their year of death) averaged $2488 per decedent-year, with a substantially higher amount spent in the last year of life (averaging $14,736 in 2011, or more than 7 times the average spending of survivors of $2029 in the final period, 2012–2014). This robustness check assigns the monetary value of a life-year to each year survived in the study period for all survivors and all decedents, net of their medical spending in all years survived. For this exercise, we use a conservative $25,000 value of a life-year. This is equivalent to attributing to medical care half of survival valued at $50,000 per life-year, or one-quarter of survival valued at $100,000 per life-year. We find that net value remains positive with this approach: the value of cumulative years survived outweighs cumulative spending among both survivors and decedents. Indeed, this method yields a much larger net value per individual with diabetes: $85,732 per diabetic for Japan, $141,969 per diabetic for Hong Kong, and $107,001 per diabetic for Taiwan (The Netherlands sample did not include decedents). Appendix provides more details about the methods for this robustness check.

Taking account of avoided treatment spending

Improvements in medical treatment may also delay the onset of major complications such as stroke and heart disease, leading to improvements in quality of life and reduced spending on treatment for those conditions. In a robustness check with the Japanese data, we explored including the value of avoided treatment spending alongside improvements in survival.

One variant used an older sample and methods directly parallel to the original Mayo Clinic study. This analysis of JMDC Inc. data between 2008 and 2012 included a sample of 4209 working-age adults with type 2 diabetes. Quality was measured in the same way as in the primary analyses: patient-level biomarkers in the baseline and final periods were inserted into the JJRE risk equations to predict 5-year risk. But in this case, we included the risk of stroke and CHD in addition to the risk of death. Any reduction in predicted modifiable risk of stroke or CHD was multiplied by the spending associated with those conditions (higher in the incident year and incremental for every subsequent year living with those complications) to estimate avoided treatment spending. We also employed the conservative assumption that net value would only be positive if the value of improved survival and avoided treatment spending more than offsets actual treatment spending (not predicted modifiable spending).

This robustness check found that control of cardiovascular risk factors improved between 2008 and 2012, with a decline in 5-year modifiable risk of stroke (from 6.0 to 5.8%) and in modifiable fatal risk (from 2.2 to 2.1%) arising primarily in older age cohorts. Mean annual inflation-adjusted spending increased 12% overall and for all cohorts except those aged 60–69. For the overall sample of 4209 individuals, the value of avoided stroke spending offsets 74% of the increase in medical spending; adding the value of improved survival (and a very small value from reduced CHD spending) offsets the increase in actual spending entirely, yielding a slightly positive net value of $45, at $100,000 per life-year. These results reinforce our conclusion that quality improvements have been at least as valuable as spending increases, even when using actual spending rather than predicted modifiable spending; in other words, a quality-adjusted price index was relatively constant across 2008–2012.

Analysis using the 2010–2014 larger Japanese sample also suggests that net value would be higher if we had incorporated non-fatal outcomes. Modifiable risk of stroke declined overall and for each quintile in the distribution of duration of diabetes, with declines of 14–17% depending on the duration. Similar reductions were observed in modifiable risk of CHD (11–16%) and non-cardiovascular mortality (3–10%). These improvements are sizable compared to

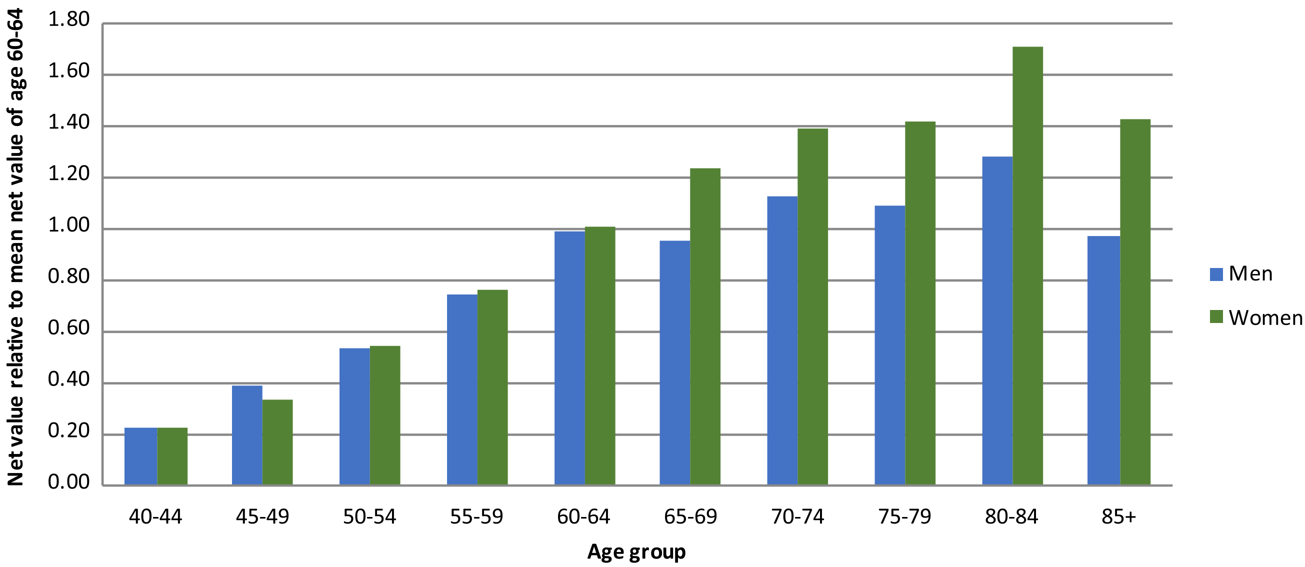

Fig. 2 Net value by sex and age groups, relative to mean net value of age 60–64 individuals in each health system. Note: each column represents the net value of that specific age–sex group relative to the mean (male + female) net value for age 60–64 adults in each health system, averaged with weights corresponding to sample size. Net values for age 70 and older exclude Japan, and thus represent weighted averages of the Netherlands, Hong Kong, and Taiwan samples, weighted by the number of patients in each sample

the slight decrease in modifiable risk of all-cause mortality of −0.0018 percentage points from a baseline risk of 2.01% (i.e., 8.96% reduction in modifiable risk of death, see Table 2). Thus, while the age–sex-standardized net value in the Japanese sample was the smallest among our four health systems, incorporating the value of quality other than mortality reduction would substantially raise the net value, and appears to be particularly important when studying a working age population. A reduction in complications (or compression of morbidity through delay in development of complications) could also contribute to improved work productivity as well as avoided treatment spending.

Discussion

Analyzing over 600,000 patient-years of medical utilization, spending, and biomarker-based health outcomes, we find a small but statistically and economically meaningful positive net value of spending on diabetes management across four distinct health systems. This finding implies that the value of better outcomes more than offsets spending increases, confirming that quality-adjustment matters quantitatively for understanding the value of medical spending.

Our estimates of net value are consistent with, and slightly higher than, those found for the US [12, 13] despite a series of conservative assumptions. First, we do not account for better quality of life or reduced probability of non-fatal adverse endpoints, such as blindness or amputation. Moreover, except for the sensitivity analysis for the Japan sample, our estimates do not include treatment spending avoided through the management of those non-fatal complications. Second, our estimates of net value are positive for a lower range of values for a life-year compared to previous studies, and are robust to attributing to medical care only a fraction of the survival improvements. Third, we included all medical spending, with no attempt to isolate the fraction of spending directly attributable to diabetes. Fourth, our age-standardized sample places greater weight on younger ages than is typical of individuals with diagnosed diabetes, yielding a conservative estimate because the net value is generally increasing with age, at least until 85+ (Fig. 2). Fifth, the estimates do not include the value of improved work productivity arising from good diabetes management, such as less absenteeism and better on-the-job productivity. Finally, we estimate survival gains based on predicted risks and remaining life expectancy after the 5-year window using a life table for the general population; none of the teams had access to life tables estimated for individuals with diagnosed diabetes. We are thus also conservative by assuming mortality rates past the 5-year window follow those of the general population, differencing out any improvement past the 5-year window that is attributable to better medical treatment. Developing and using diabetes-specific life tables would be a desired refinement of the net value estimates, especially for samples with a large proportion of individuals age 80 or older, to see if the rate of mortality improvement relative to the general population by age and sex has changed over time.

Our robustness checks suggest that incorporating the value of secondary prevention would increase the net value of diabetes care on average. The value of health spending could also be improved by investing in cost-effective primary prevention of diabetes [10], hypertension [24], stroke ([15] Lifetime Risk of Stroke Collaborators), and other chronic diseases, including improvement in leading preventable risk factors such as smoking, obesity and lack of physical activity.

Several other studies assessed changes in spending on specific conditions or groups of conditions, often finding that accounting for quality change reduced the spending increase or led to a decline in the quality-adjusted cost of treatment [21, 38]. Net value is similar to the "quality-adjusted cost of care" proposed by Lakdawalla et al. [21], which is "cost growth net of growth in the value of health improvements, measured as survival gains multiplied by the value of survival." In fact, net value is precisely its opposite: net value is positive when quality-adjusted cost decreases, and negative when quality-adjusted cost increases. For example, Lakdawalla et al. [21] estimate that for colorectal cancer, drug cost per patient increased by $34,493 between 1998 and 2005, but value of health improvements offsets most of that spending increase, resulting in the quality-adjusted cost of care increasing by $1377. This equates to a net value of – $1377 for colorectal cancer between 1998 and 2005.

The importance of quality adjustment for medical spending, and its associated disease-specific spending and outcomes, has caught the attention of relevant government statistical agencies. In the US, recommendations from multiple researchers [25] played a role in the US Bureau of Economic Analysis decision to develop the disease-specific Medical Care Expenditure Index [11]. Hall [16] provides a review of the research for the next step: quality-adjusting price indexes for specific medical conditions; she includes a useful taxonomy of process-based adjustments and outcome-based adjustments. Our net value approach falls in the latter, outcome-based category.

Further studies using these methods can help to provide quality adjustment for such disease-specific expenditure accounts, and to probe determinants of relative net value in different settings, such as accountable care organizations or pay-for-performance programs [22]. Such studies can probe some of the areas of innovation for value in chronic disease management that we were unable to address in this study. Those limitations include data that are not necessarily representative of all patients with type 2 diabetes in each health system, different years and age ranges for the different systems, risk prediction models for East Asia that are not yet widely validated,[6] and inability to consistently account for the value of avoiding non-fatal complications. Future research on these topics with other datasets and across diverse heath systems would be valuable, as would be further refinement of methods to account for quality of life among both decedents and survivors.

Conclusion

We find a positive net value of spending on diabetes care across four health systems, slightly greater in magnitude than earlier estimates of net value for diabetes care in the U.S. In other words, the value of quality improvements outweighed additional medical spending on average. If further studies reveal similarly positive net value for spending on other prominent chronic diseases, then it would indicate that quality-adjusted medical prices for chronic disease have been declining. Even a constant quality-adjusted unit cost would suggest that productivity of healthcare for chronic disease has been improving since input prices have been increasing. However, positive average net value does not imply efficiency of all marginal spending increases. Further efforts to measure and reward net value could contribute to innovations that reduce wasteful or low-value spending, support high-value innovations, and provide a better measurement of overall economic activity by understanding quality-adjusted productivity in the health sector.

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Compliance with ethical standards

Conflict of interest The authors have nothing to disclose.

Ethical review The analysis for Japan was reviewed and approved by the Stanford University Institutional Review Board (IRB). For the

[6] Indeed, even for the European system included, when the models used for the Dutch analyses were validated in Dutch diabetes populations by independent research groups in different populations than the current dataset, it was found that UKPDS overestimates cardiovascular risk in more recent Dutch populations.

Netherlands, since this research concerned analysis on secondary and fully anonymous data, no METC approval was required according to Dutch law. The analysis plan was reviewed and approved by both data sources, for VEKTIS by all Dutch health care insurers and for Zodiac by the Zodiac board. The Hong Kong analyses were approved by the seven Hong Kong Hospital Authority cluster IRBs. The analysis for Taiwan was approved by the Chang Gung Memorial Hospital IRB.

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