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Title: Cardiovascular disease and impoverishment averted due to a salt reduction policy in South Africa: an extended cost-effectiveness analysis

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Abstract:

In response to the increasing burden of hypertension-related cardiovascular disease (CVD) in South Africa, the government recently set policy targets to reduce population salt consumption to five grams per person daily. While available evidence suggests that salt reduction could reduce CVD substantially, little is known about the policy's impact on household and public finances. This study uses the extended cost-effectiveness analysis (ECEA) methodology to model the health and economic impact of South Africa's salt policy targets.

Methods and Findings:

We used survey data on blood pressure, income, and salt consumption to estimate changes in age- and sex-specific CVD death rates and incidence using published effect sizes and epidemiologic studies. We modeled the average cost of CVD care by income quintile using published facility fee schedules and drug prices, then estimated total out-of-pocket (OOP) costs and government subsidies averted. We calculated financial risk protection (FRP) in terms of catastrophic health expenditures (CHE) and cases of poverty averted using published thresholds, and we performed a sensitivity analysis.

We estimated that the policy could avert 5500 deaths and 23,000 cases of CVD per year in the population. The government could save up to US$ 51.25 million in subsidies on hypertension and CVD treatment for poorer individuals. Preventing CVD could also provide substantial FRP beyond the government's current subsidy efforts, particularly in income quintiles two, three, and four. Our results were most sensitive to the CVD mortality inputs as well as the CVD cost estimates.

Conclusions:

South Africa's salt policy could reduce total CVD mortality by 11% and result in large government savings. The policy would also protect many households from financial risk, particularly in the middle class. More empirical research is needed on the epidemiology of salt consumption, CVD mortality, and cost of CVD care. Future modeling studies could incorporate estimations of long-term economic impacts. The ECEA methodology is a useful analytic approach to evaluating public health policies, particularly when FRP and equity are of high priority to decision-makers.

INTRODUCTION

Population-based salt reduction strategies have received considerable attention from global health policymakers in recent years.[1] The recent report of the Lancet Commission on Investing in Health highlighted the key role that public policies can play in combating the rise of non-communicable diseases (NCDs) globally.[2] Many have advocated for establishing targets for reducing salt consumption to lower the prevalence of hypertension and thus prevent cardiovascular disease (CVD).[3] In South Africa, exposure to CVD risk appears to be on the rise, in part because of increases in hypertension prevalence and an aging population.[4] Consistent with this trend, recent surveys have also highlighted the increasing prevalence of poor dietary habits such as high salt consumption.[5] In 2011, the South African government proposed several CVD prevention targets, including lowering population salt intake to 5 grams per person daily. They propose to achieve this target through regulating salt content in processed foods and carrying out public media campaigns to lower discretionary salt use.[6]

The government of South Africa also has economic reasons for attempting to reduce CVD risk. CVD is associated with premature mortality and long-term disability,[1] and thus it commonly leads to absenteeism and reduced productivity[7] which result in lower macroeconomic output.[8] CVD treatment in South Africa is also costly and unaffordable to many, and the government subsidizes health care for a large proportion of the population.[9] Despite subsidies, out-of-pocket (OOP) expenditures are significant and have been found to have a disproportionate impact in lower income groups[10] and rural, underserved areas.[11] High OOP expenditures are not unique to South Africa, however: surveys in other developing countries demonstrate population groups with similar inability to pay health care costs, with consequences such as forced asset sales and borrowing.[12] Catastrophic health expenditures are particularly frequent in developing countries for conditions such as CVD that are expensive and less likely to be publicly-financed.[13]

Recently, an analytic approach called “extended cost-effectiveness analysis” (ECEA) has been developed to assess the broader health system impacts of public policies.[14] ECEA goes beyond traditional cost-effectiveness analysis by estimating the socioeconomic distribution of health gains and the financial risk protection (FRP) afforded by policies, in addition to estimating the health impact per public dollar spent.[14-16] ECEA is thus intended to inform priority setting, particularly on diseases that have a socioeconomic gradient or are associated with high OOP expenditures.[14]

Several cost-effectiveness studies have favorably analyzed population salt reduction in a variety of country settings.[17-20] Adding to this literature, an epidemiologic model of reducing salt content in South African food products was recently undertaken, demonstrating that substantial health gains could be realized from modest reductions in targeted food groups.[21] South Africa’s recently-passed salt regulations[22] reflect a new target developed by WHO for prevention and control of NCDs, and provide a unique opportunity to apply the ECEA methodology to a health policy of growing relevance in LMICs. The objective of the present study is to evaluate the health and broader economic impact of South Africa’s policy goal of reducing salt consumption from current levels to five grams per person per day.

METHODS

Overview of model

We use the ECEA modeling approach to quantify the impact of South Africa's salt reduction policy on incident CVD and its related expenditures. The ECEA salt reduction model incorporates the following steps: 1) defining the population at risk of CVD due to high salt intake, including current patterns of salt consumption and blood pressure levels, then estimating 2) the impact of the salt reduction policy on population blood pressure levels, 3) the subsequent change in incidence and mortality from CVD, 4) the reduction in expenditures on CVD attributable to lower incidence, 5) the FRP provided by the policy, and 6) the distributional impact of the policy by income quintile. The principal data inputs and their sources are listed in Table 1 and described in detail in the sections below.

Baseline characteristics of model population

The baseline characteristics of our model population were specified using Wave 3 of the National Income Dynamics Study (NiDS), a nationally representative panel survey of South Africans that was carried out in 2012.[23] We used participants' age, sex, household income, and average systolic blood pressure as baseline variables and divided participants into income quintiles. We then used data from a nutrition survey in Cape Town[24] to assign each cohort member an average salt intake in grams per day based on his or her ethnicity.

For the subsequent steps of the model wherein we estimated health or economic effects of the policy, we calculated a weighted mean effect for each income quintile using individual respondent data and survey weights provided by NiDS investigators. For ease of comparison, we estimated all effects for a cohort of one million adults divided into five income quintiles. We also used the most recent South African census data[25] to scale the estimated impact in our one million member cohort to the general population of approximately 13.77 million adults over forty years.

Effect of the salt policy on blood pressure

We calculated the mean change in salt consumption from current levels to the government's target of 5 grams per day across each quintile. We then estimated the impact of sustained salt reduction on long-term blood pressure using regression coefficients from a recent meta-analysis, including an accentuated blood pressure response to salt reduction among persons with hypertension.[26]

Cardiovascular disease averted by the salt policy

We defined four major CVD outcomes related to hypertension that are relevant in sub-Saharan Africa: stroke, ischemic heart disease (IHD), hypertensive heart failure (HHF), and end-stage renal disease due to hypertension (ESRD). We used published age- and sex-specific death rates from each of these CVD outcomes (based on vital statistics)[27] to estimate the CVD risk in each quintile. We then back-calculated the incidence of each outcome using regional case-fatality rates (CFRs),[28-31] after the method used in the 2000 Global Burden of Disease Study.[29] Because we used one-year mortality and incidence rates, we present all health and economic effects as one-year estimates.

We then estimated the policy's effect on reducing the incidence and mortality from the four CVD outcomes using age- and sex-specific hazard ratios from the South African Comparative Risk Assessment study[32] on hypertension and an observational study of vascular mortality related to blood pressure level.[33] Equations describing the calculation of health gains can be found in Supplementary Appendix 1.

Calculation of out-of-pocket medical costs

South Africa's health system is a hybrid of public and private facilities.[9] The cost of care at public facilities is partially subsidized by the government, and resulting OOP fees are determined on a sliding scale based on income and some categorical factors.[34] At private facilities, insured individuals are charged co-pays according to their medical insurance scheme; uninsured individuals are expected to pay all facility fees OOP if they are to receive care.[35] Hence, the OOP cost of CVD care in South Africa varies widely based on facility type, income level, and eligibility for subsidies. The payer mix used in our model is illustrated in Figure 1, and the algorithm we used to assign cohort members to payer categories is described in Supplementary Appendix 2.

We compiled a list of cost ingredients for each CVD outcome based on local treatment guidelines,[36,37] registry data,[30,38] and consultation with local specialists. For each ingredient, we used published fees for public[34] and private[39] facilities and converted these to OOP costs based on payer category subsidy rates. CVD outcome costs by quintile are given in Table 2, and the details of the costing methodology are given in Supplementary Appendix 3.

Private expenditures and government subsidies averted by the salt policy

We estimated the total OOP expenditures averted during the first year after incident CVD in our cohort using the expected cost and reduction in incidence of the four CVD outcomes. We also estimated the government subsidies averted by calculating the total amount of subsidy for each case of CVD in each payer category. We separately estimated the reduction in government subsidies for hypertension treatment by calculating the amount of subsidy the government would no longer pay if blood pressure levels were reduced. (For individual cases of CVD averted, we estimated the hypertension treatment costs separately from the CVD treatment costs.) Equations describing the calculation of costs averted can be found in Supplementary Appendix 1.

Financial risk protection provided by the salt policy

We estimated FRP using two separate metrics: cases of catastrophic health expenditure (CHE) averted and cases of poverty averted. To remain consistent with other South African studies,[10,11,40] we defined CHE as any case of CVD expenditure exceeding ten percent of total yearly household income. We defined CVD expenditure as impoverishing if it reduced individual income below the poverty line. While no official poverty line exists for South Africa, recent estimates have been published based on food and essential non-food expenditures.[41] For this analysis, we used a published poverty line of US$ 78 (2012) per person monthly, which estimated that 37.5 percent respondents (most of quintiles one and two) currently live in poverty. Equations describing the calculation of FRP can be found in Supplementary Appendix 1.

Sensitivity analysis

We performed a univariate sensitivity analysis on key epidemiologic and cost parameters to test their impact on our results. The ranges used in the analysis are given in Tables 1 and 2. For salt intake,[24] blood pressure reduction regression coefficients,[26] CVD death rates,[27] and CVD hazard ratios,[32,33] we used confidence intervals provided in the original studies. For the stroke[28] and HHF[30] CFRs, we also used ranges provided in the original studies. No CFR ranges were available from the studies on IHD[29] or ESRD,[31] so we used the published difference between high-income European CFRs and African CFRs to establish the high and low boundaries for IHD,[29] and used proportional variation in HHF CFRs from the literature[30] to establish the high and low boundaries for ESRD. For cost, we used a lower bound of 50 percent of the original cost and an upper bound of 200 percent of the original cost.

We also tested the sensitivity of poverty cases averted to two lower poverty lines, US$ 36 per person monthly and US$ 53 per person monthly.[41] To place our FRP estimations in context, we reassigned all subsidized cohort members to the full OOP cost of care and re-calculated the CHE and poverty cases averted; the difference between these results and the original CHE and poverty cases reflects the current FRP provided by the government. Finally, older literature from South Africa suggests that not all patients seek care when ill, and poorer individuals more so than others.[42] Unfortunately, there are no recent nationally representative estimates of care-seeking behavior, either among older adults or those with chronic diseases. Thus although in our main model we assumed all patients receive care, we tested the sensitivity of expenditures averted and FRP to proportional decreases in service utilization.

Other methods

We constructed and ran the model in STATA v. 13.0 (College Station, TX). All costs were inflated to and reported in 2012 US dollars. Because this study only estimated 1-year expenses on incident CVD, costs were not discounted. We used publicly accessible data, so no additional ethics approval was required.

RESULTS

Health gains

The major health and economic gains that could be achieved by the policy are summarized by income quintile in Table 3. In a model cohort of one million South African adults, the policy averted 403 deaths and 1680 cases of CVD per year. The distribution of deaths averted was 39 percent stroke, 34 percent HHF, 23 percent IHD, and 4 percent ESRD. The distribution of cases averted was 35 percent stroke, 52 percent HHF, 8 percent IHD, and 5 percent ESRD.

The distribution of the policy's impact in our cohort is illustrated further in Figure 2. Health gains were fairly evenly distributed across income quintiles, except for a slightly lower impact in quintile one. The age structure of this quintile was skewed towards younger adults than the other quintiles, and it was also comprised of more black African members, whose salt consumption was lower than other groups, hence the lower overall risk of CVD and impact of reducing in this group. Age-specific effects by quintile are given in Supplementary Appendix 4.

Private expenditures and government subsidies averted

In total, US$ 294,856 in out-of-pocket expenditures per year were averted in the cohort. Most of the expenditures averted were in quintiles four and five, in which individuals were much more likely to seek more-expensive private care or receive unsubsidized care in public facilities. On the other hand, US$ 2.52 million in government subsidies on CVD care per year (for stroke, IHD, HHF, and ESRD combined) were averted in the cohort. In contrast to the private expenditures, most government savings were on individuals in quintiles one through four. The vast majority of savings were on care for stroke and HHF, which, though less expensive on average than IHD and ESRD, were much more common. In addition, we calculated the reduction in government subsidies on hypertension treatment alone (i.e., in excess of the CVD subsidies) to be US$ 1.197 million per year.

Financial risk protection provided

When we estimated FRP using the CHE metric, 175 cases of CHE per year were averted in the cohort; using the poverty line metric, 144 cases of poverty per year were averted. As in the expenditure analysis, the higher proportion of HHF and stroke cases was the main driver of the FRP estimates. Figure 2 illustrates the distributional impact of the FRP provided by the policy. No cases of poverty were averted in the poorest quintile, since everyone in this quintile already lived in poverty; however, large gains would be realized in the middle income quintiles, especially quintile 2, which was most susceptible to medical impoverishment. More CHE cases were averted in the upper income quintiles; again, these results were driven by the larger expenses associated with private care. However, only two cases of poverty were averted in the highest quintile.

To put these results in context, we also calculated the current FRP provided by the government for CVD care attributable to salt intake. Without the large government subsidies on care, 1243 cases of CHE and 798 cases of poverty would be averted by the policy. Thus the policy in itself averts an additional 12% of cases of CHE and 15% cases of poverty beyond the government's existing subsidy efforts.

Sensitivity analysis

In the univariate sensitivity analysis, the health gains were most sensitive to the variation in death rates from CVD and least sensitive to the variation in hazard ratios for lower blood pressure. The economic gains were most sensitive to the variation in cost of CVD care and relatively insensitive to the epidemiologic inputs. The sensitivity analysis for deaths averted and poverty cases averted is given in Figure 4 for illustrative purposes; the remaining tornado diagrams can be found in Supplementary Appendix 5.

In addition to the main sensitivity analysis, we also modeled FRP using lower poverty lines of US$ 53 per person monthly and US$ 36 per person monthly. Under these assumptions, the policy reduced the poverty cases averted by 56 percent and 53 percent, respectively. In these scenarios, the baseline proportion already impoverished was 22.7 and 10.5 percent of the population, respectively. Finally, when we modeled lower rates of service utilization, cases of CHE or poverty averted and government subsidies averted were reduced by approximately the same percentage, e.g., if 15 percent of individuals did not seek care, FRP and government subsidies would be reduced by about 15 percent.

DISCUSSION

We analyze the economic impact of a real-world salt reduction policy at a time when targets similar to South Africa's are rapidly gaining traction globally.[3] We show that a non-communicable disease (NCD) policy can improve health in all income groups, though with different economic effects in each group. Additionally, we demonstrate that efforts to reduce population salt consumption can result in substantial cost savings to a government that heavily subsidizes CVD care.

Consistent with prior models,[18,21] our study demonstrates that considerable reductions in CVD risk in South Africans could be achieved by reducing salt consumption. The most recent South African census estimates 13.77 million adults over the age of forty.[25] Our cohort estimates would thus translate into a much larger effect in the current South African population, including 5551 deaths and 23,129 cases of CVD averted.

Viewed another way, the policy could avert up to 11% of the 49,966 deaths[27] from the four major CVD outcomes in South Africa in 2010. This salt policy will be a key piece of the so-called “25 by 25” agenda for reducing NCDs in South Africa.[1]

In addition to the modeled health benefits, we also demonstrated large out-of-pocket savings, public savings, and substantial financial risk protection from CVD expenses. Based on census data, the economic impact of the salt policy in the current population could include US$ 4.06 million in out-of-pocket expenditures on CVD averted, US$ 34.75 million government subsidies on CVD averted, and US$ 16.50 million in government subsidies on hypertension averted. The sum total of hypertension and CVD subsidies averted, then, could be US$ 51.25 million. The potential number of cases of CHE and poverty averted could be 2410 and 1988 cases, respectively.

While many salt reduction models focus on IHD and stroke reduction, we included HHF in our analysis, which is the most common hypertension-related CVD outcome in sub-Saharan Africa.[43] Much of the overall health and economic impact of salt reduction in our model – between 30-50 percent, in fact – was mediated through the reduced burden of HHF. Future analyses of CVD prevention in the African region should consider this under-appreciated condition as a key NCD target.

In the context of health system strengthening, our analysis indicates that the South African government’s current efforts to provide FRP to poorer households through subsidized CVD care seem to be effective, though at a high cost of US$ 34.75 million per year to care for CVD attributable to high salt intake. Furthermore, the government is currently piloting a national insurance scheme[44] to further expand access to affordable care – an initiative which, while laudable, is certain to increase CVD cost to government.

Our analysis demonstrates that investing in CVD prevention can bring substantial cost savings and create the fiscal space to invest in other NCD public policies.

While the total cost of the salt policy is not yet known, the most expensive components (including media campaigns) have been estimated at US$ 2 million per year (M. Freeman, personal communication – March 2013). To date, estimates have not been produced on the cost of enforcing the industry regulations; however on balance, any additional expenditure less than the total government subsidies averted – US$ 14.5 million per year considering hypertension alone or US$ 49.25 million after adding the CVD subsidies – would likely be cost saving. Our analysis thus adds to the growing body of literature that demonstrates that salt reduction policies can be highly cost-effective and even cost saving in both developed[19,45] and developing[18,20,46] settings.

The most novel component of our analysis is the estimation of FRP and distributional consequences of the salt policy. While the health gains were fairly uniform throughout the population, the middle three income quintiles – which include the vast majority of cases – experienced a substantial increase in FRP on CVD expenditure by reducing their salt consumption. Although we only used direct medical costs in our calculations of catastrophic and impoverishing expenditures, it is conceivable that averted cases of long-term disability (not modeled) would further add to the total FRP provided.

Our analysis has several important data limitations. First, the epidemiologic data have a high degree of uncertainty, which we attempted to place bounds on by performing a sensitivity analysis. However, it is conceivable that in remote locations salt consumption patterns or CVD rates might be lower, or perhaps much higher than our input parameters suggest. Furthermore, in the absence of longitudinal cohort data, we were only able to model short-term impacts on CVD epidemiology, and we do not know whether salt reduction might result in net harm to select subpopulations (e.g., individuals with advanced heart failure)[17] and reduce the net health gains. Second, the true OOP cost of CVD care is not known. It is possible that complications and comorbidities could result in much higher average costs than those we modeled, or alternatively that poor access to standard-of-care treatment could result in lower average costs than those we modeled. In light of the rapid increase in NCDs in South Africa, there is urgent need to gather empirical cost estimates on CVD to inform economic models and resource allocation.

Our results should also be interpreted with some caution. First, our analysis assumes that the salt policy is completely effective at achieving its goals and that individuals' dietary patterns change uniformly across income groups. In reality, careful monitoring and evaluation should be undertaken to ensure that this policy is actually effective; the evaluation efforts can inform policy decisions in other countries considering packages of NCD interventions. An additional caution from an economic perspective is that we were not able to model FRP by other, potentially more important metrics, e.g., distress financing or shifts in household resource allocation (e.g., away from food, education, and other essential goods and services).[47] Nor were we able to account for potentially significant changes in labor productivity (from the household perspective) or health system workforce (from the government perspective). Data permitting, future analyses could develop methodologies to incorporate these sorts of economic effects.

CONCLUSION

Shifting population salt consumption to a target distribution of five grams per person daily could avert approximately 5500 deaths and 23,000 cases of CVD per year in the South African population. The government could save up to US$ 51.25 million in subsidized care for poorer individuals, which suggests that on balance the policy would be cost-effective and perhaps cost saving. Preventing CVD would also provide substantial FRP to individuals at risk of catastrophic and impoverishing OOP expenditure, particularly in the middle class. There is a need for more empirical data to quantify the OOP cost of CVD care in developing countries and to develop models that can estimate the long-term health and economic impact of preventing chronic, non-communicable diseases.

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FINANCIAL DISCLOSURE

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AUTHOR CONTRIBUTIONS

Developed the ECEA methodology: SV and DJ. Conceptualized the analysis and coded the model: DW and ZO. Collected the data: DW. Produced the manuscript: DW.

Provided intellectual input and reviewed the manuscript: SV, RN, and DJ. Supervised the research team: RN and DJ.

COMPETING INTERESTS

The authors declare no competing interests.

ABBREVIATIONS

NCD = non-communicable disease

CVD = cardiovascular disease

OOP = out-of-pocket

ECEA = extended cost-effectiveness analysis

FRP = financial risk protection

NiDS = National Income Dynamics Survey

IHD = ischemic heart disease

HHF = hypertensive heart failure

ESRD = end-stage renal disease

CFR = case fatality rate

CHE = catastrophic health expenditure

USD = United States dollars

FIGURES

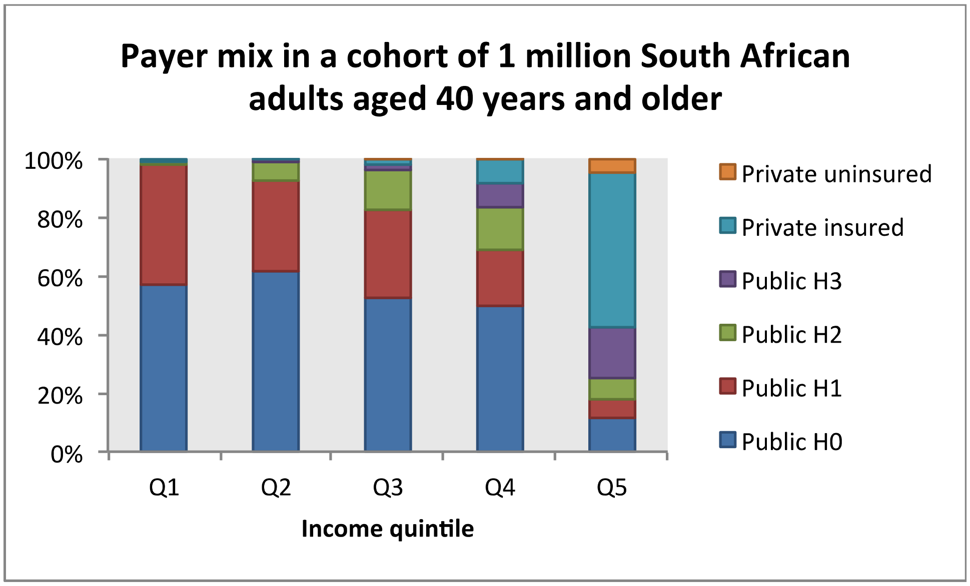

Figure 1. Payment for health services in South Africa: mix of payer categories in a cohort of 1 million adults aged 40 years or older, based on data from the National Income Dynamics Study, Wave 3.[22] H0, H1, H2, and H3 refer to sliding scale payer categories at public facilities where H0 is fully subsidized, H1 and H2 are partially subsidized, and H3 is unsubsidized. Q1 = lowest income quintile; Q5 = highest income quintile.

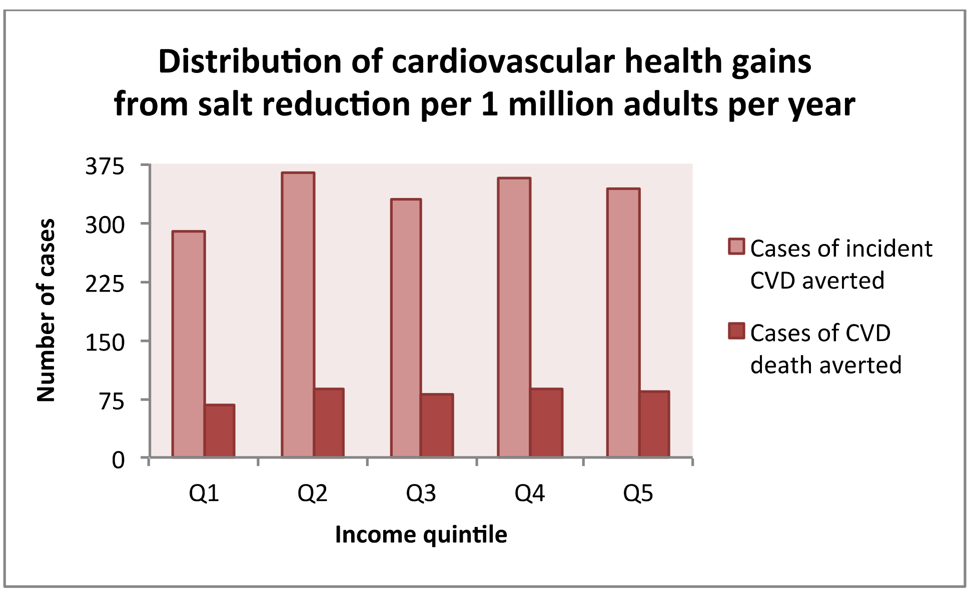

Figure 2. Distribution of potential deaths and incident cases of cardiovascular disease (CVD) averted by a salt reduction policy in South Africa. Q1 = lowest income quintile; Q5 = highest income quintile.

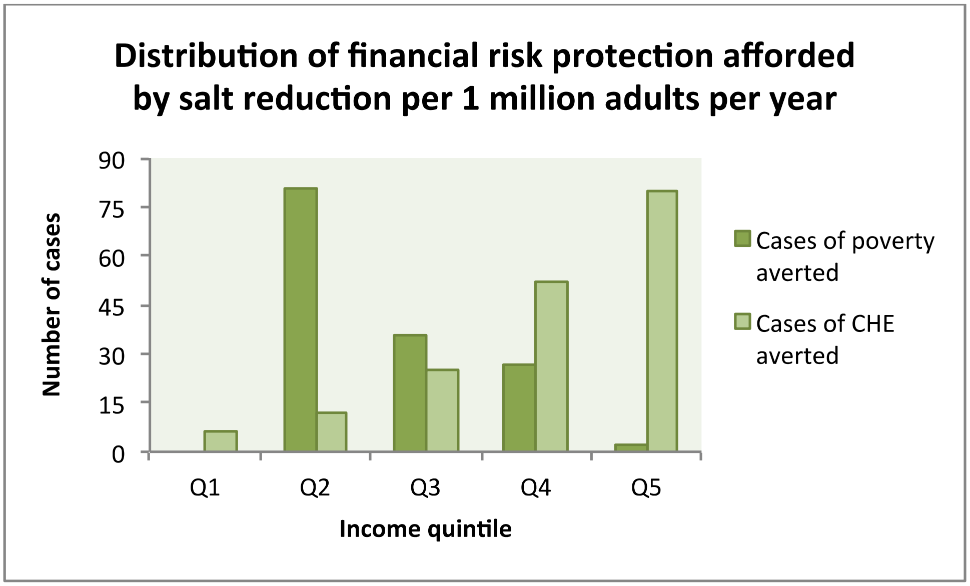

Figure 3. Distribution of potential financial risk protection from cardiovascular disease expenditure provided by a salt reduction policy in South Africa. Financial risk protection is measured separately as cases of catastrophic health expenditure (CHE) or impoverishing health expenditure. Q1 = lowest income quintile; Q5 = highest income quintile.

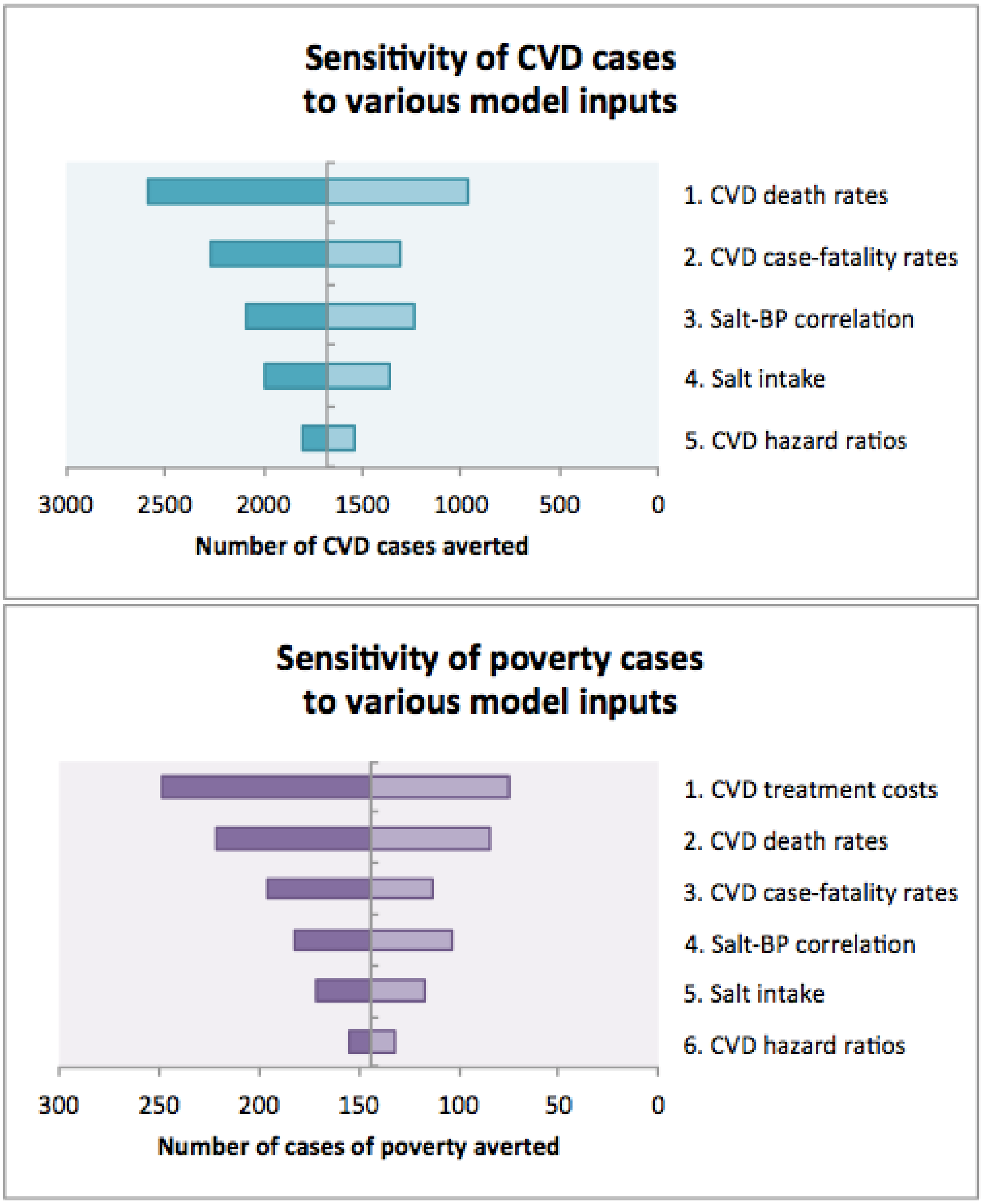

Figure 4. Sensitivity of estimates of deaths averted and poverty cases averted to variation in key model inputs

TABLES

Table 1. Main health-related inputs and parameters for the extended cost-effectiveness analysis.

Data input [reference]	Mean value per income quintile					Range used in sensitivity analysis
	Q1	Q2	Q3	Q4	Q5	
Prior mean salt intake, g/day [23]	7.8	7.9	7.9	8.0	8.6	7.3-10.5
Prior mean SBP, mmHg [22]	131.2	133.7	134.1	137.2	132.6	N/A
Mean SBP change, mmHg [25]						
Hypertensive individuals	-3.4	-3.4	-3.5	-3.6	-4.4	0.9-1.5
Mean SBP change, mmHg [25]						
Normotensive individuals	-1.7	-1.7	-1.7	-1.8	-2.1	0.3-0.9
CVD death rate* per 100,000[26]						
Stroke	1646	2079	1850	1823	1437	959-2849
IHD	1106	1424	1319	1310	1085	723-2073
HHF	704	881	778	760	591	305-1460
ESRD	88	110	104	101	90	51-186
Average CVD risk reduction achievable by policy [31,32]						
Stroke	0.08	0.08	0.08	0.09	0.10	0.02-0.19
IHD	0.07	0.07	0.07	0.07	0.08	0.03-0.16
HHF	0.16	0.16	0.16	0.18	0.19	0.09-0.33
ESRD	0.16	0.16	0.16	0.18	0.81	0.09-0.33
CVD case-fatality rate						
Stroke [27]	0.266	0.266	0.266	0.266	0.266	0.180-0.350
IHD, male [28]	0.620	0.620	0.620	0.620	0.620	0.410-0.830
IHD, female [28]	0.720	0.720	0.720	0.720	0.720	0.470-0.970
HHF [29]	0.155	0.155	0.155	0.155	0.155	0.124-0.194
ESRD [30]	0.230	0.230	0.230	0.230	0.230	0.184-0.288

SBP = systolic blood pressure, CVD = cardiovascular disease, IHD = ischemic heart disease, HHF = hypertensive heart failure, ESRD = end-stage renal disease. Q1 = poorest quintile, Q5 = wealthiest quintile.

*Death rate ranges reflect the highest and lowest death rate used for any of the five quintiles.

Table 2. Main cost inputs and parameters for the extended cost-effectiveness analysis, including ranges used in sensitivity analysis.

Yearly cost [reference]	Mean value per income quintile Q1	Q2	Q3	Q4	Q5
Hypertension	$2	$4	$7	$12	$24
(Range)	(1-5)	(2-7)	(3-13)	(6-23)	(12-48)
Stroke	$18	$39	$100	$288	$863
(Range)	(10-42)	(21-82)	(54-215)	(162-649)	(565-2260)
IHD	$22	$52	$128	$338	$992
(Range)	(13-53)	(28-111)	(71-283)	(201-805)	(730-2919)
HHF	$15	$29	$74	$212	$638
(Range)	(8-31)	(15-59)	(37-149)	(108-432)	(332-1333)
ESRD	$151	$221	$388	$630	$1731
(Range)	(75-301)	(111-442)	(194-262)	(315-1261)	(866-3462)

For details of the costing methodology, assumptions, and data sources, please see Supplementary Appendix 3.

*All costs are reported in 2012 US dollars

Table 3. The extended cost-effectiveness analysis dashboard: major health and economic impacts of salt reduction in a cohort of one million South Africa adults.

	Q1	Q2	Q3	Q4	Q5	Total
CVD deaths averted	69	86	79	86	83	403
OOP expenditures averted, US$ thousands*	$3.75	$9.92	$13.58	$45.74	$221.86	$294.86
Government subsidies averted, US$ thousands*	$524.98	$654.50	$590.20	$583.40	$170.78	$2523.85
CHE cases averted	6	12	25	52	80	175
Poverty cases averted	0	81	35	27	2	145

CVD = cardiovascular disease, OOP = out-of-pocket, CHE = catastrophic health expenditure.

*All costs are reported in 2012 US dollars.

SUPPLEMENTARY MATERIALS

Supplementary Appendix 1. Equations describing extended cost-effectiveness analysis calculations.

As described in the main text, we used individual-level survey data to estimate the health and economic effects of the salt policy by quintile. We report health and economic effects per quintile, so respondents were characterized by income quintiles q based on household income per capita, y_i. Survey weights for each respondent were used in conjunction with STATA's mean function to estimate weighted mean effects by quintile.

Deaths and cases of CVD averted
Risk of each of the CVD outcomes is age- and sex-specific, so we assigned death rates and hazard ratios to each survey respondent n_i based on these parameters. The number of deaths averted per quintile from a given CVD outcome ($D_{av,q}$) is given as:

$$D_{av,q} = \frac{200{,}000}{n_q} * \sum_{i=1_q}^{n_q} \left(1 - HR_{iq}\right) * M_{iq}$$

Where HR_{iq} is the age- and sex-specific hazard ratio for the i^{th} individual in wealth quintile q of the cohort, M_{iq} is the age- and sex-specific mortality rate from stroke or IHD for that individual, and $n_q$is the number of individuals in the NiDS who represent the 200,000-member quintile.

The number of CVD cases averted per quintile ($K_{av,q}$) by the salt reduction policy is given as:

$$K_{av,q} = \frac{D_{av,q}}{CFR}$$

Where CFR is the case-fatality rate from any of the CVD outcomes.

Private expenditures and government subsidies averted
OOP costs for the four CVD outcomes are also payer- and disease-specific, so we assigned each respondent n_i we assigned an OOP cost based on his or her payer category. The reduction in OOP expenditures per quintile from a given CVD outcome ($OOP_{av,q}$) is given as:

$$OOP_{av,q} = \frac{200{,}000}{n_q} * \sum_{i=1_q}^{n_q} \left(1 - HR_{iq}\right) * P_{iq} * C_{iq}$$

Where P_{iq} is the age- and sex-specific incidence of stroke or IHD and is given as:

$$P_{iq} = \frac{M_{iq}}{CFR}$$

And C_{iq} is the OOP cost of the CVD outcome to the i^{th} individual in income quintile q of the cohort.

The reduction in government expenditures per quintile ($Pub_{av,q}$) due to the salt reduction policy is given as:

$$Pub_{av,q} = \frac{200{,}000}{n_q} * \sum_{i=1_q}^{n_q} \left(1 - HR_{iq}\right) * P_{iq} * \begin{cases} (C_{H3} - C_{iq})\ if\ C_{H3} - C_{iq} > 0 \\ 0\ if\ C_{H3} - C_{iq} \leq 0 \end{cases}$$

Where C_{H3} is the OOP cost of stroke of the CVD outcome to individuals in public payer category H3.

Financial risk protection provided

The number of cases of catastrophic health expenditure (i.e., exceeding 10% total yearly household income) averted per quintile from a given CVD outcome ($CHE_{av,q}$) is given as:

$$CHE_{av,q} = \frac{200{,}000}{n_q} * \sum_{i=1_q}^{n_q} \left(1 - HR_{iq}\right) * P_{iq} * \begin{cases} 1\ if\ C_{iq}/(y_{iq}x_{iq}) \geq 0.1 \\ 0\ if\ C_{iq}/(y_{iq}x_{iq})\ < 0.1 \end{cases}$$

And y_{iq} is yearly household income per capita and x_{iq} is household size.

Similarly, the number of cases of poverty averted per quintile ($Pov_{av,q}$) by the salt reduction policy is given as:

$$Pov_{av,q} = \frac{200{,}000}{n_q} * \sum_{i=1_q}^{n_q} \left(1 - HR_{iq}\right) * P_{iq} * \begin{cases} 0\ if\ y_{iq} < PL \\ 1\ if\ y_{iq} - C_{iq} \leq PL \\ 0\ if\ y_{iq} - C_{iq} > PL \end{cases}$$

Where PL is the poverty line.

Supplementary Appendix 2. Determining payer mix for each income quintile.

As described in the main text, health care in South Africa is delivered through both public and private facilities. Out-of-pocket payments in public facilities are calculated based on a sliding scale of income and eligibility for free care as described below. Patients carrying insurance are charged co-pays according to the care received. Uninsured patients who wish to receive private care are only treated in private facilities if they have means to pay the full cost of care. Many such individuals are transferred to public facilities if they do not have means to pay.

In our model, "uninsured" cohort members are those who (according to the NiDS) reported a preference for private facilities, do not carry health insurance, and have sufficient income to pay the full cost of private care for stroke or IHD. Similarly, "insured" individuals are those who reported a preference for private facilities but carry health insurance and are thus eligible to pay only co-payments.

Private care patients make up a small percentage of our cohort, with most individuals receiving care at public facilities. These facilities use a sliding scale classification system of H0, H1, H2, or H3 and charge patients at the appropriate payer rate for each item or service consumed. In our model, individuals were classified as H0 – H3 if they reported preference for public facilities (according to the NiDS); or if they reported a preference for private facilities but had neither health insurance nor sufficient income to pay the full cost of private care for CVD.

Individuals eligible for H0 status (free care) include the elderly, those receiving child support, veterans, care-dependent persons, individuals with permanent disabilities, individuals in foster care, and the formally unemployed. These persons receive care free of charge in public hospitals if they can provide proof of their exempt status.

H1 individuals receive highly subsidized care upon proof of household income less than 50,000 rand per year (US$ 6095 in 2012; 1 rand = 0.1219 dollars). This is also the default payer category for individuals who cannot provide proof of income or H0 status at the point of care. H2 individuals receive partially subsidized care upon proof of household income between 50,000 – 100,000 rand (US$ 6095 – 12,190) per year. H3 individuals pay full hospital fees.

Figure 1 in the main text illustrates the proportion of individuals in our cohort who pay the rates described above. Most individuals in the lower income quintiles receive free care or pay highly subsidized rates. Conversely, there is a high demand for private care in the two highest income quintiles.

Please see the main text for references on the structure of the South African health care system. Please see Supplementary Appendix 3 for details of the costing methodology for cardiovascular disease treatment in each payer category.

Supplementary Appendix 3. Costing methodology.

To date, there are no empirical studies on the out-of-pocket cost of CVD care in South Africa. However, user fee schedules are publicly available both for public facilities and for some private facilities.[33,34] We modeled the average OOP cost of CVD care in each payer category for each of our four CVD outcomes: stroke, IHD, HHF, and ESRD.

We first developed a list of cost ingredients based on published treatment guidelines as referenced in the main text. Where ambiguity existed as to treatment standards, we consulted local specialist physicians to determine standard practices. We acknowledge that many patients might not receive best-practice care, particularly patients in less-resourced facilities, thus our ingredients lists are somewhat idealized. We also acknowledge that the ingredients approach may underestimate treatment costs because comorbidities and complications are not included. Finally, we assumed a uniform distribution of incident CVD over the entire year, such that the average individual would pay for six months of chronic outpatient treatment in addition to acute CVD events.

Facility costs
For acute stroke, heart attack, and heart failure treatment, we assumed that all patients would be taken to the nearest health facility by emergency medical services. All patients would be triaged in an emergency department. All stroke and IHD patients would be admitted to an intensive care unit (ICU) for 24 hours for stabilization and then would spend another five or four days on a general ward, respectively (K. Moeketsi, personal communication – Dec 2012). We estimated that 10% of HHF patients would be admitted to an ICU for cardiogenic shock and be stabilized over two days, then spend another five days on a general ward. The remaining 90% of HHF patients would spend seven days on a general ward.[29]

There are no studies on inpatient management of chronic kidney disease in South Africa. We assumed that ESRD patients would incur the majority from of day admissions to a renal dialysis unit (three times weekly) rather than from acute kidney injury hospitalization, thus we only considered outpatient facility and provider costs for ESRD. Of note, we did not include dialysis costs for ESRD cases over 60 years, as such individuals are not be eligible for long-term dialysis (B. Rayner, personal communication – Nov 2013).

For outpatient care, we assumed all patients would incur six months of secondary prevention costs following initial hospitalization. We thus included two primary health clinic assessments in the outpatient fees. Additionally, we recognized that some patients would receive care at level 2 and level 3 facilities, which are more expensive. We thus used survey data to create weighted average costs based on the proportion seeking care at each level.[9]

Provider costs
For inpatient admissions, we assumed that all patients would be evaluated by an emergency department physician, an intensive care specialist (where applicable), and a general ward physician. When sedation was required for procedures, we included anesthesiologist

consultation fees. We further assumed that IHD patients would receive a cardiology consultation and stroke patients would receive physical and occupational therapy services. We included technician fees and radiologist consulting fees for imaging studies. We also included nursing fees where appropriate.

For outpatient care, in addition to primary care assessments for all patients, we assumed that IHD patients would also be referred to a cardiologist once and that that ESRD patients would be assessed by a nephrologist at least once monthly.

Diagnostic and treatment costs
The fee schedules above outline pharmacy dispensary fees but not the cost of medications themselves. In order to calculate drug costs, we obtained price lists for all standard generic CVD medications from Groote Schuur Hospital (W. Bryant, personal communication – Dec 2012) and the University of Cape Town Private Academic Hospital (T. Ferger, personal communication – Feb 2013) for public and private facilities, respectively.

For stroke patients, we assumed 70% of strokes were ischemic and the remaining 30% hemorrhagic.[26] We assumed that all patients would receive appropriate neuroimaging (CT scan and/or cerebral angiography) and that 1% of patients would be eligible for fibrinolytic therapy with alteplase (B. Mayosi, personal communication – Dec 2012). We included electrocardiography, carotid duplex ultrasonography, and transthoracic echocardiography in the routine stroke workup. We included the cost of aspirin and hydrochlorothiazide for both acute and chronic stroke treatment, and we included the cost of simvastatin and warfarin for select patients with lipid disorders or atrial fibrillation.[36]

For IHD patients, we used published registry data on acute coronary syndrome treatment in South Africa to determine practice patterns and thus cost ingredients.[37] We assumed 40% ST-elevation myocardial infarction and 60% non-ST-elevation acute coronary syndrome and distributed the proportion of patients receiving thrombolytics, cardiac catheterization, coronary stenting, and anticoagulation according to registry data. We assumed all patients underwent transthoracic echocardiography as well as chest radiography and electrocardiogram. We also included the cost of aspirin, clopidogrel, beta-blockers, and simvastatin according to the frequency of usage reported in the registry. Finally, we assumed that 8% of IHD patients would be eligible for coronary artery bypass graft surgery and thus added this to the total weighted average IHD cost.

For HHF patients, we followed a similar approach to the IHD methodology as registry data for heart failure in sub-Saharan Africa have recently been published.[29] We assumed all patients with new-onset heart failure underwent echocardiography, chest radiography, electrocardiogram, and noninvasive stress testing to exclude ischemia. For inpatients in cardiogenic shock, we assumed dobutamine and nitrate infusion while in ICU. For all patients, we assumed diuretic infusion gradually tapered to oral therapy at discharge, as well as digoxin for some according to registry data. For outpatient therapy, we included the cost of angiotensin-converting enzyme inhibitors, beta-blockers, diuretics, digoxin, and spironolactone according to the frequency used in the heart failure registry. For both HHF and IHD, we did not consider include the potential cost of cardiac transplantation, since this is infrequently available.

For ESRD patients, we included the cost of renal ultrasound and urinalysis in the initial workup, as well as placement of a permanent dialysis catheter. We assumed all eligible patients would undergo hemodialysis three times weekly. We assumed all patients would be taking erythropoiesis-stimulating agents and phosphate binders. We did not consider the potential cost of renal transplantation, since this is infrequently available.

Finally, for the routine management of hypertension, we included ingredients listed in the latest South African hypertension guidelines [35] including electrocardiogram, urine dipstick, serum chemistries and glucose. We assumed that 50% of patients would be on hydrochlorothiazide alone and the remainder on two drugs: hydrochlorothiazide and either of amlodipine or enalapril. Aside from antihypertensive use for specific CVD indications (e.g., enalapril for left ventricular dysfunction), we considered all hypertension costs separately from CVD treatment costs.

We assigned private uninsured patients the total cost of private care. We multiplied this total cost by 13.9% to obtain the average co-pay amount that insured patients would pay out-of-pocket based on the South African National Health Accounts (available at http://www.who.int/nha/country/zaf/en/).

Table 1. OOP costs of hypertension and CVD outcomes per payer category.

Payer category	Hypertension	Stroke	IHD	HHF	ESRD
H0	0	0	0	0	0
H1	5	24	27	22	324
H2	29	360	519	252	1661
H3	60	2043	2240	1523	3402
Private insured	12	532	625	392	1701
Private uninsured	87	3830	4494	2822	23643

All costs are given in 2012 US dollars. Please see Supplementary Appendix 2 for descriptions of the payer categories and methodology.

Supplementary Appendix 4. Age structure and ethnic composition of the cohort by income quintile.

Table 1. Age structure of the cohort by income quintile.

Age group	Q1	Q2	Q3	Q4	Q5
40-44 years	18	16	19	16	22
45-49 years	19	16	15	16	20
50-54 years	19	14	14	16	17
55-59 years	15	14	15	12	14
60-64 years	10	12	12	14	10
65-69 years	6	8	9	10	6
70-74 years	5	9	8	7	5
75-70 years	3	5	4	4	3
80+ years	3	5	6	4	3

Values are given as percentages.

Table 2. Ethnic composition of the cohort by income quintile.

Ethnic group	Q1	Q2	Q3	Q4	Q5
African	93	89	79	75	54
Mixed ancestry	7	10	20	22	19
Asian/Indian	0	0	1	2	4
White	0	0	0	2	23

Values are given as percentages.

Supplementary Appendix 5. Univariate sensitivity analysis of key model inputs not provided in the main text.

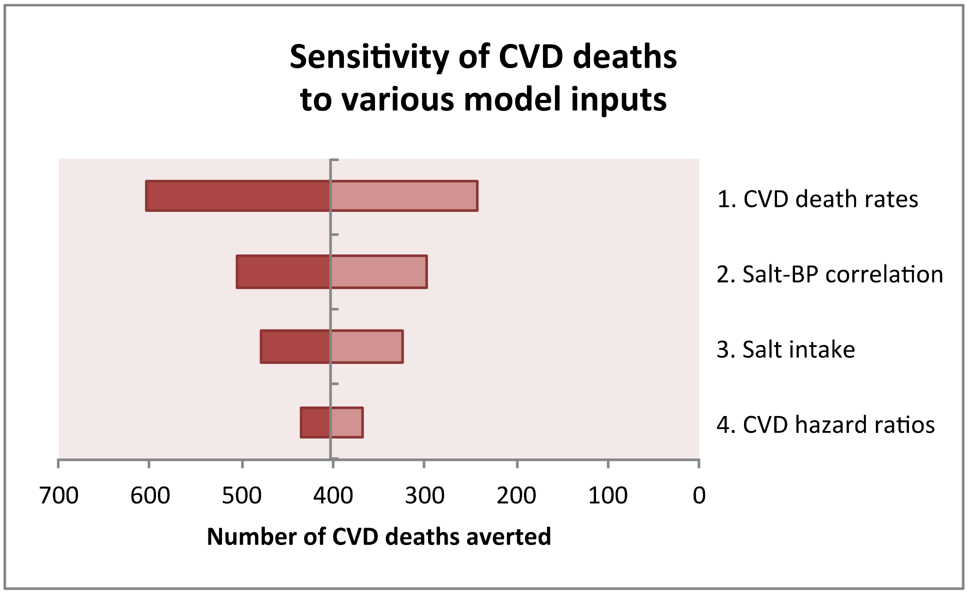

Figure 1. Sensitivity of CVD deaths averted to key model inputs.

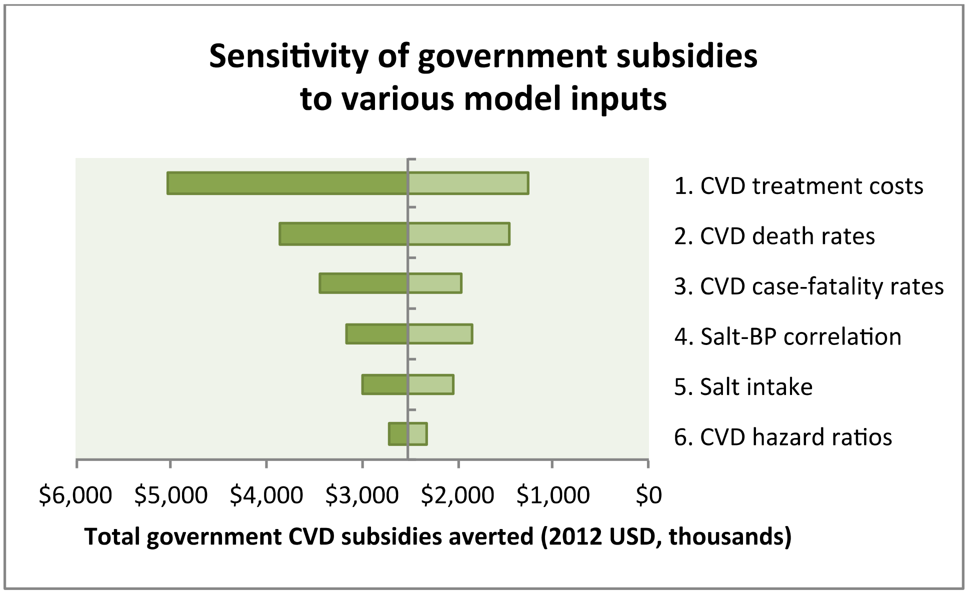

Figure 2. Sensitivity of government subsidies averted to key model inputs.

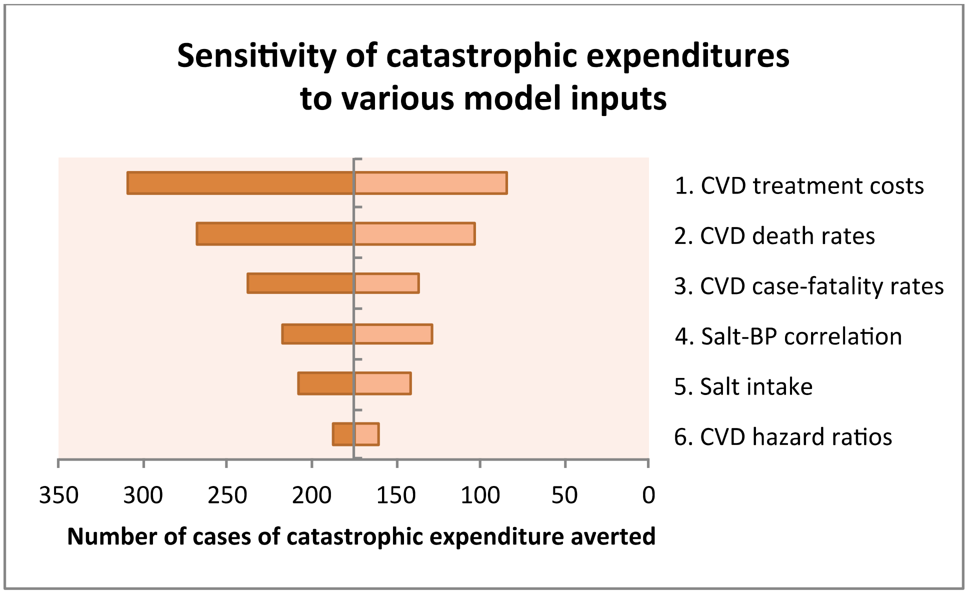

Figure 3. Sensitivity of CHE cases averted to key model inputs.