Population Health Impact and Cost-Effectiveness of Community-Supported Agriculture Among Low-Income US Adults: A Microsimulation Analysis

Sanjay Basu, MD, PhD, Jessica O'Neill, Edward Sayer, PsyD, Maegan Petrie, BA, Rochelle Bellin, BA, and Seth A. Berkowitz, MD, MPH

Objectives. To estimate the population-level effectiveness and cost-effectiveness of a subsidized community-supported agriculture (CSA) intervention in the United States.

Methods. In 2019, we developed a microsimulation model from nationally representative demographic, biomedical, and dietary data (National Health and Nutrition Examination Survey, 2013–2016) and a community-based randomized trial (conducted in Massachusetts from 2017 to 2018). We modeled 2 interventions: unconditional cash transfer ($300/year) and subsidized CSA ($300/year subsidy).

Results. The total discounted disability-adjusted life years (DALYs) accumulated over the life course to cardiovascular disease and diabetes complications would be reduced from 24 797 per 10 000 people (95% confidence interval [CI] = 24 584, 25 001) at baseline to 23 463 per 10 000 (95% CI = 23 241, 23 666) under the cash intervention and 22 304 per 10 000 (95% CI = 22 084, 22 510) under the CSA intervention. From a societal perspective and over a life-course time horizon, the interventions had negative incremental cost-effectiveness ratios, implying cost savings to society of –$191 100 per DALY averted (95% CI = –$191 767, –$188 919) for the cash intervention and –$93 182 per DALY averted (95% CI = –$93 707, –$92 503) for the CSA intervention.

Conclusions. Both the cash transfer and subsidized CSA may be important public health interventions for low-income persons in the United States. (*Am J Public Health.* Published online ahead of print November 14, 2019: e1–e8. doi:10.2105/AJPH.2019.305364)

Diet-related disease is a major cause of morbidity and premature mortality in the United States[1] and disproportionately affects individuals with lower socioeconomic status.[2,3] For this reason, interventions to improve diet quality in individuals with lower socioeconomic status are a public health priority. Food insecurity, inadequate or uncertain access to nutritious food as a result of cost, is thought to be a major source of these disparities,[4,5] as the perceived or real price of fruits and vegetables remains a barrier to increased intake.[6–10]

One strategy for improving diet quality is community-supported agriculture (CSA).[11] In the CSA model, individuals purchase a "share" of a farm's produce in advance of the growing season and then receive weekly allotments throughout the season. A recent randomized clinical trial found that a CSA was effective in improving diet quality for participants drawn from a federally qualified community health center over a 2-year period.[12] Improvements in diet quality are linked to substantially lower cardiovascular morbidity and mortality.[13–18] Mechanistically, increasing fruit and vegetable intake appears to reduce consumption of sodium, increase consumption of potassium, and reduce peripheral insulin resistance.[19–22] However, because the effect of improved diet quality on health outcomes may only become apparent over long time horizons, it is difficult to study in the context of a randomized trial. This argues for the use of microsimulation modeling to inform policy by estimating the population-level changes that may occur with sustained intervention.

Here, we assessed the potential effectiveness and cost-effectiveness (from both a health care and societal perspective) of a CSA intervention among low-income US adults by using a nationally representative simulation model. We tested our a priori hypothesis that the CSA intervention would be more cost-effective than providing the equivalent value in cash.

METHODS

We designed an individual-level microsimulation model for the analysis. A microsimulation model samples from survey data to capture the covariance of key input parameters (e.g., the correlation between demographics, nutrition profile, health biomarkers, and disease incidence), as opposed to Markov cohort models that focus on population averages.[23] Hence, microsimulation models are useful for identifying intervention impacts for populations affected by multiple simultaneous risk factors and comorbidities.[24,25]

In the microsimulation (Appendix, Figure A, available as a supplement to the online

ABOUT THE AUTHORS

Sanjay Basu is with Research and Analytics, Collective Health, San Francisco, CA, and the Center for Primary Care, Harvard Medical School, Boston, MA. Jessica O'Neill and Rochelle Bellin are with Just Roots, Greenfield, MA. Edward Sayer and Maegan Petrie are with The Community Health Center of Franklin County, Greenfield. Seth A. Berkowitz is with the Division of General Medicine and Clinical Epidemiology and the Cecil G. Sheps Center for Health Services Research, University of North Carolina at Chapel Hill.

Correspondence should be sent to Seth A. Berkowitz, MD, MPH, 5034 Old Clinic Bldg, CB #7110, Chapel Hill, NC 27599-7110 (e-mail: seth_berkowitz@med.unc.edu). Reprints can be ordered at http://www.ajph.org by clicking the "Reprints" link.

This article was accepted August 20, 2019.
doi: 10.2105/AJPH.2019.305364

version of this article at http://www.ajph.org), we constructed a simulated US population with demographic features of age, sex, and race/ethnicity (non-Hispanic White, non-Hispanic Black, Hispanic/Latino, or other). We sampled repeatedly from survey data described in the Baseline Risk section to simulate the typical distribution of key health variables including current nutrition and biomedical profile; because both the demographic and health data were from the National Health and Nutrition Examination Survey (NHANES), both were considered population representative.

We then used validated risk equations—one for the risk of atherosclerotic cardiovascular disease events (myocardial infarction or stroke)[26] and one for type 2 diabetes mellitus and its microvascular complications (nephropathy, neuropathy, and retinopathy), as well as all-cause mortality[27,28]—to estimate the 10-year and life-course risk of cardiovascular and metabolic disease events. We then examined how much these cardiovascular and metabolic disease event rates would be expected to change if individuals were provided $300 per year in cash or a $300-per-year subsidy to be used to purchase a CSA share. The effect estimates were based on a trial in Massachusetts (NCT03231592), which provided $300 a year to participate. Those in the intervention group were required to purchase a CSA share. The CSA share entitled participants to once weekly produce pick up over 24 weeks (from June to November of a given year). The cost of the CSA share did not vary by age. Adults (aged ≥ 18 years) were eligible to participate.

Baseline Risk

The data sources and input parameters are summarized in Appendix, Table A. We generated a simulation of the civilian, noninstitutionalized US population by sampling weighted data from the latest 2 cycles (2013–2016) of NHANES.[29] We drew the randomized trial sample from participants at a federally qualified health center (and the surrounding low-income county) with body mass index greater than 25 kilograms divided by the square of height in meters. To emulate the lower socioeconomic status population this type of intervention might be applied to, our simulation included NHANES participants with body mass index greater than 25 kilograms divided by the square of height in meters who either had household income less than 200% of the federal poverty level when adjusted for household size or were Medicaid beneficiaries (or both), resulting in an unweighted sample of n = 73 248 (representing a weighted 121.9 million individuals).

Appendix, Table B compares demographic and clinical characteristics of the NHANES and trial samples. We obtained micronutrients and macronutrients in grams or kilocalories per person per day by sampling from two 24-hour dietary recalls in NHANES, from which we calculated the Healthy Eating Index (HEI) score (version 2015) by using a previously published approach.[30] We obtained an individual's biomedical profile by sampling from NHANES survey, examination, and laboratory data. We input these data into the revised Pooled Cohort Equations for atherosclerotic cardiovascular disease to predict 10-year and life-course risk of myocardial infarction or stroke[26] (Appendix, Table C) and into the RECODe equations (Risk Equations for Complications of type 2 Diabetes) to estimate risk of diabetes-contingent complications (including myocardial infarction and stroke, retinopathy, nephropathy, and neuropathy; Appendix, Table D).[27,28]

Both sets of equations have been previously validated against diverse, longitudinal US cohort data sets.[26,28] We estimated diabetes incidence and life-course years remaining (by age, sex, and race/ethnicity) by sampling from Centers for Disease Control and Prevention data.[31,32] We updated individual covariates with each passing year based on the risk of outcome and mortality with that outcome and with a linear secular trend by age and sex.

Postintervention Risk

We simulated 2 interventions: (1) provision of $300 per person per year in cash, with guidance about healthy eating given at the time of provision but no restrictions on how the money was used or (2) provision of a $300-person-per-year subsidy used to purchase a CSA share. We selected these interventions for simulation because there are randomized trial data relating these interventions to changes in diet quality, and cost-effectiveness analysis for these strategies had not previously been performed. In the CSA intervention, individuals received a weekly share of farm produce during the 6-month growing season (June to November), along with information about how to use the produce and examples of healthy recipes. For the main simulation, we simulated intervention participation at 100%, and we conducted sensitivity analyses to reflect various reduced levels of participation.

In a previous randomized trial,[12] the cash intervention was observed to produce a 7% (95% confidence interval [CI] = 3%, 11%) increase in HEI score, and the CSA intervention was observed to produce a 13% (95% CI = 9%, 17%) increase in HEI score. We used these effect sizes (without subgroup analysis) to estimate how much the change in diet quality attributable to each intervention would be expected to change each of the disease outcome endpoints. As the trial results were estimated at the individual person level, we incorporated them directly into the individual-level effect size estimates for simulated persons. Specifically, we reviewed the literature to find randomized trials (when available) or prospective cohort studies that examined how the change in diet quality reflected by any of 4 validated diet quality indices (HEI, Alternative Healthy Eating Index, Dietary Approaches to Stop Hypertension, and Mediterranean Diet Score) corresponded to a change in each outcome, averaging across all available information, and converted to a 10% increase in diet quality index.[13–16,33,34]

Cost-Effectiveness Analysis

We computed the DALYs accumulated and dollars expended under the baseline, cash, and CSA intervention scenarios. We defined DALYs as the years of life lost from the disease plus the years of life lived with disability (years weighted by a disutility weight reflecting the degree of loss of life quality from the disease). Following current cost-effectiveness guidelines,[35,36] we computed these outcomes on both a 10-year policy time horizon and from a life-course perspective, as well as from both a health care perspective and a societal perspective (see Appendix, Table E for Consolidated Health Economic Evaluation

Reporting Standards checklist).[13,37] We estimated DALYs averted over 10 years and over the life course by using health state utility values published in a previous comprehensive survey.[38]

The health care perspective included the \$300 per person per year intervention cost, plus a 16.7% (\$50) overhead rate for the cash intervention and a 90.3% (\$271) overhead rate for the CSA intervention, based on the trial experience. This overhead rate includes factors such as farm supplies, labor, and costs associated with administering the CSA and does not include costs associated with research. In addition, we included health care costs per disease outcome, based on our estimates from the Optum Clinformatics Database of low-income US persons nationwide, which included payments to health care providers, medications, and procedures, as well as out-of-pocket costs for patients both at the time of the event and each year of life thereafter. The societal perspective included 2 additional costs: (1) economic benefits to the local economy[39,40] and (2) lost work productivity because of the health outcomes.[41,42] We modeled the economic benefits by using a "money multiplier" approach that accounts for both gains and losses. For example, because the money multiplier, with regard to the local economy, is greater for an additional \$1 spent at a small farm compared with a supermarket, our societal perspective estimates account for both gains in business experienced by the farm and loss of business experienced by a supermarket.

For both the health care and societal perspectives, we computed the incremental cost-effectiveness ratio (ICER) as the change in dollars expended from baseline to the intervention condition (cash or CSA) divided by the change in DALYs averted from baseline to the intervention condition. We discounted both costs and DALYs at a standard 3% annual rate.

Sensitivity Analyses

We performed 5 sets of sensitivity analyses. First, we simulated reduced levels of participation from the baseline level of 100% participation among eligible persons to identify the degree to which the ICER changed at varying participation levels. Second, we computed how much more effective at changing diet quality the CSA intervention would need to be, compared with the cash intervention, to achieve the same ICER when taking account of the higher overhead rate of the CSA intervention. Third, we estimated how much less costly the CSA intervention would need to be to achieve the same ICER as the cash intervention when taking account of the greater effectiveness of the CSA. Fourth, we estimated the ICER if the intervention only produced behavior change for the initial year of intervention, followed by reversion to baseline preintervention dietary quality.

Finally, across all simulations, we performed probabilistic sensitivity analysis by Monte Carlo sampling 10 000 times from Gaussian distributions constructed around the mean and 95% CIs around all input parameters to estimate the distribution around each outcome metric and to plot the cost-effectiveness plane. Input data and statistical code for reproduction of the analyses are available at https://github.com/sanjaybasu/CSA.

RESULTS

The included, unweighted NHANES study sample had a mean age of 58.1 years (interquartile range [IQR] = 47.0–71.0), was 55.9% female, included 19.7% Black and 12.8% Hispanic individuals, and had a mean income of 113.4% of the federal poverty level. The sample had a mean HEI score of 51.2 (IQR = 40.4–61.0; on a scale from 0 to 100, in which the latter indicates perfect adherence to the 2015 Dietary Guidelines for Americans).[43] Additional characteristics are detailed in Table 1.

Baseline Risk

The estimated median baseline 10-year risk of the weighted, nationally representative simulated sample was 8.5% for atherosclerotic cardiovascular disease events (95% CI = 0.0, 43.1), 8.1% for incident diabetes (95% CI = 5.0, 8.9), 2.4% for end-stage renal disease among those with diabetes (95% CI = 1.3, 8.8), 13.7% for neuropathy among those with diabetes (95% CI = 2.4, 48.5), 8.0% for retinopathy among those with diabetes (95% CI = 2.1, 36.2), and 8.3% for all-cause mortality (95% CI = 0.4, 46.9). The corresponding life-course risk was 15.6% for atherosclerotic cardiovascular disease events (95% CI = 0.4, 56.0), 18.5% for incident diabetes (95% CI = 6.8, 29.6), 5.8% for end-stage renal disease among those with diabetes (95% CI = 1.3, 28.3), 26.4% for neuropathy among those with diabetes (95% CI = 12.9, 66.3), and 16.4% for retinopathy among those with diabetes (95% CI = 9.2, 45.9).

Postintervention Risk

For the cash intervention, we estimated a reduction in the median 10-year risk of each outcome to 8.2% for atherosclerotic cardiovascular disease events (95% CI = 0.0, 41.7), 7.3% for incident diabetes (95% CI = 4.2, 8.3), 2.4% for end-stage renal disease among those with diabetes (95% CI = 1.3, 8.7), 13.5% for neuropathy among those with diabetes (95% CI = 2.3, 47.9), 7.8% for retinopathy among those with diabetes (95% CI = 2.0, 34.6), and 7.8% for all-cause mortality (95% CI = 0.3, 44.4). The corresponding life-course risk reduced to 15.2% for atherosclerotic cardiovascular disease events (95% CI = 0.4, 54.5), 16.7% for incident diabetes (95% CI = 6.0, 26.5), 5.8% for end-stage renal disease among those with diabetes (95% CI = 1.3, 28.1), 26.0% for neuropathy among those with diabetes (95% CI = 12.7, 65.6), and 15.9% for retinopathy among those with diabetes (95% CI = 9.0, 44.7).

The reduction in risk from the cash intervention would be expected to reduce the number of atherosclerotic cardiovascular disease events by 60.9 per 10 000 people (95% CI = 58.0, 63.9), the number of incident cases of type 2 diabetes mellitus by 117.5 per 10 000 (95% CI = 115.0, 120.3), the number of cases of end-stage renal disease by 10.8 per 10 000 (95% CI = 5.9, 14.7), the number of cases of diabetic neuropathy by 39.4 per 10 000 (95% CI = 31.4, 47.3), and the number of cases of diabetic retinopathy by 41.1 per 10 000 (95% CI = 33.3, 48.6) over a life-course time horizon (Figure 1).

For the CSA intervention estimated to produce a 13% (95% CI = 9, 17) increase in HEI score, we estimated a reduction in the median 10-year risk of each outcome to 8.0% for atherosclerotic cardiovascular disease events (95% CI = 0.0, 40.8), 6.5% for incident diabetes (95% CI = 3.6, 7.7), 2.4% for

TABLE 1—Descriptive Statistics on the Study Sample: United States, National Health and Nutrition Examination Survey, 2013–2016

Characteristic	Mean (IQR) or %
Age, y	58.1 (47.0–71.0)
Female	55.9
Black	19.7
Hispanic	12.8
Income, % of federal poverty level	113.4 (73.0–148.0)
Healthy Eating Index, score (0–100)	51.2 (40.4–61.0)
Body mass index, kg/m^2	33.2 (28.1–36.2)
Systolic blood pressure, mm Hg	128.2 (116.0–138.0)
Total cholesterol, mg/dL	184.0 (156.0–207.0)
High-density lipoprotein cholesterol, mg/dL	50.4 (41.0–58.0)
Diabetes	39.3
Hemoglobin A1c	6.3 (5.5–6.5)
Serum creatinine, mg/dL	1.0 (0.7–1.0)
Urine microalbumin:creatinine ratio	105.0 (5.6–24.9)
Current tobacco smoker	21.8
Cardiovascular disease history	9.0
Blood pressure treatment	62.4
Statin treatment	7.1
Diabetes treatment	4.4
Anticoagulation treatment	0.6

Note. IQR = interquartile range. Statistics describe properties of the unweighted National Health and Nutrition Examination Survey Study (2013–2016) after applying the inclusion criteria of household income less than 200% of the federal poverty level (according to US Department of Health and Human Services guidelines for the year the data were collected) or enrollment in Medicaid health insurance, and a body mass index of 25 kg/m^2 or greater (n = 73 248).

end-stage renal disease among those with diabetes (95% CI = 1.3, 8.7), 13.4% for neuropathy among those with diabetes (95% CI = 2.3, 47.2), 7.5% for retinopathy among those with diabetes (95% CI = 2.0, 33.4), and 7.4% for all-cause mortality (95% CI = 0.3, 42.1). The corresponding life-course risk reduced to 14.8% for atherosclerotic cardiovascular disease events (95% CI = 0.4, 53.2), 14.9% for incident diabetes (95% CI = 5.3, 24.2), 5.7% for end-stage renal disease among those with diabetes (95% CI = 1.3, 28.3), 25.7% for neuropathy among those with diabetes (95% CI = 12.5, 64.8), and 15.5% for retinopathy among those with diabetes (95% CI = 8.7, 43.4).

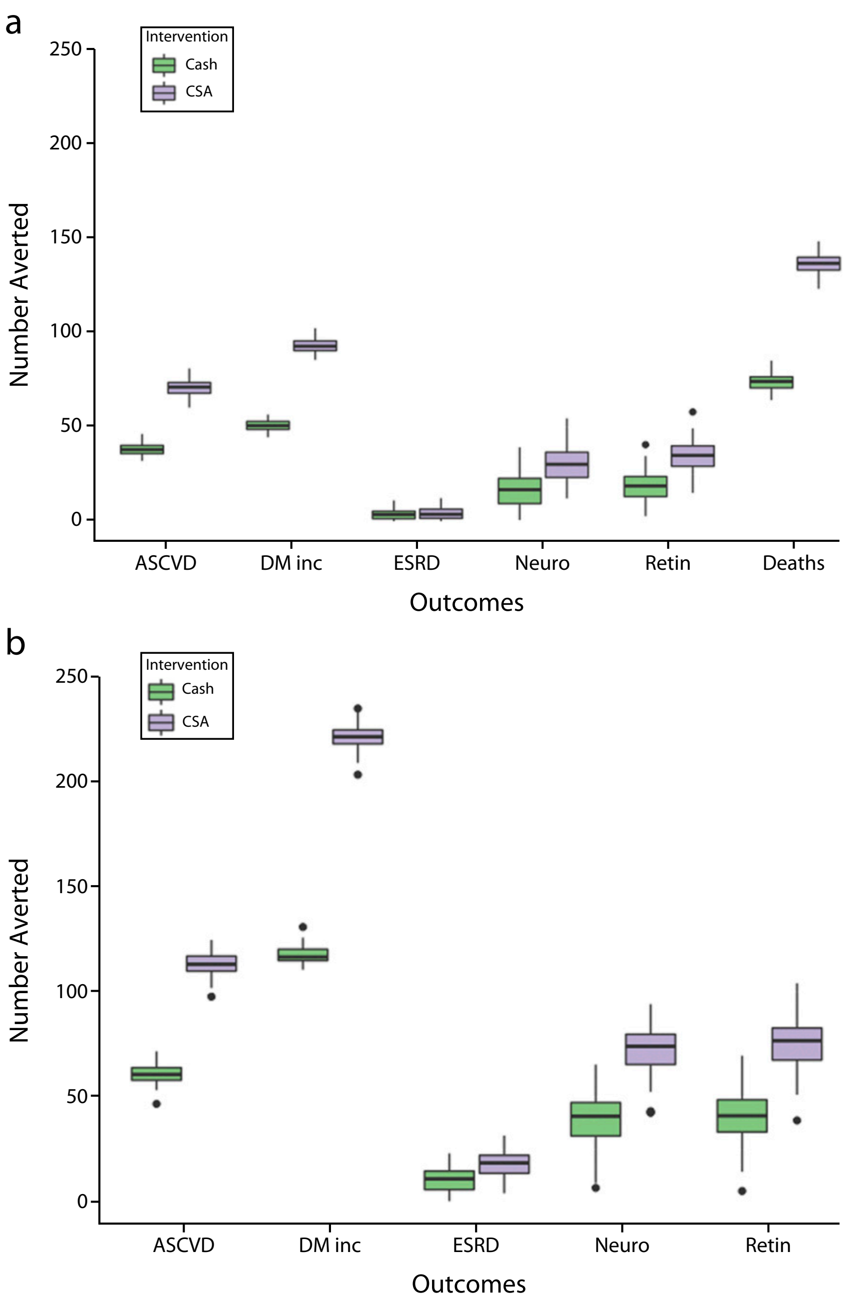
The reduction in risk from the CSA intervention would be expected to reduce the number of atherosclerotic cardiovascular disease events by 113.4 per 10 000 people (95% CI = 110.0, 117.0), the number of incident cases of type 2 diabetes mellitus by 221.3 per 10 000 (95% CI = 218.2, 224.8), the number of cases of end-stage renal disease by 18.3 per 10 000 (95% CI = 13.7, 22.2), the number of cases of diabetic neuropathy by 72.8 per 10 000 (95% CI = 65.5, 79.8), and the number of cases of diabetic retinopathy by 76.2 per 10 000 (95% CI = 67.6, 82.8) over a life-course time horizon.

Cost-Effectiveness Analysis

Total discounted DALYs accumulated over a 10-year policy horizon decreased from 8277 per 10 000 people (95% CI = 8195, 8366) at baseline to 7854 per 10 000 (95% CI = 7768, 7950) under the cash intervention and 7490 per 10 000 (95% CI = 7405, 7580) under the CSA intervention (Table 2). In both interventions, more DALYs were averted through averted atherosclerotic cardiovascular disease events than from the other disease endpoints. Total discounted DALYs accumulated over a life-course horizon decreased from 24 797 per 10 000 people (95% CI = 24 584, 25 001) at baseline to 23 463 per 10 000 (95% CI = 23 241, 23 666) under the cash intervention and 22 304 per 10 000 (95% CI = 22 084, 22 510) under the CSA intervention.

From a health care perspective, total discounted health care costs (including intervention costs) over 10 years increased from $164.63 million (95% CI = $157.78 million, $166.21 million) per 10 000 people to $189.51 million (95% CI = $187.68 million, $191.13 million) per 10 000 under the cash intervention and $214.11 million (95% CI = $212.27 million, $215.83 million) per 10 000 under the CSA intervention. In both interventions, more health care dollars were saved through averted cardiovascular disease costs than from the other diseases. Total discounted health care costs (including intervention costs) over a life-course horizon increased from $253.35 million (95% CI = $251.55 million, $255.22 million) per 10 000 people over 10 years to $327.23 million (95% CI = $235.42 million, $329.04 million) per 10 000 under the cash intervention and $389.64 million (95% CI = $387.76, $391.53 million) per 10 000 under the CSA intervention. From a health care perspective, the interventions had an ICER of $58 736 per DALY averted (95% CI = $57 654, $60 007) for the cash intervention and $62 864 per DALY averted (95% CI = $62 300, $63 155) for the CSA intervention over a 10-year time horizon, and an ICER of $55 379 per DALY averted (95% CI = $54 990, $55 291) for the cash intervention and $54 661 per DALY averted (95% CI = $54 473, $54 708) for the CSA intervention over a life-course time horizon.

From a societal perspective, incorporating economic benefits of the interventions for the agricultural sector and work productivity, total discounted societal savings over 10 years were $90.85 million (95% CI = $90.58 million, $91.13 million) per 10 000 under the cash intervention and $104.24 million (95% CI = $103.98 million, $104.52 million) per 10 000 under the CSA intervention. Total



Notes. ASCVD = atherosclerotic cardiovascular disease events (myocardial infarctions and strokes); death = all-cause mortality; DM inc = incident type 2 diabetes mellitus; ESRD = diabetes-related end-stage renal disease or renal failure; Neuro = diabetes-related neuropathy; Retin = diabetes-related retinopathy. Boxplots display the interquartile range (box), median (bold horizontal line), 1.5 times the interquartile range (whiskers), and outliers (points).

FIGURE 1—Averted Disease Outcomes per 10 000 People and Reduction in Disease Outcomes From Cash and Community-Supported Agriculture (CSA) Interventions Over (a) 10-Year and (b) Life-Course Time Horizons: United States

discounted societal costs savings over a life-course horizon were $328.84 million (95% CI = $327.65 million, $329.89 million) per 10 000 under the cash intervention and $368.64 million (95% CI = $367.50 million, $369.80 million) per 10 000 under the CSA intervention. From a societal perspective, the interventions had a negative ICER, implying cost savings, of –$155 719 per DALY averted (95% CI = –$159 426, –$154 583) for the cash intervention and –$69 570 per DALY averted (95% CI = –$69 865, –$69 360) for the CSA intervention over a 10-year time horizon, with less savings over this time horizon because of higher overhead costs from the CSA. The interventions had an ICER of –$191 100 per DALY averted (95% CI = –$191 767, –$188 919) for the cash intervention and –$93 182 per DALY averted (95% CI = –$93 707, –$92 503) for the CSA intervention over a life-course time horizon.

Sensitivity Analyses

We found that the ICERs did not change when varying participation levels, as the fewer DALYs averted with lower participation reduced proportionately to dollars spent.

We found that the CSA intervention would have to produce a 20% increase in HEI score (95% CI = 16%, 24%), as compared with its observed 13% increase, to achieve the same ICER as the cash intervention from a societal perspective over a life-course time horizon, given the higher overhead rate of the CSA intervention. By contrast, the CSA intervention would have to cost $198 per annum (95% CI = $170, $226) less, from a baseline cost of $571, to have a similar societal perspective life-course ICER as the cash intervention. We estimated the ICER if the intervention only produced behavior change for the initial year of intervention, followed by reversion to baseline preintervention dietary quality (but still cost the same amount into perpetuity, despite losing effectiveness), the interventions would have an ICER of $1.08 million per DALY averted (95% CI = $939 909, $1.21 million) for the cash intervention and $945 600 per DALY averted (95% CI = $458 478, $1.42 million) for the CSA intervention from a societal perspective over a lifetime horizon.

The incremental cost-effectiveness plane showing results of the probabilistic sensitivity analysis is displayed in Appendix, Figure B.

TABLE 2—Cost-Effectiveness Analysis: United States

	10-Year			Life-Course		
	Baseline	Cash	CSA	Baseline	Cash	CSA
DALYs accumulated, mean (95% CI) per 10 000 population						
Atherosclerotic cardiovascular disease events	2 256 (2 244, 2 273)	2 138 (2 215, 2 158)	2 039 (2 027, 2 058)	6 469 (6 434, 6 511)	6 122 (6 083, 6 163)	5 829 (5 788, 5 871)
Incident diabetes	214 (205, 222)	179 (172, 188)	153 (145, 161)	1 344 (1 316, 1 374)	1 141 (1 115, 1 167)	972 (947, 992)
End-stage renal disease	512 (503, 522)	504 (493, 515)	495 (485, 505)	2 524 (2 498, 2 548)	2 431 (2 397, 2 455)	2 355 (2 322, 2 383)
Diabetic neuropathy	1 253 (1 237, 1 269)	1 181 (1 170, 1 197)	1 121 (1 107, 1 134)	4 428 (4 391, 4 459)	4 148 (4 112, 4 182)	3 907 (3 872, 3 937)
Diabetic retinopathy	957 (947, 968)	895 (883, 908)	845 (833, 855)	3 457 (3 420, 3 490)	3 217 (3 188, 3 345)	3 010 (2 980, 3 038)
All-cause mortality	3 085 (3 059, 3 112)	2 955 (2 925, 2 983)	2 837 (2 808, 2 868)	6 574 (6 526, 6 620)	6 404 (6 346, 6 454)	6 231 (3 872, 3 937)
Total	8 277 (8 195, 8 366)	7 854 (7 768, 7 950)	7 490 (7 405, 7 580)	24 797 (24 584, 25 001)	23 463 (23 241, 23 666)	22 304 (22 084, 22 510)
Health care costs (economic losses), mean $ (95% CI) in millions per 10 000 population						
Intervention costs, including overhead	. . .	33.08 (33.07, 33.09)	53.79 (53.77, 53.80)	. . .	88.94 (88.91, 88.98)	144.49 (144.38, 144.55)
Atherosclerotic cardiovascular disease events	63.70 (63.29, 64.07)	59.93 (59.52, 60.30)	61.67 (61.29, 62.02)	87.98 (87.54, 88.38)	82.81 (82.46, 83.17)	85.20 (84.76, 85.60)
Incident diabetes	8.68 (8.57, 8.79)	6.87 (6.77, 6.96)	7.69 (7.61, 7.80)	15.68 (15.60, 15.78)	12.61 (12.52, 12.70)	14.05 (13.97, 14.14)
End-stage renal disease	42.84 (42.16, 43.54)	42.26 (41.34, 43.04)	42.64 (41.74, 43.50)	76.20 (75.32, 77.14)	73.14 (72.24, 74.05)	74.44 (73.54, 75.36)
Diabetic neuropathy	37.36 (37.10, 37.66)	36.10 (35.82, 36.37)	36.69 (36.35, 36.97)	55.04 (54.79, 44.32)	52.63 (52.33, 52.94)	53.74 (53.45, 54.06)
Diabetic retinopathy	12.05 (11.95, 12.14)	11.27 (11.16, 11.37)	11.63 (11.51, 11.73)	18.45 (18.30, 18.60)	17.08 (16.97, 17.20)	17.72 (17.60, 17.83)
Total	164.63 (157.78, 166.21)	189.51 (187.68, 191.13)	214.11 (212.27, 215.83)	253.35 (251.55, 255.22)	327.23 (235.42, 329.04)	389.64 (387.76, 391.53)
Societal savings (economic gains), mean $ (95% CI) in millions per 10 000 population						
Agricultural sector net profit gains	. . .	40.26 (40.25, 40.28)	52.56 (52.54, 52.58)	. . .	108.26 (108.21, 108.30)	141.20 (141.15, 141.26)
Disease-related economic productivity gains	. . .	50.59 (50.34, 50.86)	51.68 (51.44, 51.94)	. . .	220.58 (219.44, 221.59)	227.44 (226.36, 228.54)
Total	. . .	90.85 (90.58, 91.13)	104.24 (103.98, 104.52)	. . .	328.84 (327.65, 329.89)	368.64 (367.50, 369.80)

Note. CI = confidence interval; CSA = community-supported agriculture; DALYs = disability-adjusted life years. Discounted DALYs and costs, from a health care and societal perspective, estimated under the baseline (preintervention), cash intervention, and CSA intervention scenarios over 10-y and life-course time horizons. DALYs and costs were discounted at a 3% annual rate. The societal perspective includes cost savings attributable to increased agricultural economic sector profits and workplace productivity attributable to lower disease events.

DISCUSSION

Combining data from a community-based randomized trial of cash and CSA interventions with national surveys, we developed and implemented a microsimulation model to assess the potential impact and cost-effectiveness of improving dietary quality on cardiovascular disease and type 2 diabetes outcomes among low-income US adults. We observed that from a health care spending perspective, both interventions would be expected to have incremental cost-effectiveness ratios less than $100 000 per DALY averted, with the cash intervention being more cost-effective in the short term (10-year time horizon) but the CSA intervention having equivalent cost-effectiveness in the long run (life-course time horizon). Furthermore, we observed that from a societal perspective both interventions would be expected to produce net cost savings. Notably, we refuted our a priori hypothesis that the CSA intervention would be more cost-effective than providing a cash-based incentive alone. The CSA intervention would have to increase its positive effects on diet or reduce its costs to be similarly cost-saving.

This study is consistent with and expands previous work that estimated the effectiveness and cost-effectiveness of nutritional subsidies in lower-income individuals. A previous randomized study found improvements in diet quality for a 30% subsidy on the purchase of fruit and vegetables via the Supplemental Nutrition Assistance Program (SNAP),[44] and previous modeling studies of this type of intervention have estimated positive effects on health and health care spending.[45,46] A recent cost-effectiveness analysis of economic incentive programs offered through Medicaid, Medicare, or both found that these programs could be highly cost-effective.[47]

This study adds to the literature by modeling a different type of intervention—one based in a CSA and that is not restricted to SNAP participants. Instead, this type of intervention could be offered through clinics or as a health insurance benefit. Indeed, care systems, payers, and employers are already experimenting with such a benefit.[48–50] An interesting finding in this study was that while both programs were cost-saving from a societal perspective, they were not cost-saving from a health care system perspective. This exemplifies the so-called "wrong pocket" problem whereby stakeholders may have less incentive to invest in programs that are, overall, cost-saving, when the savings will not accrue to the stakeholders making the investment. Innovative financing strategies that recognize these types of programs as public goods may be needed to spur, and sustain, investment that is ultimately beneficial for society.[51]

As with all modeling-based assessments, our evaluation is subject to important limitations. First, we projected data from a trial in Massachusetts to the nation. Because there are demographic differences between the sample in this trial and the national population, the trial results may not generalize well if there are heterogeneous treatment effects across groups defined by characteristics (such as age, gender, race/ethnicity, or household size) that differ between the trial and NHANES sample.

Second, we assumed that the key health and economic benefits of the simulated interventions would be mediated through changes in diet quality.[13]

Third, we were not able to capture all possible benefits (and harms) from the intervention. For example, we lacked data and the ability to quantify secondary gains from CSA-type interventions that may be intangible but still important from a societal perspective—such as community- and relationship-building effects. Hence, despite the higher overhead and lower incremental cost-effectiveness, CSA interventions may be favored over cash interventions because of factors such as perceived risk of cash diversion, improved social capital with a CSA, and other potential benefits not cataloged here. On the other hand, an important benefit of "cash-benchmarking"—that is, comparing the effectiveness and cost-effectiveness of an intervention to an unconditional cash transfer—is that such an approach homes in on the specific benefits of the intervention itself, as opposed to the financial value of the intervention. Furthermore, it helps to quantify the costs of the paternalism imposed by program restrictions.[52]

Finally, we considered only 2 possible versions of interventions meant to improve diet quality in the study population. As further work relating changes in diet to other interventions or different variations of the strategies studied (e.g., higher or low subsidy values) becomes available, it would make sense to include additional interventions to the set studied.

The results of this study suggest several directions for future work. First, it is important to replicate trial results in different contexts to enhance generalizability. Next, given that there now appear to be multiple cost-effective interventions for improving diet quality in low-income populations, it will be important to investigate how to best deploy such policies to maximize population health impact. Given the complexity of socioeconomic disparities in diet-related illness, there are likely to be no "silver bullets." Instead, a combination of programs with different eligibility criteria, benefit levels, and interventional approaches will likely be needed. Better understanding for whom a given program is most beneficial, and how one program might interact with others, will help inform public policy for improving health.

Overall, our simulation study suggests that both an unconditional cash transfer and CSA-based interventions may be cost-effective for improving diets among low-income persons in the United States. These programs may generate health improvements, agricultural economic benefits, productivity gains, and ultimately societal cost-savings. AJPH

CONTRIBUTORS

S. Basu and S. A. Berkowitz originated the study, conducted analyses, and drafted the article. J. O'Neill, E. Sayer, M. Petrie, and R. Bellin made substantial contributions to the acquisition and interpretation of the data and revised the article critically for intellectual content. All authors give approval to the final version to be published.

ACKNOWLEDGMENTS

Research reported in this publication was supported by the US Department of Agriculture under grant agreement 16FMPPMA0001, the Blue Cross Blue Shield Foundation of Massachusetts, and by the National Institute of Diabetes and Digestive and Kidney Diseases of the National Institutes of Health under award K23DK109200 (S. A. B.).

Note. The content is solely the responsibility of the authors and does not necessarily represent the official views of the Department of Agriculture, Blue Cross Blue Shield Foundation of Massachusetts, the National Institutes of Health, or of any current or former employer of the authors.

CONFLICTS OF INTEREST

J. O'Neill and R. Bellin are employees of Just Roots. S. Basu is an employee of Collective Health. All other authors declare that they have no conflicts to report.

HUMAN PARTICIPANT PROTECTION

Institutional review board approval was obtained for this work by IntegReview institutional review board (protocol FMPP2016—Just Roots). Participants in the randomized clinical trial that served as the basis for the effect estimates of the intervention provided written informed consent. The cost-effectiveness analyses were considered exempt from institutional review board review as non–human participant research as they involved only analysis of already collected, de-identified data without participant contact.

REFERENCES

1. US Burden of Disease Collaborators, Mokdad AH, Ballestros K, et al. The state of US health, 1990–2016: burden of diseases, injuries, and risk factors among US states. *JAMA*. 2018;319(14):1444–1472.

2. Wang DD, Leung CW, Li Y, et al. Trends in dietary quality among adults in the United States, 1999 through 2010. *JAMA Intern Med*. 2014;174(10): 1587–1595.

3. Sugiyama T, Shapiro MF. The growing socioeconomic disparity in dietary quality: mind the gap. *JAMA Intern Med*. 2014;174(10):1595–1596.

4. Seligman HK, Schillinger D. Hunger and socioeconomic disparities in chronic disease. *N Engl J Med*. 2010; 363(1):6–9.

5. Morales ME, Berkowitz SA. The relationship between food insecurity, dietary patterns, and obesity. *Curr Nutr Rep*. 2016;5(1):54–60.

6. McMorrow L, Ludbrook A, Macdiarmid JI, Olajide D. Perceived barriers towards healthy eating and their association with fruit and vegetable consumption. *J Public Health (Oxf)*. 2017;39(2):330–338.

7. Stallings TL, Gazmararian JA, Goodman M, Kleinbaum D. Agreement between the perceived and actual fruit and vegetable nutrition environments among low-income urban women. *J Health Care Poor Underserved*. 2015;26(4): 1304–1318.

8. Dijkstra SC, Neter JE, van Stralen MM, et al. The role of perceived barriers in explaining socioeconomic status differences in adherence to the fruit, vegetable and fish guidelines in older adults: a mediation study. *Public Health Nutr*. 2015;18(5): 797–808.

9. Price J, Riis J. Behavioral economics and the psychology of fruit and vegetable consumption. *J Food Stud*. 2012:1(1):1–13.

10. Bertmann FMW, Barroso C, Ohri-Vachaspati P, Hampl JS, Sell K, Wharton CM. Women, infants, and children cash value voucher (CVV) use in Arizona: a qualitative exploration of barriers and strategies related to fruit and vegetable purchases. *J Nutr Educ Behav*. 2014; 46(3 suppl):S53–S58.

11. Seguin RA, Morgan EH, Hanson KL, et al. Farm Fresh Foods for Healthy Kids (F3HK): an innovative community supported agriculture intervention to prevent childhood obesity in low-income families and strengthen local agricultural economies. *BMC Public Health*. 2017; 17(1):306.

12. Berkowitz SA, O'Neill J, Sayer E, et al. Health center-based community-supported agriculture: an RCT. *Am J Prev Med*. 2019; Epub ahead of print.

13. Sotos-Prieto M, Bhupathiraju SN, Mattei J, et al. Association of changes in diet quality with total and cause-specific mortality. *N Engl J Med*. 2017;377(2): 143–153.

14. Sotos-Prieto M, Bhupathiraju SN, Mattei J, et al. Changes in diet quality scores and risk of cardiovascular disease among US men and women. *Circulation*. 2015; 132(23):2212–2219.

15. Schwingshackl L, Chaimani A, Hoffmann G, Schwedhelm C, Boeing H. A network meta-analysis on the comparative efficacy of different dietary approaches on glycaemic control in patients with type 2 diabetes mellitus. *Eur J Epidemiol*. 2018;33(2):157–170.

16. Ley SH, Pan A, Li Y, et al. Changes in overall diet quality and subsequent type 2 diabetes risk: three US prospective cohorts. *Diabetes Care*. 2016;39(11): 2011–2018.

17. Saneei P, Salehi-Abargouei A, Esmaillzadeh A, Azadbakht L. Influence of Dietary Approaches to Stop Hypertension (DASH) diet on blood pressure: a systematic review and meta-analysis on randomized controlled trials. *Nutr Metab Cardiovasc Dis*. 2014; 24(12):1253–1261.

18. Fung TT, Pan A, Hou T, et al. Long-term change in diet quality is associated with body weight change in men and women. *J Nutr*. 2015;145(8):1850–1856.

19. Hashemi R, Rahimlou M, Baghdadian S, Manafi M. Investigating the effect of DASH diet on blood pressure of patients with type 2 diabetes and prehypertension: randomized clinical trial. *Diabetes Metab Syndr*. 2019;13(1): 1–4.

20. Van Hulst A, Paradis G, Harnois-Leblanc S, Benedetti A, Drapeau V, Henderson M. Lowering saturated fat and increasing vegetable and fruit intake may increase insulin sensitivity 2 years later in children with a family history of obesity. *J Nutr*. 2018;148(11): 1838–1844.

21. Zhang Y, Zhang D-Z. Associations of vegetable and fruit consumption with metabolic syndrome. A meta-analysis of observational studies. *Public Health Nutr*. 2018; 21(9):1693–1703.

22. Ali A, Yazaki Y, Njike VY, Ma Y, Katz DL. Effect of fruit and vegetable concentrates on endothelial function in metabolic syndrome: a randomized controlled trial. *Nutr J*. 2011;10(1):72.

23. Basu S. Microsimulation. In: Basu S. *Modeling Public Health and Health Care Systems*. Oxford University Press. 2017. Available at: http://oxfordmedicine.com/view/10.1093/med/9780190667924.001.0001/med-9780190667924-chapter-8. Accessed April 4, 2019.

24. Basu S, Seligman H, Bhattacharya J. Nutritional policy changes in the Supplemental Nutrition Assistance Program: a microsimulation and cost-effectiveness analysis. *Med Decis Making*. 2013;33(7): 937–948.

25. El-Sayed AM, Galea S, eds. *Systems Science and Population Health*. New York, NY: Oxford University Press; 2017.

26. Yadlowsky S, Hayward RA, Sussman JB, McClelland RL, Min Y-I, Basu S. Clinical implications of revised pooled cohort equations for estimating atherosclerotic cardiovascular disease risk. *Ann Intern Med*. 2018;169(1): 20–29.

27. Basu S, Sussman JB, Berkowitz SA, Hayward RA, Yudkin JS. Development and validation of Risk Equations for Complications Of type 2 Diabetes (RECODe) using individual participant data from randomised trials. *Lancet Diabetes Endocrinol*. 2017;5(10): 788–798.

28. Basu S, Sussman JB, Berkowitz SA, et al. Validation of Risk Equations for Complications of Type 2 Diabetes (RECODe) using individual participant data from diverse longitudinal cohorts in the US. *Diabetes Care*. 2018;41(3): 586–595.

29. Centers for Disease Control and Prevention, National Center for Health Statistics. National Health and Nutrition Examination Survey. NHANES questionnaires, datasets, and related documentation. Available at: https://wwwn.cdc.gov/nchs/nhanes/Default.aspx. Accessed April 24, 2018.

30. Krebs-Smith SM, Pannucci TE, Subar AF, et al. Update of the Healthy Eating Index: HEI-2015. *J Acad Nutr Diet*. 2018;118(9):1591–1602.

31. Arias E, Heron M, Xu J. United States Life Tables, 2014. *National Vital Statistics Reports*. August 14, 2017. Available at: https://www.cdc.gov/nchs/data/nvsr/nvsr66/nvsr66_04.pdf. Accessed April 4, 2019.

32. Centers for Disease Control and Prevention. Incidence of diagnosed diabetes. February 20, 2019. Available at: https://www.cdc.gov/diabetes/data/statistics-report/incidence-diabetes.html. Accessed April 4, 2019.

33. Intensive blood-glucose control with sulphonylureas or insulin compared with conventional treatment and risk of complications in patients with type 2 diabetes (UKPDS 33). UK Prospective Diabetes Study (UKPDS) Group [Erratum in *Lancet*. 1999;354(9178):602]. *Lancet*. 1998; 352(9131):837–853.

34. Vijan S, Sussman JB, Yudkin JS, Hayward RA. Effect of patients' risks and preferences on health gains with plasma glucose level lowering in type 2 diabetes mellitus. *JAMA Intern Med*. 2014;174(8): 1227–1234.

35. Sanders GD, Neumann PJ, Basu A, et al. Recommendations for conduct, methodological practices, and reporting of cost-effectiveness analyses: Second Panel on Cost-Effectiveness in Health and Medicine. *JAMA*. 2016;316(10):1093–1103.

36. Neumann PJ, Ganiats TG, Russell LB, Sanders GD, Siegel JE, eds. *Cost-Effectiveness in Health and Medicine*. 2nd ed. New York, NY: Oxford University Press; 2016.

37. Husereau D, Drummond M, Petrou S, et al. Consolidated Health Economic Evaluation Reporting Standards (CHEERS) statement. *BMJ*. 2013;346:f1049.

38. Salomon JA, Haagsma JA, Davis A, et al. Disability weights for the Global Burden of Disease 2013 study. *Lancet Glob Health*. 2015;3(11):e712–e723.

39. Hardesty S. Economic impact reports. Available at: http://sfp.ucdavis.edu/pubs/Economic_Impact_Reports. Accessed April 4, 2019.

40. NC State Extension. Local food systems: clarifying current research. Available at: https://content.ces.ncsu.edu/local-food-systems-clarifying-current-research. Accessed April 4, 2019.

41. Song X, Quek RG, Gandra SR, Cappell KA, Fowler R, Cong Z. Productivity loss and indirect costs associated with cardiovascular events and related clinical procedures. *BMC Health Serv Res*. 2015;15(1):245.

42. Ng YC, Jacobs P, Johnson JA. Productivity losses associated with diabetes in the US. *Diabetes Care*. 2001; 24(2):257–261.

43. Office of Disease Prevention and Health Promotion, US Department of Health and Human Services. 2015–2020 Dietary Guidelines for Americans. Available at: https://health.gov/dietaryguidelines/2015. Accessed April 4, 2019.

44. Food and Nutrition Service, US Department of Agriculture. Healthy Incentives Pilot final evaluation report. Available at: https://www.fns.usda.gov/snap/healthy-incentives-pilot-final-evaluation-report. Accessed October 10, 2018.

45. Choi SE, Seligman H, Basu S. Cost effectiveness of subsidizing fruit and vegetable purchases through the Supplemental Nutrition Assistance Program. *Am J Prev Med*. 2017;52(5):e147–e155.

46. Mozaffarian D, Liu J, Sy S, et al. Cost-effectiveness of financial incentives and disincentives for improving food purchases and health through the US Supplemental Nutrition Assistance Program (SNAP): a microsimulation study. *PLoS Med*. 2018;15(10): e1002661.

47. Lee Y, Mozaffarian D, Sy S, et al. Cost-effectiveness of financial incentives for improving diet and health through Medicare and Medicaid: a microsimulation study. *PLoS Med*. 2019;16(3):e1002761.

48. University of Vermont Medical Center. The root of good health: fresh food. Burlington Free Press. Available at: https://www.burlingtonfreepress.com/story/sponsor-story/uvm-medical-center/2017/07/19/root-good-health-fresh-food/103774038. Accessed March 13, 2019.

49. FairShare CSA Coalition. Health insurance rebates. Available at: https://www.csacoalition.org/how-to-pick-a-farm/health-insurance-rebates. Accessed March 13, 2019.

50. Rossi JJ, Woods TA, Allen JE. Impacts of a community supported agriculture (CSA) voucher program on food lifestyle behaviors: evidence from an employer-sponsored pilot program. *Sustainability*. 2017;9(9):1543.

51. Nichols LM, Taylor LA. Social determinants as public goods: a new approach to financing key investments in healthy communities. *Health Aff (Millwood)*. 2018;37(8): 1223–1230.

52. Center for Global Development. Committing to cost-effectiveness: USAID's new effort to benchmark for greater impact. Available at: https://www.cgdev.org/publication/committing-cost-effectiveness-usaids-new-effort-benchmark-greater-impact. Accessed April 5, 2019.