HHS Public Access

Author manuscript

Am J Prev Med. Author manuscript; available in PMC 2020 November 01.

Published in final edited form as:

Am J Prev Med. 2019 November ; 57(5): e143–e152. doi:10.1016/j.amepre.2019.02.023.

Cost Effectiveness of Nutrition Policies on Processed Meat: Implications for Cancer Burden in the U.S.

David D. Kim, PhD[1], **Parke E. Wilde, PhD**[2], **Dominique S. Michaud, ScD**[3], **Junxiu Liu, PhD**[2], **Lauren Lizewski, MPH**[2], **Jennifer Onopa, MS, RDN**[2], **Dariush Mozaffarian, MD, DrPH**[2], **Fang Fang Zhang, MD, PhD**[2], **John B. Wong, MD**[4]

[1]Center for the Evaluation of Value and Risk in Health, Institute for Clinical Research and Health Policy Studies, Tufts Medical Center, Boston, Massachusetts;

[2]Friedman School of Nutrition Science and Policy, Tufts University, Boston, Massachusetts;

[3]Department of Public Health and Community Medicine, Tufts University School of Medicine, Boston, Massachusetts;

[4]Division of Clinical Decision Making, Tufts Medical Center, Boston, Massachusetts

Abstract

Introduction: Processed meat is associated with increased risk of colorectal and stomach cancer, but health and economic impacts of policies to discourage processed meats are not well established. This paper aims to evaluate the cost effectiveness of implementing tax and warning labels on processed meats.

Methods: A probabilistic cohort-state transition model was developed in 2018, including lifetime and short-term horizon, healthcare and societal perspectives, and 3% discount rates for costs and health outcomes. The model simulated 32 subgroups by age, gender, and race/ethnicity from the U.S. adult population and integrated nationally representative 2011–2014 data on processed meat consumption with etiologic effects of processed meat consumption on cancer incidence, medical and indirect societal costs, and policy costs.

Results: Over a lifetime, the 10% excise tax would prevent 77,000 colorectal (95% uncertainty interval=56,800, 107,000) and 12,500 stomach (95% uncertainty interval=6,880, 23,900) cancer cases, add 593,000 (95% uncertainty interval=419,000, 827,000) quality-adjusted life years, and generate net savings of $2.7 billion from societal perspectives. The warning label policy would avert 85,400 (95% uncertainty interval=56,600, 141,000) and 15,000 (95% uncertainty interval=6,860, 34,500) colorectal and stomach cancer cases and add 660,000 (95% uncertainty interval=418,000, 1,070,000) quality-adjusted life years with net savings of $4.5 billion from societal perspectives. In subgroup analyses, greater health and economic benefits accrued to (1)

Address correspondence to: David D. Kim, PhD, Center for the Evaluation of Value and Risk in Health, Institute for Clinical Research and Health Policy Studies, Tufts Medical Center, 800 Washington St., Box 063, Boston MA 02111. dkim3@tuftsmedicalcenter.org.

younger subpopulations, (2) subpopulations with greater cancer risk, and (3) those with higher baseline processed meat consumption.

Conclusions: The model shows that implementing tax or warning labels on processed meats would be a cost-saving strategy with substantial health and economic benefits. The findings will encourage policy makers to consider nutrition-related policies to reduce cancer burden.

INTRODUCTION

Consumption of processed meat—those preserved through salting, other preservatives, or curing (e.g., ham, bacon, sausages)—is associated with the risk of developing colorectal and stomach cancer.[1–4] The International Agency for Research on Cancer classified processed meats as carcinogenic to humans based on the strength and consistency of evidence.[5, 6]

Reducing the consumption of processed meat could improve population health and avoid costs associated with cancer, which accounted for $80.2 billion in annual healthcare costs.[7] Existing population-level policies, such as warning labels for smoking or taxes on sugar-sweetened beverages (SSBs), have been shown to be effective in altering risky behaviors.[8–11] Although similar policies, including taxes or warning labels, have been proposed to discourage processed meat consumption,[12, 13] the potential impact of such policies has not been examined. Using a U.S. population-based cost-effectiveness model, this paper compares the projected cancer and economic outcomes of taxes and warning labels on processed meats to status quo (no policy).

METHODS

The Dietary and Cancer Outcome Model is a probabilistic state-transition cohort model that projects the population effect of nutrition policies on cancer outcomes. The model consists of (1) six health states: healthy without cancer, initial treatment with colorectal cancer, continuous care with colorectal cancer, initial treatment with stomach cancer, continuous care with stomach cancer, and dead (from cancer or other causes); (2) the annual likelihood of changes in health; and (3) the lifetime consequences of such changes on health outcomes and economic costs.[14] The model estimated health benefits (life years, quality-adjusted life years [QALYs], cancer incidence, and years living with cancer) and economic impact (e.g., policy implementation costs, healthcare costs, and productivity benefits). Table 1 and Appendix Figure 1 provide input parameters and the model structure.

Following the updated reporting guidelines,[15] the model assessed the incremental changes through implementing the two policies versus the status quo from healthcare and societal perspectives, along with an Impact Inventory table that listed important outcomes to be considered from both perspectives (Appendix Table 1). Incremental cost-effectiveness ratios were separately calculated for each policy versus the status quo. To account for input parameter uncertainty, probabilistic sensitivity analysis was performed using probability distributions for all input parameters. The results reported the 95% uncertainty intervals (UI) based on the 2.5 and 97.5 percentiles of 1,000 simulations. In the base-case analysis, the model used a lifetime horizon and discounted both costs and health outcomes at 3% per year. All analyses and model development were conducted in Stata, version 14 and R, version 3.3.1.[16, 17] The model validation and the source code are available in the Appendix.

Study Population

Using the two most recent cycles (2011–2012 and 2013–2014) of the National Health and Nutrition Examination Survey (NHANES), 32 subgroups were created from four age groups (20–44, 45–54, 55–64, and >65 years), both sexes (males and females), and four race/ethnicity groups (non-Hispanic whites, non-Hispanic blacks, Hispanics, and others). All analyses estimated population-level outcomes by combining the 32 subgroup-level groups according to NHANES survey design and sampling weights.

Measures

The baseline intake of processed meat was estimated through linking the NHANES dietary data with corresponding Food Patterns Equivalents Database, which provides disaggregated information of the U.S. Department of Agriculture food code into the specific 37 food groups, including processed meat[18, 19] (Appendix Text 2). To simulate processed meat intake, the model applied a two-step approach: (1) using binomial distributions to select processed meat consumers and then (2) gamma distributions to capture the skewed distribution of processed meat intake among those who consume processed meat.

A dose–response meta-analysis reported that the daily consumption of each 50 grams of processed meat is associated with a RR of 1.16 (95% CI=1.08, 1.26) for developing colorectal cancer and of 1.18 (95% CI=1.01, 1.38) for developing stomach cancer.[2–4] The RR denotes ratio measures of effect (e.g., risk ratios, rate ratios, or ORs) and is adjusted for potential confounders, such as age, sex, smoking status, alcohol consumption, energy intake, and BMI. The association between processed meat and cancer risk incorporates the average effects of any substitution for processed meats with either healthier or non-healthier choices.

Findings from prospective cohort studies suggested that processed meat intake was not associated with colorectal cancer incidence within the first 4 years, but the association became stronger after 4–12 years.[20] Thus, the base-case analysis applied a 5-year latency period between onset of reduced processed meat intake and its impact on cancer incidence. The model also assumed that reduced processed meat consumption does not confer survival benefit after developing cancer[21] and that the joint chance of developing both cancers simultaneously to be negligible although individuals could develop both cancers.

The U.S. Cancer Statistics, the official federal cancer statistics, provided colorectal and stomach cancer incidence for 32 subgroups.[22, 23] To account for underlying trends in cancer incidence, average annual percentage changes in age-adjusted incidence rates were estimated from 1999 to 2013, and then applied these to the 2013 baseline incidence to project future incidence for each cancer site[24] (Appendix Table 2, Appendix Text 3). Using 5-year relative survival data,[23] the model estimated cancer-specific excess annual mortality rates, and combined these with the age-, sex-, and race/ethnicity-stratified general population mortality data.[25]

Three modeled policy interventions are (1) status quo (no change), (2) a 10% federal excise tax, and (3) a warning label informing the public that frequent consumption of processed meat may increase the risk of cancer. Given limited data, the base-case analysis assumed that the policy effect on processed meat consumption remains constant over time and is identical across population subgroups. The reduction in the intake was converted into the relative reduction for cancer risk. Appendix Texts 4 and 5 discuss the approach in detail.

Federal excise taxes are currently applied to a variety of products in the U.S. and in contrast to sales taxes, increase the consumers' pre-purchase price for specific items.[26] From the U.S.-based price elasticity estimates (changes in purchases because of cost) for deli meat products,[27, 28] a 10% excise tax would reduce processed meat intake by 9% (UI=5%, 15%), assuming 100% price pass through to the consumer,[29] with a 50% pass through examined in sensivity analysis.[30]

The cost of implementing the processed meat tax was estimated to be 2% of the tax revenue, assuming equal burdens on government administration and industry compliance.[31–33] Tax revenues were calculated from post-intervention national expenditure data on processed meat consumption including at home and away from home food purchase data.[34, 35] (Appendix Text 6)

The warning label policy was modeled as a government warning label on the consumer-facing packaging of all retail processed meat products. A recent meta-analysis showed that food labeling on unhealthy foods (e.g., SSBs, foods higher in saturated fat) would lead to a 13.0% (UI=0.2%, 25.7%) relative reduction,[36] similar to the effect sizes of warning labels on cigarettes.[37, 38]

The warning label intervention costs included the costs of industry labeling production and government oversight. Using the Food and Drug Administration Labeling model, which is designed to estimate the cost of label changes for various Food and Drug Administration–regulated products, the industry costs were derived by multiplying a unit cost per universal product code with the number of universal product codes for meat-frozen and meat/poultry-canned.[39] Government costs were added as an additional 25% of industry labeling costs based on prior literature.[40] (Appendix Text 7)

Healthcare expenditures were based on (1) annual costs of cancer care for initial (with treatment), continuous, and end-of-life phases[24]; and (2) background medical spending among individuals without cancer, based on a nationally representative 2013–2014 Medical Expenditure Panel Survey data (Appendix Table 4).[41] Non-healthcare costs among cancer survivors included (1) productivity loss[42] and (2) time costs for treatment.[43] All costs were expressed in 2014 U.S. dollars and the Personal Health Care index was used to adjust total medical expenditures for inflation.[44] Health-related quality of life weights for patients with colorectal and stomach cancer reflected three different phases of cancer care,[45, 46] and for methodologic consistency, had all been assessed with the three-level EQ-5D, a preference-based, multi-attribute utility instrument.[47]

Scenario, Sensitivity, and Subgroup Analysis

Scenario analyses were conducted to examine the potential impact of a set of different modeling choices and assumptions. The plausible alternative values are chosen as they are likely to occur as a set of parameters in each scenario. Under a conservative scenario, the model applied a 10-year (rather than 5-year) latency period while simultaneously lowering the impact of the 10% tax on processed meat intake to a 3% (UI=1%, 5%) reduction, from 9% (UI=5%, 15%), based on the price elasticity of fast-food intake.[48] Similarly, the effect of warning label policy was reduced to 4% (UI=2%, 8%), from 13% (UI=0.2%, 25.7%).[49] Under an optimistic scenario, the model assumed that background colorectal and stomach incidence in 2013 remained constant over time, applied a larger effect size of both policies, such as 13% (UI=10%, 15%) for the tax and 20% (UI=15%, 25%) for the warning label, applying evidence from different studies.[28, 37, 50]

The population impact of the two nutrition policies was analyzed for each of the 32 subgroups using subpopulation size estimates from NHANES. Additional sensitivity analyses were conducted to examine the effect of (1) shorter analytic time horizons of 10, 15, and 25 years for policy makers interested in near-term return on investment durations, (2) different discounting rates of 0% and 5% (instead of 3%), and (3) 50% pass through of the tax burden (instead of 100% pass through).

RESULTS

In 2011–2014, the overall U.S. adult population (249.4 million) consumed average 42.0 grams of processed meat daily. Males consistently consumed more than females across all age groups, and Hispanic males aged 45–54 years had the highest mean consumption (86.4 grams, SE=7.86) among the 32 subgroups. About one third of U.S. adults (34.6%) reported no processed meat intake. The prevalence of no consumption was lowest in non-Hispanic black males (22.6%), and non-Hispanic white males (25.1%). Among the 163 million adult processed meat consumers (65.4% of 250 million U.S. adults), mean daily consumption was 64.2 grams. Among the 163 million American adults who consume processed meats, the 10% excise tax and warning label policy would decrease the mean daily processed meat intake by 6.1 grams (SE=0.5) and 8.5 grams (SE=0.5) per person, respectively (Appendix Tables 5 and 6).

Over the population's lifetime, the model estimated that a 10% excise tax would prevent 77,000 (95% UI=56,800, 107,000) cases of colorectal cancer and 12,500 (95% UI=6,880, 23,900) cases of stomach cancer, leading to 778,000 (95% UI=533,000, 1,100,000) fewer person-years with colorectal cancer, and 593,000 (95% UI=419,000, 827,000) additional QALYs gained. Similarly, the warning label policy was estimated to avert 85,400 (95% UI=56,600, 141,000) incident colorectal and 15,000 (95% UI=6,860, 34,500) incident stomach cancer cases while adding 660,000 (95% UI=418,000, 1,070,000) QALYs (Table 3).

From the average annual processed meat expenditure of $125.96 per person with a 10% tax, the expected tax revenue was $12.60 per person, yielding an annual tax administration cost (2% of tax revenue) of 25.2 cents per person. Applying 25.2 cents to the size of the U.S.

adult population in 2016,[51] the tax policy intervention costs were $62.9 million per year. A mandated warning label would cost $1.95 million annually to the industry for a major label change to all processed meat products and $0.49 million per year (25% of the industry labeling costs) to the government for regulatory oversight. Assuming 30 years as the effective period for both policies, the net present value of the policy intervention costs with a 3% annual discount rate was $1.3 billion for the tax and $50.3 million for the warning label.

A 10% excise tax on processed meats would save $1.14 billion (95% UI= −1.90, 7.10) in healthcare costs and generate an additional $2.89 billion savings (95% UI=1.08, 6.26) from nonhealthcare costs (i.e., time costs and productivity effects). After accounting for $1.3 billion of policy intervention costs over the next 30 years, the excise tax was cost saving (i.e., reducing costs and extending QALYs), with lifetime net savings of $2.70 billion from a societal perspective. From a healthcare sector perspective, the 10% excise tax was still considered extremely cost-effective with an incremental cost-effectiveness ratio of $270 per QALY gained.

Similarly, the warning label policy would save $1.31 billion (95% UI= −.28, 8.21) in healthcare costs and $3.26 billion (95% UI=1.04, 7.55) in non-healthcare costs. Considering $50.3 million warning label costs over the next 30 years, this policy was also dominant, with net savings of $1.26 billion and $4.52 billion from healthcare and societal perspectives.

Under conservative scenarios, both the excise tax and warning label policies remained cost saving or highly cost-effective from both perspectives. For example, the excise tax still prevented 61,900 (95% UI=56,800, 70,000) incident colorectal and 8,380 (95% UI=6,880, 11,600) incident stomach cancer cases, added 472,000 (95% UI=419,000, 531,000) QALYs, and saved $1.85 billion from a societal perspective.

Not surprisingly, under optimistic scenarios, health benefits and cost savings for both policies increased. For example, the warning label policy would avert 108,000 (95% UI=56,600, 171,000) colorectal cancer and 20,700 (95% UI=6,860, 44,900) stomach cancer cases and add 899,000 (95% UI=418,000, 1,440,000) QALYs with healthcare savings of $1.49 billion and societal savings of $5.74 billion (Figure 1, Appendix Table 7).

Both policies remained cost saving across all 32 population subgroups. Larger health and economic benefits were seen among (1) younger subpopulations due to a longer exposure time for accruing the benefits of nutrition policy changes, (2) subpopulations with greater cancer burdens (e.g., non-Hispanic black men), and (3) those with higher baseline processed meat consumption (e.g., Hispanic men aged 45–54 years; Appendix Tables 8A and 8B). When examining alternative analytic time horizons, even for a 10-year time horizon (rather than lifetime), both policies are cost saving from both perspectives, compared with the status quo (Figure 2). For example, over 10 years, the tax policy would produce 44,900 (95% UI=36,800, 54,400) QALYs gained while saving $1.22 billion and $1.86 billion from healthcare and societal perspectives. (Appendix Tables 9) A 5% discount rate (instead of 3%) reduced the magnitude of health benefits and economic savings but did not change the conclusions (Appendix Table 10).

Under the assumption of 50% pass through of the tax burden to consumers, the impact of reduced intake is halved. Although the lifetime impact of reduced cancer burden and cost effectiveness was attenuated, the tax policy remained a cost-saving strategy (Appendix Text 8).

DISCUSSION

Considering policy costs, health gains, and healthcare and indirect savings, the model suggests that either a 10% excise tax or a warning label on processed meats would prevent substantial numbers of cancer cases and be cost saving with robust results in scenario and sensitivity analyses. Among the two proposed policies, the model estimated that the warning label could provide similar health and economic benefits with lower intervention costs than the tax policy, although the impact of the warning label policy was less confident due to greater uncertainty in the effect size. Nonetheless, both policies would lead to substantial health gains and cost savings. The tax policy would also generate substantial government revenue (not accounted for in the analyses) which could be used for other health promotion programs.

Valuing a year of life in perfect health as $100,000 ($100,000/QALY) and using a societal perspective,[52–54] the lifetime net monetary benefits (i.e., differences between the monetized value of QALYs and the associated costs) of implementing the excise tax would be $597 billion and the warning label, $664 billion. Our findings are consistent with recent findings that population-based strategies to target dietary consumption are cost saving.[55–57]

Despite population-based approaches, particular subgroups with greater cancer burdens or higher baseline intake of processed meat (e.g., non-Hispanic black men and Hispanic men aged 45–54 years) can benefit more from these policies. With relative higher cancer burden in these populations, the proposed policies may contribute to reducing health disparities. However, the health and economic consequences of an excise tax or warning label for processed meat products may also affect socioeconomic subgroups differently. For instance, a tax may produce more substantial reductions in consumption among lower-income individuals, whereas a warning label may produce greater reductions among more educated individuals.[28, 58, 59] Although such effects would be unlikely to alter the overall findings or inference for these national policies, further study on its impact on disparities would be important.

Both excise taxes and warning labels on unhealthy food products are legally feasible.[26, 60] Although the study did not aim to evaluate political feasibility, policy efforts to discourage the consumption of harmful foods have been accelerating in the U.S. (SSB taxes in multiple cities[61]; sodium warnings on New York City restaurant menus[62]) and globally (SSB and junk food taxes[63, 64]; Chile’s Black Box warning labels on packaged foods[65]). Recently, policymakers have begun to focus on processed meats: for example, members of the New York City council recently proposed banning processed meats in all public schools, which would influence up to 1 million meals served to children each day.[66] The study findings add further insights to inform such ongoing policy discussions.

Limitations

Potential limitations include the following: Simulation modeling forecasts the likely health benefits and cost effects from the existing data, and findings depend on the underlying validity of key estimates. For example, the effect of a policy on changing processed meat consumption and the etiologic effects of processed meat consumption on cancer are each estimated based on best available data with uncertainty. Thus, the findings should be considered the best available estimates of potential effects, as well as uncertainty in these effects, for policymakers to consider and help inform nutrition-related health policies and their evaluation to reduce cancer.

Aside from general population mortality, additional competing mortality risks were not explicitly modeled. Because processed meat consumption may be associated with other chronic disease risk factors that affect mortality and that are changing over time (e.g., increasing obesity or decreasing smoking), not accounting for these competing risks may under- or over-estimate the number of cancers cases avoided, but quantifying and incorporating these effects into the model would be difficult. Also, the policy effect sizes were not derived from actual implementations for processed meats but derived from existing effects from taxes on SSBs and warning labels for smoking.

CONCLUSIONS

The model shows that implementing a population-wide excise tax or warning label on processed meats could meaningfully reduce the incidence of colorectal and stomach cancer, with net cost savings from a societal perspective. With the growing interest in and demand for policy interventions on unhealthy foods, it is important to understand the potential health and fiscal impact of population-based nutrition policies.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

ACKNOWLEDGMENTS

Fang Fang Zhang, MD, PhD and John B. Wong, MD are joint senior authors on this work.

All of the listed authors were supported through the National Institute on Minority Health and Health Disparities (NIMHD) R01MD011501-01A1. The NIMHD had no role in in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Dr. Mozaffarian reports research funding from the National Institutes of Health and the Gates Foundation; personal fees from GOED, Nutrition Impact, Pollock Communications, Bunge, Indigo Agriculture, Amarin, Acasti Pharma, Cleveland Clinic Foundation, America's Test Kitchen, and Danone; scientific advisory board, Elysium Health (with stock options), Omada Health, and DayTwo; and chapter royalties from UpToDate; all outside the submitted work.

REFERENCES

1. Siegel RL, Miller KD, Jemal A. Cancer statistics, 2017. CA Cancer J Clin. 2017;67(1):7–30. 10.3322/caac.21387. [PubMed: 28055103]
2. World Cancer Research Fund, American Institute for Cancer Research. Food, nutrition, physical activity, and the prevention of cancer: a global perspective. Washington, DC: AICR, 2007.

3. World Cancer Research Fund International, American Institute for Cancer Research. Continuous Update Project: Diet, Nutrition, Physical Activity and Colorectal Cancer. www.wcrf.org/colorectal-cancer-2017. Published 2017 Accessed February 22, 2019.
4. World Cancer Research Fund International, American Institute for Cancer Research. Continuous Update Project: Diet, Nutrition, Physical Activity and Stomach Cancer. www.wcrf.org/stomach-cancer-2016. Published 2016 Accessed February 22, 2019.
5. Bouvard V, Loomis D, Guyton KZ, et al. Carcinogenicity of consumption of red and processed meat. Lancet Oncol. 2015;16(16):1599–1600. 10.1016/S1470-2045(15)00444-1. [PubMed: 26514947]
6. International Agency for Research on Cancer (IARC). IARC Monographs evaluate consumption of red meat and processed meat [press release]. www.iarc.fr/en/media-centre/pr/2015/pdfs/pr240_E.pdf. Published 2015 Accessed February 22, 2019.
7. American Cancer Society. Economic Impact of Cancer. www.cancer.org/cancer/cancer-basics/economic-impact-of-cancer.html. Published 2018 Accessed February 22, 2019.
8. Falbe J, Thompson HR, Becker CM, Rojas N, McCulloch CE, Madsen KA. Impact of the Berkeley excise tax on sugar-sweetened beverage consumption. Am J Public Health. 2016;106(10):1865–1871. 10.2105/AJPH.2016.303362. [PubMed: 27552267]
9. Finkelstein EA, Zhen C, Bilger M, Nonnemaker J, Farooqui AM, Todd JE. Implications of a sugar-sweetened beverage (SSB) tax when substitutions to non-beverage items are considered. J Health Econ. 2013;32(1):219–239. 10.1016/j.jhealeco.2012.10.005. [PubMed: 23202266]
10. Hammond D, Fong GT, McDonald PW, Cameron R, Brown KS. Impact of the graphic Canadian warning labels on adult smoking behaviour. Tob Control. 2003;12(4):391–395. 10.1136/tc.12.4.391. [PubMed: 14660774]
11. Noar SM, Hall MG, Francis DB, Ribisl KM, Pepper JK, Brewer NT. Pictorial cigarette pack warnings: a meta-analysis of experimental studies. Tob Control. 2016;25(3):341–354. 10.1136/tobaccocontrol-2014-051978. [PubMed: 25948713]
12. Farm Animal Investment Risk and Return (FAIRR). The Livestock Levy: Are regulators considering meat taxes? www.fairr.org/resource/livestock-levy-regulators-considering-meat-taxes/. Published 2017 Accessed February 22, 2019.
13. Center for Science in the Public Interest. Processed Meat Petition To USDA Food Safety and Inspection Service. https://cspinet.org/resource/processed-meat-petition. Published 2016 Accessed February 22, 2019.
14. Siebert U, Alagoz O, Bayoumi AM, et al. State-transition modeling: a report of the ISPOR-SMDM Modeling Good Research Practices Task Force-3. Value Health. 2012;15(6):812–820. 10.1016/j.jval.2012.06.014. [PubMed: 22999130]
15. 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. 10.1001/jama.2016.12195. [PubMed: 27623463]
16. R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, 2016 www.R-project.org/. Accessed February 22, 2019.
17. StataCorp. Stata Statistical Software: Release 14 In. College Station, TX: StataCorp LP; 2015.
18. Bowman SA, Clemens JC, Friday JE, Thoerig RC, Moshfegh AJ. Food Patterns Equivalents Database 2011–12: Methodology and User Guide. 2014; Available from: www.ars.usda.gov/ARSUserFiles/80400530/pdf/fped/FPED_1112.pdf. Published 2014 Accessed February 22, 2019.
19. CDC, National Center for Health Statistics. National Health and Nutrition Examination Survey. www.cdc.gov/nchs/nhanes/index.htm. Published 2018 Accessed February 22, 2019.
20. Bernstein AM, Song M, Zhang X, et al. Processed and unprocessed red meat and risk of colorectal cancer: analysis by tumor location and modification by time. PLoS One. 2015;10(8):e0135959 10.1371/journal.pone.0135959. [PubMed: 26305323]
21. Meyerhardt JA, Niedzwiecki D, Hollis D, et al. Association of dietary patterns with cancer recurrence and survival in patients with stage III colon cancer. JAMA. 2007;298(7):754–764. 10.1001/jama.298.7.754. [PubMed: 17699009]
22. U.S. Cancer Statistics Working Group. United States Cancer Statistics: 1999–2014 Incidence and Mortality Web-based Report. www.cdc.gov/uscs. Published 2017 Accessed February 22, 2019.

23. CDC. United States Cancer Statistics: Public Information Data. https://wonder.cdc.gov/cancer.html. Accessed October 20, 2017.
24. Mariotto AB, Yabroff KR, Shao Y, Feuer EJ, Brown ML. Projections of the cost of cancer care in the United States: 2010–2020. J Natl Cancer Inst. 2011;103(2):117–128. 10.1093/jnci/djq495. [PubMed: 21228314]
25. National Center for Health Statistics. The National Vital Statistics System: Mortality data. www.cdc.gov/nchs/nvss/deaths.htm. Published 2018 Accessed February 22, 2019.
26. Pomeranz JL, Wilde P, Huang Y, Micha R, Mozaffarian D. Legal and administrative feasibility of a federal junk food and sugar-sweetened beverage tax to improve diet. Am J Public Health. 2018;108(2):203–209. 10.2105/AJPH.2017.304159. [PubMed: 29320289]
27. Dong D, Davis CG, Stewart H. The quantity and variety of households' meat purchases: a censored demand system approach. Agric Econ. 2015;46(1):99–112. 10.1111/agec.12143.
28. Lusk JL, Tonsor GT. How meat demand elasticities vary with price, income, and product category. Appl Econ Perspect Policy. 2016;38(4):673–711. 10.1093/aepp/ppv050.
29. Cawley J, Frisvold D, Hill A, Jones D. The impact of the Philadelphia beverage tax on prices and product availability. NBER Work Pap Ser. 2018;24990 10.3386/w24990.
30. Falbe J, Rojas N, Grummon AH, Madsen KA. Higher retail prices of sugar-sweetened beverages 3 months after implementation of an excise tax in Berkeley, California. Am J Public Health. 2015;105(11):2194–2201. 10.2105/AJPH.2015.302881. [PubMed: 26444622]
31. City of Berkeley. Contract with Muniservices, LLC/Soda Tax Implementation. Published 2014.
32. Aaron H, Gale WG. Economic effects of fundamental tax reform. Brookings Institution Press; 2010.
33. Orzechowski W, Walker R. The tax burden on tobacco: historical compilation. Volume 44 Arlington, VA: Orzechowski and Walker, 2009.
34. U.S. Bureau of Labor Statistics. Consumer Expenditure Survey. www.bls.gov/cex/. Published 2018 Accessed February 22, 2019.
35. Garasky S, Mbwana K, Romualdo A, Tenaglio A, Roy M. Foods Typically Purchased by Supplemental Nutrition Assistance Program (SNAP) Households. November) Prepared by IMPAQ International, LLC for U.S. Department of Agriculture, Food and Nutrition Service; 2016.
36. Shangguan S, Afshin A, Shulkin M, et al. A meta-analysis of food labeling effects on consumer diet behaviors and industry practices. Am J Prev Med. 2019;56(2):300–314. 10.1016/j.amepre.2018.09.024. [PubMed: 30573335]
37. Huang J, Chaloupka FJ, Fong GT. Cigarette graphic warning labels and smoking prevalence in Canada: a critical examination and reformulation of the FDA regulatory impact analysis. Tob Control. 2014;23(suppl 1):i7–12. 10.1136/tobaccocontrol-2013-051170. [PubMed: 24218057]
38. Azagba S, Sharaf MF. The effect of graphic cigarette warning labels on smoking behavior: evidence from the Canadian experience. Nicotine Tob Res. 2013;15(3):708– 717. 10.1093/ntr/nts194. [PubMed: 22990228]
39. Muth M, Bradley S, Brophy J, Capogrossi K, Coglaiti M, Karns S. 2014 FDA Labeling Cost Model. RTI International, U.S. Food and Drug Administration; 2015.
40. Gortmaker SL, Wang YC, Long MW, et al. Three interventions that reduce childhood obesity are projected to save more than they cost to implement. Health Aff (Millwood). 2015;34(11):1932–1939. 10.1377/hlthaff.2015.0631. [PubMed: 26526252]
41. Agency for Healthcare Research and Quality. The Medical Expenditure Panel Survey (MEPS). www.meps.ahrq.gov/mepsweb/. Published 2018 Accessed February 22, 2019.
42. Zheng Z, Yabroff KR, Guy GP Jr., et al. Annual medical expenditure and productivity loss among colorectal, female breast, and prostate cancer survivors in the United States. J Natl Cancer Inst. 2016;108(5):djv382 10.1093/jnci/djv382.
43. Yabroff KR, Guy GP Jr., Ekwueme DU, et al. Annual patient time costs associated with medical care among cancer survivors in the United States. Med Care. 2014;52(7):594–601. 10.1097/MLR.0000000000000151. [PubMed: 24926706]
44. Dunn A, Grosse SD, Zuvekas SH. Adjusting health expenditures for inflation: a review of measures for health services research in the United States. Health Serv Res. 2018;53(1):175–196. 10.1111/1475-6773.12612. [PubMed: 27873305]

45. Farkkila N, Sintonen H, Saarto T, et al. Health-related quality of life in colorectal cancer. Colorectal Dis. 2013;15(5):e215–e222. 10.1111/codi.12143. [PubMed: 23351057]
46. Zhou HJ, So JB, Yong WP, et al. Validation of the functional assessment of cancer therapy-gastric module for the Chinese population. Health Qual Life Outcomes. 2012;10:145 10.1186/1477-7525-10-145. [PubMed: 23194009]
47. EuroQol Research Foundation. EQ-5D Instruments: About EQ-5D. https://euroqol.org/eq-5d-instruments/. Published 2017 Accessed February 22, 2019.
48. Afshin A, Penalvo JL, Del Gobbo L, et al. The prospective impact of food pricing on improving dietary consumption: a systematic review and meta-analysis. PLoS One. 2017;12(3):e0172277 10.1371/journal.pone.0172277. [PubMed: 28249003]
49. Levy DT, Mays D, Yuan Z, Hammond D, Thrasher JF. Public health benefits from pictorial health warnings on U.S. cigarette packs: a SimSmoke simulation. Tob Control. 2017;26(6):649–655. 10.1136/tobaccocontrol-2016-053087. [PubMed: 27807299]
50. Roberto CA, Wong D, Musicus A, Hammond D. The influence of sugar-sweetened beverage health warning labels on parents' choices. Pediatrics. 2016;137(2):e20153185 10.1542/peds.2015-3185. [PubMed: 26768346]
51. Census Bureau, U.S. Department of Commerce. U.S. Census Bureau QuickFacts: United States. www.census.gov/quickfacts/fact/table/US/PST045216. Accessed February 22, 2019.
52. Neumann PJ, Cohen JT, Weinstein MC. Updating cost-effectiveness–the curious resilience of the $50,000-per-QALY threshold. N Engl J Med. 2014;371(9):796–797. 10.1056/NEJMp1405158. [PubMed: 25162885]
53. Nimdet K, Chaiyakunapruk N, Vichansavakul K, Ngorsuraches S. A systematic review of studies eliciting willingness-to-pay per quality-adjusted life year: does it justify CE threshold? PLoS One. 2015;10(4):e0122760 10.1371/journal.pone.0122760. [PubMed: 25855971]
54. Ryen L, Svensson M. The willingness to pay for a quality adjusted life year: a review of the empirical literature. Health Econ. 2015;24(10):1289–1301. 10.1002/hec.3085. [PubMed: 25070495]
55. 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. 10.1016/j.amepre.2016.12.013. [PubMed: 28153648]
56. Webb M, Fahimi S, Singh GM, et al. Cost effectiveness of a government supported policy strategy to decrease sodium intake: global analysis across 183 nations. BMJ. 2017;356:i6699 10.1136/bmj.i6699. [PubMed: 28073749]
57. Gortmaker SL, Wang YC, Long MW, et al. Three interventions that reduce childhood obesity are projected to save more than they cost to implement. Health Aff (Millwood). 2015;34(11):1932–1939. 10.1377/hlthaff.2015.0631. [PubMed: 26526252]
58. Townsend J, Roderick P, Cooper J. Cigarette smoking by socioeconomic group, sex, and age: effects of price, income, and health publicity. BMJ. 1994;309(6959):923–927. 10.1136/bmj.309.6959.923. [PubMed: 7950662]
59. Farrelly MC, Nonnemaker JM, Watson KA. The consequences of high cigarette excise taxes for low-income smokers. PLoS One. 2012;7(9):e43838 10.1371/journal.pone.0043838. [PubMed: 22984447]
60. Pomeranz JL, Mozaffarian D, Micha R. Can the government require health warnings on sugar-sweetened beverage advertisements? JAMA. 2018;319(3):227–228. 10.1001/jama.2017.19209. [PubMed: 29340685]
61. Paarlberg R, Mozaffarian D, Micha R. Can U.S. local soda taxes continue to spread? Food Policy. 2017;71:1–7. 10.1016/j.foodpol.2017.05.007.
62. NYC Health. Sodium Warning Labels for Chain Restaurants. www1.nyc.gov/site/doh/health/health-topics/national-salt-reduction-initiative.page. Published 2018 Accessed May 17, 2018.
63. Batis C, Rivera JA, Popkin BM, Taillie LS. First-year evaluation of Mexico's tax on nonessential energy-dense foods: an observational study. PLoS Med. 2016;13(7):e1002057 10.1371/journal.pmed.1002057. [PubMed: 27379797]

64. Jou J, Techakehakij W. International application of sugar-sweetened beverage (SSB) taxation in obesity reduction: factors that may influence policy effectiveness in country-specific contexts. Health Policy. 2012;107(1):83–90. 10.1016/j.healthpol.2012.05.011. [PubMed: 22727243]

65. Rodriguez L The implementation of new regulations on nutritional labelling in Chile. www.wto.org/english/tratop_e/tbt_e/8_Chile_e.pdf. Accessed April 20, 2018.

66. Cabrera F, Rosenthal HK, Brannan JL, et al. Resolution calling upon the New York City Department of Education to ban processed meats from being served in New York City public schools. http://legistar.council.nyc.gov/LegislationDetail.aspx?ID=3458218&GUID=E2D39627-1649-42BB-AF90-A7E364FE5329&Options=ID|Text|&Search=cabrera. Published 2018 Accessed May 4, 2018.

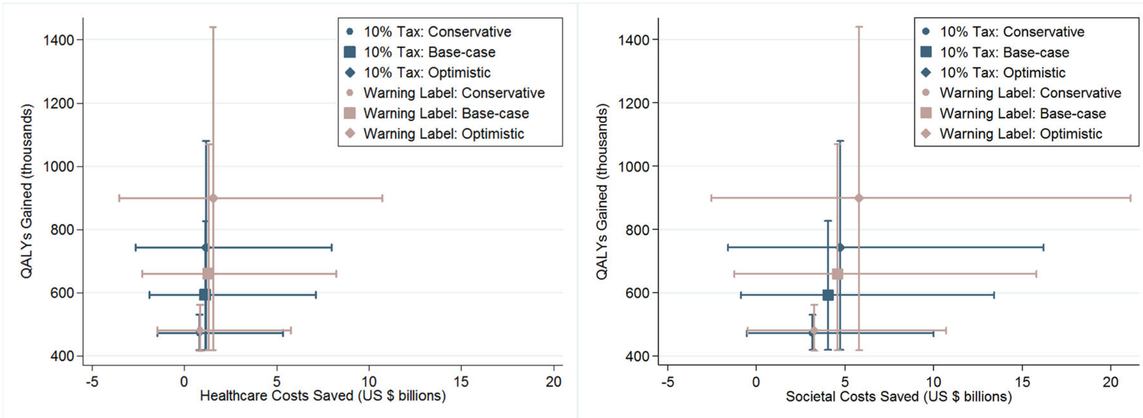

Figure 1.

Impact of nutrition policies under different scenarios.

Note: Under the scenario analyses, three modeling choices were varied: (1) the latency period, (2) approaches to project secular trends in cancer incidence, and (3) the policy effect size. For the 10% tax policy, (1) the conservative scenario: 3% effect size (uncertain range: 1%–5%), a 10-year latency period, and a historical trend from 1999–2013; (2) the base-case scenario: 9% effect size (5%–15%), a 5-year latency period, and a historical trend from 1999–2013; and (3) the optimistic scenario: 13% effect size (10%–15%), no latency period, and a constant trend as of 2013. For the warning label policy, (1) the conservative scenario: 4% effect size (2%–8%), a 10-year latency period, and a historical trend from 1999–2013; (2) the base-case scenario: 12.5% effect size (2%–23%), a 5-year latency period, and a historical trend from 1999–2013; and (3) the optimistic scenario: 20% effect size (15%–25%), no latency period, and a constant trend as of 2013. From a societal perspective, societal costs included savings from both healthcare costs and non-healthcare costs, including time costs associated with receiving medical care and productivity. Appendix Table 7 provides full results of the scenario analyses.

QALYs, quality-adjusted life years.

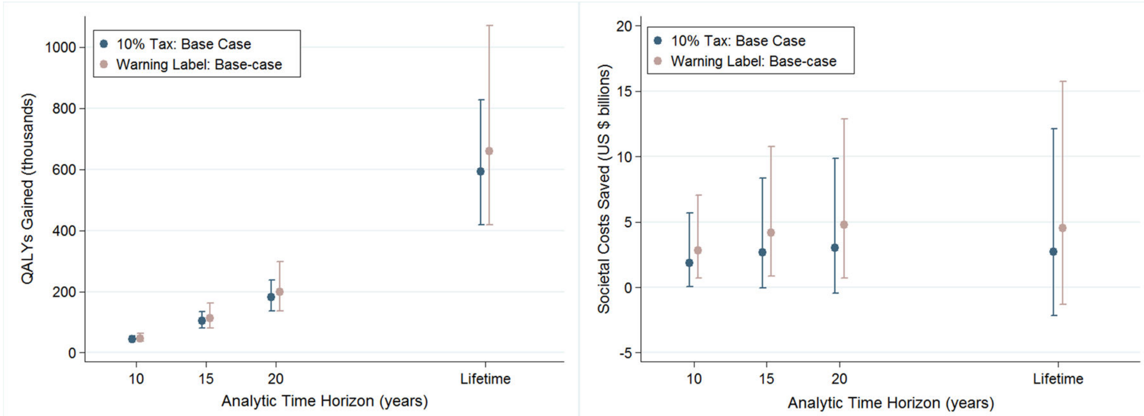

Figure 2.

Impact of analytic time horizons on cost effectiveness of nutrition policies.

Note: Even for a 10-year time horizon (rather than lifetime), both policies were net cost-savings from healthcare and societal perspectives, compared with the status-quo. Appendix Table 9 provides full results from the sensitivity analysis of the analytic time horizon. QALYs, quality-adjusted life years.

Table 1.

Key Input Parameters in the Dietary and Cancer Outcome Model[a]

Variable	Base-case value	Uncertainty range	Distribution	Source
Baseline intake characteristics				
A proportion of meat eaters (%)	Appendix Table 6		Binomial	NHANES
Average processed meat intake among meat-eaters (g/day)	Appendix Table 6		Gamma	NHANES
Policy intervention characteristics				
Effect size (% reduction in processed meat intake)				
10% federal excise tax	9	5–15	Beta	Dong et al., 2015[27]; Lusk et al., 2016[28]; Appendix Text 4
Mandatory warning label	13	0.2–25.7	Beta	Shangguan et al., 2018[36] Appendix Text 5
Intervention costs ($ per year)				
10% federal excise tax	62.9 million	-	-	Appendix Text 6
Mandatory warning label	2.44 million			Appendix Text 7
Cancer statistics				
Incidence, colorectal and stomach cancer	Appendix Table 2 and Appendix Text 3		Beta	USCS
Annual probability of dying from cancer[b]				
Colorectal cancer	0.091	0.069–0.115	Beta	NPCR
Stomach cancer	0.199	0.160–0.242	Beta	NPCR
Relative risk of processed meat and cancer (per 50g/day increase in processed meat)				
Colorectal cancer	1.16	1.08–1.26	Log normal	CUP, 2017[3]
Stomach cancer	1.18	1.01–1.38	Log normal	CUP, 2016[4]
Health-related quality of life (HRQOL)				
Colorectal cancer				
Initial phase	0.761	0.703–0.814	Beta	Farkkila et al., 2013[45]
Continuous phase	0.834	0.784–0.878	Beta	Farkkila et al., 2013[45]
End-of-life phase	0.644	0.544–0.733	Beta	Farkkila et al., 2013[45]

Variable	Base-case value	Uncertainty range	Distribution	Source
Stomach cancer				
Initial phase	0.839	0.762–0.901	Beta	Zhou et al., 2012[46]
Continuous phase	0.862	0.788–0.922	Beta	Zhou et al., 2012[46]
End-of-life phase	0.680	0.480–0.834	Beta	Zhou et al., 2012[46]
Annual healthcare expenditures (HCE), $[c]				
Colorectal cancer				
Initial phase, male	63,300	3,300–307,000	Gamma	Mariotto et al., 2011[24]
Initial phase, female	65,800	3,800–302,000	Gamma	Mariotto et al., 2011[24]
Continuous phase, male	4,800	280–21,700	Gamma	Mariotto et al., 2011[24]
Continuous phase, female	3,200	180–14,500	Gamma	Mariotto et al., 2011[24]
End-of-life phase, male	94,800	4,600–456,000	Gamma	Mariotto et al., 2011[24]
End-of-life phase, female	87,800	5,700–358,000	Gamma	Mariotto et al., 2011[24]
Stomach cancer				
Initial phase, male	84,400	4,300–403,000	Gamma	Mariotto et al., 2011[24]
Initial phase, female	75,400	3,900–352,000	Gamma	Mariotto et al., 2011[24]
Continuous phase, male	4,600	300–20,700	Gamma	Mariotto et al., 2011[24]
Continuous phase, female	4,300	210–21,400	Gamma	Mariotto et al., 2011[24]
End-of-life phase, male	114,000	5,500–524,000	Gamma	Mariotto et al., 2011[24]
End-of-life phase, female	109,000	6,500–485,000	Gamma	Mariotto et al., 2011[24]
Background HCE, general population	Appendix Table 4		Gamma	MEPS
End-of-life HCE, general population	40,956	26,700–59,300	Gamma	Hogan et al., 2001[67]
Productivity loss among cancer survivors ($ per year)				
Colorectal cancer survivors[d]	5,930	2,730	12,400	Zheng et al., 2016[42]
Annual time spent on medical care (hours)				
Age <65 years				
Without cancer	13.6	8.32–19.1	Normal	Yabroff et al., 2014[43]
With cancer	30.1	18.4–43.4	Normal	Yabroff et al., 2014[43]
Age >65 years				
Without cancer	36.9	23.1–50.5	Normal	Yabroff et al., 2014[43]

Variable	Base-case value	Uncertainty range	Distribution	Source
With cancer	55.0	33.0–76.1	Normal	Yabroff et al., 2014[43]
Mean hourly wage ($)	24.5			BLS

[a]All costs were expressed in 2014 U.S. Dollars.

[b]Annual probabilities of dying from specific cancer were derived from the 5-year relative survival data available from the CDC's National Program of Cancer Registries.

[c]Because the original source did not provide uncertainty estimates, the model assumed the SEs were 20% of the mean estimate to generate gamma distribution.

[d]Because of no data available for stomach cancer survivors, the model applied the productivity loss among colorectal cancer survivors to stomach cancer survivors.

NHANES, National Health and Nutrition Examination Survey; USCS, United States Cancer Statistics; CUP, Continuous Update Project; MEPS, Medical Expenditures Panel Survey; BLS, Bureau of Labor Statistic

Table 2.

Base-Case Results[a]: Lifetime Consequences for Nutrition Policies to Reduce Processed Meat Intake (All U.S. Adult Population, 250 million)

	Overall health outcomes		Cancer-specific outcomes						Costs, 2014 U.S. $, in millions				ICER, $ per QALY	
Policy intervention	**Life years**	**QALYs**	**CRC cases**	**CRC deaths**	**CRC PYs**	**SC cases**	**SC deaths**	**SC PYs**	**Intervention costs[b]**	**Healthcare costs**	**Time costs**	**Productivity effects**	**Healthcare sector perspective**	**Societal perspectiv[c]**
Policy scenario 1: 10% excise tax														
Incremental effects vs status quo	497,000	593,000	−77,000	−55,000	−778,000	−12,500	−11,100	−57,900	1,300	−1,140	−192	−2,700	270	Cost-saving
(2.5 percentile, 97.5 percentile)	(348,000, 694,000)	(419,000, 827,000)	(−107,000, −56,800)	(−77,100, −39,500)	(−1,100,000, −533,000)	(−23,900, −6,880)	(−21,000, −5,980)	(−116,000, −26,500)	N/A	(−7,100, 1,900)	(−490,0)	(−5,770, −1,080)		
Policy scenario 2: warning label														
Incremental effects vs status quo	553,000	660,000	−85,400	−61,300	−865,000	−15,000	−13,200	−69,400	50.3	−1,310	−213	−3,040	Cost-saving	Cost-saving
(2.5 percentile, 97.5 percentile)	(346,000, 898,000)	(418,000, 1,070,000)	(−141,000, −56,600)	(−100,000, −39,300)	(−1,440,000, −531,000)	(−34,500, −6,860)	(−30,300, −5,930)	(−167,000, −26,200)	N/A	(−8,210, 2,280)	(−613, 38.9)	(−6,930, −1,080)		

[a]The base-case analysis assumed a lifetime horizon and discounted future costs, life years and QALYs at 3% per year. The results reported the mean estimates with 95% uncertainty interval.

[b]Policy intervention costs represented the net present value over 30 years of the effective period with a 3% discount rate. The impact of nutrition policies was assumed one-time effect that would last at the reduced processed meat intake.

[c]A societal perspective included healthcare costs, time costs associated with receiving medical care, and productivity effects.

LYs, life years; QALYs, quality-adjusted life years; CRC, colorectal cancer; SC, stomach cancer; PY, person-years; ICER, incremental cost-effectiveness ratio.