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Estimated health outcomes of breast cancer screening in the national breast and cervical cancer early detection program by race/ethnicity

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Abstract

Purpose: To estimate the number of screenings received, life-years (LYs) saved, and number of screenings per LY saved per woman who participated in the National Breast and Cervical Cancer Early Detection Program (NBCCEDP) (Program) compared with those who did not participate (no Program).

Methods: We developed a time-to-event simulation model to compare the outcomes of women participating in the Program vs. no Program, categorized by race/ethnicity. Model input parameters included data from the Program's minimum data elements, United States Cancer Statistics, National Health Interview Survey, and published literature. The Program's impact was calculated as the difference in LYs between the Program and no Program using data from 2010 to 2019.

Results: Among 1 million women of all races/ethnicities who participated in the NBCCEDP in the last 10 years, 457,152 (standard deviation [SD]: 848) received more screenings than those who did not participate. These participants saved an average of 0.027 LYs per woman screened. In addition, we estimated that about 17 screenings would be required to save an additional 1 LY per woman screened in the Program compared with no Program. Per woman screened by race/ethnicity, non-Hispanic Black women had the highest estimated 0.075 LYs saved, followed by Hispanic women with 0.025 LYs, non-Hispanic White with 0.014 LYs, and non-Hispanic American Indian/Alaska Native and Asian/Pacific Islander had the least health outcome with 0.011 LYs.

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Conclusion: The reported findings underscore the importance of providing preventive health services to populations that might not otherwise have access to these services.

Keywords

Breast cancer; Cancer prevention; Breast cancer screening; NBCCEDP; Cancer in subpopulations

Introduction

Breast cancer diagnoses and poor health outcomes disproportionately affect women by race/ethnicity [1]. For example, non-Hispanic White (NHW) women have the highest breast cancer incidence rate, but non-Hispanic Black (NHB) women have the highest mortality rate [1]. From 1998 to 2018, breast cancer incidence in Hispanic and NHW women decreased [2], the incidence for NHB, non-Hispanic American Indian/Alaska Native (NH AI/AN), and non-Hispanic Asian or Pacific Islander (NH API) women increased [2]. For example, during the last two decades, the absolute change in breast cancer incidence rate per 100,000 for NH API women increased by 21.1, while the incidence for NHW women decreased by 11.5 [2].

Breast cancer screening can detect cancer at earlier stages when it is easier to treat [3]. The US Preventive Services Task Force (USPSTF) currently recommends that all women aged 40–74 years receive biennial screening mammography [4]. Although the Affordable Care Act (ACA) requires most insurers to cover mammograms at no cost for women starting at age 40 years, women who are uninsured or underinsured may not have access to affordable screenings and diagnostic testing, which may lead to more advanced-stage breast cancer diagnoses than among those who receive screenings as recommended by the USPSTF [3–5]. The National Breast and Cervical Cancer Early Detection Program (NBCCEDP) (hereafter called Program) aims to reduce breast and cervical cancer morbidity and mortality by providing screening and diagnostic services to women between the ages 40–64 years (breast) and ages 21–64 years (cervical) who have low-income and are uninsured, or underinsured [6]. Participants diagnosed by the Program with cancer or pre-cancer are referred for treatment under the Medicaid Program waiver [6]. Women 65 years or older are eligible for insurance by Medicare but may still receive services through the Program if they don't have Medicare [7].

A prior modeling evaluation of the Program (1991–2006) found that breast cancer screenings through the NBCCEDP resulted in an additional increase in life expectancy that ranged from 0.031 to 0.081 life-years (LYs) saved per woman screened [8]. Similarly, the same study reported that among 1.8 million women who participated in the Program, 100,800 LYs were saved compared with women who did not participate [8]. This was the first model-based study to quantify the Program's impact compared with women who did not participate [8]. Since these findings were published, there have been many improvements in technology related to breast cancer screening and changes in recommendations for screening, diagnosis, and treatment [9, 10]. For example, X-ray machines were originally used for mammograms until the Food and Drug Administration (FDA) approved full-field digital mammography in 2000 [9]. The improvements in breast screening technologies have helped to provide a clearer image of the breast for more accurate diagnoses of cancer [10].

The advancement in breast cancer treatment with precision medicine, starting with FDA approval of anti-human epidermal growth factor receptor 2 (HER2) antibodies in 1998 and tyrosine kinase inhibitors in 2007, has significantly increased breast cancer survival [11, 12].

In addition to the changes in breast cancer screening, diagnosis, and treatment technologies, in the past decade, the healthcare system has also changed with the implementation of the ACA [13, 14]. Similarly, the USPSTF recommendations for mammograms have also changed [4, 15]. Based on these changes, the previously estimated impact of the NBCCEDP, measured by LYs saved, may be outdated. Further, a previous model-based study of the Program did not consider differences by race/ethnicity [8].

The objectives of this study are to estimate the following health outcomes: (a) the number of screenings received per woman, (b) LYs saved per woman screened, and (c) the number of screenings per LY saved for a woman who participated in the Program. All the outcomes were compared with the counterfactual scenario if the Program was absent. These estimates were stratified by race/ethnicity—NHW, NHB, NH AI/AN and API, and Hispanic. Because of the small sample size, NH AI/AN and API were combined for the stability of the estimates and henceforth denoted as “NH AIAN/API.”

Methods

Model overview and data

A time-to-event model was used to simulate the health outcomes reported in this study. Additionally, we also used a microsimulation model that simulated the occurrence of events for each individual included in the model. The structure of the model and how the components are connected are presented in Fig. 1, and the expanded model structure is provided in Figure S1. Table 1 presents the general model data input parameters and their associated values. In the study, we used different databases to obtain the populations used to measure women not in the “No Program” (counterfactual scenario). The counterfactual approach used was adapted from prior studies [8, 16]. Similarly, Blumberg (2016) employed the uninsured rate as a counterfactual to estimate the impact of the Affordable Care Act on the nonelderly population [17]. First, we used the Program input parameters, which included the number of women enrolled in the Program, demographic characteristics, and previous screening patterns obtained from the Program’s administrative database called Minimum Data Elements (MDEs) from 2010 to 2019. Second, we used pooled data from the National Health Interview Survey (NHIS) from 2010, 2013, and 2015. We also included data from 2018 and 2019 in the study. In these years of study, we used the following question: “Have you ever received a mammogram [18]? Data from 2018 were not pooled into the early years because they fall into different sample design. Further, data from 2016 and 2017 were not included in this study because the variable of interest (Have you ever received a mammogram?) was not available in these years. Similarly, data from 2019 also were not pooled because of a major redesign of the survey. Using the responses to this question, we obtained the weighted percentage of women who received a mammogram by age group. Third, we used the United States Cancer Statistics (USCS) to provide data on the stage of breast cancer diagnosis [1]. Fourth, we used the National Program of Cancer Registries (NPCR) quality control data to estimate the survival of women with breast

cancer [19]. Fifth, we used data from the Hoerger et al. study to determine a woman's screening behaviors, whether she was an annual, biennial, or irregular screener, respectively [8, 16]. Finally, we used data from the Trentham-Dietz et al. study to inform the survival of women without a breast cancer diagnosis [20]. All these input data were categorized by race/ethnicity (e.g., NHW, NHB, NH AIAN/API, and Hispanic). All the data used in this study were secondary datasets in which the information was deidentified. Hence the study did not meet the criteria for human subjects research, which is consistent with applicable federal law and the Centers for Disease Control and Prevention policy [21].

Program demographics and growth

The time-to-event model had four input events: screening at Program entry, subsequent screening behavior, breast cancer diagnosis, and survival (Fig. 1). We obtained age and race/ethnicity parameters for both new and existing participants from the Program's MDEs database Version 7.0. Analysis of the database revealed a shift in the composition of Program participants over time. For instance, in 2010, new participants were primarily NHW women. However, by 2014–2015, Hispanic women became the predominant new participants. This observation is presented in supplement figures S2A and B.

To simulate the changes in the Program's composition based on demographic characteristics such as race/ethnicity, we categorized existing participants as those who had received a screening from the Program before 2010. On the other hand, new participants were defined as those who received their first screening from the Program. We used a generalized additive model to analyze the number of new and existing participants. The analysis indicated a decreasing trend in the number of screenings provided by the Program from 2010 to 2019, as shown in Supplement Figure S3.

Screening frequency

In this study, we used screening frequency to determine the level of participation in the Program for women who have an income of $\leq 250\%$ of the federal poverty level (FPL). The details of how we obtained the screening frequency are provided in the screening section in the supplement. Briefly, in the study, we assumed that every participant in the NBCCEDP received a screening when they enrolled in the Program. Once a woman received her initial screening mammogram, subsequent mammograms were based on the approach used in a previously published study [8, 16]. According to this approach, eligible women were categorized as annual, biennial, or irregular screeners. Annual screeners were defined as women who had screenings at an average interval of ≤ 1.5 years. Biennial screeners had screenings at an average interval between > 1.5 to < 2.5 years. Irregular screeners had screenings at an average interval of ≥ 2.5 years. We used the NBCCEDP's MDEs database to estimate the age at which women had their first Program-funded mammogram and the intervals between subsequent mammograms for those who participated in the Program. Additionally, we utilized NHIS data from 2010, 2013, 2015, 2018, and 2019 to estimate mammography patterns among uninsured women as a representation of mammography screening in a scenario without the Program.

Breast cancer diagnosis

We obtained age-specific and stage-specific breast cancer incidence data from the USCS [1]. The USCS combines data from CDC's NPCR and the National Cancer Institute's Surveillance, Epidemiology, and End Results (SEER) Program [1]. The age-specific incidence of breast cancer was used to determine the time it takes to diagnose breast cancer in the model. The NPCR data linked to the Program MDEs data provided information on women in four mutually exclusive insurance categories: insured (private or public), those who ever participated in the Program (Program participants), those without insurance (no Program), and those with Medicaid. In the subsequent analysis, women with Medicaid were excluded from the NPCR data. These data were aggregated and used in a Cox proportional hazards model to calculate the likelihood of a Program participant and a woman in no Program receiving a breast cancer diagnosis compared to women who were insured from 2010 to 2019. We used women with insurance as the reference group in the Cox proportional hazards model because the national incidence rate of breast cancer by race/ethnicity from 2010 to 2019 was used as the baseline hazard for the time a woman was diagnosed with breast cancer. The national breast cancer incidence rate represented the incidence for women in the "insured" given that about 70% of women under 65 years and all women over 65 years old were covered by private or public insurance (excluding Medicaid) [22].

The NPCR data for nine years (2008–2017) provided information on the proportion of women in each known stage of breast cancer diagnosis (i.e., ductal carcinoma in situ [DCIS], local, regional, and distant) sorted by age group, race/ethnicity, and insurance status [1]. We averaged these stage proportions over the nine years and applied them uniformly across the study period from 2010 to 2019.

Estimating breast cancer survival rates among women

To estimate the survival rates of women diagnosed with breast cancer, we utilized data from the NPCR [19]. Specifically, we analyzed survival over a 5-year period by examining death records from NPCR from 2008 to 31 December 2016. Our analysis involved creating Cox proportional hazard models tailored for each racial/ethnic group. Within these models, we considered several factors that could influence survival rates:

- a. Insurance status, which was divided into three categories: those enrolled in a specific program (Program), those with insurance (insured), and those without insurance (uninsured).
- b. The stage at which breast cancer was diagnosed, ranging from DCIS to local, regional, and distant stages.
- c. The age at diagnosis was categorized into 5-year age groups: 40–44, 45–49, 50–54, 55–59, 60–64, and 65–99 years.

In the hazard regression models, we used the following referent groups against which other groups were compared: (a) insured individuals for insurance status, (b) DCIS for cancer diagnosis stage, and (c) the age group of 40–44 for age at diagnosis. It was assumed that women diagnosed with DCIS had the same chance of survival as women without a breast cancer diagnosis [23, 24].

Estimating survival rates for women without a breast cancer diagnosis

To estimate survival rates for women without a breast cancer diagnosis, we utilized the age-period-cohort (APC) model by Trentham-Dietz et al. [20]. The APC model compared survival rates for women with breast cancer to those without. The model incorporates data from CDC WONDER to determine all-cause mortality rates by age and race/ethnicity for the general female population, including women with and without breast cancer. For insured women without breast cancer, we calculated their survival rates by adjusting the all-cause mortality rates from the APC model. We subtracted the mortality rate specific to breast cancer, which was determined using a Cox proportional hazards model that considered factors such as age at diagnosis, stage at diagnosis, and insurance status.

Next, to calculate survival rates for women in the Program and those in no Program, we applied hazard ratios associated with being diagnosed with DCIS obtained from the Cox proportional hazards model. The hazard ratios allowed us to adjust the all-cause mortality rate obtained from insured women in the APC model to reflect those in the Program and no Program scenario. Finally, we subtracted the adjusted all-cause mortality rates for women in the Program and in no Program, as well as the mortality rates for women with breast cancer, from the survival rates for women without breast cancer. This calculation provided us with mortality rates for women without a breast cancer diagnosis in both the Program and no Program scenarios. Finally, although it is often overlooked in medical research, the Cox proportional hazards, which assumes that hazard ratios between different groups remain constant over time, was tested. We tested this assumption using Grambsch and Therneau's statistical test, which evaluates whether there is a significant relationship between scaled Schoenfeld residuals and time.[25].

Calculating health outcomes

The health outcomes calculated for this study were: (1) the average number of screenings received, per woman, (2) LYs saved per woman screened, and (3) the average number of screenings per LYs saved for a woman. These health outcomes were compared with the Program versus no Program scenarios from 2010 to 2019. To estimate these health outcomes, we simulated a sample of 500,000 women over 500 times among women who participated in the Program during the study period compared to no Program. Based on the recommendations of the *ISPOR-SMDM Modeling Good Research Practices Task Force* [26], we used a 6-month cycle length in the model. This is short enough to ensure timely diagnosis and treatment and provide quality care for those with abnormal screening [27].

The simulation results were expressed in terms of per one million women aged 40–64 years who received mammograms through the Program. We calculated the number of screenings per woman and the accompanying standard deviation (SD) as the difference between the estimated total number of women screened in the Program and no Program. The estimated number of LYs saved and their associated SD were calculated in the same manner. The minimum age was modeled to be 40 years and the maximum to be 100 years. This is because a woman is eligible for the Program at 40 years of age and the maximum age of 100 years was the maximum age available for the mortality data. Further, to address the question

of how many additional screenings per woman are required for the Program to save one additional LY, we used the following expression [25]:

$$\left(\frac{\text{Number of screenings}}{\text{per woman per LY saved}} \right) = \frac{\text{Estimated incremental number of screenings due to NBCCEDP}}{\text{Estimated incremental number of LYs saved due to NBCCEDP}}$$

This ratio measures the efficiency of the screening process in the Program. The incremental number of screenings and LYs saved are the difference between the estimated total screenings in the Program and no Program.

All the estimated health outcomes were reported by racial/ethnic groups. Data processing was performed in R version 4.2.2 (R Foundation for Statistical Computing, Vienna, Austria). All estimates were conducted using Python version 3.9.7 with pandas version 1.2.0 and NumPy version 1.20.3 (Python Software Foundation, Beaverton, Oregon).

Sensitivity analysis

While probabilistic sensitivity analysis may be beneficial for understanding overall parameter uncertainty, it is challenging to identify which parameters, particularly policy-related ones, should be emphasized from the program management perspective. Thus, we concentrated on the one-way sensitivity analysis of program screening-related parameters, as shown in Fig. 2. We performed one-way sensitivity analyses to assess the effects of alternative assumptions about screening behavior among Program participants. The proportions of each screening behavior used for the sensitivity analyses are presented in supplement Table S1. In the sensitivity analysis, results were compared to the results using the base case values, the mean value of the parameter, which is presented in Table 1. We ran two analyses for the percent of insured women (proxy for Program participants) who have ever had a mammogram, and two analyses for each screening behavior (annual, biennial, or irregular). The value for the percentage of women who have ever had a mammogram was decreased to be the minimum value of the 95% confidence interval (CI) around the mean and increased to be the maximum value of the 95% CI around the mean. The proportion of annual screeners was (1) increased by 10%, and (2) decreased by 10%. The same method was followed for biennial and irregular screeners. We changed the proportions of each screening behavior category by 10% to simulate hypothetical scenarios of what would happen if Program participants received screenings more or less regularly.

Results

Base case results

The incremental screenings per million women who participated in the NBCCEDP compared with those who did not participate by race/ethnicity were estimated to be 457,152 (SD: 848) (Table 2). For specific racial/ethnic populations, the estimated incremental screening ranged from 423,277 (SD: 1,351) for NHW to 507,856 (SD: 1,710) for Hispanic women.

Among a sample of 1 million women screened from 2010 to 2019 in all age and racial/ethnic- groups, the Program added a total of 27,444 (SD: 515) LYs saved to the life

expectancy of the participants. Across specific racial/ethnic groups, NHB women saved an additional 75,132 (SD: 1,724) LYs, followed by Hispanic women with about 25,000 (SD: 852) LYs, NHW women with 14,215 (SD: 649) LYs, and the lowest by NH AIAN/API with 10,805 (SD: 1,672) LYs saved (Table 2).

Per woman screened from all racial/ethnic groups, the Program saved 0.027 LYs (or equivalent to 10.02 days) (Table 3). By specific race/ethnicity, the Program saved 0.075 LYs (or 27.44 days) for NHB, 0.025 LYs (or 9.13 days) for Hispanic, 0.014 LYs (or 5.19 days) for NHW, and 0.011 LYs (or 3.95 days) for NH AIAN/API woman, respectively. For all racial/ethnic groups, we estimated that about 17 screenings would be required to save an additional LY per woman in the Program. This estimate was substantially lower for NHB women with an average number of six screenings, moderately higher for Hispanic and NHW women with an average number of 20 and approximately 30 screenings, respectively, and significantly higher for NH AIAN/API women with an average number of 42 screenings are required to save an additional LY per woman in the Program.

Sensitivity analyses

In Fig. 2, we present the results of one-way sensitivity analyses that compare the base case results with absolute (relative) changes in the number of screenings received by Program participants from 2010 to 2019. The number of screenings received by participants was found to be most sensitive to changes in screening behavior, such as whether participants were annual, biennial, or irregular screeners. The sensitivity analysis revealed variations resulting in differences ranging from -7,400 to 11,300 in the absolute number of screenings, with a relative percent change ranging from -0.5% to +0.8%. Interestingly, when using the upper and lower bounds of the 95% confidence intervals for the weighted percentage of women who had ever had a mammogram, there was relatively no change (<0.05%) observed in the results.

Discussion

This study provides estimates of the health outcomes of NBCCEDP on breast cancer screening in low-income, uninsured women in the past 10 years. Overall women who participated in the Program received more screenings and gained more LYs than women in no Program scenario. Compared with no Program, women screened through NBCCEDP by all races/ethnicities gained an average of 0.027 LYs (or the equivalent of 10 days) per woman. Among racial/ethnic groups, NHB women were estimated to have the highest benefit, with 0.075 LYs saved (or 27.44 days). They also have the least number of screenings required to gain 1 additional LY by participating in the Program. The estimated LYs saved presented in this paper are based on approximately 15% of the eligible women currently reached by the Program [13]. If the proportion of eligible women screened by the NBCCEDP were to increase, the estimated preventive health benefits for these women would significantly improve [28].

In the United States, access to cancer screening is dependent upon having health insurance [29]. As a result, preventive healthcare measures such as cancer screening or immunizations may be underused [30]. For more than 30 years, the NBCCEDP, through its vast network

of public and private health care providers, has played an indispensable role in delivering breast and cervical cancer screening and diagnostic services at no cost to populations with low-income and who are uninsured [8, 13, 31–33]. These efforts have substantial impacts on these populations who have historically experienced high rates of poverty [34] and low rates of health insurance coverage [35]. As reported in this study, NHB and Hispanic women had the highest number of LYs saved, which is an indicator of improved life expectancy for these populations. Further, our findings indicate that when resources are allocated effectively and efficiently to subpopulations that have historically worse health outcomes, the returns on such investments are substantial. Moreover, the results suggest that ongoing investment in outreach and support services for these groups will lead to significant health improvements in the future. Additionally, screening and diagnosing breast cancer at earlier stages not only improves prognosis but also reduces out-of-pocket expenses and financial hardship, often referred to as ‘financial toxicity,’ associated with treatment and its lasting effects [36, 37]. Through screening and early detection provided by the NBCCEDP, eligible women could be spared from the disproportionate financial burdens experienced by many low-income, uninsured, or underinsured women.

At first glance, the estimated LYs saved per woman who participated in the Program might appear small compared to other national preventive health programs, such as immunization programs [38, 39]. However, comparison with other national prevention programs is difficult for many reasons, including differences in study characteristics, data used, populations, and study methodology. These factors notwithstanding, we compared our results with those from previously published studies to contextualize and evaluate the credibility of our findings. This is presented in Table 4, which displays a comparison of the findings in LYs saved per person alongside outcomes from selected population-based preventive health services [8, 31, 38–43]. These data provide some validation for the estimated LYs saved for breast cancer screening in the Program, which compares favorably to other preventive health services, such as colorectal and lung cancer screening. In colorectal screening, the population aged ≥ 50 years screened with colonoscopy every 10 years or every three or five years with adenoma, was reported to save 0.0220 LYs (or 8.04 days) [42]. Similarly, lung cancer screening with low-dose computed tomography was reported to save 0.0316 LYs (or 11.54 days) [41]. On the other hand, breast cancer screening through NBCCEDP gains fewer LYs than other preventive health services. For example, all childhood immunizations were reported to save 0.1233–0.1273 LYs (or 45.04–46.50 days) [38, 39]. Furthermore, current smokers aged 55 years old attending smoking cessation counseling in a lung cancer screening setting were reported to save 0.1188 LYs (or 43.40 days) [40].

Several factors could have contributed to our estimate of 0.0274 LYs saved (or 10.02 days gained), which is 48.9% lower than the previously reported estimate of 0.056 LYs saved (or 20.45 days) [8] for women of all racial/ethnic groups participating in the Program. Among the factors are advancements in breast cancer screening, diagnostic, and treatment technologies that have improved early detection and reduction in morbidity and mortality [9, 44–49]. For example, digital mammography provides clearer images than traditional film mammography and allows for better visualization of abnormal results. Furthermore, targeted treatments such as human epidermal growth factor receptor 2 drugs (e.g., trastuzumab) and endocrine therapies (e.g., tamoxifen and aromatase inhibitors) have also significantly

contributed to improved health outcomes in the past years [50–53]. These advancements in medical imaging technologies imply that more women may be screened per life-year saved. For instance, in this study, we found that, on average, 17 screenings would be required to save 1 LY in the Program. The impact of these imaging technologies in reducing cancer-related mortality has been remarkable, however, in the past decade, improvements in access to healthcare services through insurance coverage, adherence to recommended screenings and treatments [4], and individual awareness of overall health and well-being may have also contributed to improved breast cancer health outcomes.

Another factor could be that we used 10 years of data in the current study, while the previous study used 16 years. Other factors contributing to the differences in the reported LYs saved could be differences in study methodology. The previous study adopted a microsimulation model developed by the Cancer Intervention and Surveillance Modeling Network (CISNET), which contains breast cancer natural history, screening history, breast cancer mortality, early detection and treatment, and other-cause mortality modules [46, 54–56]. The previous study did not use USCS data for survival because survival data were not consistently available for all central cancer registries at the time of that analysis. So, the breast cancer survival estimates used in the previous study were based on the parameters obtained in the CISNET models, which reflected the survival of women with breast cancer in the general population, not women who met the eligibility for Program services. In our current study, we used a time-to-event model, which contains screening history as well as early detection and treatment modules. We did not include a natural history component because we wanted to quantify the impact of the Program's efforts to provide breast cancer screening and diagnostic services at no cost, regardless of the natural history related to breast cancer. We also wanted to estimate the benefits of Program participation by race/ethnicity, which was not included in prior research.

Our study has some limitations. First, our analysis focused only on LYs saved and did not account for health-related quality of life (HRQoL) of the Program participants. The characteristics of HRQoL may include social functioning, physical mobility, capacity for self-care, mental health, pain from mammography screening, and potential harms arising from false-positive diagnoses or overdiagnosis (such as the identification of tumors that would never have become a clinical problem in the patient's lifetime). These HRQoL measures are usually used as an adjustment factor to the estimated LYs saved—hence called quality-adjusted life-years (QALYs) saved. Second, our study includes only the Program's direct effects on breast cancer survival and does not consider how the Program may have helped uninsured women gain access to the healthcare system, leading to better care for conditions besides breast cancer. For example, the Well-Integrated Screening and Evaluation for Women Across the Nation (WISEWOMAN) program provides heart disease and stroke prevention screening to Program-eligible women [57]. Under the Breast and Cervical Cancer Prevention and Treatment Act of 2000 (Public Law 106–354), Program participants also have the ability to gain access to breast cancer treatment through Medicaid, which covers many other conditions. Third, we also note that in this study, we did not directly include the benefits of general preventive health services such as reducing obesity, improving physical activity, and reducing excessive alcohol consumption [58]. These primary prevention activities are part of the mission of the CDC's National Comprehensive

Cancer Control Program, which provides health prevention education to everyone, including Program-eligible women [59]. Fourth, as stated earlier, the reported population average of LYs saved appears small because (1) breast cancer does not develop in 7 out of 8 women, (2) in general, screening detects about 87% of cancers early [60], (3) some women in whom cancers are screen-detected would have survived in the absence of screening, and (4) some women in whom cancer is screen-detected early will still die. Fifth, as stated earlier, we tested the Cox proportional hazards model assumption, which indicated a violation. However, many studies have reported that this assumption is often overlooked or fails to hold in medical research [61–67]. Nevertheless, the estimated health outcomes LYs saved for the eligible women in the NBCCEDP were not compromised. Sixth, we acknowledge that while time-to-event models effectively capture short- to medium-term outcomes, they may not fully reflect the long-term effects of screening. Another issue with the data used to derive input parameters (e.g., survival gain with the NBCCEDP) is loss to follow-up, which can introduce bias and may lead to an underestimation of the true effects of screening interventions. Additionally, time-to-event models struggle with time-varying effects. Despite these limitations, a recent study demonstrated that the time-to-event approach could produce results similar to those of the Markov model [68]. Our use of a time-to-event model provides robust estimates for evaluating the NBCCEDP's impact on breast cancer screening outcomes within a relevant timeframe.

Finally, we did not distinguish the effects of different insurance coverage (e.g., state Medicaid expansion for women less than age 65 years or Medicare coverage for women 65 years or older) or different screening technologies—such as mammography, digital mammography, or other breast cancer screening methods—on the Program's effectiveness in breast cancer survival. In the NBCCEDP, it is difficult to determine whether the eligible women are uninsured or underinsured. Based on previous studies, this may have affected the outcomes reported in this study [69]. Another limitation of this study is that the program lacks the ability to monitor the long-term breast cancer screening behavior of the eligible women.

Similar to past analyses, our estimates suggest that implementing the Program has improved the LYs of women who participated in the Program during the study period. The estimated improvement in LYs is more profound for NHB and Hispanic women, who usually face significant societal and structural barriers to obtaining affordable, preventive health care services like mammography screening [70, 71]. Our results suggest that the Program is beneficial for all eligible women by upholding its purpose to help improve health outcomes for those receiving preventive health services through timely screening and diagnosis, access to quality care, and by focusing on organizational-level factors that influence screening and early detection [6, 72]. The findings also demonstrate the combined and ongoing efforts by the CDC, states, tribal, and territorial programs, healthcare providers, and community partners to improve access to preventive cancer screening services for low-income, uninsured, or underinsured populations.

In this and other studies, it is noteworthy to emphasize that USPSTF recommends breast cancer screening starting at age 40 years [4]. However, over the past two decades, there has been growing evidence that cases of breast cancer diagnosed before age 40 are increasing

[73, 74], and the economic burden associated with breast cancer in this age group is substantial [75]. This trend underscores the need for more sensitive and effective screening methodologies that can be applied to younger populations, particularly for those with more aggressive forms of breast cancer, who may be diagnosed at later stages due to the lack of routine screening recommendations for this age group.

It is important to note that in our study, NHB and Hispanic women have the highest number of estimated LYs (or days) saved and the lowest number of screenings required to achieve an additional LY. These findings indicate that when resources are allocated effectively and efficiently to subpopulations that have historically worse health outcomes, the returns on such investments are substantial. Moreover, the results suggest that ongoing investment in outreach and support services for these groups will lead to significant health improvements in the future. They are encouraging and are consistent with the Program's efforts over the past 30 years to effectively and efficiently reduce or eliminate health differences that contribute to worse health outcomes for specific populations. Such populations may include people living in rural communities and racial/ethnic groups who have not benefited from the progress made against cancer. The findings reported in this study emphasize the importance of providing preventive health care to populations who might not otherwise have access to these services.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Data availability

Data availability statement: The data that support the findings of this article are available from the authors upon request.

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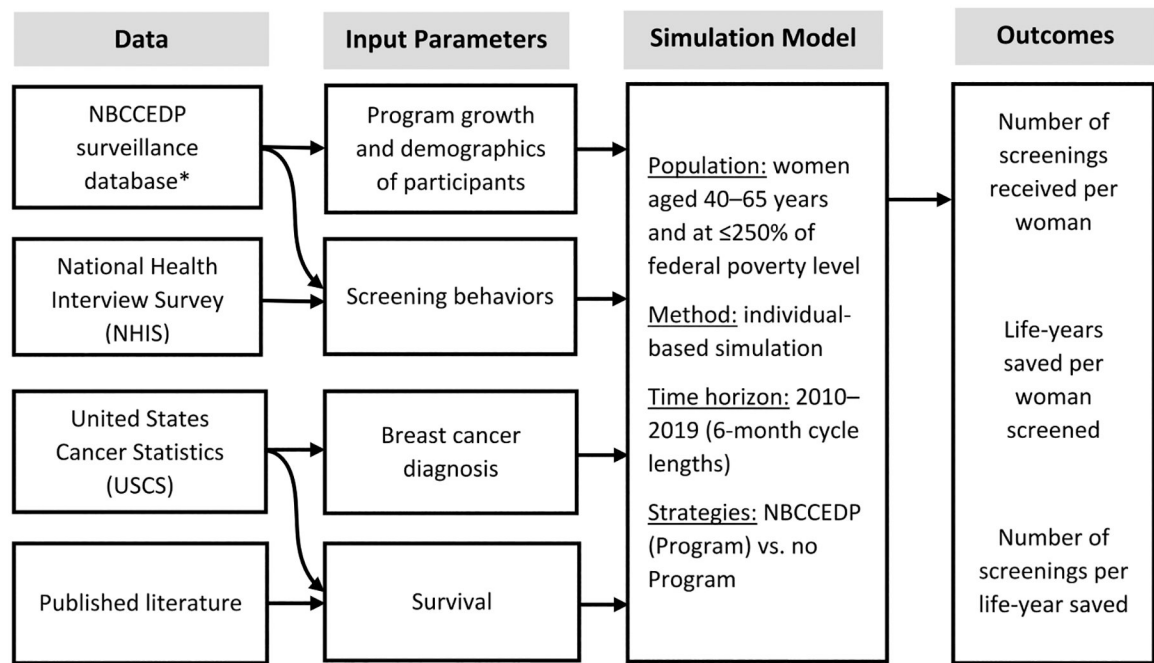
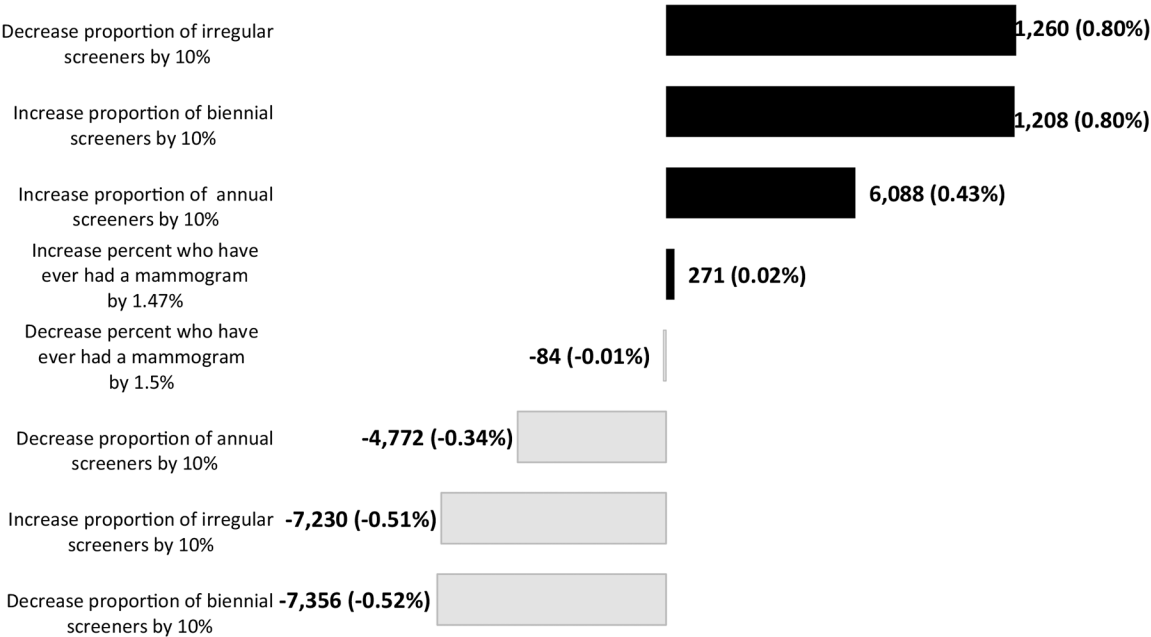


Fig. 1. Model schematic for the time-to-event model used to estimate the number of screenings received per woman and the life-years saved for Program participants versus no Program. *It is also called Minimum Data Elements (MDEs)



*The values presented are absolute change (and relative change) in the number of screenings received by Program participants compared to the base case results.

In this figure, the term “screeners” refers to those women who received breast cancer screening annually, biennially, or irregularly.

Fig. 2. The sensitivity analysis examines how changes in screening behavior affect the number of women screened per 1 million*. *The values presented are absolute change (and relative change) in the number of screenings received by Program participants compared to the base case results. In this figure, the term “screeners” refers to those women who received breast cancer screening annually, biennially, or irregularly

Table 1

Model parameters, value, and data sources

Parameter		Base case value ^a	Minimum ^a	Maximum ^a	Source ^b	
Screening behaviors	Screening initiation from NHIS 2010, 2013, 2015 ^c	–	76.100	75.100	77.100	16
		Weighted percentage of insured				
	Screening initiation from NHIS 2018 ^c	–	48.800	46.700	50.800	16
		Weighted percentage of uninsured				
		–	76.200	74.300	78.000	16
		Weighted percentage of insured				
		–	53.600	48.400	58.800	16
		Weighted percentage of uninsured				
Screening initiation from NHIS 2019 ^c	–	76.100	74.500	77.700	16	
	Weighted percentage of insured					
Breast cancer diagnosis	The proportion of women screened by the Program vs. uninsured	–	53.000	48.300	57.700	16
		Weighted percentage of uninsured				
		Program				
		Annual	0.496	0.495	0.497	8
		Biennial	0.260	0.258	0.261	8
		Irregular	0.244	0.243	0.246	8
	Uninsured	Annual	0.256	0.250	0.262	6, 8
		Biennial	0.199	0.192	0.206	6, 8
		Irregular	0.545	0.540	0.550	6, 8
		Program				
		DCIS	0.134	0.133	0.134	30
		Local	0.461	0.461	0.461	30
	Stage distribution ^d	Regional	0.349	0.349	0.349	30
		Distant	0.057	0.057	0.057	30
		Uninsured				
		DCIS	0.133	0.133	0.133	30
Other insurance	Local	0.413	0.413	0.413	30	
	Regional	0.321	0.321	0.321	30	
	Distant	0.134	0.133	0.134	30	
	DCIS	0.193	0.193	0.193	30	
	Local	0.515	0.515	0.515	30	
	Regional	0.253	0.252	0.253	30	
	Distant	0.039	0.039	0.039	30	
	Incidence per 100,000 women ^e	–	345.743	306.347	385.138	30

Parameter	Base case value ^a	Minimum ^a	Maximum ^a	Source ^b
Survival				
Percent of all deaths due to breast cancer ^f	4.764%	4.265%	5.388%	29
All-cause mortality per 100,000 women ^f	4,094.162	3,880.690	4,324.942	29
Non-breast cancer mortality per 100,000 women ^f	4,026.702	3,815.926	4,254.576	29

DCIS, ductal carcinoma in situ; NHIS, National Health Interview Survey

^aThe base case is the mean value used for the model and the minimum and maximum values are the 95% confidence interval bounds around the base case

^bNumbers correspond to the citation number listed in the Reference section

^cWeighted percentage of women who had received a mammogram before, by insurance status, ages 40–100 years

^dProportion, all ages, and racial/ethnic groups

^eAll racial/ethnic groups, insurance, and ages 40–100 years

^fAges 40–99 years, 2010–2019, and all racial/ethnic groups

Table 2

Estimated results of the Program and no Program scenarios per 1 million women who received breast cancer services in NBCCEDP by race/ethnicity, 2010—2019

Parameter	Women participating in the Program per 1 million					Women not participating in the Program per 1 million				
	All race/ ethnicity	Non-Hispanic White	Non-Hispanic Black	Non-Hispanic AIAN/AP ^a	Hispanic	All race/ ethnicity	Non-Hispanic White	Non-Hispanic Black	Non-Hispanic AIAN/AP ^a	Hispanic
Number of screenings received (SD)	1,405,206 (1,982)	1,296,159 (3,212)	1,463,980 (5,511)	1,439,245 (7,822)	1,509,369 (4,166)	948,054 (2,059)	872,883 (3,107)	1,013,244 (5,308)	991,631 (7,380)	1,001,513 (4,215)
Incremental number of screenings received (SD)	457,152 (848)	423,277 (1,351)	450,736 (2,248)	447,614 (3,186)	507,856 (1,710)	—	—	—	—	—
Number of LYs saved (SD)	84,030,602 (15,703)	83,156,111 (23,779)	80,956,498 (41,271)	87,942,350 (48,935)	85,675,544 (26,335)	84,003,157 (15,683)	83,141,896 (23,767)	80,881,366 (41,404)	87,931,545 (48,851)	85,650,560 (26,373)
Incremental number of LYs saved (SD)	27,444 (515)	14,215 (649)	75,132 (1,724)	10,805 (1,672)	24,984 (852)	—	—	—	—	—

LYs, life-years; NBCCEDP, National Breast and Cervical Cancer Early Detection Program; SD, standard deviation

^aNon-Hispanic AIAN/API race/ethnicity includes American Indian or Alaska Native persons and those who identify as Asian, Native Hawaiian, or other Pacific Islander. These racial/ethnic groups were combined because of their small sample size. However, NBCCEDP supports each tribe and tribal organization's programs

Table 3

Estimated life-years saved per woman screened and number of screenings required to save one LY

Race/ethnicity groups	LYs saved per woman screened (days)	Number of screenings required per LY saved (SD)
NBCCEDP-breast cancer screening for all race/ethnicity	0.027 (10.024)	16.663 (0.313)
Non-Hispanic, White	0.014 (5.192)	29.840 (1.376)
Non-Hispanic, Black	0.075 (27.442)	6.002 (0.138)
Non-Hispanic, AIAN/API ^a	0.011 (3.946)	42.465 (6.923)
Hispanic	0.025 (9.125)	20.351 (0.696)

LYs, life-years; SD, standard deviation; AIAN/API, American Indian, or Alaska Native; Asian, Native Hawaiian, or other Pacific Islander

^aNon-Hispanic AIAN/API includes those who identify as American Indian or Alaska Native and Asian, Native Hawaiian, or other Pacific Islander. These racial/ethnic groups were combined because of their small sample size. However, NBCCEDP supports each tribe and tribal organization's programs

Table 4

Life-years saved by selected preventive health services

Intervention	Target population	LYs saved per person	Data sources, year
Update of NBCCEDP—breast cancer screening for all race/ethnicity	Low-income, uninsured women aged 40–64 years	0.0274	Authors' estimate
Non-Hispanic White	Low-income, uninsured women aged 40–64 years	0.0142	Authors' estimate
Non-Hispanic Black	Low-income, uninsured women aged 40–64 years	0.0751	Authors' estimate
Non-Hispanic AIAN/API ^a	Low-income, uninsured women aged 40–64 years	0.0108	Authors' estimate
Hispanic	Low-income, uninsured women aged 40–64 years	0.0250	Authors' estimate
NBCCEDP—breast cancer screening	Low-income, uninsured women aged 40–64 years	0.0560	Hoerger et al. 2011 [8]
NBCCEDP—cervical cancer screening	Low-income, uninsured women aged 18 or 21–64 years	0.0060	Ekwueme et al. 2014 [28]
NBCCEDP—cervical cancer screening	Low-income, uninsured women aged 40–64 years	0.0030	Ekwueme et al. 2014 [28]
Colorectal cancer screening	Aged ≥ 50 years with FOBT	0.0041	Maciosek et al. 2010 [34]
Smoking-cessation counseling for current smokers in the lung cancer screening setting	Aged ≥ 55 years	0.1188	Cadham et al. 2021 [35]
Smoking-cessation counseling after AMI	Aged ≥ 65 years	0.0053	Buchholz et al. 2017 [38] ^b
Cholesterol screening	Aged ≥ 50 years	0.0028	Maciosek et al. 2010 [34]
Hypertension screening	Aged ≥ 18 years	0.0011	Maciosek et al. 2010 [34]
Obesity screening	Aged ≥ 18 years	0.0001	Maciosek et al., 2010 [34]
All childhood immunizations	Children from birth to age 10 years	0.1273	Carrico et al. 2022 [33] ^c
All childhood immunizations	Children aged < 5 years	0.1233	Maciosek et al. 2010 [34]
Influenza immunization	Aged ≥ 50 years	0.0024	Maciosek et al. 2010 [34]

AMI, acute myocardial infarction; FOBT, fecal occult blood test; LYs, life-years; NBCCEDP, National Breast and Cervical Cancer Early Detection Program

^aNon-Hispanic AIAN/API includes those who identify as American Indian or Alaska Native and Asian, Native Hawaiian, or other Pacific Islander. These racial/ethnic groups were combined because of their small sample size. However, NBCCEDP supports each tribe and tribal organization's programs

^bThe reported mean LYs saved per person was calculated by the authors using data on ages 65–90 years presented in the Buchholz et al. 2017 paper

^cThe authors calculated the reported mean LYs saved per person using data on total cases of all childhood diseases averted and the associated total LYs gained reported in the Carrico et al. 2022 article; the childhood immunizations included in this study were diphtheria, tetanus, pertussis, hepatitis A, hepatitis B, Haemophilus influenza type b, measles, mumps, rubella, streptococcus pneumoniae, polio, rotavirus, and varicella