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Economies of scale in federally-funded state-organized public health programs: results from the National Breast and Cervical Cancer Early Detection Programs

Justin G. Trogdon,

Department of Health Policy and Management, Gillings School of Global Public Health, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA

Donatus U. Ekwueme,

Division of Cancer Prevention and Control, Centers for Disease Control and Prevention, 4770 Buford Highway, NE, MS F-76, Atlanta, GA 30341, USA

Sujha Subramanian, and

RTI International, Research Triangle Park, NC, USA

Wesley Crouse

RTI International, Research Triangle Park, NC, USA

Abstract

This study investigates the existence of economies of scale in the provision of breast and cervical cancer screening and diagnostic services by state National Breast and Cervical Cancer Early Detection Program (NBCCEDP) grantees. A translog cost function is estimated as a system with input factor share equations. The estimated cost function is then used to determine output levels for which average costs are decreasing (i.e., economies of scale exist). Data were collected from all state NBCCEDP programs and District of Columbia for program years 2006–2007, 2008–2009 and 2009–2010 (N=147). Costs included all programmatic and in-kind contributions from federal and non-federal sources, allocated to breast and cervical cancer screening activities. Output was measured by women served, women screened and cancers detected, separately by breast and cervical services for each measure. Inputs included labor, rent and utilities, clinical services, and quasi-fixed factors (e.g., percent of women eligible for screening by the NBCCEDP). 144 out of 147 program-years demonstrated significant economies of scale for women served and women screened; 136 out of 145 program-years displayed significant economies of scale for cancers detected. The cost data were self-reported by the NBCCEDP State programs. Quasi-fixed inputs were allowed to affect costs but not economies of scale or the share equations. The main analysis accounted for clustering of observations within State programs, but it did not make full use of the panel data. The average cost of providing breast and cervical cancer screening services decreases as the number of women screened and served increases.

Correspondence to: Donatus U. Ekwueme.

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Keywords

Cost; Cost function; Breast cancer; Cervical cancer; Screening

1 Introduction

Public health programs are increasingly being asked to demonstrate that they are allocating resources efficiently [1]. Doing so can be especially challenging for programs that distribute resources across many sites for implementation (e.g., Federal programs operated through State public health agencies). Public health programs, without a competitive market for their “output” (e.g., number of women screened for cancer), have to create and rely upon mechanisms and incentives other than profit maximization to track costs and measure efficiency. An efficient program is one that is minimizing its average total cost for a given level of output, which is equivalent to maximizing its output for a given level of expenditures (e.g., costs per woman screened). Thus, a sufficient summary measure for operating efficiency, and to represent programs’ “production” technology, is a program’s cost per unit of output.

Assuming programs operate efficiently, the cost function can be used to examine how average costs vary with the level of output. If a public health program exhibits economies of scale, then average cost should decrease as output increases. For example, a screening program in which cost per woman decreases as more women are screened exhibits economies of scale. Economies of scale can result from fixed costs, such as purchases of mammography equipment, being spread out over more women served. Economies of scale also occur when operational efficiency (e.g., management, information systems) improves as more women are served and screened. Economies of scale imply that improving reach to people in need of services could simultaneously improve cost efficiency.

This study examines the existence of economies of scale for the National Breast and Cervical Cancer Early Detection Program (NBCCEDP), a program created in 1990 by the U.S. Congress under the Breast and Cervical Cancer Mortality Prevention Act (Public Law 101–354) and run by the Centers for Disease Control and Prevention (CDC). The NBCCEDP’s goal is to reduce disparities in breast and cervical cancer mortality rates and to provide low-income uninsured women with greater access to breast and cervical cancer screening and diagnostic services. Since 2000, with the implementation of the Breast and Cervical Cancer Prevention and Treatment Act (Public Law 106–354), women diagnosed with cancer through the NBCCEDP are enrolled in State Medicaid programs to receive treatment. As the largest organized cancer screening program in the United States, the NBCCEDP is a complex system of 68 individual screening programs, operated in all 50 States, the District of Columbia (DC), 5 U.S. territories, and 12 American Indian and Native Alaskan tribal organizations [2]. Detailed descriptions of the NBCCEDP have been presented previously [2, 3]. Preliminary evidence for a subset of NBCCEDP programs suggested that average costs are inversely related to the number of services provided, which is suggestive of economies of scale [4]. However, to our knowledge, no flexible cost function has yet been applied to ascertain the existence of economies scale in delivering preventive health services in the NBCCEDP or other mass screening programs. In this study, we investigated the extent of economies of scale in the provision of breast and cervical cancer screening and diagnostic services (i.e., output) in NBCCEDP programs.

2 Methods

A cost function represents the least-cost way for a program to produce a given level of output (e.g., number of women served) given the prices of inputs into the screening process (e.g., labor) [5]. A flexible translog cost function was estimated as a system with input factor (e.g., labor) share equations using cost and output data collected from all State programs and DC for program years 2006–2007, 2008–2009, and 2009–2010 [5]. The estimated cost function was then used to determine output levels (e.g., number of women served) for which average costs are decreasing or increasing. The estimated translog cost function treated breast and cervical services as separate outputs. This approach captured the differences in screening and diagnostic technologies between the two types of cancer. It also allowed us to test whether average costs decline with increases in both services (economies of scope). We also controlled for other constraints on production that are external to the programs and fixed in the short run (i.e., quasi-fixed inputs), such as the size of the population eligible for NBCCEDP.

Under the assumption that programs are minimizing costs for a given level of services, the estimated cost function provides a complete description of how resources are utilized to produce breast and cervical cancer screening and diagnostic services. Cost function estimation does not require an assumption of profit maximization, which makes it ideal for public programs like the NBCCEDP. It does, however, assume that programs are cost minimizers. Although there are no explicit economic incentives to minimize costs (i.e., a profit motive), other factors like external review and public audits could lead to cost minimization [4]. Unlike a production function approach, the cost function approach more easily allows the analysis of multiple outputs. Furthermore, the assumption of fixed input prices under competitive market conditions is more plausible than the assumption of fixed input quantities. We empirically tested properties of the estimated cost function that have to hold under the cost minimization condition.

2.1 Translog cost function

To determine whether the NBCCEDP exhibits economies of scale, we estimated the minimum average cost function for the program using the following transcendental logarithmic (or translog) cost function:

$$\text{In}\, C=\alpha_0+\sum_i \beta_i \ln Y_i+\frac{1}{2}\sum_i\sum_j \beta_{ij}\ln Y_i \ln Y_j+\sum_i \alpha_i \ln P_i+\frac{1}{2}\sum_i\sum_j \alpha_{ij}\ln P_i \ln P_j+\sum_i\sum_j \delta_{ij}\ln Y_i \ln P_j+\sum_i \gamma_i \ln Q_i+\rho \ln T, \quad (1)$$

where C is total cost, Y is the vector of outputs (e.g., breast and cervical services), P is the vector of input prices, Q is a vector of quasi-fixed inputs that affect programmatic delivery (e.g., population of women aged 18 to 64), and T is the time period of the observation [5, 6]. The translog cost function does not impose any a priori restrictions on the production technology. To avoid proliferation of parameters with our relatively small estimation sample, we did not interact the quasi-fixed inputs with outputs or prices. As is customary, we assumed that the cross-output and cross-price effects are symmetric (i.e., $\beta_{ij} = \beta_{ji}$ and $\alpha_{ij} = \alpha_{ji}$). Economic theory suggests that cost functions are homogenous of degree one—a Z percent increase in all input prices will raise total costs by Z percent:

$$\ln(C(ZP, Y, Q, T)) = \ln(ZC(P, Y, Q, T))$$
$$= \ln(Z) + \ln(C(P, Y, Q, T)) \forall P$$

Substituting the translog cost function (Eq. 1) in the expression above implies, with a little algebra, the following set of constraints on the parameters [5]:

$$\sum_i \alpha_i = 1, \quad (2)$$

$$\sum_i \alpha_{ij} = \sum_j \alpha_{ij} = 0, \quad (3)$$

and

$$\sum_{\mathrm{i}} \delta_{\mathrm{ij}} = \sum_{\mathrm{j}} \delta_{\mathrm{ij}} = 0. \quad (4)$$

In addition to these constraints, the structure of the translog cost function implies a specific relationship between the share of costs attributable to each input and the existing parameters. Shephard's lemma shows that the derived demand for input X_i can be computed by partially differentiating the cost function with respect to the input price P_i:

$$\partial C / \partial P_i = X_i$$

Using Shepard's lemma, the rules of differentiation for natural logs, and the translog cost function in Eq. (1) yields:

$$\frac{\partial \ln C}{\partial \ln P_i} = \frac{\partial C}{\partial P_i}\left(\frac{P_i}{C}\right) = \frac{P_i X_i}{C} = S_i$$
$$= \alpha_i + \sum_j \delta_{ij} \ln Y_j + \sum_j \alpha_{ij} \ln P_j \quad (5)$$

for every *i*, where S_i is the proportion of C attributable to input *i*. We calculated the shares (S_i) from the data by dividing the cost of input *i* by the total cost. Including these share equations improves the efficiency of the model because they contain no additional parameters; thus, we estimated Eqs. 1 and 5 as a system of seemingly unrelated regressions [7]. We dropped one share equation from the system because the shares must sum to one [5]. This system of equations was estimated via maximum likelihood using Stata 12 [8]. To account for the use of pooled panel data, we clustered standard errors at the State level. Before estimating this system of equations, we normalized each variable around its geometric mean. This step ensures that each variable is equal to zero at its arithmetic mean after logarithmic transformation [6].

2.2 Economies of scale and scope

The multi-output translog cost function allows a formal test for both economies of scale and scope. Economies of scale can be measured by the change in total cost when all outputs are increased by the same proportion. Differentiating the cost function (Eq. 1) with respect to all output yields:

$$\varepsilon = \sum_i \frac{\partial \ln C}{\partial \ln Y_i}$$

ε is the elasticity of total cost with respect to output. If this elasticity is less than one, then the proportional increase in costs is less than the proportional increase in output and economies of scale exist, or

$$1-\varepsilon>0 \quad (6)$$

Because all variables are normalized to zero about their geometric means, for the average program Eqs. 1 and 6 simplify to

$$1-\sum_i \beta_i>0 \quad (7)$$

On the other hand, economies of scope exist if a program can produce multiple outputs at a lower cost than it could if it produced only a single output. This will be true if the marginal cost of producing output *i* (Y_i) decreases as production of output *j* (Y_j) increases:

$$\frac{\partial^2 C}{\partial Y_i \partial Y_j}<0, \quad (8)$$

where $i \neq j$. In the translog cost function (Eq. 1), this is approximately equivalent to

$$\beta_i \beta_j + \beta_{ij} < 0, \quad (9)$$

where $i \neq j$ [6].

2.3 Tests for cost minimization and functional form

The translog cost function requires the assumption that programs minimize costs. As noted, factors like external review and public audits could lead to cost minimization despite the absence of free-market pressures [4]. There is evidence that cost minimization does occur in nonmarket health care systems [9]. We formally tested whether or not State-level programs in the NBCCEDP minimize costs.

Cost minimization requires that four properties are satisfied. As is common in translog estimation, we assumed linear homogeneity (Eq. 2) and empirically tested for the remaining properties. The second property, monotonicity in output, requires that costs increase with increased output:

$$\sum_i \frac{\partial \ln C}{\partial \ln Y_i} > 0 \quad (10)$$

for every observation. If costs did not increase as outputs increase (i.e., the program could produce more at no extra cost), that would signal inefficient uses of resources. Input costs would be wasted when they could have been used to generate more output, violating cost minimization.

The third property, monotonicity in input prices, requires that costs increase (or stay the same) with increased input prices—that is, that Eq. 5 is strictly nonnegative for every observation and input price *i*. If not, (i.e., input prices increase and overall costs decrease), then there must be some other mix of the same inputs that would have generated more output before, which would not be cost minimizing.

Finally, concavity in input prices requires that costs increase at a decreasing rate (or stay the same) as input prices increase. If input prices doubled, and the program did not alter its input mix, then cost would grow linearly with factor prices. Since the program can always choose not to alter its behavior, its costs cannot grow faster than linearly with changes in input prices. If the program takes advantage of substitution opportunities, costs will grow slower than linearly with input prices. The second derivative (Hessian) matrix of the translog cost function (Eq. 1) with respect to the vector of input prices (*P*) is

$$\begin{bmatrix} \alpha_{ii} & \cdots & \alpha_{ij} \\ \vdots & \ddots & \vdots \\ \alpha_{ji} & \cdots & \alpha_{jj} \end{bmatrix} - \begin{bmatrix} S_i & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & S_j \end{bmatrix} + \begin{bmatrix} S_i S_i & \cdots & S_i S_j \\ \vdots & \ddots & \vdots \\ S_j S_i & \cdots & S_j S_j \end{bmatrix} \quad (11)$$

which must be negative semidefinite for concavity in input prices. To test this, we evaluated the eigenvalues of Eq. 11 at the program mean [9].

2.4 Data sources

2.4.1 Costs—Cost data for each of the NBCCEDP programs were collected using the Cost Assessment Tool (CAT), which was developed to ensure accurate and consistent cost reporting from each of the 68 programs administered by CDC [3, 10]. Data were collected annually for three program years: 2006–2007, 2008–2009, and 2009–2010. Five programs reported data from 2007 to 2008 in lieu of 2009–2010. We pooled the 3 years in the analysis. Programs reported all programmatic costs and in-kind contributions. In-kind contributions were any non-cash contributions to the program that could be given cash value (e.g., differentials between charges and Medicare rates or donated space). The NBCCEDP program-years included in our analysis were for established programs that had been operating for more than 20 years. Thus, implementation (i.e., start-up) costs were not included in the analysis. Programs were required to allocate expenditures to a list of specific program activities, such as screening and diagnostic follow-up or case management. Estimates of the relative focus on breast or cervical care for each of these activities were obtained. The categories in which these costs were reported allowed us to allocate expenditures to specific inputs in the share equations.

After all the data were compiled, a series of quality checks was conducted to identify any obvious errors in the data. These errors were corrected via direct correspondence with the programs in question. Because of inconsistent data reporting, we excluded tribes and territories from our analysis, leaving 51 programs spanning the 50 States and the District of Columbia, each with 3 years of data. Because NBCCEDP programs are not allowed to exceed their funding levels, program-years in which total costs differed by more than 10 % from adjusted annual funding were also excluded due to quality concerns ($N=6$). This left a total of 147 program-years in our final, unbalanced sample. Costs were updated to 2010 U.S. dollars using the overall consumer price index [11].

2.4.2 Output—Our primary definition of output is women served, which is the total number of women who were screened by the program or referred to the program for diagnostic follow-up only. We also explored two alternative definitions of output in our analyses. The number of women screened denotes women who were screened for breast or cervical cancer by the program, excluding women who were screened elsewhere and referred to the NBCCEDP for diagnostic follow-up. The number of breast and cervical cancers detected includes both in situ and invasive cancers that were identified by screening through the NBCCEDP. Two program-years had no cancers detected, leaving 145 program-years for analyses with cancers detected as the output measure. In our main analysis, we included two separate measures for each output above, one each for breast and cervical services.

Data on the number of women served or screened and the number of cancers detected were obtained from the NBCCEDP's surveillance database and the CAT. The NBCCEDP database reports the values of output that are attributable to Federal funds, whereas the CAT reports these values for non-Federal funds. Using our output definitions, a woman who is screened for both breast and cervical cancer would be counted twice, once for each screening test received in the program. Although the NBCCEDP's primary focus is on cancer screening, it also spends resources on non-screening activities that support their primary screening goals, including outreach and public awareness. Because the ultimate goal of the programs is to provide services, we implicitly assumed that all costs are attributable to screening-related activities [4].

2.4.3 Price of labor—As a proxy for the price of labor, we constructed a price index using data on employment from the CAT and State-level wages from the Bureau of Labor Statistics [12]. In the CAT, programs were required to list the number of employees on payroll and the type of work that each of these employees conducted. Using this information, we identified seven different occupations that were included in the BLS data and that correspond to the types of employees listed in the CAT (e.g., registered nurse, statistician; see Table 1). To obtain a representative market basket for employment, we calculated the proportion of total employment that each of these occupations constitutes at the national level in the NBCCEDP. We then calculated a weighted average of median hourly wages for each State from yearly BLS wage data using these proportions as weights. States with missing wage data for a given occupation ($N=17$ program-years with one missing occupation) were assigned the average wage for the Census region.

2.4.4 Price of rent and utilities—For the price of rent and utilities (i.e., capital), we adapted the methods employed in the American Chamber of Commerce Research Association (ACCRA) Cost of Living Index [13]. The ACCRA Cost of Living Index consists of survey data that report the price of food, housing, utilities, transportation, and health care in cities and towns across the United States. Weights for the ACCRA Cost of Living Index are derived from the BLS' Consumer Expenditure Survey.

For our analysis, we focused on housing and utility prices. The housing component of the index reflects the price of renting or buying a new residence. Although the NBCCEDP is subject to commercial real estate prices, evidence suggests that residential and commercial real estate prices are correlated [14]. The utilities component of the index is constructed using the costs of electricity and telephone service.

We calculated housing and utility indices using ACCRA data from years 2006–2010. We limited our analysis to locations that had an observation in each of the 4 program-years of data. Using the same methods and weights used by ACCRA, we constructed price indices that coincided with the NBCCEDP program years for each location in the data. State-level price indices were obtained by calculating the average index value in each State, weighing each location with population data from the U.S. Census Bureau [15].

2.4.5 Price of clinical services—The prices of clinical services in the NBCCEDP are tied to Medicare reimbursement rates. We used Medicare Geographic Adjustment Factors (GAFs) to account for regional variation in prices. Medicare reimbursement rates are adjusted using three Geographic Pricing Cost Indices (GPCIs). Every procedure covered by Medicare is divided into physician work, practice expense, and malpractice insurance components, which vary by the amount of labor, skill, equipment, and risk involved in the procedure. Each of these three components is adjusted using the GPCIs to determine the reimbursement rate for a certain procedure in a given location. On average, the physician work, practice expense, and malpractice insurance GPCIs constitute 52.47 %, 43.67 %, and 3.87 % of the final cost share, respectively [16]. We used these values as weights to combine the GPCIs and obtain the GAF for each Medicare locality. State-level estimates were obtained by averaging the GAFs for all localities in each State with equal weight.

2.4.6 Quasi-fixed inputs—Our cost function includes a set of quasi-fixed inputs that affect the ability of State programs to deliver care. These inputs are fixed and out of the State programs' control, at least in the short-run (i.e., quasi-fixed). We evaluated breast and cervical screening compliance rates, breast and cervical cancer incidence rates, a measure of limited access to primary care services, the percentage of women eligible for breast or cervical cancer screening by the NBCCEDP, the State population of women aged 18–64, State population density, and a time trend for inclusion in the model. Because of limited sample size, we used Akaike and Bayesian information criteria to determine which variables would be included in our final specification. The final model includes a time trend; the population of women aged 18–64; State population density; and the percentage of women eligible for cervical cancer screening by the NBCCEDP, estimated using the Current Population Survey [15, 17]. Women are eligible for the NBCCEDP if they are within the target age range, are uninsured or underinsured, and have a household income under 185–250 % of the Federal poverty line, depending on State criteria [18].

2.5 Sensitivity analyses

In addition to our main analysis, we performed a series of sensitivity analyses to explore the impact of alternative assumptions on the measure of scale economies. In the first sensitivity analysis, we included in-kind contributions in the dependent variable. In another, we estimated Eq. 1 in a random effects framework, omitting the share equations because of computational constraints. We also estimated the main analysis while excluding observations from New York and California, which had substantially larger output than other State-level programs.

In a final sensitivity analysis, we estimated single output models that examined breast and cervical services of the NBCCEDP separately. In this case, we allocated all costs to breast or cervical care using activity totals and program-reported estimates of programmatic emphasis on these activities and used these values as our dependent variables. We included a single output in Eqs. 1 and 5 and added a fourth quasi-fixed input to the model. This quasi-fixed input was the number of women served for breast or cervical cancer over the total number of women served, which served as a measure of program focus. Lastly, we used the population of women aged 40–64 and the number of women eligible for breast cancer screening as quasi-fixed inputs in our breast-specific model.

3 Results

3.1 Descriptive

Programs' costs and outputs varied considerably (Table 2). Average annual program costs were $5.51 million (standard deviation [SD]=$7.70 million) without in-kind contributions included and $6.59 million (SD=$8.17 million) with in-kind contributions. The average number of women served was 13,037 (SD=26,239) for breast cancer services and 8,489 (SD=11,095) for cervical cancer services. Clinical costs constituted the majority of total program costs (52.0 %; SD=14.8 %) and the majority of breast cancer service costs (57.2 %; SD=14.7 %).

3.2 Main analysis

Statistically significant economies of scale existed for the average program-year for each output measure, with the largest economies of scale for cancers detected and the smallest economies of scale for women served (Table 3). There were no significant economies or diseconomies of scope for the average program-year among the output measures. At the program-year level, 144 out of 147 observations demonstrated significant economies of scale for women served and women screened at the 95 % confidence level for a one-sided test of Eq. 7. Similarly, 136 out of 145 program-years displayed significant economies of scale for cancers detected. No observations demonstrated significant diseconomies of scale.

In terms of programs, the vast majority demonstrated economies of scale in all three program years in our analysis: 86 % for women served, 84 % for women screened, and 78 % for cancers detected (Table 4). Only one program for women served and one program for cancers detected had no significant economies of scale in any of the three program years studied.

In all models, price effects were significant and positive. Higher State populations significantly increase total cost, whereas the results for the other quasi-fixed inputs were inconclusive. On the basis of the Akaike Information Criteria (AIC) and the Bayesian Information Criteria (BIC), the women served model provided the best fit of the three models, and as a result we limit our discussion of the sensitivity analyses to this output measure.

3.3 Tests for cost minimization and functional form

Tests failed to reject the null hypothesis that programs in the NBCCEDP minimize costs. Monotonicity in output (Eq. 10) holds for all program-years for women served, 143 out of 147 program-years for women screened, and 134 out of 145 program-years for cancers detected. Monotonicity in output (Eq. 10) was not significantly positive or negative for all other program-years. Similarly, all fitted share equations were positive, indicating monotonicity in input prices. The eigenvalues of Eq. 11 were not significantly positive, so we failed to reject that the matrix was negative semi-definite, and consequently, that the data were concave in input prices. Thus, we conclude that the data do not violate the cost minimization assumption and that the translog cost function is an acceptable functional form for this analysis.

3.4 Sensitivity analyses

Table 5 reports the results of alternative two-output models with women served as the output measure. All alternative specifications estimated statistically significant economies of scale for the average program-year. Including in-kind contributions in the dependent variable along with total cost slightly increased the economies of scale and economies of scope estimates. Estimating Eq. 1 in a random effects framework indicated substantially increased economies of scale relative to the main analysis and rejected economies of scope. The AIC and BIC for the random effect model are very different from the other models because the random effect model was estimated without the share equations. Dropping New York and California program-years, which are large programs and potential outliers, did not substantially alter the results of the main analysis (Table 5). The AIC and BIC indicate that the main analysis provided the best fit of the data.

Single-output models, which evaluated women served for breast and cervical cancer screening and diagnostic services separately, estimated significant economies of scale for breast and cervical services (Table 6). These estimates provide evidence of product-specific economies of scale. In both models, the variable representing the share of all women served for that particular output was insignificant. This is consistent with the insignificant economies of scope that were observed in most of the two-output models. Figures 1 and 2 illustrate the average cost curve, its relationship with the program-year observations, and the levels of output at which we detect significant economies of scale for breast and cervical cancer screening, respectively. In these figures, we hold all price and quasi-fixed variables constant at the mean.

4 Discussion

This study finds strong and robust evidence of economies of scale in the provision of breast and cervical cancer screening and diagnostic services by NBCCEDP programs. This implies that the average cost of providing breast and cervical cancer screening services decreases as the number of women screened and served increases. In fact, 98 % (144/147) of the program-years we analyzed were operating at a level where economies of scale had not been exhausted. These economies of scale could result from improved operating efficiency or the ability to spread the costs of large investments over more women. Given current screening penetration rates by State NBCCEDP programs, opportunities exist to increase the share of eligible women screened [18]. Increasing the number of women these programs serve could reach more women in need and improve cost efficiency at the same time.

The results of this study are consistent with those of a previous study that found that average costs were lower for programs that provided more services [4]. Relative to that previous study, this study analyzed more complete cost data using the flexible cost function, which has never been applied to the NBCCEDP programs over a longer time period. Our approach improves upon the existing literature in several ways. First, our estimation sample was more inclusive than previous analyses of NBCCEDP costs [3, 4]. We analyzed data from all State programs and DC, each for up to 3 years [10]. Second, we had a more complete picture of the cost structure of the programs, including non-Federal funding and services, in-kind contributions, cost shares for major input factors such as labor and clinical services, and allocations to breast and cervical services.

Together, this and a previous study suggest that economies of scale that may have been present early in the development of the NBCCEDP are still present even in the more mature programs [4]. In addition, we failed to reject our assumption of cost minimization by NBCCEDP State programs. Evidence of cost minimization by publicly funded programs has been found in the hospital industry as well [9]. The consistency with earlier studies provides support for our finding that as more women are screened in the NBCCEDP program the cost per additional woman screened declines significantly.

The results presented in this study are subject to several limitations. First, the cost data were self-reported by the NBCCEDP State programs. Although several internal and external validity checks were included as part of the cost collection, some cost categories did not have another source of information against which to verify the programs' reports (e.g., non-CDC funding, in-kind contributions) [10]. Results for economies of scale were robust to alternative treatment of these cost categories. Second, quasi-fixed inputs were allowed to affect costs but not economies of scale or the share equations. This assumption is restrictive but necessary because of the limited sample size; full interactions of the quasi-fixed inputs with the other variables would have led to an unreasonable number of parameters to estimate. Finally, although the main analysis accounted for clustering of observations within State program, it did not make full use of the panel data. We estimated a random effect model without the share equations, but algorithms do not yet exist to estimate a system of random effect equations with cross-equation constraints.

Cost function estimation is a valid approach to assessing economies of scale in publicly funded programs. This study's analysis will be used to calculate alternative cost indices to help CDC make resource allocation decisions and analyze the results of those decisions. We hope that it will allow the NBCCEDP to improving operating efficiency and provide breast and cervical cancer screening services to more women in need.

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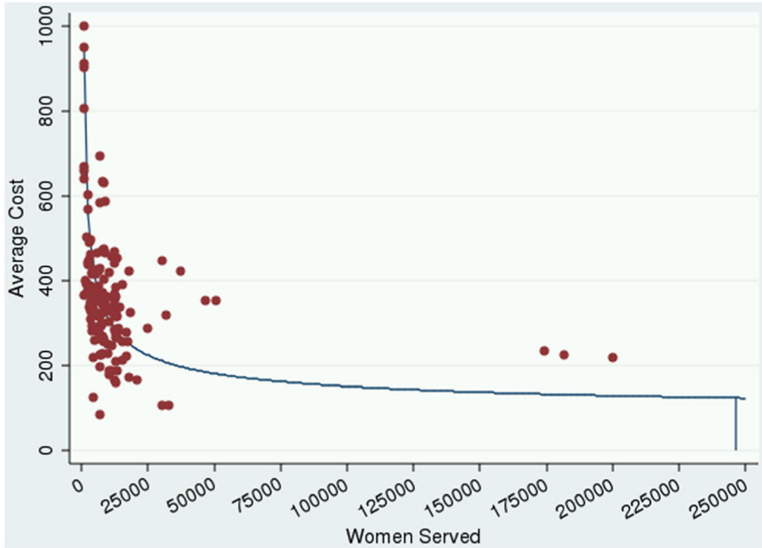

Fig. 1.
Average cost per woman served—breast cancer screening. The average cost curve is represented by the blue line, and the program-year observations are shown as red points on the graph. We find economies of scale for all levels of output below the value indicated by the drop line. All levels of output above this value demonstrate neither significant economies nor diseconomies of scale

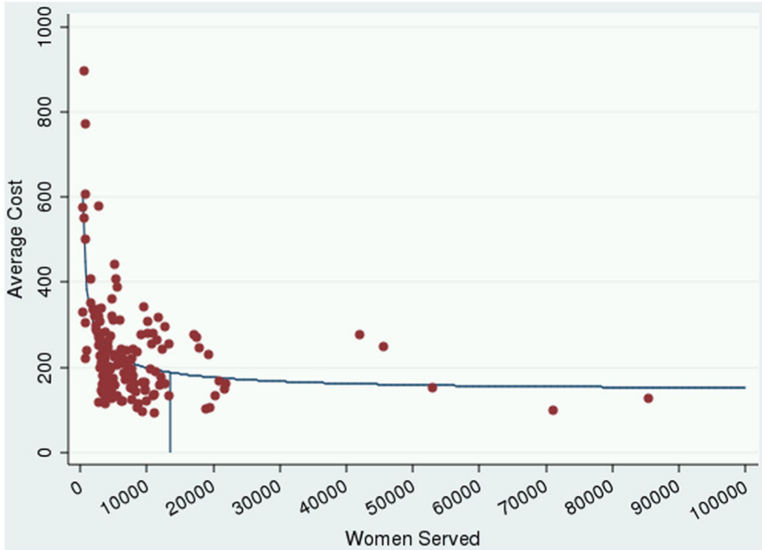

Fig. 2.

Average cost per woman served—cervical cancer screening. The average cost curve is represented by the blue line, and the program-year observations are shown as red points on the graph. We find economies of scale for all levels of output below the value indicated by the drop line. All levels of output above this value demonstrate neither significant economies nor diseconomies of scale

Table 1

Crosswalk for BLS occupations

CAT occupation	BLS occupation
Administrative assistant	Secretaries and administrative assistants, except legal, medical, and executive
Case manager	Registered nurses
Data manager	Database administrators
Info tech specialist	Medical records and health information technicians
Program director	General and operations managers
Program manager	Medical and health services managers
Public health nurse	Registered nurses
Services coordinator	Registered nurses
Epidemiologist/statistician	Statisticians

BLS bureau of labor statistics; *CAT* cost assessment tool

Table 2

Descriptive analysis of the NBCCEDP State Programs 2006–2010 (N=147 program-years)

	Mean	SD	Min	Max
Dependent variables				
Total cost (millions $)	5.51	7.70	0.46	54.41
Total cost and in-kind (millions $)	6.59	8.17	0.54	54.41
Total cost, breast (millions $)	3.85	6.12	0.37	43.59
Total cost, cervical (millions $)	1.66	1.84	0.09	11.55
Share of cost—labor (%)	19.4	10.8	3.6	65.2
Share of cost—clinical (%)	52.0	14.8	5.1	81.7
Share of cost—clinical, breast (%)	57.2	14.7	6.4	91.0
Share of cost—clinical, cervical (%)	41.0	17.8	3.1	81.2
Output variables				
Women served, breast	13,037	26,239	708	200,281
Women served, cervical	8,489	11,095	280	85,422
Women screened, breast	10,681	25,545	222	197,833
Women screened, cervical	7,612	10,575	87	83,127
Cancers detected, breast	129	132	4	857
Cancers detected, cervical	121	202	0	1,410
Price variables				
Wage index	29.78	3.77	23.06	39.86
Capital price index	111.08	34.69	78.34	232.89
Geographic Adjustment Factor index	98.87	6.60	90.45	128.80
Quasi-fixed inputs				
Eligible population (%), breast	7.0	2.8	1.8	16.3
Eligible population (%), cervical	9.4	3.6	2.1	21.0
State population of women aged 40–64 (millions)	1.01	1.09	0.09	5.84
State population of women aged 18–64 (millions)	1.90	2.12	0.16	11.54
Population density (inhabitants/square mile)	383	1,369	1	9,822
Percentage served for breast	57.0	9.7	24.9	79.3
Percentage served for cervical	43.0	9.7	20.7	75.1

Table 3

Main analysis results

	Served			Screened			Detected		
Parameter	**Value**	**SE**	***P* Value**	**Value**	**SE**	***P* Value**	**Value**	**SE**	***P* Value**
Constant	−0.022	0.040	0.586	−0.075	0.041	0.067	−0.015	0.073	0.836
Output, breast	0.289	0.112	0.009	0.158	0.113	0.163	0.386	0.135	0.004
Output, cervical	0.367	0.101	0.000	0.399	0.097	0.000	0.101	0.050	0.046
Output squared, breast	−0.190	0.182	0.297	−0.067	0.117	0.567	0.130	0.155	0.403
Output squared, cervical	−0.106	0.179	0.553	0.206	0.188	0.274	−0.058	0.072	0.424
Output, breast * output, cervical	0.190	0.187	0.309	−0.002	0.148	0.990	0.002	0.077	0.982
Wage index	0.193	0.013	0.000	0.194	0.013	0.000	0.191	0.013	0.000
Capital price index	0.287	0.020	0.000	0.285	0.020	0.000	0.292	0.020	0.000
GAF index	0.519	0.016	0.000	0.521	0.016	0.000	0.517	0.015	0.000
Wage index squared	−0.154	0.139	0.269	−0.183	0.133	0.170	−0.178	0.133	0.181
Wage index * capital price index	0.016	0.085	0.853	0.014	0.084	0.867	−0.018	0.078	0.817
Wage index * GAF index	0.138	0.112	0.218	0.169	0.105	0.108	0.196	0.112	0.079
Capital price index squared	0.166	0.101	0.099	0.197	0.106	0.064	0.159	0.086	0.065
Capital price index * GAF index	−0.182	0.049	0.000	−0.211	0.054	0.000	−0.141	0.050	0.005
GAF index squared	0.044	0.112	0.695	0.042	0.103	0.682	−0.055	0.122	0.652
Output, breast * wage index	−0.026	0.028	0.349	−0.025	0.025	0.335	−0.049	0.016	0.002
Output, breast * capital price index	0.010	0.040	0.800	0.026	0.034	0.453	−0.003	0.020	0.882
Output, breast * GAF index	0.016	0.025	0.507	−0.001	0.023	0.964	0.052	0.016	0.001
Output, cervical * wage index	−0.032	0.031	0.296	−0.030	0.028	0.276	−0.005	0.012	0.706
Output, cervical * capital price index	−0.022	0.047	0.634	−0.043	0.044	0.330	−0.022	0.017	0.191
Output, cervical * GAF index	0.054	0.027	0.045	0.073	0.027	0.007	0.027	0.011	0.020
Time trend	−0.021	0.030	0.472	0.003	0.030	0.922	−0.053	0.034	0.122
Eligible population, cervical	0.164	0.085	0.054	0.042	0.093	0.650	0.172	0.145	0.238
Population density	−0.031	0.025	0.226	−0.053	0.018	0.004	−0.011	0.036	0.751
State population of women aged 18–64	0.139	0.056	0.013	0.268	0.058	0.000	0.229	0.109	0.035
Economies of scale if >0	0.344	0.061	0.000	0.444	0.069	0.000	0.513	0.118	0.000
Economies of scope if <0	0.296	0.185	0.054	0.061	0.130	0.319	0.041	0.080	0.306

	Served			Screened			Detected		
Parameter	**Value**	**SE**	***P* Value**	**Value**	**SE**	***P* Value**	**Value**	**SE**	***P* Value**
AIC	−477.3			−453.6			−356.7		
BIC	−420.5			−396.8			−300.2		

SE standard error; *AIC* Akaike information criteria; *BIC* Bayesian information criteria; *GAF* geographic adjustment factor

Table 4

Number of programs displaying significant economies of scale by program outcome measure

	Percent of programs (N)		
Number of program-years	**Served**	**Screened**	**Detected**
3	86 (44)	84 (43)	78 (40)
2	12 (6)	14 (7)	12 (6)
1	0 (0)	2 (1)	8 (4)
0	2 (1)	0 (0)	2 (1)

Table 5

Alternative two-output (breast and cervical cancer screening) models

	Main analysis		Total cost and in-kind		Random effects model		No NY or CA	
	Point estimate	*P* value	Point estimate	*P* value	Point estimate	*P* value	Point estimate	*P* value
Economies of scale if >0	0.344	0.000	0.390	0.000	0.527	0.000	0.341	0.000
Economies of scope if <0	0.296	0.054	0.321	0.073	0.332	0.025	0.270	0.087
AIC	−477.3		−405.7		−23.6		−451.0	
BIC	−420.5		−348.9		39.2		−395.0	

AIC Akaike information criteria; *BIC* Bayesian information criteria

Table 6

Single-output models, women served

	Breast		Cervical	
	Point estimate	***P* value**	**Point estimate**	***P* value**
Economies of scale if >0	0.399	0.000	0.245	0.007
Percentage of women served for output measure	−0.187	0.329	0.311	0.194
AIC	−443.5		−343.8	
BIC	−398.6		−298.9	

AIC Akaike information criteria; *BIC* Bayesian information criteria