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Do mobile units contribute to spatial accessibility to mammography for uninsured women?

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ABSTRACT

Limited spatial accessibility to mammography, and socioeconomic barriers (e.g., being uninsured), may contribute to rural disparities in breast cancer screening. Although mobile mammography may contribute to population-level access, few studies have investigated this relationship. We measured mammography access for uninsured women using the variable two-step floating catchment area (V2SFCA) method, which estimates access at the local level using estimated potential supply and demand. Specifically, we measured supply with mammography machine certifications in 2014 from FDA and brick-and-mortar and mobile facility data from the community-based Breast Screening and Patient Navigation (BSPAN) program. We measured potential demand using Census tract-level estimates of female residents aged 45–74 from 5-year 2012–2016 American Community Survey data. Using the sign test, we compared mammography access estimates based on 3 facility groupings: FDA-certified, program brick-and-mortar only, and brick-and-mortar plus mobile. Using all mammography facilities, accessibility was high in urban Dallas-Ft. Worth, low for the ring of adjacent counties, and high for rural counties outlying this ring. Brick-and-mortar-based estimates were lower for the outlying ring, and mobile-unit contribution to access was observed more in urban tracts. Weak mobile-unit contribution across the study area may indicate suboptimal dispatch of mobile units to locations. Geospatial methods could identify the optimal locations for mobile units, given existing brick-and-mortar facilities, to increase access for underserved areas.

1. Introduction

In the United States, rural women are less likely to receive breast cancer screening and stay up to date on screening compared to women in urban areas (Bennett et al., 2011, 2012; Coughlin et al., 2008; Horner-Johnson et al., 2015; Leung et al., 2014; Nguyen-Pham et al., 2014). When diagnosed with breast cancer, rural women are more likely to face diagnostic delays, be diagnosed with late-stage cancer, experience more invasive treatments, and skip adjuvant therapies (Markossian et al., 2014; Markossian and Hines, 2012; Robertson et al., 2004). Limited spatial accessibility to mammography, in addition to socioeconomic barriers, may contribute to these suboptimal outcomes among rural women (Doescher and Jackson, 2009; Roche et al., 2017; Williams et al., 2015). Spatial accessibility takes into account both the location of healthcare facilities relative to the population who uses them and ease with which the population can reach them (Guagliardo, 2004).

There are several limitations in prior studies of healthcare accessibility, and these limitations bias accessibility estimates. Some limitations produce overestimates of access; for example, being unable to calculate street network distance, account for traffic congestion, or include typical screening utilization patterns and facility business environments (Celaya et al., 2010; Eberth et al., 2014; Engelman et al., 2002; Maheswaran et al., 2006). Other limitations can bias estimates in unknown ways; for example, the static assignment of women to counties or the closest facility based on their residential location ignores that women may receive services at facilities located in other counties (Luo and Wang, 2003) or further away than the closest facility (Alford-Teaster et al., 2016; Rosenkrantz et al., 2017). Limitations in capturing the full set of available mammography facilities could result in underestimates of access; for example, studies typically do not include mobile mammography unit locations and availability.

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Although mobile mammography has been perceived as a low-cost method to increase access for rural and uninsured populations (DeBruhl et al., 1996; Lee et al., 2016; McCoy et al., 1992; Sickles et al., 1986, 1987; Skinner et al., 1995; Vellozzi et al., 1996), which have lower screening utilization (63% rural vs 73% urban; 53% uninsured vs 80% insured) and poor access to health care (Casey et al., 2001; Doescher and Jackson, 2009; Elkin et al., 2010; Office of Disease Prevention and Health Promotion, 2020; Peipins et al., 2012), few studies have approached the allocation of mobile units from a health-system perspective. One study determined optimal locations of mobile primary care units given hospitals and satellite clinics in Georgia (Lapierre et al., 1999), highlighting the need for mobile units to be included in a regional, comprehensive accessibility strategy. Another study characterized counties according to type of mammography facilities available (permanent, permanent and mobile, mobile, none) and explored the association of facility type with mammography utilization (Engelman et al., 2002). In lieu of a system perspective, literature regarding locational decision-making for mobile mammography units is context-based, focusing on acceptability of mobile screenings at worksites, existing clinics, churches, shopping centers, and community organizations (Derose et al., 2002; Reynolds et al., 1997; Skinner et al., 1995; Steinberg, 2001).

The goal of this study is to estimate spatial accessibility to mammography in urban and rural North Texas using mammography facility location, mammography utilization, and population level data to (1) evaluate the contribution of mobile mammography availability to mammography access for underinsured women in the region, (2) describe the areas where mobile vans were sent, and (3) describe how patient-level mammography utilization was associated with spatial accessibility. Specifically, we aim to explore whether mobile mammography appointments offered to underserved women in the region during 2015–2017 appreciably contributed to mammography access, and how that contribution was dispersed across the region. To our knowledge, this ecological study produces the first set of spatial accessibility estimates reflecting population-level mammography usage, local business environments, and mobile mammography schedules; and the first to assess how mobile units shape regional spatial accessibility to mammography.

2. Methods

We defined our study area as all North Texas counties falling within the smallest possible box containing the counties adjacent to the 36 counties served by the Breast Screening and Patient Navigation (BSPAN) program. BSPAN is a regional demonstration program funded by the Cancer Prevention Institute of Texas designed to reduce payment-based barriers to mammography for low-income women. We collected information about the supply and demand of mammography in our 93-county North Texas study area, and calculated three variable 2-step floating catchment area models (V2SFCA) to estimate spatial accessibility for un- and underinsured women residing in these counties. Then, we compared spatial accessibility to mammography utilization data.

2.1. Data

The U.S. Food and Drug Administration (FDA) certifies all mammography facilities in the U.S. through the Mammography Quality Standards Act (Mammography Quality Standards Act (MQSA), 1992). Through a Freedom of Information Act request, we collected the addresses and numbers of machines for all Texas mammography facilities certified during 2015. We excluded facilities not serving the general population (e.g., military clinics), and used the machines at the remaining facilities as the FDA-certified brick-and-mortar portion of mammography supply.

We collected mammography utilization data from the Breast Screening and Patient Navigation (BSPAN) program, described in detail elsewhere (Inrig et al., 2017; Lee et al., 2017). BSPAN has connected > 20,000 women to breast cancer care since 2012. We queried the program's electronic health records (EHR) database for all mammography appointments completed between June 1, 2015 and July 31, 2017; geocoded women's residential addresses and mammography facility addresses; and calculated the street network distances from each woman's residence to the nearest brick-and-mortar facility, the nearest mobile unit, and the facility she used in ArcGIS 10.3 (ESRI, 2014; ESRI and TeleAtlas, 2012). We used residential data to explore mammography usage by urban vs rural location and brick-and-mortar vs mobile facilities, and facility data to represent the brick-and-mortar portion of the mammography supply used by program participants.

Like many rural mammography screening programs (Fayanju et al., 2013; Fife et al., 2001; Gardner et al., 2012; Roth et al., 2009), BSPAN employs two mobile mammography units, each equipped with a single digital mammography machine. BSPAN staff schedule mobile units to visit community centers, churches, worksites, and special events. For each event, mobile unit records included the number of available appointments and the address. We geocoded event addresses using Google's Geocoding API (Google Maps Platform, 2018).

The United States Government Accountability Office estimates that a single mammography machine can offer 6000 appointments in a year (3 mammograms/h, 8 h/day, 5 days/week, 50 weeks/year), a number accepted in other studies of mammography access (Eberth et al., 2014; Elkin et al., 2010; U.S. Government Accountability Office, 2006). Brick-and-mortar facilities offer all of these appointments in the same place, but mobile units spread out their appointments among the places they visit; therefore, the number of machines added to the supply of mammography by mobile units must be spread among the places the mobile unit visited. We divided the number of mammography appointments available at each mobile event by the estimated number of appointments available for a machine operating at full capacity for one year. We included this number as the mobile portion of the mammography supply within the study area.

Our study focuses on uninsured women seeking mammography. To estimate mammography demand among uninsured women living our study area, we downloaded 5-year (2012-2016) American Community Survey population estimates at the block-group level for uninsured women aged 45–75, which corresponds with USPSTF mammography guidelines for normal-risk women stating that women ages 50–74 years old should receive biennial screening mammography (Siu, 2016). We also downloaded block-group level estimates for all women aged 45–75. We calculated two sets of population-weighted Census tract centroids from these block-group data in ArcGIS 10.3 (ESRI, 2014).These centroids (population centers) represent the spatial distribution of screening demand within our study area. We calculated network distance and travel time between population centers and facilities using Network Analyst in ArcGIS 10.3.

2.2. Analysis

2.2.1. Variable 2-step floating catchment area

We estimated spatial accessibility to mammography at the census tract level using the V2SFCA method, one of many variants of the simple 2SFCA method. Simple 2SFCA uses two steps to describe the spatial distribution of potential accessibility with local provider-to-population ratios (Luo and Wang, 2003). In the first step, supply for each provider's catchment area is calculated by summing the populations sizes (P) at locations (k) that are within a travel time (d_0; the catchment area) from each provider location (j), and computing the provider-to-population ratio (R) as $R_j = \frac{S_j}{\sum_{k \in \{d_{kj} \le d_0\}} P_k}$. The supply at provider location (S_j) can be modeled in a number of ways; we chose mammography machines as our measure of supply. In the second step, for each population location, the Step 1 provider-to-population ratios of the

Table 1
Summary of V2SFCA model specifications.

	Other studies				Our study		
Component	Study 1 (Rahman et al., 2009)	Study 2 (Dai, 2010)	Study 3 (Lian et al., 2012)	Study 4 (Eberth et al., 2014)	Model 1	Model 2	Model 3
Demand	Study-specific population located at unweighted ZIP code centroids	ZIP code residents located at population-weighted ZIP code centroids	Block group residents located at population-weighted block group centroids	Block group residents located at population-weighted block group centroids	Census tract centroids Weighted by number of uninsured female residents aged 45–74		
Supply	Mammography facilities from CO Dept of public health and environment	USDA-certified mammography facilities	Mammography machines at USDA-certified mammography facilities	Mammography machines at USDA-certified mammography facilities	Mammography machines at *all* FDA-accredited mammography facilities (N = 368 machines)	Mammography machines at *program-associated* FDA-accredited mammography facilities (N = 101 machines)	Model 2 machines *plus* machines available at BSPAN mobile locations within study period (N = 102 machines)
Catchments	10, 20, 30, 40, or 50 miles*	10-min travel time[a]	30 min travel time divided into multiple zones [a]	60-min travel time [a]	Because mammography volume is lower in rural areas: - Urban base mammography threshold of 4800 per machine - Rural base mammography threshold of 1500 per machine Because mammography screening rates are lower in rural areas: - Urban machine-to-woman threshold ratio of 1:8219 - Rural machine-to-woman threshold ratio of 1:9524		
Distance decay	No distance decay	Continuous Gaussian distance decay [a]	Tested fast and slow distance decay separately [a]	No distance decay	Because rural women drive further for mammography: - Fast urban decay of {1, 0.60, 0.25, 0.05} - Slow rural decay of {1, 0.80, 0.25, 0.05}		

Study 1 = Rahman S, Price JH, Dignan M, Rahman S, Lindquist PS, Jordan TR. Access to Mammography Facilities and Detection of Breast Cancer by Screening Mammography: A GIS Approach. Int J Canc Prev. 2009;2:403–13.
Study 2 = Dai D. Black residential segregation, disparities in spatial access to health care facilities, and late-stage breast cancer diagnosis in metropolitan Detroit. Health & Place. 2010;16:1038–52.
Study 3 = Lian M, Struthers J, Schootman M. Comparing GIS-Based Measures in Access to Mammography and Their Validity in Predicting Neighborhood Risk of Late-Stage Breast Cancer. PLOS ONE, 2012;7:e43000.
Study 4 = Eberth JM, Eschbach K, Morris JS, Nguyen HT, Hossain MM, Elting LS. Geographic disparities in mammography capacity in the South: a longitudinal assessment of supply and demand. Health Services Research. 2014;49:171–185.
[a] No urban/rural difference in model specification.

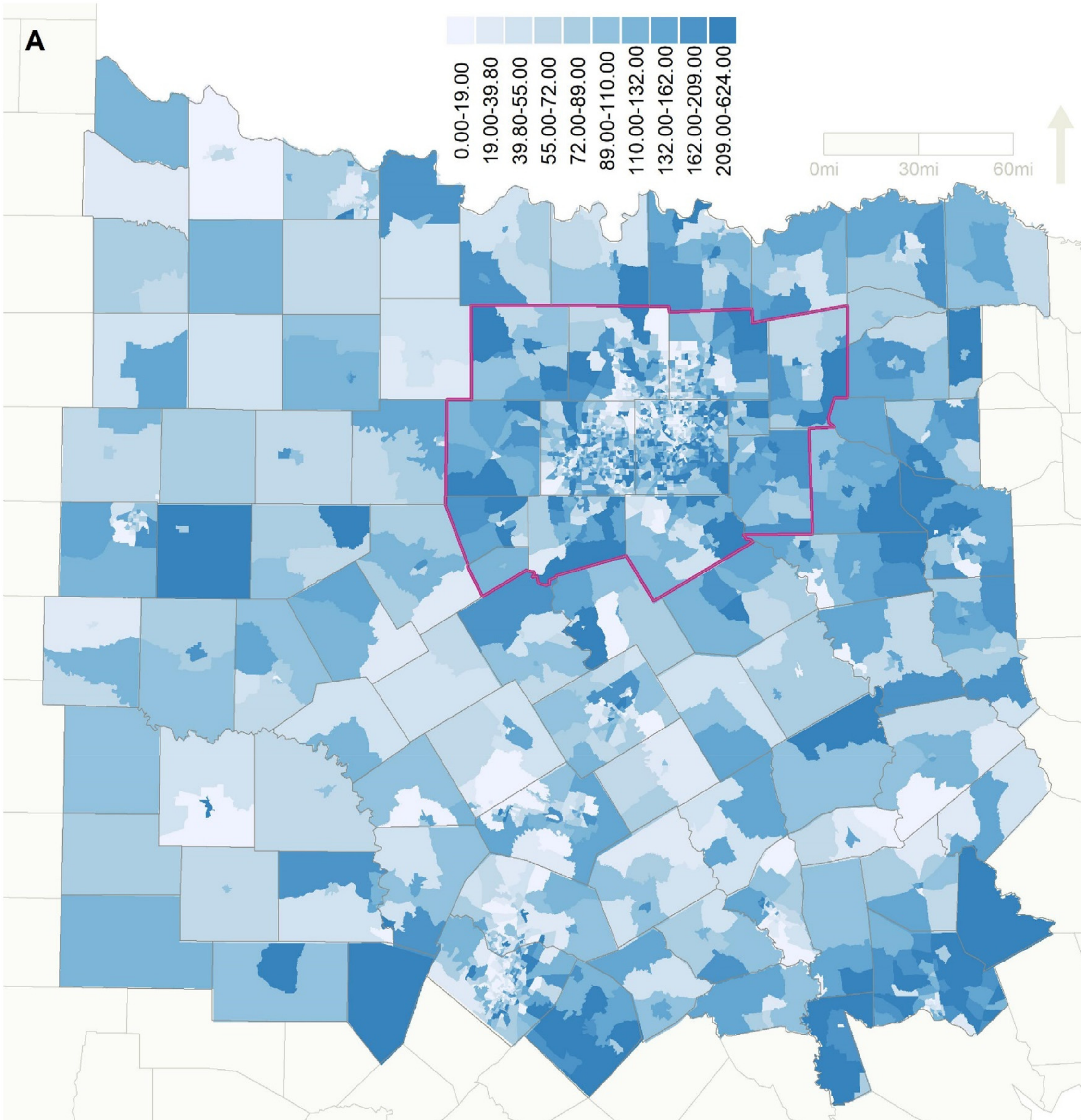


Fig. 1. Map of the study area describing (A) the percent of female residents with health insurance in the study area, (B) locations of all FDA-certified mammography facilities and Census tract centroids weighted by number of uninsured women ages 45–74, and (C) spatial access ratios from the V2SFCA model using all FDA-certified facilities.

providers within a specified travel time (d_0) are summed into access scores (A_i) such that $A_i = \sum_{j\in\{d_{ij}\le d_0\}} R_j = \sum_{j\in\{d_{ij}\le d_0\}} \frac{S_j}{\sum_{k\in\{d_{kj}\le d_0\}} P_k}$.

The V2SFCA method (Luo and Whippo, 2012) includes a feedback loop in each step to accommodate (1) access to care decreasing with increasing patient drive time, and (2) variation in catchment area sizes (e.g., due to neighborhood or clinic type). Before computing the provider-to-population ratio in Step 1, the summed population size within each provider service area is compared to a preset threshold. If the summed population size is smaller, then the catchment size is increased slightly and the population size re-summed and re-compared. This is repeated until the summed population is larger than the population threshold. In Step 2, the summed provider-to-population ratios undergo the same iterative procedure until the ratios are equal to or larger than the provider-to-population threshold ratio.

Urban and rural mammography facilities face different business environments, and standard economic theory indicates that these reflected in supply- and demand-side differences among the urban and rural markets, regardless of underlying causes. On the supply side, mammography reimbursement can only cover part of its total cost in academic medical centers, but if mammography machines are operating at capacity then losses can be overcome by giving screening priority to patients likely to need follow-up diagnostic radiology (Chen et al., 2004). However, this is not an effective strategy in rural clinics (Sistrom and McKay, 2005). Rural mammography facilities expect to supply fewer mammograms than urban facilities (Engelman et al., 2002) because, on the demand side, fewer rural (63% rural vs 73% urban) women receive mammography (Casey et al., 2001; Doescher and Jackson, 2009) which leads to lower machine utilization in rural facilities (Radiology Business Management Association, 2009). Failing to account for these differences in screening behaviors among urban vs rural women could lead to overestimates of demand in rural areas, and, since our V2SFCA estimates of access are based on machine-to-provider ratios, overestimates of access in rural areas. Therefore, we apply different base population thresholds, machine-to-woman ratios, and distance decay assumptions for urban versus rural populations and facilities.

We set the base population threshold for urban facilities to 4800

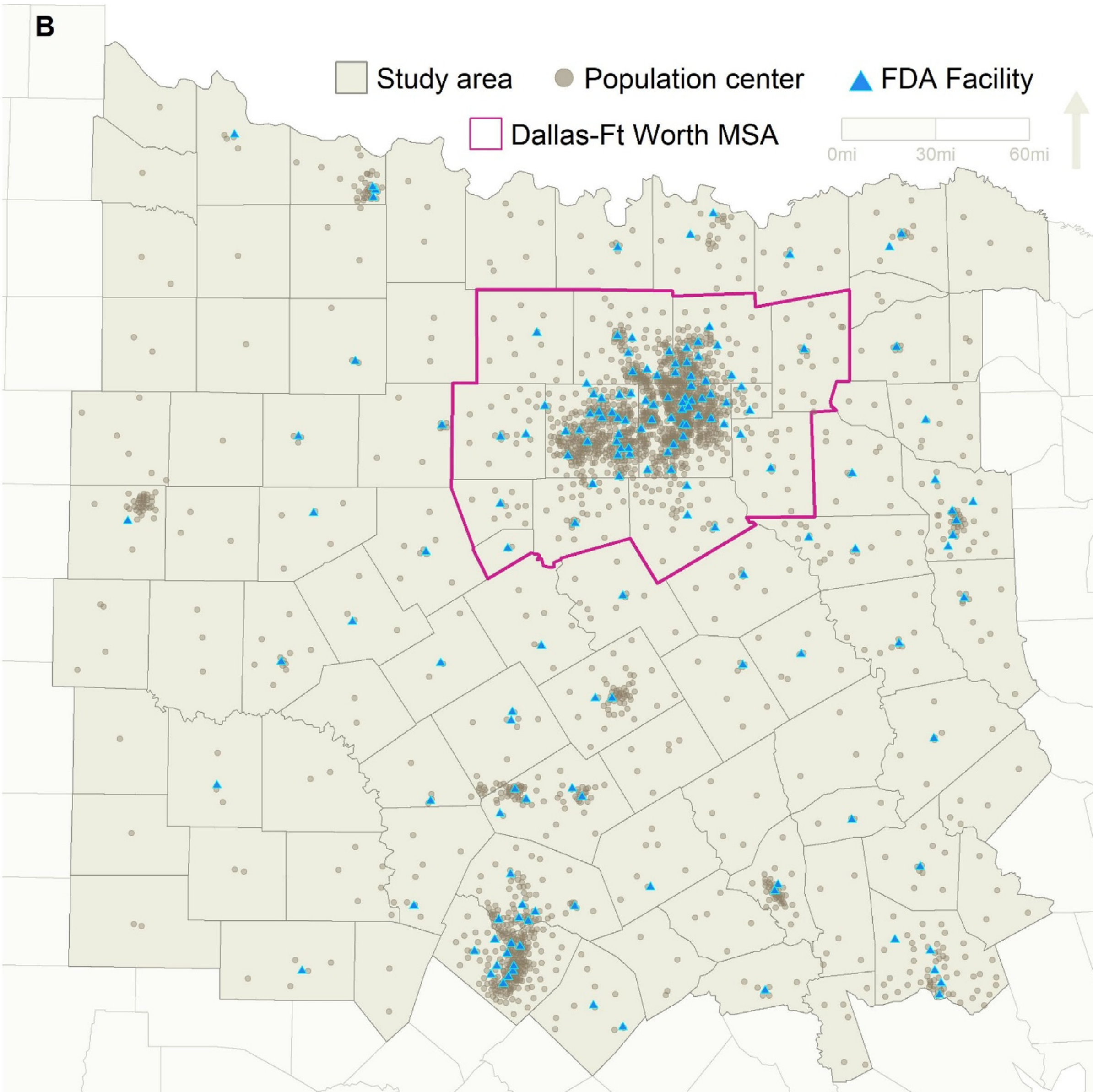


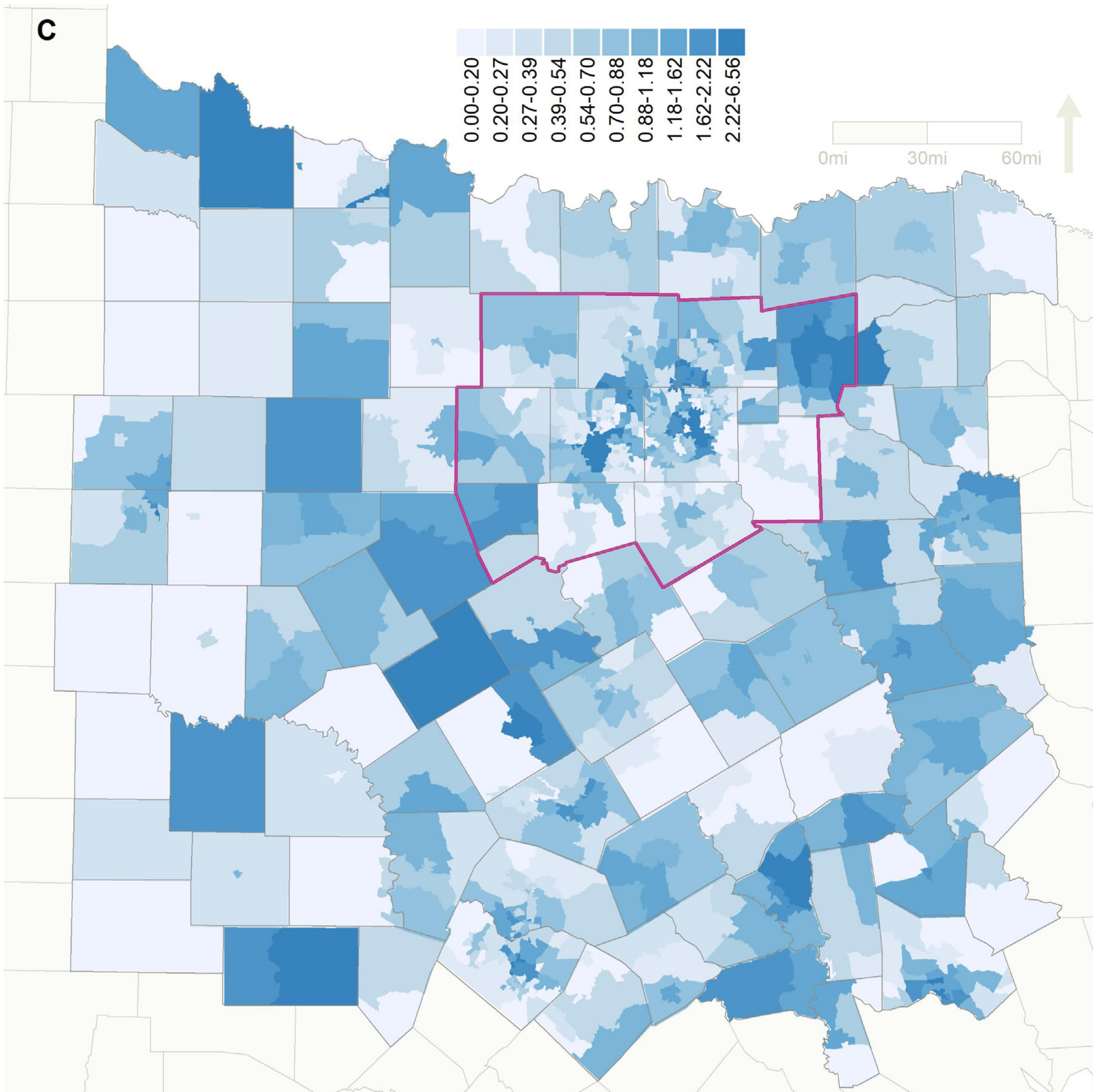
Fig. 1. (*continued*)

women and the base population threshold for rural facilities to 1500 because this corresponds to the yearly number of screening mammograms each type of facility will expect to provide (Engelman et al., 2002). For urban populations, we set machine-to-woman ratio threshold to 1:8219 because this corresponds to the maximum number of women that one machine at an urban facility operating at full capacity (U.S. Government Accountability Office, 2006) could serve given that 73% of urban women undergo mammograms each year (Office of Disease Prevention and Health Promotion, 2020). We set the machine-to-woman ratio threshold for rural populations to 1:9524 because this corresponds to the maximum number of women that one machine at a rural facility operating at full capacity could serve given that 59% of rural women undergo mammograms each year (Office of Disease Prevention and Health Promotion, 2020).

Women who live at the edge (vs the center) of a catchment area are less willing to drive to the center of the catchment area for care, and rural women will drive further for mammography than urban women. To account for this, we created fast urban ($w_i = \{1, 0.60, 0.25, 0.05\}$) and slow rural ($w_i = \{1, 0.80, 0.55, 0.15\}$) distance decay weights following previous studies (McGrail, 2012; Wan et al., 2012a, 2012b). We used Rural-Urban Commuting Area (RUCA) codes from the U.S. Department of Agriculture Economic Research Service (2010) and Classification Scheme C from the WWAMI Rural Health Research Center (Hart et al., 2005) to classify Census tracts as urban versus rural.

To study differences in access scores arising from differences in the supply of mammography, we allowed our three models to take differing inputs for facilities. In Model 1, we included machines located inside all brick-and-mortar FDA-accredited facilities within our study area. In Model 2, we included only machines located inside BSPAN brick-and-mortar facilities. In Model 3, we included machines located inside BSPAN brick-and-mortar locations and mammography units. Table 1 provides a summary of these model specifications.

We calculated spatial access scores from the V2SFCA model using R (R Core Team, 2014), and converted access scores to spatial access ratios (SPARs) by dividing each set of scores by the mean access score (Wan et al., 2012a). We focus on SPARs because they (1) are more comparable when distance decay schemes are unknown or different across strata such as urban/rural locations, and (2) represent the scaled contribution of mobile mammography to spatial access across the region. Using the sign test, we compared SPARs from the BSPAN brick-



FDA=Food and Drug Agency; MSA=metropolitan statistical area

Fig. 1. (*continued*)

and-mortar model with SPARs from the full BSPAN model. We also compared the distribution of SPARs from these models among tertiles of high, medium, and low FDA facility access.

2.2.2. *Comparing spatial accessibility with mammography use*

To describe BSPAN program reach into areas of need (i.e., low rates of insurance or access to FDA-certified mammography facilities), we calculated and compared summary statistics of program utilization. At the facility level, we calculated the distance from each facility to the population centroids weighted by all age-appropriate women, and to centroids weighted by only age-appropriate *uninsured* women. We counted how many facilities were located in low, medium, and high-access tracts, and how many were located in tracts with a low, medium, and high percentage of insured age-appropriate women. At the individual-level, we counted how many non-BSPAN facilities, and how many brick-and-mortar BSPAN facilities, were closer to each woman's residence than the facility she chose. Finally, we calculated the numbers and percentages of BSPAN women living in low, medium, and high access tracts who were screened. We compared summary statistics for each of these measures between two groups: (1) BSPAN women who received mammography at brick-and-mortar facilities and (2) BSPAN women who received mammography at mobile units. We made these comparisons separately for urban and rural facilities.

3. Results

Spatial accessibility estimates using all FDA-certified mammography facilities (Model 1) reflect facility proximity to population centers weighted by the underlying distribution of uninsured women of mammography age (Fig. 1A [population] and 1B [centroids]). These estimates show comparatively high spatial access in the Dallas-Fort Worth (DFW) Metropolitan Area (MSA; Fig. 1C), and a ring of low access scores in counties adjacent to the MSA surrounded by a ring of counties with high access scores. In contrast, accessibility estimates using only BSPAN facilities (Model 2) reflect significantly fewer facilities available to uninsured women living in the second ring of outlying counties (Fig. 2A), leading to fainter concentric ring patterns in spatial access ratios (Fig. 2B).

The BSPAN program deployed mobile units 202 times to 95 unique locations during the study period, increasing the total supply of mammography within the region by 6439 appointments. The mobile program added the equivalent of 1.07 machines to the mammography

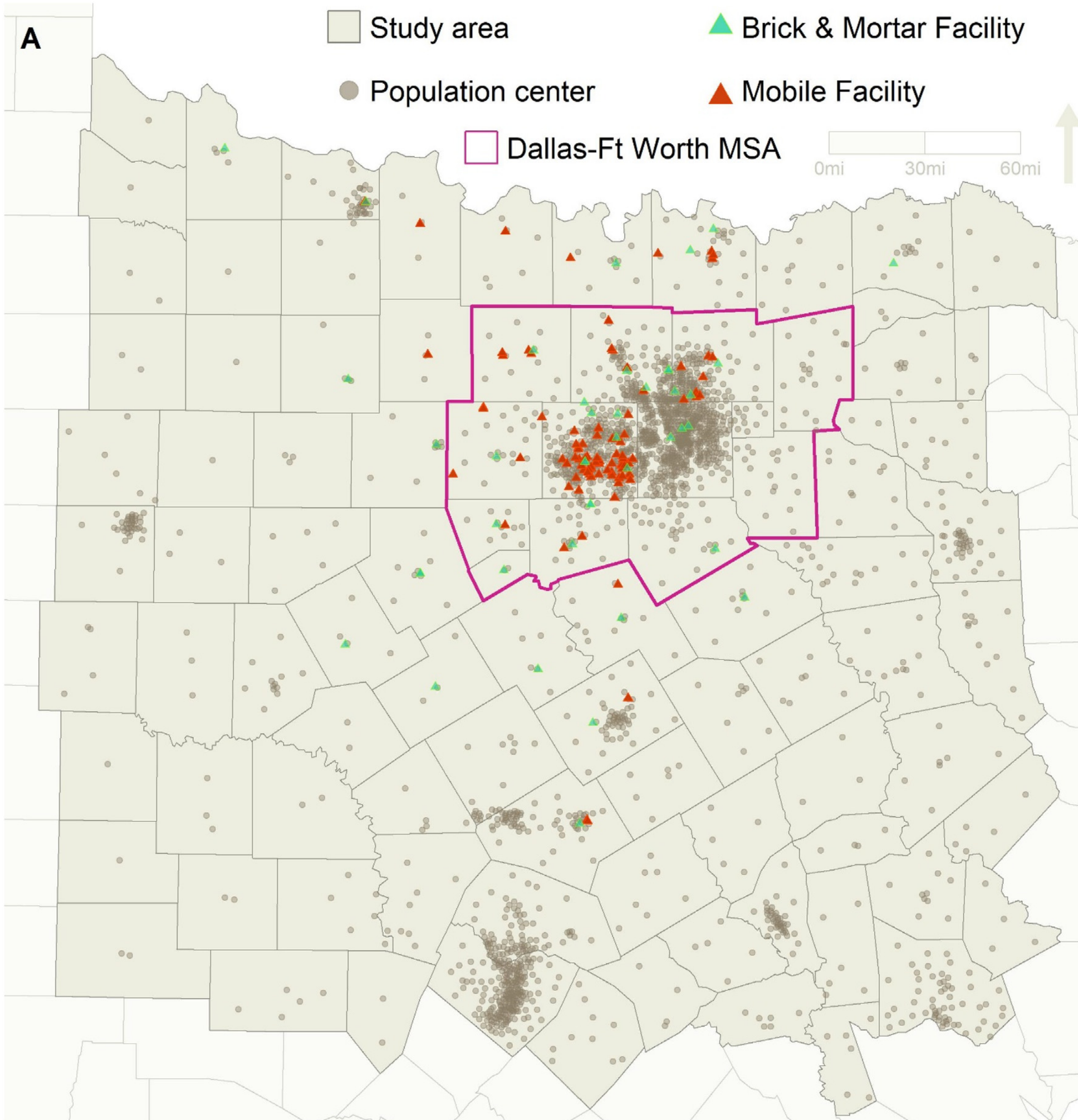


Fig. 2. Map of the study area describing (A) locations of BSPAN brick-and-mortar facilities, BSPAN-sponsored mobile mammography stops, and Census tract centroids weighted by number of uninsured women ages 45–74; (B) spatial access ratios from the V2SFCA model with BSPAN brick-and-mortar facilities only; and (C) difference in spatial access ratios from estimated BSPAN brick-and-mortar facilities only vs BPSAN brick-and-mortar facilities and mobile mammography stops.

supply (Table 2). Maps of spatial access ratios from both BSPAN models are similar between the brick-and-mortar (Fig. 2B) vs mobile models (not shown). The majority (73.4%) of Census tracts were ranked < 5 spots higher or lower in the mobile model compared to the brick-and-mortar model only (Fig. 2C).

The distribution of facility type differed in both urban and rural areas (Table 2). Of the 130 unique BSPAN mammography locations, 109 were urban and 21 were rural. Urban tracts had 23 brick-and-mortar facilities and 86 unique mobile sites; rural tracts had 12 brick-and-mortar facilities and just 9 unique mobile sites. In rural areas, compared to brick-and-mortar facilities, mobile sites were located farther from population centers of age-relevant women (1.43 vs 3.59 min travel time). This difference was not significant when the population centers were weighted by percent of women who were uninsured. In urban areas, mobile units were located closer to both age-relevant (1.97 vs 2.58 min travel time) and age- and insurance-relevant (2.03 vs 2.69 min travel time) population centers compared to brick-and-mortar facilities. Only one brick-and-mortar facility was located in an urban low-access tract and no brick-and-mortar facilities were located in rural low-access tracts. In urban—but not rural—areas, mobile units visited more low- and medium-access tracts than brick-and-mortar facilities in rural areas (urban: $p = 0.025$; rural: $p = 0.068$).

Patterns of utilization differed among women who received screening mammography at brick-and-mortar vs mobile facilities (Table 3) in both rural and urban tracts. Of the 4480 women who received screening mammography with BSPAN, only 162 (2.9%) received a mammogram at a rural facility (110 brick-and-mortar; 52 mobile). Travel time to the *nearest* facility was shorter for women who went to urban mobile vs urban brick-and-mortar facilities (7.64 vs 13.25 min); however, travel time to the *chosen* facility was longer for urban mobile vs urban brick-and-mortar facilities (22.32 vs 20.61 min). Travel time to *chosen* facility also was closer for women who went to rural brick-and-mortar facilities vs mobile units (15.94 vs 30.31 min) but travel time to *nearest* facility did not differ for women visiting rural mobile units vs brick-and-mortar facilities. Women who went to urban brick-and-mortar facilities drove past slightly more BSPAN facilities than women who went to an urban mobile unit (2.22 vs 2.01 facilities were closer than the chosen one). The direction of this difference was

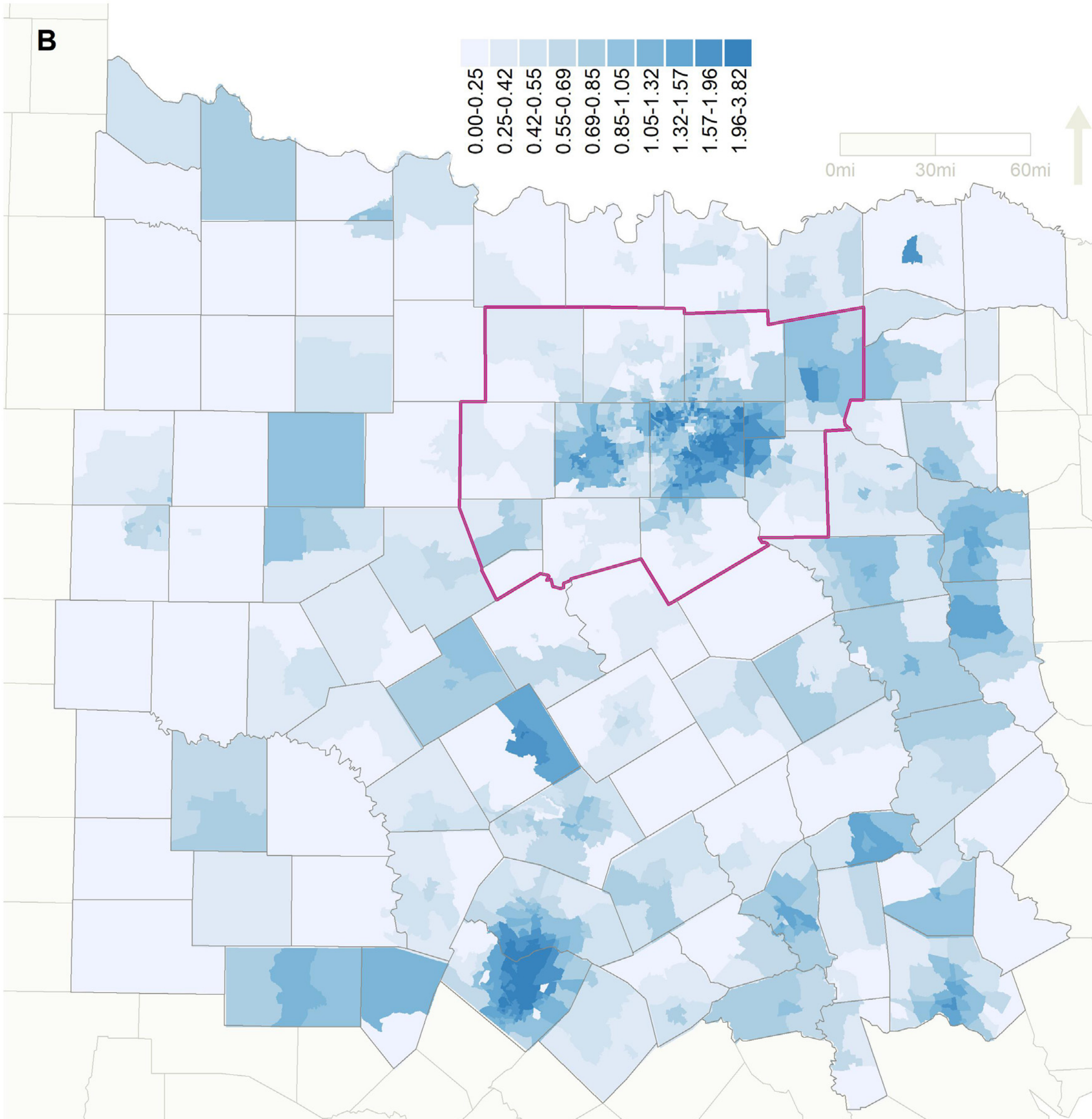


Fig. 2. (*continued*)

opposite but not significant (0.08 vs 1.06 facilities were closer than the chosen on; p = 0.317) for women who went to rural facilities.

Comparison of the SPARs–interpreted here as the number of screening opportunities per 1000 uninsured female residents in a Census tract compared to the average across the study area—from the brick-and-mortar vs mobile estimates via the sign test shows that deployment of mobile units modified slightly, yet statistically significantly, the distribution (i.e., ranked order of tract) of spatial accessibility (Table 4). SPARs from urban tracts with low or moderate FDA-based access scores, and moderate insurance rates, had statistically significant higher ranked order in the V2SFCA models with mobile units. However, SPARs from urban high-access tracts, and extreme insurance rates, had statistically significant lower ranked order in the models with mobile units. SPARs in rural tracts in the lowest two tertiles of access and insurance had statistically significant higher ranked order in models including the mobile units.

4. Discussion

Rural counties have high mammography access when we assume that all women can access all mammography facilities. However, when we accounted for insurance-based barriers we found differences in patterns of spatial accessibility. We found differences in BSPAN reach and utilization for brick-and-mortar facilities vs mobile units in urban and rural areas. Inclusion of mobile units in our spatial accessibility models redistributed accessibility across the study area. Our study is the first to incorporate expected local population-level mammography use, local business environments, and screening mammography utilization data to explore whether mobile screening units contribute to spatial access.

Our V2SFCA estimations offer improvements compared to previous estimates of spatial access to mammography. First, we focused on uninsured vs all women (Dai, 2010; Eberth et al., 2014; Rahman et al., 2009; Rosenkrantz et al., 2017). Second, we incorporated supply- and demand-level factors that differentially affect catchment sizes in urban vs rural areas; specifically, we assumed different base populations and different machine-to-woman thresholds reflecting different mammography utilization patterns in rural vs urban areas. Third, we specified different rates of decay for urban vs rural areas to more realistically mimic a woman's likelihood of traversing a catchment area to receive mammography. Fourth, we included information regarding mobile mammography units.

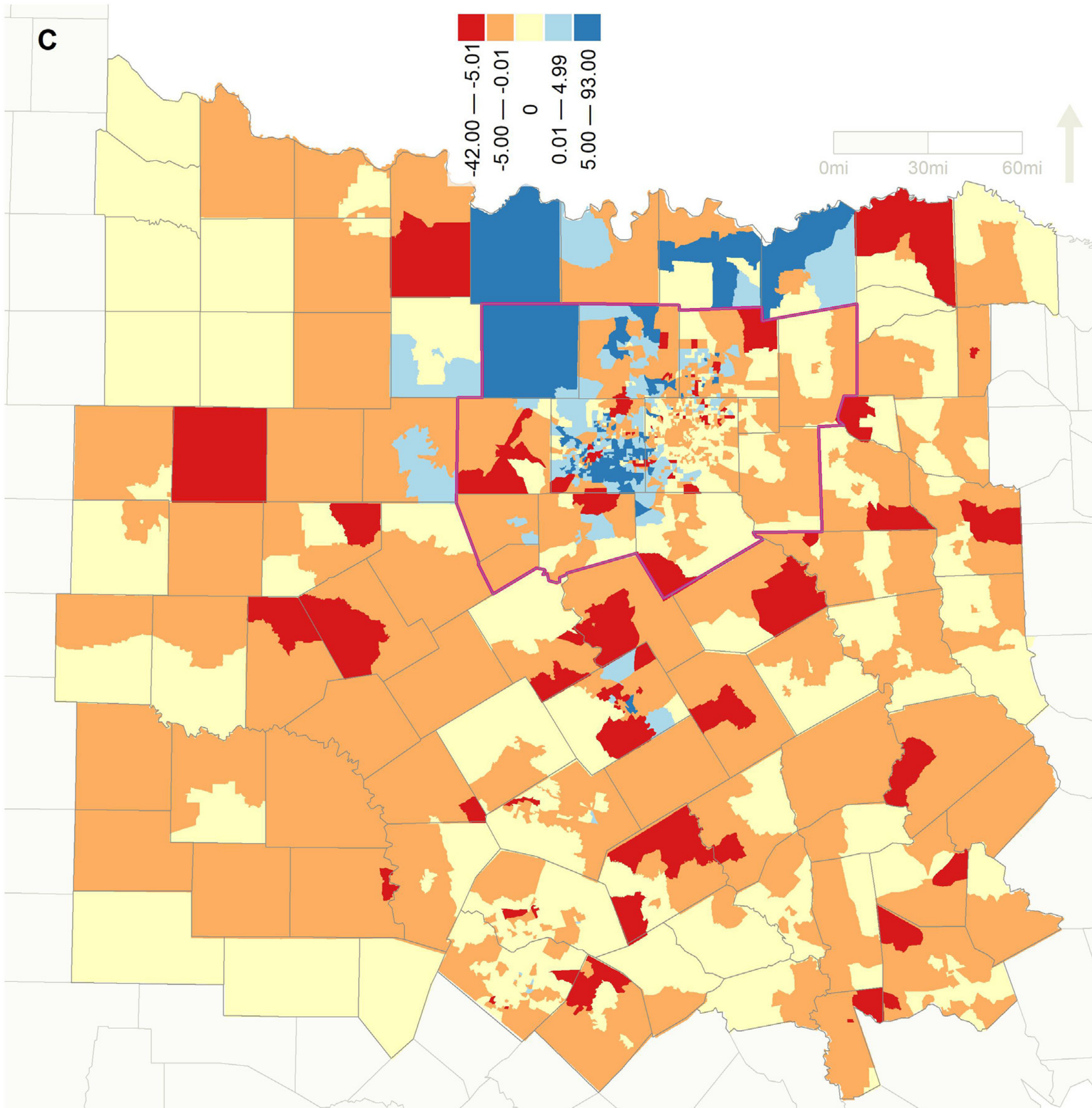


Fig. 2. (*continued*)

Our results underscore the need for comprehensive regional planning of mobile unit deployment, and subsidization of mobile units for use as a bridge to preventive care in sparsely populated areas. We demonstrated that relative spatial accessibility for all women with all facilities differs greatly from those of the uninsured population, and that mobile units have the potential to modify the existing spatial distribution of accessibility. Importantly, the mobile units did not contribute appreciably to mammography access uniformly across the study area. Like other mobile mammography programs (Carkaci et al., 2013; DeBruhl et al., 1996; Moulavi et al., 1999; Sickles et al., 1987; Wolk, 2013), BSPAN relied on community requests for mobile units and required a minimum number of scheduled appointments before a unit could be deployed. These requirements could have constrained rural deployments, and likely contributed to mobile units being deployed only 23% of days within the study window.

Because screening mammography in brick-and-mortar facilities is not usually profitable (Chen et al., 2004), facilities offering screening mammography must also offer follow-up care or other services in order to cover costs (Sistrom and McKay, 2005). If the purchase of mammography machines must be bundled with capital outlays for other equipment, then augmenting the supply of mammography via brick-and-mortar facilities represents a disproportionately large investment to suppliers. Therefore, it is important to ensure mobile units are deployed to areas where markets for other medical services cannot support the investment required for operation of mammography machines—for example, in rural areas where comparatively fewer women have mammography and engagement in preventive care is low (Casey et al., 2001; Doescher and Jackson, 2009; Zhang et al., 2000).

We found that women frequently did not choose the closest mammography facility to their residence, and that population centers in rural areas are further from the nearest brick-and-mortar facilities compared to population centers in urban areas. These results coincide with previous studies. For example, it is well-documented in the literature that women do not choose the closest mammography facility and that rural women live further away from mammography facilities (Alford-Teaster et al., 2016; Johnston et al., 2014; Onitilo et al., 2014; Rosenkrantz et al., 2017).

By comparing women who received screening mammography at brick-and-mortar facilities vs mobile units in both urban and rural areas, we found nuances in facility choice. Previous studies conclude that a woman may travel further to a brick-and-mortar facility if she believes mammography quality there is superior to a mobile unit (Chen et al., 2004; Suter et al., 2002). Our results indicate that women who used urban brick-and-mortar facilities were willing to pass a greater

Table 2
Characteristics of BSPAN program facilities.

	All facilities N (%)/avg (SD)[a]	Brick & Mortar facilities N (%)/avg (SD)[a]	Mobile facilities N (%)/avg (SD)[a]	P-value
Urban	119	29	90	
Distance—Facility to centroids weighted by				
Female residents age 45–74	2.06 (1.98)	2.58 (2.10)	1.97 (1.95)	**0.024**
Uninsured female residents age 45–74	2.13 (1.97)	2.69 (2.24)	2.03 (1.9)	**0.035**
Facilities or mobile sites located in tracts with[b]				
Low insurance rates	42 (38.5)	10 (43.5)	32 (37.2)	0.099
Medium insurance rates	47 (43.1)	6 (26.1)	41 (47.7)	
High insurance rates	20 (18.3)	7 (30.4)	13 (15.1)	
Facilities or mobile sites located in tracts with[c]				
Low FDA mammography access	28 (25.7)	1 (4.3)	27 (31.4)	**0.025**
Medium FDA mammography access	32 (29.4)	10 (43.5)	22 (25.6)	
High FDA mammography access	49 (45)	12 (52.2)	37 (43.0)	
Rural	11	6	5	
Distance—Facility to centroids weighted by				
Female residents age 45–74	3.32 (1.77)	1.43 (0.68)	3.59 (1.71)	**0.004**
Uninsured female residents age 45–74	3.25 (1.94)	2.21 (1.01)	3.40 (2.00)	0.183
Facilities or mobile sites located in tracts with[b]				
Low insurance rates	13 (61.9)	9 (75.0)	4 (44.4)	0.386
Medium insurance rates	5 (23.8)	2 (16.7)	3 (33.3)	
High insurance rates	3 (14.3)	1 (8.3)	2 (22.2)	
Facilities or mobile sites located in tracts with[c]				
Low FDA mammography access	1 (4.8)	0 (0)	1 (11.1)	0.068
Medium FDA mammography access	12 (57.1)	5 (41.7)	7 (77.8)	
High FDA mammography access	8 (38.1)	7 (58.3)	1 (11.1)	

[a] Avg = average; SD = standard deviation. P-values correspond to the appropriate χ^2 or *t*-test for each variable.
[b] Insurance tertiles denoting the proportion of age-relevant women with health insurance in a census tract corresponded to (0–0.828), (0.83–0.910), (0.911–1.0).
[c] FDA mammography access tertiles correspond to spatial access ratios from model 1, where all FDA-certified facilities were included (tertiles of access = [0–0.409], [0.41–1.084], [1.085–5.681]).

Table 3
Characteristics of urban vs rural BSPAN program participants by insurance and spatial access scores.

	All patients N (%)/avg (SD)[a]	Brick-and-mortar patients N (%)/avg (SD) [a]	Mobile patients N (%)/avg (SD) [a]	P-value
By urban facility	4480	3629	851	
Travel time to nearest facility	12.18 (8.97)	13.25 (8.69)	7.64 (8.74)	< **0.001**
Travel time to chosen facility	20.93 (19.96)	20.61 (18.55)	22.32 (25.08)	< **0.001**
Facilities closer than chosen facility	2.18 (3.29)	2.22 (2.84)	2.01 (4.75)	< **0.001**
Women coming from tracts with[b]				
Low insurance rates	2158 (48.2)	1819 (50.1)	339 (39.8)	< **0.001**
Medium insurance rates	1498 (33.4)	1173 (32.3)	325 (38.2)	
High insurance rates	824 (18.4)	637 (17.6)	187 (22.0)	
Women coming from tracts with[c]				
Low FDA mammography access	1513 (33.8)	1221 (33.6)	292 (34.3)	0.486
Medium FDA mammography access	1321 (29.5)	1060 (29.2)	261 (30.7)	
High FDA mammography access	1646 (36.7)	1348 (37.1)	298 (35.0)	
By rural facility	162	110	52	
Travel time to nearest facility	14.8 (16.16)	15.11 (17.26)	14.15 (13.67)	0.884
Travel time to chosen facility	20.55 (25.35)	15.94 (18.15)	30.31 (34.36)	**0.002**
Facilities closer than chosen facility	0.4 (2.53)	0.08 (0.31)	1.06 (4.39)	0.317
Women coming from tracts with[b]				
Low insurance rates	57 (35.2)	45 (40.9)	12 (23.1)	0.020
Medium insurance rates	73 (45.1)	49 (44.5)	24 (46.2)	
High insurance rates	32 (19.8)	16 (14.5)	16 (30.8)	
Women coming from tracts with[c]				
Low FDA mammography access	21 (13.0)	10 (9.1)	11 (21.2)	< **0.001**
Medium FDA mammography access	83 (51.2)	45 (40.9)	38 (73.1)	
High FDA mammography access	58 (35.8)	55 (50.0)	3 (5.8)	

[a] Avg = average; SD = standard deviation. P-values correspond to the appropriate χ^2 or t-test for each variable.
[b] Insurance tertiles denoting the proportion of age-relevant women with health insurance in a census tract corresponded to (0–0.828), (0.83–0.910), (0.911–1.0).
[c] FDA mammography access tertiles correspond to spatial access ratios from model 1, where all FDA-certified facilities were included (tertiles of access[0–0.409], [0.41–1.084], [1.085–5.681]).

number of program-associated facilities in order to reach their chosen facility; however, women who used urban mobile units drove farther to reach the mobile unit than women using urban brick-and-mortar facilities. In our study, women in rural areas did not live (but did travel) significantly farther to use mobile facilities compared to brick-and-mortar facilities. It is possible that women used a convenient mobile unit near their workplace, or that mammography unit visits to rural locations did not temporally coincide with a noted need for screening.

Our results emphasize the need for a regional perspective in spatially balancing BSPAN's portfolio of facility contracts. Building the BSPAN network of contracted facilities began with the aim of securing at least one brick-and-mortar facility contract in every rural county.

Table 4
Contribution of mobile facilities to tract-level BSPAN program accessibility by tertiles of access and mammography.

	Brick-and-mortar SPARs[a] avg (SD)	Mobile SPARs[a] avg (SD)	Tracts with SPAR[a] changes (N)	P-value
Urban tracts				
FDA mammography access[b]				
Low (n = 750)	999.934 (655.13)	1000.13 (653.91)	408	< **0.001**
Medium (n = 710)	977.444 (616.84)	977.66 (615.73)	363	< **0.001**
High (n = 708)	1218.297 (661.85)	1217.649 (660.75)	327	< **0.001**
Insurance rates[+]				
Low (n = 722 tracts)	1164.494 (657.64)	1164.304 (656.460)	328	< **0.001**
Medium (n = 698)	984.131 (647.52)	984.305 (646.35)	364	< **0.001**
High (n = 748)	1038.098 (643.96)	1037.925 (642.76)	406	< **0.001**
Rural tracts				
FDA mammography access[b]				
Low (n = 42)	175.894 (259.98)	177.109 (259.15)	8	**0.008**
Medium (n = 83)	462.058 (301.24)	463.692 (299.92)	19	< **0.001**
High (n = 87)	872.512 (333.78)	871.484 (333.33)	21	< **0.001**
Insurance rates[c]				
Low (n = 71)	552.185 (397.01)	552.82 (395.64)	16	< **0.001**
Medium (n = 95)	568.159 (421.99)	569.036 (420.39)	23	< **0.001**
High (n = 46)	667.451 (377.62)	666.68 (377.12)	9	0.004

[a] SPARs = spatial access ratios which can be interpreted as the number of screening opportunities per 1000 uninsured female residents in a census tract compared to the average number of screening opportunities per 1000 uninsured female residents of the entire study area; Avg = average; SD = standard deviation. P-values are from the dependent sample sign test.

[b] FDA mammography access tertiles correspond to spatial access ratios from the model 1, where all FDA-certified facilities were included (tertiles of access = [0–0.439], [0.44–1.089], [1.09–5.04]).

[c] Insurance tertiles denoting the proportion of age-relevant women with health insurance in a census tract corresponded to (0–0.828), (0.83–0.910), (0.911–1.0).

Multiple factors impinged on the planned approach (Inrig et al., 2017), and the network was assembled without regard to clustering of facilities between or within counties. For example, no efforts were made to select facilities located far from other same-county facilities or close to county borders. The location of contracted brick-and-mortar facilities within the network influences the scope of need for mobile units. Taking care to minimize catchment area redundancy by choosing brick-and-mortar facilities in specific locations could create a network that is designed to embrace targeted, flexible mobile mammography strategies – thereby strengthening the overall accessibility of the network, enabling responses to changes in screening needs driven by community change, and ultimately providing more women with services. Future work should determine the spatially optimal configuration of brick-and-mortar facility mix and mobile unit deployments.

Our study has limitations. For the woman-level analysis, we excluded appointments that were not for screening mammography. During the study period, BSPAN worked with 14,044 unique women and interacted with these women 25,243 times; of these interactions, we chose to include only appointments coded as screening mammography. Program data for this study were not designed a priori to collect residential and provider information relevant for accessibility estimates. Therefore, we excluded some women because screening location (N = 637) or residential information (N = 1239) from the EHR was invalid and could not be recovered from program records. For our accessibility estimates, we did not take into account operating hours of each facility, which could bias mammography capacity upward, and thus higher estimated accessibility. Finally, the role of the ecological fallacy in 2SFCA studies has been discussed previously elsewhere (Ghorbanzadeh et al., 2020; Ngui and Apparicio, 2011; Rodgers et al., 2012; Williams and Wang, 2014; Yin, 2019), and it is important to note that our study provides only population-level information and cannot be used to infer mammography access, intention to receive mammography, or reasons underlying facility selection for any given individual.

5. Conclusion

By adjusting existing variable 2-step floating catchment area methods to better reflect differences in urban vs rural mammography facilities and business environments, incorporating program facility data, and using weighted population centroids, we were able to estimate access to mammography for uninsured women. Through our inclusion of mobile unit data, we were able to document how the BSPAN program's mobile mammography units influenced spatial access. Although we did not find large contributions to access scores associated with mobile units, we found that mobile unit deployment modified the spatial distribution of access within the program's service area. Future research should identify spatially optimal locations for brick-and-mortar facilities, and determine optimal routing and location schedules for mobile units to create a robustly accessible network of mammography providers for uninsured women in underserved areas.

CRediT authorship contribution statement

Amy E. Hughes:Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization.**Simon C. Lee**:Conceptualization, Methodology, Resources, Data curation, Writing - review & editing, Supervision, Project administration, Funding acquisition.**Jan M. Eberth**:Methodology, Resources, Data curation, Writing - review & editing.**Emily Berry**:Investigation, Resources, Data curation, Writing - review & editing.**Sandi L. Pruitt**:Conceptualization, Methodology, Resources, Writing - review & editing, Supervision.

Declaration of competing interest

The authors claim no conflicts of interest.

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