Published in final edited form as:
Health Place. 2019 March ; 56: 165–173. doi:10.1016/j.healthplace.2019.01.017.

Using spatially adaptive floating catchments to measure the geographic availability of a health care service: Pulmonary rehabilitation in the southeastern United States

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Abstract

A spatially adaptive floating catchment is a circular area that expands outward from a provider location until the estimated demand for services in the nearest population locations exceeds the observed number of health care services performed at the provider location. This new way of creating floating catchments was developed to address the change of spatial support problem (COSP) by upscaling the availability of the service observed at a provider location to the county-level so that its geographic association with utilization could be measured using the same spatial support. Medicare Fee-for-Service claims data were used to identify beneficiaries aged ≥ 65 years who received outpatient pulmonary rehabilitation (PR) in the Southeastern United States in 2014 (n = 8798), the number of PR treatments these beneficiaries received (n = 132,508), and the PR providers they chose (n = 426). The positive correlation between PR availability and utilization was relatively low, but statistically significant (r = 0.619, p < 0.001) indicating that most people use the nearest available PR services, but some travel long distances. SAFCs can be created using data from health care systems that collect claim-level utilization data that identifies the locations of providers chosen by beneficiaries of a specific health care procedure.

1. Introduction

In contemporary spatial accessibility to health care literature, floating catchments are areas surrounding provider locations or population locations. Supply-side floating catchments surround providers and include the population that reside within each catchment (Luo and Wang, 2003; Luo, 2004). Demand-side floating catchments surround population locations and include the providers that practice within each catchment (Luo and Wang, 2003; Luo, 2004). This paper introduces a new way of creating supply-side floating catchments called

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spatially adaptive floating catchments (SAFCs). An SAFC is a circular area that expands outward from a provider location until the estimated demand for services in the nearest population locations exceeds the observed number of health care services performed at the provider location.

Previous methods for creating supply-side floating catchments used thresholds defined by fixed Euclidean distances from provider locations to population locations (Wang et al., 2010; Lian et al., 2012; Lu et al., 2015) or fixed travel times along a road network (Luo and Qi, 2009; McGrail and Humphreys, 2009a). Many studies used a 30- to 60-min drive time as a "reasonable" estimate of the amount of time that people will travel to seek care (Lee, 1991; Luo and Wang, 2003; Bagheri et al., 2005; Wang and Luo, 2005; Dai, 2010; McGrail, 2012; Delamater, 2013). However, people regularly travel longer distances (Chan et al., 2006; Ward et al., 2014; Charlton et al., 2015), travel time varies based on the type of service (Chan et al., 2006), and travel times are dependent on urban-rural status (Alvino et al., 2017). Another way of creating floating catchments is to allow their size to adapt to a population threshold, but this strategy has not been widely adopted. One such study set the size of the floating catchments according to a metropolitan size category (McGrail, 2009). Another created floating catchments by defining a threshold number of people needed to support a health care service. That study used an *a priori* threshold of 1 person to 3500 primary care providers (Luo and Whippo, 2012), but this ratio was specific to primary care (Lee, 1991). Like spatially adaptive filter areas (Talbot et al., 2000; Tiwari and Rushton, 2005; Matthews, 2018), these variably-sized floating catchments were larger in areas with small populations and smaller in areas with large populations.

The variable size of an SAFC for a given provider depends on two threshold parameters. The first parameter is the number of services observed at the provider location (the supply). The second parameter is the expected number of services at the population locations nearest to the provider (the demand). Together, these parameters augment or attenuate the size of each SAFC depending on how much demand in the nearest population locations was potentially satisfied by the observed number of services at each provider location. Health care utilization data provides an empirical basis for estimating both threshold parameters because it contains information about the observed number of patients, the total number of procedures each one received, and the location of their chosen providers. Modeling supply and demand simultaneously is an essential property of any spatial accessibility measure (Joseph and Phillips, 1984; Radke and Mu, 2000; Higgs, 2004; Cho et al., 2014).

Pulmonary rehabilitation (PR) was used to illustrate the method for creating SAFCs. PR is an evidence-based treatment for patients with chronic obstructive pulmonary disease (COPD). More than 15 million Americans report having been diagnosed COPD (Wheaton et al., 2015), which is an irreversible respiratory disease that worsens over time before symptoms are clinically present (Wheaton et al., 2015). After participating in a PR program, patients with COPD have better exercise outcomes, fewer chronic co-morbidities, and a higher quality of life (Ries et al., 2007). However, a typical PR program lasts 8–12 weeks, with 2 or 3 sessions per week (Spruit et al., 2013). Given the length and frequency of this treatment, adhering to a PR regimen maybe difficult if a provider is not locally available. Thus, a second goal of this study was to test whether the spatial accessibility to PR services in an area was associated with the level of PR utilization in that area. The results of the second goal highlight the importance of validating a spatial accessibility measure against health measures expected to be associated with the specific health care procedure, such as rates of utilization or of a health outcome that can mitigated by the procedure. While this study focused on PR, these methods can be replicated using any procedure in a health care utilization database as long as the procedures used by individual patients can be linked to the locations where their health care services were provided.

2. Methods

2.1. Study setting

The study region consists of 964 counties that comprise the Southeastern United States Census Region, which includes Alabama, Kentucky, Mississippi, Tennessee, Delaware, the District of Columbia, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, and West Virginia. The states in this region have the highest COPD prevalence, Medicare hospitalizations for COPD, and COPD-related mortality compared to other areas in the United States (Ford et al., 2013; Croft et al., 2016, 2018).

2.2. Health care utilization data: Medicare claims data

In the United States, the Department of Health and Human Services, Centers for Medicare & Medicaid Services (CMS) administers the public insurance program commonly called Medicare. US citizens aged ≥ 65 years become eligible for benefits on the first day of the month that they turn 65; CMS refers to these patients as beneficiaries. A Medicare claim is generated for any encounter between a Medicare beneficiary and their health care provider that was reimbursed by CMS. Claims can be submitted for outpatient visits, prescriptions, outpatient procedures, inpatient care, and long-term care. A claim has information about the billing service provider, location of service, patient demographics, details of the service performed and the diagnoses for which the service was provided. Beneficiaries can have multiple claims for the same type of procedure as long as they occurred during different encounters.

Administrative data in the 2014 100% Medicare Limited Data Set (LDS) – Outpatient Files[1] contains all Fee-for-Service (FFS) claims submitted by hospital outpatient departments, rural health clinics, and outpatient rehabilitation facilities. This dataset contains a file about each outpatient FFS beneficiary and another file about the claims for each beneficiary filed to Medicare by their service providers. The two files were linked on claim identifier, beneficiary identifier, and date of service. Individual procedures can then be tabulated for either the residential counties of the beneficiaries or the provider locations. This is a reciprocal relationship where the total number of PR treatments delivered to the beneficiaries equals the total number of treatments delivered by the PR providers.

The study population included Medicare beneficiaries aged ≥ 65 years who used PR or who had a COPD diagnosis identified on any Medicare claim in 2014. Healthcare Common

[1]Standard Analytical Files (Medicare Claims), see: https://www.cms.gov/Research-Statistics-Data-and-Systems/Files-for-Order/LimitedDataSets/index.html.

Procedure Coding System (HCPCS) code G0424[2] was used to identify beneficiaries who used pulmonary rehabilitation for COPD. International Classification Diseases, 9th edition Clinical Modification (ICD-9-CM) codes 490–492 or 496 were used to identify beneficiaries with COPD. Providers were any organizational entity that provided PR services to the beneficiaries and billed Medicare for the PR services they provided in 2014 (n = 426). Providers were geocoded to the centroid of the ZIP Code Tabulation Area (ZCTA) of the ZIP Code of their practice location listed in the National Provider Identifier (NPI) database; procedures were attributed to the same ZCTA centroid when multiple providers were located within the same ZCTA.

2.3. Creating spatially adaptive floating catchment areas

In this study, the population locations were the 2010 Census block group centroids in the Southeastern United States (n = 50,097). Creating SAFCs required a PR demand estimate for each of these population locations. To calculate those demand estimates, a single PR utilization rate was calculated for the study region using the number of observed PR treatments among beneficiaries aged ≥ 65 years as the numerator and the total number of people aged ≥ 65 years as the denominator. Eq. (1) shows how the crude PR utilization rate for the entire southeastern United States was calculated.

Equation 1: The pulmonary rehabilitation utilization rate in the Southeastern United States

$$U_r = \frac{o_r}{p_r} \quad (1)$$

r = The study region

U_r = The regional pulmonary rehabilitation utilization rate

O_r = observed number of pulmonary rehabilitation procedures among Medicare beneficiaries aged ≥ 65 years

P_r = population aged ≥ 65 years

COPD is a highly prevalent chronic condition. Since any patient diagnosed with COPD could potentially benefit from PR, some level of PR demand exists wherever there are people at-risk for the disease, even those with no nearby providers. This geographically continuous demand provides a theoretical basis for creating an *estimated demand field* (EDF), which is the geographic distribution of the number of expected procedures provided to patients at each population location. The estimated PR demand was calculated by multiplying the PR utilization rate in the study region (Eq. (1)) by the total number of people aged ≥ 65 years in each Census block group. An important property of the EDF is that the total number of expected PR procedures in all population locations in the study region is

[2]Although PR may be prescribed for pulmonary conditions other than COPD, they are billed under other HCPCS codes. Medicare covers PR only for patients with moderate to severe COPD. Therefore, use of HCPCS code G0424 in this study is assumed to be for COPD.

equal to the observed number of PR procedures performed at all provider locations. Eq. (2) shows how the EDF was calculated. Panel A in Fig. 1 shows a theoretical example for creating the EDF.

Equation 2: The estimated demand for pulmonary rehabilitation; or the expected number of procedures at each population location

$$E_i = U_r * P_i \quad (2)$$

where,

E_i = the expected number of procedures at population location

i = index of population locations

U_r = The regional pulmonary rehabilitation utilization rate (from Eq. (1))

r = The study region

P_i = number of people ≥ 65 years at a population location

Identifying the set of population locations that comprise an SAFC required the creation of a *j*-to-*i* matrix of Euclidean distances from each provider location ($j = 426$) to each population location ($i = 50{,}097$). For a given provider location, the demand for PR estimated at the nearby population locations accumulated as the distances between *j* and *i* increased. The algorithm terminated when the accumulated demand for PR at the population locations nearest to a provider location exceeded the observed number of PR procedures performed at that provider location. Information about all population locations, and whether they were members of the set that defined an SAFC, were stored in a database for later use. To visualize the geographic extent of an SAFC, geographic information system software was used to create a variably-sized buffer around the provider location; the Euclidean distance associated with the provider defined the size of the buffer. The provider-level utilization rate is approximately equal to the regional utilization rate (U_r); it is only approximate because the estimated demand in the population locations that comprise the SAFC will slightly exceed the observed number of procedures at the provider location. Eq. (3) shows how to identify the set of population locations that define a catchment. Panel B in Fig. 1 shows a theoretical example for creating these catchments.

Equation 3: Identification of the set of population locations that define a spatially adaptive 98/floating catchment

$$C_j = \in \left(O_j \geq \sum_i E_i\right) \quad (3)$$

where,

i = index of population locations

j= index of provider locations

C_j =Catchment area

E_i = the expected number of procedures at population location (from Eq. (2))

O_j = observed number of procedures at provider location

The availability at each population location represents how much demand for PR could have been potentially satisfied by the number of PR procedures observed at each provider location. The availability field is comprised of all population locations in the region. Since catchments overlap, the availability field is calculated by multiplying the estimated demand at a population location by the number of times that it is a member of any SAFC. All population locations located within an SAFC have availability values > 0, but the population locations with the highest availability values are within the areas where SAFCs overlap. Eq. (4) shows how the PR availability was calculated for each population location. Panel C in Fig. 1 shows a theoretical example for creating the availability field.

Equation 4: The availability of pulmonary rehabilitation at each Census block group.

$$A_i = E_i * w \quad (4)$$

where,

i = index of population locations

A_i = the availability of pulmonary rehabilitation at each population

location

E_i = the estimated demand for PR at population location (from Eq. (2))

w = weight; the number of times that a population location is a member of any SAFC

2.4. Measuring the geographic association between pulmonary rehabilitation availability and utilization

The second goal of this study was to evaluate whether county-level PR availability was associated with county-level PR utilization. PR utilization rates among PR utilizers were expressed as PR visits per beneficiary, calculated using the total number of PR procedures in each county as the numerator and the number of beneficiaries with COPD that used PR in each county as the denominator. Pearson’s R was used to measure this association. However, service availability was measured at point locations (e.g., the practice locations of the providers) and service utilization was measured within areas (e.g., the residential counties of the PR patients). To test the association, both needed to be measured using a common spatial support. Our approach to addressing this Change of Spatial Support Problem (COSP)

(Gotway and Young, 2007) was to aggregate the PR availability estimated for each population location to the county-level. While aggregating the observed procedures to the counties where providers were located would be a simpler approach, it would produce unrealistic availability measures because providers routinely treat patients who do not reside within the provider county and patients often use providers in counties other than their residential county. Eq. (5) shows how to aggregate the PR availability measured in block groups to the county-level. Panel D in Fig. 1 shows a theoretical example for creating the county-level measure of availability.

Equation 5: The county-level availability of pulmonary rehabilitation

$$A_c = \sum_i (A_{ci}) \quad (5)$$

where,

C = index of county

i = index of population location

A_c = the availability of pulmonary rehabilitation

A_{ci} = the availability of pulmonary rehabilitation in the Census block groups located within county

2.5. Tabulating availability by population group

PR availability was also aggregated by age, sex, race, metropolitan status, and state of residence. The group-specific expected number of procedures were tabulated into one of 120 population subgroups resulting from the combination of five age groups (65–69, 70–74, 75–79, 80–84, and 85 and older), two race groups (non-Hispanic white and African American), 2 sexes, and six metropolitan status groups defined using the 2013 NCHS Urban-Rural Classifications Scheme for Counties (Ingram and Franco, 2013). The NCHS classification scheme assigns all counties in the United States to one of six categories (four metropolitan, one micropolitan, and one non-core). We combined the NCHS urban-rural classes into three categories (large central and fringe metropolitan, medium and small metropolitan, and nonmetropolitan category).

2.6. Materials

The CMS outpatient data was queried using SAS 9.3 (SAS Institute, NC). Census block group-level demographic data was downloaded from the National Historical Geographic Information System database (Manson et al., 2017). ArcGIS 10.5 (ESRI, Redlands, CA) was used to make all maps, to calculate the x, y coordinates of provider locations (ZCTA centroids) and population locations (Census block group centroids), and to create buffers around the provider locations to represent the geographic extent of each SAFC. STATA 14 (StataCorp, College Station, TX) was used to create an origin-destination matrix of Euclidean distances between provider locations (j) and Census block group centroids (i).

2.7. A theoretical example for creating spatially adaptive floating catchments

Fig. 1 presents a theoretical example of the entire method for creating spatially adaptive floating catchments. The theoretical scenario consists of a population of 4000 people uniformly distributed into 400 hypothetical block groups nested within four hypothetical counties; each block group contains 10 people. These hypothetical block groups are displayed as uniform grid cells of equal height and width for illustration, but real Census block groups have irregular shapes and sizes. In this hypothetical population, 60 beneficiaries had 120 treatments at one of three PR providers, but the observed number of PR procedures differed by provider (e.g., 32 for provider 1, 16 for provider 2, and 72 for provider 3). In this scenario, the regional PR utilization rate among all beneficiaries in the four counties was 3.0%. Panel A shows the estimated demand field for each population location, which was calculated by multiplying the population of each block group by the regional PR utilization rate (Eq. (2)). Since each block group had 10 people, the estimated demand for PR services in each block group is 0.3 PR procedures. Panel B shows that the SAFCs for the three providers overlap. Their size is a function of the observed availability at a provider location and the geographic distribution of PR demand on the EDF (Eq. (3)). Panel C shows the availability field, which is estimated demand for PR weighted by the number of times each block group was a member of an aggregating the PR availability at each block group to the county-level SAFC (Eq. (4)). Panel D shows the process used to address the COSP by (Eq. (5)).

3. Results

There were 650,423 unique Medicare beneficiaries with a diagnosis of COPD in 2014 (Table 1). Among this group, 8798 (1.4%) received 132,508 PR treatments during the 2014 calendar year. The PR utilization rate among the beneficiaries aged ≥ 65 years diagnosed with COPD was highest among those aged 75–84 years (1.6%) and lowest among those aged 85 years and older (1.0%); higher among white (1.4%) than African-American beneficiaries (0.8%); higher among men (1.5%) than women (1.3%); and higher in the large metropolitan (1.8%) and medium and small metropolitan counties (1.6%) than in the nonmetropolitan counties (0.7%). The PR utilization rate ranged from 0.8% in Kentucky and West Virginia to 2.0% in Delaware. The number of PR treatments per beneficiary per year in the Southeastern United States was 15.1, which varied little by age and race. There were slight differences for males (15.5) versus females (14.6). Small variations in utilization were observed in large metropolitan (14.7), medium and small metropolitan areas (15.1), and nonmetropolitan areas (16.0). Differences in treatment intensity were highest when stratified by state, which ranged from 13.3 treatments per beneficiary in Kentucky to 16.9 treatments per beneficiary in Alabama.

The practice locations of the PR providers and the observed number of PR treatments in counties where providers were located is shown in Fig. 2A. All PR providers were located only within 24% of the counties in the region (n = 230). The spatially adaptive floating catchment areas for the 426 provider providers in the Southeastern United States are shown in Fig. 2B. SAFCs are generally small in densely populated areas, even for those providers who performed a large number of PR procedures. SAFCs are larger in less densely populated areas, even if they only performed a small number of PR procedures. There is weak positive, but statistically significant correlation between the number of procedures and the size of the catchments (Pearson's R = 0.351, $p < 0.001$). County-level estimates of PR availability are shown in Fig. 2C. The observed number of PR treatments among PR beneficiaries is shown in Fig. 2D. Based on the county-level maps, PR availability (Fig. 2C) and PR utilization rates (Fig. 2D) appear to be highly correlated. Pearson's R correlation coefficients confirm that they are associated (Pearson's R= 0.619, $p < 0.001$). Furthermore, this correlation coefficient is much higher than when the PR availability was measured using only the counties where PR providers were located ($r = 0.256$, $p < 0.001$) as shown in Fig. 1A.

Only 69.6% of the population of adults aged ≥ 65 years in the Southeastern United States resided inside at least one of the 426 PR catchments (Table 2). This value did not vary significantly by age, sex, or race. PR catchments tended to be located in metropolitan counties. Populations residing in nonmetropolitan counties had the lowest proportion of their population residing in a PR catchment (51.8%), but there was little difference between the small and medium metropolitan counties (74.3%), and large metropolitan counties (73.4%). There were no Medicare claims for PR by providers within Washington DC in 2014; Medicare beneficiaries residing in DC used PR providers located in Virginia or Maryland. The result is that DC had relatively low percentage of aged population who resided inside a PR catchment (52.8%) despite being located in a highly urbanized area. For the other states, the proportion of aged adults residing in a PR catchment ranged from 30.5% in Kentucky to 94.5% in Delaware.

4. Discussion

This study illustrates the method for creating spatially adaptive floating catchments. These catchments expand outward from a provider location until the estimated demand for services in the nearest population locations exceeds the observed number of procedures performed at each provider location. While in this study, the measure of spatial accessibility at each population location is a binary value (e.g., inside versus outside), SAFCs highlight areas with no service availability (e.g., outside an SAFC) and areas with excess availability (e.g., areas within SAFC overlap). These supply-side SAFCs can be used as "step one" catchments for the two-step floating catchment area method (Luo and Qi, 2009; McGrail, 2012; Delamater, 2013; Luo and Whippo, 2012; Langford et al., 2016). We found a significantly positive association between the geographic patterns of PR availability and PR utilization (e.g., treatments per PR beneficiary) suggesting that people who used PR were more likely adhere to their PR program in areas where PR services were locally available. This finding would not have been possible without first addressing the Change in Spatial Support Problem.

The results also show that a higher proportion of the nonmetropolitan population reside outside a PR catchment when compared with the metropolitan population. One reason for the observed differences is that less population-dense areas do not have enough people to support delivery of PR services. One strategy to address these rural differences in PR utilization would be to locate new PR facilities in areas that would allow equitable access to care. Another way to minimize these differences would be PR programs deliverable outside a traditional PR facility via telemedicine, video or web-based instruction, or instruction via a smart phone application.

Two features set SAFCs apart from previous floating catchment methods. The size of an SAFC depends on two threshold parameters—supply and demand. The PR demand parameter was estimated at each population location to create the estimated demand field. The PR supply parameter was estimated using the observed number of services at each provider location. The second feature is that health care utilization data was used to create procedure-specific SAFCs. Utilization data provides an empirical basis for estimating the supply and demand threshold parameters, which is an improvement from current approaches based on arbitrarily defined fixed distances and travel times or on *a priori* population threshold definitions. SAFCs can be created for any procedure in a health care utilization database as long as the health care procedures used by individual patients can be linked to the locations of their chosen service providers. For example, the HCPCS for pulmonary rehabilitation is G0424, but SAFCs can potentially be created for any of the 10,155 procedure codes recognized by Medicare.

Contrast our approach to measuring spatial accessibility using the number of procedures observed at a provider location to most spatial accessibility studies, which focus on types of providers or facilities that could potentially provide a service; a recent study demonstrated the importance of using the observed number of procedures rather than the number of providers (Josey et al., 2018). Some examples of a provider-based approach includes measuring spatial accessibility to primary care (Luo and Wang, 2003; Guagliardo, 2004; Crooks and Schuurman, 2012; Lewis and Longley, 2012; McGrail and Humphreys, 2015), pulmonologists (Croft et al., 2016), pediatric hospitals (Guagliardo et al., 2004; Jablonski and Guagliardo, 2005; Mayer, 2008; Garcia et al., 2015), cancer centers (Onega et al., 2008, 2014; Shi et al., 2012), stroke centers (Leira et al., 2012), and emergency services (Pedigo and Odoi, 2010; Busingye et al., 2011). While we argue the importance of measuring spatial accessibility to health care procedures rather than types of providers, the SAFC method can be performed in the provider-based context. Researchers who do not have access to health care utilization data can adopt a less robust method for creating SAFCs as long as they have data about the locations of providers and populations. Their estimated demand fields would be derived by multiplying the provider-to-population ratio of the study region to the number of people residing at each population location. Like the procedure-based SAFCs, the catchments would expand outward from each provider location until the demand for providers in the nearby populations exceeds the number of providers at each provider location. However, the full procedure-based SAFC method provides a mechanism for researchers to focus on measuring spatial accessibility to specific health care procedures rather than to general types of providers.

4.1. Ways to improve spatially adaptive floating catchments in future research

There are several ways that the method for creating SAFCs can improved in future research. First, alternate estimated demand fields (EDF) could be created to represent different demand scenarios. The scenario described in this report used Medicare claims data to estimate the demand in the total population aged ≥ 65 years. However, a more realistic EDF might be based on an estimate of the people most likely to benefit from the procedure, such as beneficiaries diagnosed with COPD. This is would be an improvement because this scenario reported in this study underestimates PR demand since claims data only contains information about patients who used PR rather than the larger set of people who needed PR, but did not obtain it. Future researchers could also use small area estimation procedures (Zhang et al., 2014) to create alternate demand scenarios.

Another way to improve this method would be to calculate travel times along a street network rather than distances in Euclidean space. Euclidean distances were used to reduce the computational burden associated with creating an origin-destination (O/D) matrix consisting of 21.3 million dyads (426 PR provider locations and 50,097 Census block groups). The shape and orientation of network-based SAFCs could be very different from SAFCs calculated from Euclidean distances. Network-based SAFCs would appear spiky indicating that some population locations are further away in Euclidean space but are easier to traverse via a street network. Likewise, the orientation of a network-based SAFC might be elongated when a provider is located near the center of a linear feature. The measure of association between avail-ability and utilization could be very different depending on how much the shape and orientation of Euclidean versus network-based catchments differ.

A third way to improve the SAFC method would be to incorporate a distance decay parameter to reflect that the likelihood of utilization of a service declines as distance from the provider to the population in-creases. This study assumed that a given provider was equally likely to provide services to nearby populations as they were to provide services to more distant populations. Furthermore, the distance decay parameter should be specific to the health care service being studied. For example, the likelihood of utilization would decay rapidly for services that require frequent visits over extended periods (e.g., pulmonary rehabilitation, primary care, dialysis, or some cancer treatments like radiation and chemotherapy) or for conditions that require urgent or emergent care (e.g., labor and delivery, percutaneous coronary intervention, or emergency care). On the other hand, the likelihood of utilization would decay slowly for low frequency procedures such as colonoscopy (a procedure that is performed at long intervals ranging from 1 year to 10 years) or other types of cancer treatment. Procedure-specific distance decay parameters can be estimated based on the distances (or travel times) that patients were observed to have travelled to their chosen providers, or using the number of providers the patient bypassed to arrive at their chosen provider location.

4.2. A strength and some limitations with using Medicare data to measure spatial accessibility

One advantage of using Medicare data to measure spatial accessibility is that a substantial portion of the direct cost of healthcare is paid for by Medicare care, which leaves transportation and other ancillary costs as the primary obstacles to obtaining care. However, there are several limitations associated with using administrative health care claims data for measuring spatial accessibility. First, a wider range of analyses could be conducted with more geographically detailed patient data, but the 100% Outpatient Medicare Limited

Dataset only includes the residential county of the patient. Second, white and African American have the most reliable race data in the Medicare data while beneficiaries of other other race groups were excluded. Third, the observed claims data do not represent the full demand for PR in the region for several reasons. Patients who were prescribed the PR will not be included in the utilization data if they were unable to access PR services. Only 65% of Medicare beneficiaries were enrolled in Fee-for-Service (FFS) plans but claims for those enrolled in Medicare Advantage (MA) plans are not reported to CMS. People who used PR in other settings, such as Veteran Affairs hospitals, were not included in the Medicare claims data. Conversely, the observed utilization data does not represent the full capacity of the given provider. Providers who treat persons aged ≥ 65 years also treat younger patients or perform other health care procedures. Thus, provider capacity is the ability to provide a specific type of service (e.g., pulmonary rehabilitation) to a specific population group (e.g., white or African Americans aged ≥65 years). Despite the incomplete utilization data about providers and populations that were used to create PR SAFCs, we suspect that their sizes would be very similar to SAFCs based on a more complete dataset as long as the cases were missing completely at random. For example, if PR utilization data became available for additional population groups, the two parameters that define the threshold (e.g., the number of observed procedures at each provider location, and the expected number of procedures at each population location) would increase at the same rate. Identifying the circumstances under which a set of SAFCs are spatially invariant may increase their generalizability to the entire population despite the lack of complete data.

5. Conclusion

This paper presents spatially adaptive floating catchments as a new method for creating health service catchments based on observed health care utilization data about patients and their chosen providers. The catchments expand outward from the provider locations until the estimated demand for services in the nearest population locations exceeds the observed number of PR procedures performed at each provider location. This study used health care utilization data to measure spatial accessibility to a specific procedure rather than spatial accessibility to types of providers who could potentially provide the procedure. The positive association noted here, that PR utilization is associated with PR availability, highlights the importance of validating measures of spatial accessibility to any given procedure against other individual- or population-level health measures known to be related to the procedure. Contemporary literature describes two essential properties of any spatial accessibility measure, including the importance of modeling supply and demand simultaneously (Joseph and Phillips, 1984; Radke and Mu, 2000; Cho et al., 2014; Higgs, 2004), and the importance of accounting for distance decay (Luo and Whippo, 2012). We propose an additional consideration. A measure of spatial accessibility to a given healthcare service should be significantly associated with the geographic pattern of its utilization, or to a health outcome measure for which the service was developed to address. Such a test could provide stronger evidence of the importance and validity of measuring spatial accessibility to health care services.

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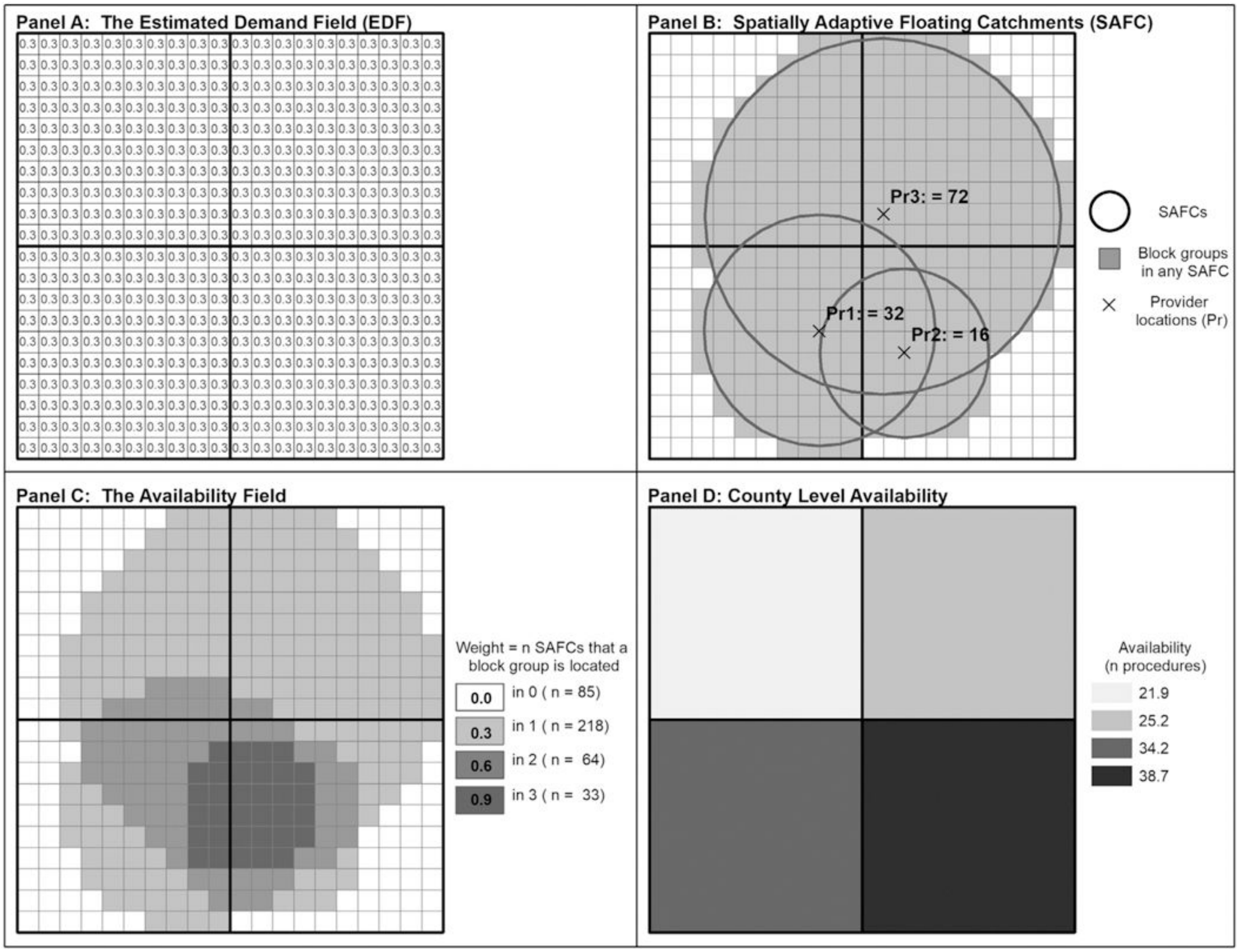

Fig. 1.

An overview of the procedure used to create the estimated demand field (EDF), the spatially adaptive floating catchments (SAFC), the availability field, and then to address the Change of Spatial Support problem by aggregating the block group-level availability to the county-level. Panel A: The EDF is calculated by multiplying the regional utilization rate among Medicare beneficiaries by the population at each block group. Panel B: Spatially adaptive floating catchments expand outward from each provider location until the estimated demand for services exceeds the number of available services at the provider location. Panel C: The availability field is calculated by multiplying the estimated demand in a block group by the number of times that it is a member of an SAFC. Panel D: County-level availability is calculated by aggregating availability measure at each block group to the county-level.

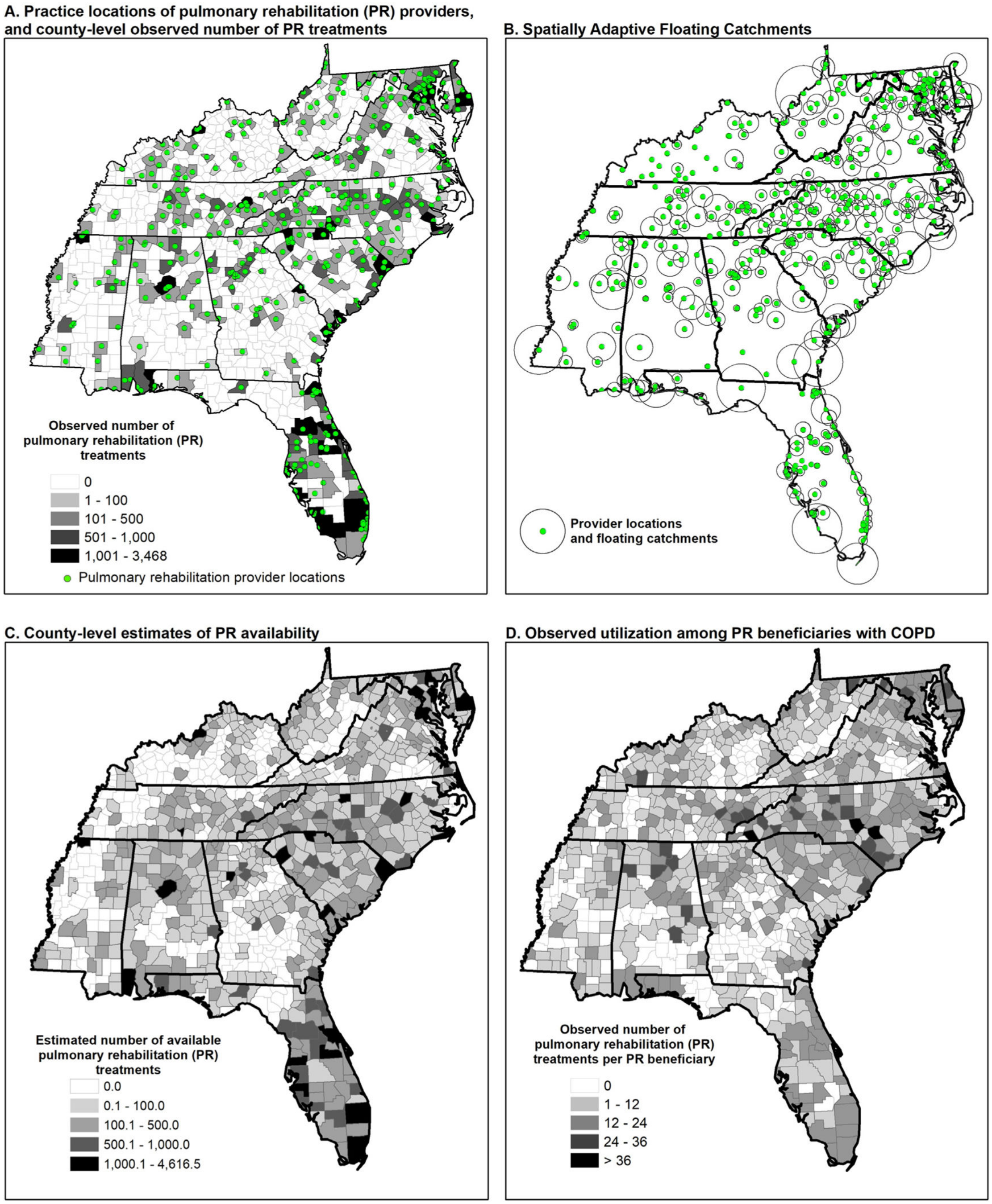

Fig. 2.

A. Practice locations of pulmonary rehabilitation (PR) providers, and county-level observed number of PR treatments; B. PR provider locations and catchments; C. County-level estimates of PR availability; D. Observed utilization among PR beneficiaries with COPD.

Table 1

Utilization of pulmonary rehabilitation (PR) among outpatient Medicare beneficiaries diagnosed with chronic pulmonary obstructive disease (COPD) in the Southeastern United States by selected characteristics, 2014.

Group	Beneficiaries diagnosed with COPD	PR beneficiaries (n)	PR treatments (n)	Procedures per PR beneficiary
Total	650,423	8798	132,508	15.1
Age (years)				
65–74	167,328	2180	32,091	14.7
75–84	292,694	4719	71,786	15.2
85 and Older	190,401	1899	28,631	15.1
Race				
White	579,300	8229	123,935	15.1
African American	71,123	569	8573	15.1
Sex				
Men	293,913	4356	67,564	15.5
Women	356,510	4442	64,944	14.6
Metropolitan Status[a]				
Large Central/Fringe Metropolitan	190,096	3342	49,027	14.7
Medium/Small Metropolitan	248,413	3958	59,569	15.1
Nonmetropolitan	211,914	1498	23,912	16.0
State				
AL	46,241	407	6881	16.9
DC[a]	–	–	–	–
DE	8727	177	2805	15.8
FL	125,552	2475	34,236	13.8
GA	63,458	694	10,089	14.5
KY	63,648	509	6788	13.3
MD	41,176	805	13,224	16.4
MS	34,631	314	4615	14.7
NC	83,639	1346	21,741	16.2
SC	44,466	723	12,052	16.7
TN	52,051	526	7675	14.6
VA	61,232	740	11,240	15.2
WV	31,849	253	3845	15.2

[a]Note: Data for the District of Columbia was suppressed because there were fewer than 10 pulmonary rehabilitation beneficiaries. To prevent recovery of the suppressed values, the suppressed data was combined into the state of Maryland.

Table 2

Percent of total population aged ≥ 65 years in the Southeastern United States who resided inside a pulmonary rehabilitation (PR) catchment, by selected characteristics: 2014.

Group		Residential population inside PR catchment (n)	% population inside a PR catchment
Total		6,987,433	69.6
Age (years)			
65–74		3,367,920	68.4
75–84		2,002,332	69.9
85 and Older		1,617,181	72.0
Race			
White		5,921,615	69.2
African American		1,035,419	70.4
Sex			
Men		1,347,113	69.0
Women		1,729,480	69.6
Metropolitan Status[a]			
Large Central/Fringe Metropolitan		2,919,995	73.4
Medium/Small Metropolitan		2,967,566	74.3
Nonmetropolitan		1,069,473	51.8
Metropolitan Status and Race			
Large Central/Fringe Metropolitan	White	2,388,046	73.6
	African American	531,949	72.7
Medium/Small Metropolitan	White	2,618,815	73.9
	African American	348,751	77.6
Nonmetropolitan	White	914,754	51.6
	African American	154,719	53.4
State			
AL		388,691	60.4
DC[a]		33,780	52.8
DE		116,836	94.5
FL		2,019,775	72.9
GA		613,877	62.3
KY		172,866	30.5
MD		571,095	87.0
MS		199,115	53.3
NC		1,031,602	86.7
SC		495,979	80.4
TN		477,454	57.2
VA		657,637	71.8
WV		178,327	60.9

[a]National Center for Health Statistics (NCHS) Urban-Rural Classification Scheme for Counties, 2013.