Spatial Accessibility of Primary Care in England: A Cross-Sectional Study Using a Floating Catchment Area Method

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Objective. To analyze the general practitioners (GPs) with regard to the degree of urbanization, social deprivation, general health, and disability.

Data Sources. Small area population data and GP practice data in England.

Study Design. We used a floating catchment area method to measure spatial GP accessibility with regard to the degree of urbanization, social deprivation, general health, and disability.

Data Collection. Data were collected from the Office for National Statistics and the general practice census and analyzed using a geographic information system.

Principal Findings. In all, 25.8 percent of the population in England lived in areas with a significant low GP accessibility (mean z -score: -4.2); 27.6 percent lived in areas with a significant high GP accessibility (mean z -score: 7.7); 97.8 percent of high GP accessibility areas represented urban areas, and 31.1 percent of low GP accessibility areas represented rural areas (correlation of accessibility and urbanity: $r = 0.59$; $p < .001$). Furthermore, a minor negative correlation with social deprivation was present ($r = -0.19$; $p < .001$). Results were confirmed by a multivariate analysis.

Conclusion. This study showed substantially differing GP accessibility throughout England. However, socially deprived areas did not have poorer spatial access to GPs.

Key Words. Access, GP, England, GIS, social deprivation

In 2007, former British health secretary Alan Johnson stated, “All patients in this country, no matter where they live or what their background, should enjoy first-class primary care services. I want to see more convenient opening hours and more general practitioners in deprived and less well served areas” (Kmietowicz 2007). Despite efforts being made, the general practitioner (GP) workforce is still regarded as inadequate (Dayan et al. 2014). Hence, a 10-point GP workforce action plan was passed in 2015 issued by the NHS England, the Health Education England, the General Practitioners

Committee, and the Royal College of General Practitioners (Snow-Miller 2015). In short, this plan aimed to recruit, retain, and return the GP workforce within the NHS. If this initiative remains unsuccessful, the growing demand of health care might produce a dramatic mismatch between resources and patient needs estimated at £30 billion a year by 2020/21 (NHS England 2014). However, current health care demand can only be met by a balanced national GP workforce distribution. Therefore, “less well served areas” have to be identified. This can be achieved by the use of robust assessment tools such as the measurement of “spatial accessibility.” This concept describes the potential access to GPs in terms of availability (represented by the number of GPs in a particular area) and accessibility (represented by the distance to GPs) (Guagliardo 2004). Aside from spatial factors, access to GPs is influenced by non-spatial factors such as social barriers (Penchansky and Thomas 1981). Studies have shown that a lower socioeconomic status and the degree of disability are negatively correlated with access to health care (Sharrocks et al. 2014; Knight and Lindfield 2015). Furthermore, a low socioeconomic status is associated with negative health outcomes (Mackenbach et al. 2008; Elgar et al. 2015). Since distinct health inequities were documented between the least and the most deprived areas in England, an existent geographically varying need for health care services must be assumed (Newton et al. 2015).

In 2013, the importance of an adequate access to GPs has been emphasized by the NHS England introducing a 7-day access plan to their services (Iacobucci 2014). Due to changes in practice registration policies in 2015, patients within NHS England are free to consult a practitioner of their choice (Department of Health 2015). To further optimize the local distribution of GPs, future policies and initiatives have to be tailored to local needs and shortcomings. Hence, there is a need for reliable and accurate assessments of the spatial access to GPs across England. Currently, the investigation of spatial accessibility on a national scale is limited to simple measurements such as physician-to-population ratios (PPR) or the number of GPs within a fixed catchment area (Todd et al. 2015). However, PPRs do not account for border crossing, are blind to variabilities within bordered areas, do not incorporate distance, and are fixed to administrative boundaries. Therefore, new

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methodologies using geographic information systems (GIS) have recently arisen (Luo and Qi 2009). Such methodologies include the possibility to estimate demand using a discrete-choice framework for primary care. So far, this has been hindered by the technical inability to perform necessary big data analysis (Dunn and Shapiro 2014).

The objective of this study was to assess GP accessibility in England on a big data scale using a discrete-choice model. The aim of this big data approach was to answer the following questions of high relevance for physicians, patients, and policy makers: (1) To what extent does GP accessibility differ in England? (2) Is GP accessibility correlated with the degree of urbanization, social deprivation, general health, or degree of disability?

METHODS

Setting

The analysis was performed on Lower Layer Super Output Area level (LSOA; $n = 32,844$) as supplied by the Office for National Statistics (ONS). A second analysis was performed using Workplace Zones (WZ; $n = 50,868$). The analysis for LSOAs assumed that the population seeks health care where they live. The analysis for WZ assumed that the population seeks health care where they work (Mitchell 2014). Due to differing geographies, comparison of LSOA and WZ was performed on Middle Layer Super Output Area level (MSAO; $n = 6,791$). The total population size used for analysis was 53,012,456 (LSOA) and 25,087,843 (WZ). For the comparison of work and living locations, the population of LSOAs was reduced to residents in employment. Furthermore, we included 35,597 GPs (full-time equivalents; FTE) working in 7,875 general practices. Finally, 183 cities in England were analyzed (“developed land use areas” of $>10 \text{ km}^2$).

Data Sources

Demographic Data. Population data of LSOAs and WZs were retrieved from the ONS as of 2011 (Office for National Statistics 2016a,b).

Spatial Datasets. Spatial data were retrieved from the open geography portal of the ONS and the Ordnance Survey (Crown Copyright 2016; Office for National Statistics 2016c). In particular, the following datasets were used for analysis:

- LSOA boundaries and population weighted centroids as of 2011.
- WZ boundaries and population weighted centroids as of 2011.
- MSOA boundaries as of 2011.
- Developed land use areas (DLUA) from “Meridian 2” dataset as of 2016.
- NHS Commissioning Regions (CR) as of 2015.
- NHS Area Teams (AT) as of 2013.
- NHS Clinical Commissioning Groups (CCG) as of 2015.

Road Network Data. Road network data of England were derived from TomTom MultiNet data (TomTom N.V., Amsterdam, the Netherlands) as of 2016.

Data of GPs in England. Data of GPs (FTE) were retrieved from the general practice census as of 2014 (Health & Social Care Information Centre 2015a). Postal addresses were obtained by the “EPRACCUR” file from the Health and Social Care Information Centre (Health and Social Care Information Centre 2015b). We generated geographic coordinates with a geocoding process using the Google Maps API (Google Inc., Mountain View, CA, USA).

Spatial GP Accessibility

We are trying to measure accessibility of GP practices in various geographic locations x in England. Generally speaking, our measure of accessibility is the ratio: Summed capacity of GP practices within a pre-specified distance of location x divided by the summed demand for services from those practices across all locations. GP accessibility was measured with the integrated Floating Catchment Area (iFCA) method (Bauer and Groneberg 2016). This method is based on the Two Step Floating Catchment Area (2SFCA) method and its improvements, for example, the enhanced (E)2SFCA method and the modified (M)2SFCA method (Luo and Wang 2003; Luo and Qi 2009; Delamater 2013). The iFCA addresses limitations of earlier accessibility measurements using variable catchment sizes (i.e., the maximum distance that patients are willing to drive varies between areas), distance decay (i.e., the probability to visit a GP decreases with increasing distance), and competition parameters (i.e., the allocation of demand among all available GPs). The iFCA method can be displayed using the following formula:

$$AI_x = \sum_{y \in (d_{xy} \leq C_x)} \frac{S_y \cdot f_{adj}(d_{xy}) \cdot f_{con}(d_{xy})}{\sum_{x \in (d_{xy} \leq C_x)} P_x \cdot f_{adj}(d_{xy}) \cdot Huff_x} \quad (1)$$

AI_x is the accessibility index at population location x . S_y is the capacity of a GP practice (FTE) at location y (i.e., the GP practice characterized by its location). P_x is the population size at population location x (i.e., the population weighted centroids of LSOA and WZ). All distances (in minutes) between x and y (d_{xy}) were calculated that were within a predefined maximum catchment size dependent on the travel mode: 60 minutes for automobile (CAR), 60 minutes for public transport (BUS), and 30 minutes for walking (WALK). All distances were computed as the travel time on public roads from location x to location y . We used several restrictions on the road network (such as “avoid private roads”) for CAR and BUS in combination with mode-specific traffic behaviors provided by TomTom MultiNet data (TomTom N.V.). Furthermore, we used a 25 percent slower travel speed for BUS compared to CAR. The default travel speed for WALK was set to 4 km/hour.

$f_{adj}(d_{xy})$ is the adjusted and $f_{con}(d_{xy})$ the constant distance decay function. Both functions are based on the cumulative distribution function of the logistic function (downward sigmoid function). $f_{adj}(d_{xy})$ is adjusted to the distance distribution (median and standard deviation; SD) of the nearest 100 practices (WALK: first five practices) for each population location x .

$$f_{adj}(d_{xy}) = \frac{1 + e^{\frac{(\text{Median}) \cdot \pi}{\text{SD} \cdot \sqrt{3}}}}{1 + e^{\frac{(d_{xy} - \text{Median}) \cdot \pi}{\text{SD} \cdot \sqrt{3}}}}} \quad (2)$$

Both decay functions return weight values between 0 and 1. The adjusted function reflects the differing travel behavior of patients depending on the availability of GPs: In rural areas with less GP availability, patients are more likely to travel longer distances compared to an urban area where there is no need to travel long distances. The constant function smoothly fits all adjusted functions within the predefined maximum catchment size and guarantees its adherence. We used the nearest 100 practices for the adjustment according to McGrail et al., who also used 100 practices as the cutoff to successfully model rural–urban catchment distinctions (McGrail 2012). C_x is the effective catchment size and is defined as the distance d for which $f_{adj}(d) \cdot f_{con}(d) = 0.01$. This cutoff was reported as a critical value within sigmoid functions approaching zero allowing to neglect values beyond this point

(Kwan 1998; Wang 2007). To preserve a minimum catchment of 15 minutes for CAR and BUS (5 minutes for WALK), the minimum median distance to the nearest 100 practices was set to 7.5 minutes (2.5 for WALK) and the minimum SD was set to 3 minutes (1 minute for WALK). $Huff_x$ represents the probability of demand according to the Huff Model, which accounts for competition (Huff 1964). Therefore, the probability of demand from population location x is adjusted to alternative competing GPs across all other locations z , as long as those are within the effective catchment size C_x of population location x .

$$Huff_x = \frac{S_y \cdot f_{adj}(d_{xy})}{\sum_{Z \in (d_{xz} \leq C_x)} S_z \cdot f_{adj}(d_{xz})} \quad (3)$$

Confounders

Area Measure of Deprivation. Deprivation was measured by the Index of Multiple Deprivation 2015 (IMD) from the Department for Communities and Local Government in England (Department for Communities and Local Government 2016).

Degree of Urbanization. We used the Rural–Urban Classification (RUC 2011) for small area geographies in its updated form (Bibby and Brindley 2013).

General Health and Disability. Data from the ONS were used to determine disabilities and the general health of the English population (Office for National Statistics 2016a). We used the proportion of people to the total population on LSOA level, who rated their disabilities as “day-to-day activities limited a lot” and their general health as “bad or very bad.”

Geospatial and Statistical Analysis

For the statistical analysis, *SPSS 23* (IBM, Armonk, NY, USA) has been used. We tested for significant differences with the Kruskal–Wallis test. A correlation analysis was performed with the non-parametric Spearman’s Rho (r) test with a two-tailed test for significance. We further performed a multivariate regression analysis on CCG level.

Mathematical computations were done with *RStudio* (R Core Team, Vienna, Austria) using the packages “rootSolve” and “plyr.” For all geospatial analyses and data preparations, *ArcMap 10.4* and *ArcGIS Pro 1.3* (ESRI Inc.,

Redlands, USA) were used. Furthermore, based on the Getis-Ord G_i^* statistic, a hot spot analysis with false discovery rate correction was performed. The Getis-Ord G_i^* statistic was used to identify significant clusters of high and low accessibility indices. For the computation, we generated a spatial weight matrix that related each population location to its nearest 10 neighboring population locations and/or all population locations within a 2 km radius.

RESULTS

In all, 130 million distances between population locations and GP practices were calculated and analyzed. Based on these data, GP accessibility in England was mapped (Figure 1).

The GP accessibility distribution pattern showed a clear tendency of higher GP accessibility in or around major cities such as London, Manchester, or Liverpool. Especially in London, GP accessibility was high (highest AI-score for CAR in LSOA "Westminster 018A" with $AI = 0.318$). In comparison, rural areas in the Mideast, Southwest, and Northwest of England had lower GP accessibility. This accessibility pattern was similar for patients traveling by car and by bus. For walking patients, this pattern was more dispersed; however, the tendency toward major cities remained. The visual findings were statistically supported in the hot spot analysis, which revealed hot spots (high GP accessibility) in or around major cities and cold spots (low GP accessibility) in the Mideast, Southwest, and Northwest of England. In terms of population numbers, 13,661,907 people in England (25.8 percent of the total population) lived in a significant cold spot (mean z -score: -4.2 ; $p < .001$), whereas 14,610,125 people (27.6 percent of the total population) lived in a significant hot spot (mean z -score: 7.7 ; $p < .001$). In other words, half of the population in England lived in mismatched areas. In terms of area, 69,458 km^2 of England (52.2 percent) represented cold spots and 6,272 km^2 (4.7 percent) hot spots. In terms of urbanity, 97.8 percent of areas (LSOA level) representing hot spots (total of 8,830) were urban areas, whereas 31.1 percent of LSOAs representing cold spots (total of 8,469) were rural areas. Regarding health geography in England, significant differences were present for the combined car, bus, and walking GP accessibility (CUMULATIVE) on all three levels ($p < .001$): On the NHS Commissioning Region level ($n = 4$), London had the highest GP accessibility (13.3) and South of England the lowest (7.2). On the NHS Area Team level ($n = 25$), the lowest GP accessibility was present in East Anglia (4.7) and the highest in London (13.3). On the NHS Clinical

Figure 1: Distribution of Accessibility Indices (AI) in England. CI: Confidence Interval, Calculated with the Getis-Ord Gi* Statistic

Note. CAR, BUS, and WALK Represent the Travel Modes (see text). CCG: NHS Clinical Commissioning Group. AT: NHS Area Team. CR: NHS Commissioning Region. Contains National Statistics Data © Crown Copyright and Database Right [2011–2015].

Commissioning Group level ($n = 209$), NHS North Norfolk had the lowest (4.0) and NHS Central London (Westminster) the highest (14.9). Detailed results for every LSOA are provided within Appendix SA2, and results for the NHS Clinical Commissioning Groups (CCG) are provided within Appendix SA3.

As further revealed in our analysis, the entire English population (except for the Isle of Scilly) had access to at least 12 GP practices by CAR within a catchment area of 60 minutes. There were 11 population locations with no access to a GP practice by BUS and 6,482 (19.7 percent) by WALK. Focusing on the populations' work locations, a similar distribution pattern of GP accessibility was present compared to living locations. This finding corresponded with a correlation of $r = 0.93$ ($p < .001$) for both work and living locations. The effective catchment area, which was used to calculate GP accessibility in England, varied geographically depending on the travel mode (Table 1). It was negatively correlated with the degree of urbanization (CAR and BUS: $r = -0.79$; $p < .001$ and WALK: $r = -0.55$; $p < .001$): the more urban the area, the smaller the respective catchment area.

Also, the demand for GP practices was estimated. Assuming patients will only use their car as means of transportation, an average of 4,406 patients per practice were calculated. This estimated demand was strongly positively

Table 1: Descriptive Results for Lower Layer Super Output Areas (LSOAs)

	CAR	BUS	WALK
OD pairs (n)	39,556,793	27,801,000	125,826
Average distance to closest GP (minutes)	2.2	2.7	13.1
Effective catchment area (minutes)			
Mean (SD)	27.6 (10.9)	31.6 (12.1)	26.2 (4.2)
Range	15.0–60.0	15.0–60.0	7.5–30.0
Number of GP practices within effective catchment area (n)			
Mean (SD)	215 (126)	173 (87)	2 (2)
Range	1–792	0–612	0–17
Accessibility Index			
Overall mean (SD)	0.063 (0.039)	0.051 (0.025)	0.001 (0.001)
Range	0.003–0.318	0.000–0.249	0.000–0.073
1st quintile mean (SD)	0.034 (0.005)	0.027 (0.007)	0 (0)
2nd quintile mean (SD)	0.044 (0.003)	0.038 (0.002)	0.9E^{-4} (0.7E^{-4})
3rd quintile mean (SD)	0.053 (0.003)	0.046 (0.002)	4.6E^{-4} (1.4E^{-4})
4th quintile mean (SD)	0.064 (0.004)	0.056 (0.003)	10.7E^{-4} (2.3E^{-4})
5th quintile mean (SD)	0.120 (0.056)	0.086 (0.031)	28.1E^{-4} (21.6E^{-4})

OD, origin destination; SD, standard deviation.

correlated with the actual number of registered patients in each practice ($r = 0.80$; $p < .001$).

For quality assurance purposes, we provide benchmark data of the iFCA method with earlier methods of GP accessibility assessments by car: There was a positive correlation of $r = 0.13$ ($p < .001$) with the 2SFCA method, $r = 0.21$ ($p < .001$) with the E2SFCA method, and $r = 0.49$ ($p < .001$) with the M2SFCA method.

GP Accessibility and Urbanity

In contrast to the general trend of a positive correlation between urban areas and GP accessibility ($r = 0.59$, $p < .001$), large differences were revealed focusing on large cities such as Leeds, Liverpool, Manchester, and London (Figure 2).

Figure 2: GP Accessibility (CUMULATIVE) in Major Cities. Major Cities Were Defined According to the Urban–Rural Classification (RUC 2011: A1)

Note. Within the Boundaries of the Displayed Major Cities, 31 out of 10,817 LSOAs Were Classified Otherwise (e.g., “Urban City and Town”). Contains National Statistics Data © Crown Copyright and Database Right [2011].

In London, Liverpool, and Manchester, high GP accessibility was present (London: 12.9; Liverpool: 12.2; and Manchester: 10.6; for CUMULATIVE). However, in Leeds, GP accessibility was significantly lower (8.4; $p < .001$). These results were further supported by the hot spot analysis (Figure 2). The differences were due to a mismatched demand and supply of the GP workforce in Leeds: The mean distance to the nearest 100 GP practices by car was longer in Leeds (14.7 minutes) compared to Manchester (11.8 minutes), Liverpool (11.8 minutes), or London (9.8 minutes). Furthermore, our analysis showed that the higher the distance-based probability of patients was to visit a GP practice by car, the higher and therefore unbalanced was the patient-to-GP ratio (Figure 3).

This trend, however, was not present in London, Liverpool, and only to a minor extent in Manchester. This translated into accessibility indices (CAR) of 0.048 in Leeds, 0.063 in Manchester, 0.074 in Liverpool, and 0.118 in London. Therefore, a mismatch of demand and supply in easy to reach GP practices led to a lower GP accessibility in Leeds.

Furthermore, 179 cities were analyzed in addition to the above-mentioned major cities. GP accessibility was higher in these urban areas compared to the remaining more rural parts of England (CUMULATIVE: 10.0 vs. 7.3;

Figure 3: Relationship of the Distance-Based Probability of Patients to Visit a GP Practice and the Patient-to-FTE Ratio

Note. FTE: GP Full-Time Equivalents. The Distance-Based Probability Was Measured by Car.

Table 2: Ranking Out of $n = 183$ English Cities Regarding GP Accessibility (CUMULATIVE)

<i>Rank</i>	<i>Lowest GP Accessibility</i>		<i>Highest GP Accessibility</i>	
1	Carlisle	4.0	Southport	13.5
2	Whitehaven	4.0	Kirkby (Meyerside)	13.1
3	King's Lynn	4.1	London	13.1
4	Spalding	4.3	Liverpool	13.0
5	Wellingborough	4.4	Barnsley (Yorkshire)	12.9
6	Boston	4.5	Lichfield	12.8
7	Peterborough	4.6	Tamworth	12.6
8	Huntingdon	4.7	Stafford	12.5
9	Lowestoft	4.7	Redditch	12.5
10	Ipswich	4.8	Reigate	12.4

$p < .001$). Still, significant differences also remained among cities (see Table 2 for a ranking of cities with the lowest and highest GP accessibility).

There were even cities in England where GP accessibility was as low as in some rural areas. In Appendix SA4, detailed results are presented for all 183 cities.

GP Accessibility, Social Deprivation, and General Health on LSAO Level

GP Accessibility and Social Deprivation. The analysis showed a correlation of GP accessibility with the overall Index of Multiple Deprivation (IMD) of $r = -0.19$ ($p < .001$). This result indicates that a higher GP accessibility was related to more deprived areas. Further analyses of IMD domains and subdomains showed a positive correlation with the subdomain “Geographic Barriers” ($r = 0.46$; $p < .001$), which relates to the physical proximity of local services including GP practices.

GP Accessibility and Health. The analysis revealed no relevant correlation with the proportion of people who rated their health as “bad or very bad” ($r = 0.08$) and those who rated their degree of disability as “day-to-day activities limited a lot” ($r = 0.02$).

GP Accessibility on CCG Level

We estimated a multivariate model allowing for multi-membership regarding the following variables aggregated on CCG level:

- Social deprivation (overall IMD score)
- Geographic barriers (IMD subdomain score)
- Urbanization (RUC 2011)
- General health (ONS data)
- CCG size (population size)

The multivariate model was significant (F -test: $p < .001$), showed no multicollinearity (Durbin–Watson test: 1.704), and explained more than half of accessibility variability on CCG level ($R^2 = 0.532$). The analysis revealed that, similar to the analysis on LSOA level, social deprivation had a significant minor effect on GP accessibility on CCG level (beta: -0.221 ; $p < .01$), which means the higher the GP accessibility the more deprived was the area. Furthermore, the CCG size had no effect on GP accessibility, which means there were no economies of scale present. The degree of urbanization had the highest impact on GP accessibility on CCG level (beta: 0.533 ; $p < .001$). Furthermore, geographic barriers measured by the IMD subdomain also showed a significant effect (beta: -0.336 ; $p < .001$). However, geographic barriers leading to lower GP accessibility had to be expected. Lastly, general health did not have a significant effect on GP accessibility. In sum, the multivariate analysis on CCG level confirmed the results reported on LSOA level.

DISCUSSION

This study showed substantially differing GP accessibility throughout England. We identified differences in GP accessibility among major cities such as London, Liverpool, or Leeds. Furthermore, spatial GP accessibility was significantly lower in rural areas than in urban areas. Regarding work locations, no significant difference was found for GP accessibility compared to living locations. Interestingly, the confounder analysis revealed a minor negative correlation with social deprivation, which means the higher the GP accessibility for patients the more deprived the area. Finally, no relevant correlation with general health and the degree of disability was present.

In 2015, the Kings Fund, an influential think tank dedicated to improve the state of health care in England, postulated four necessary management changes within the health care workforce on national level (Addicott et al. 2015). In this respect, they strongly suggested a more robust assessment of the GP workforce regarding supply and demand. Therefore, the present study used a recently improved method, which is generally accepted to offer a

realistic approach for the analysis of supply and demand within the GP workforce (Luo and Qi 2009; McGrail and Humphreys 2014; Bauer and Groneberg 2016). In the past, efforts have already been expended to improve patients' access to their GPs (e.g., by implementing a 7-day GP access scheme). But results are unsatisfying thus far (Iacobucci 2015). In this context, our findings can be used for the identification of GP accessibility variations throughout England and hereby possibly improving the delivery of care. Specifically, the present analysis demonstrated a more than three times higher GP accessibility in cities such as Southport, Kirkby or London and Liverpool compared to Carlisle, Whitehaven, King' Lynn, or Spalding. Also, larger cities such as Leeds exhibited a relatively low degree of GP accessibility. The NHS may use these data for practical planning and allocation purposes.

This study represents a highly sophisticated analysis of GP accessibility in England using large datasets to map GP accessibility in great detail revealing opportunities to rebalance supply and demand of GPs in England. Furthermore, this discrete-choice model enables health care planners to predict demand on GP practices by only requiring data of (1) geocoded population sizes and (2) GP practice locations. This can be helpful to predict market shares of GPs and to avoid spatial GP concentration as demonstrated in our analysis (e.g., in urban areas). Such concentrations have been reported to lead to higher service prices (up to 30 percent) charged by physicians in the US health care system (Dunn and Shapiro 2014). Although this issue is irrelevant within the English taxation funded health care system, the applicability of the methodology within other health care systems could be helpful to predict market shares in those settings. This could be even more important since predicted market shares, rather than actual shares, have been reported to remove endogeneity attributable to higher quality physicians attracting more patients (Kessler and McClellan 2000). Therefore, predicted market shares are necessary when studying the monetary effect of market concentration and, in part, to correct for the endogeneity of clinic choice in subsequent equations of interest.

It has to be noted that two arbitrary parameters within the iFCA method remain a limitation: distance decay and catchment sizes. We used the cumulative distribution function of the logistic function. However, other functions, such as the Gaussian function, have also been used (Wang 2012). So far, there is no clear evidence to support one function over the other. In our study, we demonstrated varying effective catchment sizes with larger catchment sizes in less urban areas ($r = -0.76$; $p < .001$). However, defining catchment sizes depends on a variety of factors, including international

differences as well as differences due to health care systems (Allan 2014). Regarding market sizes as reported above, Dunn et al. used catchment sizes to physician services as small as a 20-minute driving-time radius, although they defined market sizes “as the 80-minute driving-time boundary surrounding the census-tract centroid” (Dunn and Shapiro 2014). Therefore, their definition of market sizes is conceptually similar to the catchment sizes used in our study. Todd et al. operationalized access by living within a 1.6 km straight line distance to a GP practice. However, such simplifications of catchment areas have strong limitations compared to the present approach, especially because they are insensitive for congestive areas with more than one GP available (Guagliardo 2004). Still, the general necessity of both (distance decay and variable catchment sizes) is well described in the literature along with a general lack of valid empirical data to support the appropriate choice (Luo and Qi 2009; Wang 2012; Allan 2014). Furthermore, public transport as modeled within our study (BUS) has limitations, since public transport includes a walking part (from and to bus stops) and official time schedules. In our analysis, we did not account for time schedules and walking time from and to bus stops. Furthermore, this study only provides data of potential GP accessibility, which is different from patients actually visiting a GP (Guagliardo 2004). Also, mainly relative data are reported: Belonging to the lower quantiles of GP accessibility is not necessarily tantamount to a low absolute GP accessibility. However, benchmark data regarding absolute GP accessibility threshold scores are lacking. Lastly, the non-physician workforce has been neglected in this study, although they play an important role in the delivery of primary care and have been proposed as a possible solution to the shortage of GPs (Auerbach et al. 2013). Advanced practice nurses or nurse practitioners, for example, can provide health care for patients with chronic conditions and for monitoring purposes. Furthermore, the geographic variation of the non-physician workforce may have a compensating effect in areas with a fewer GP workforce. However, the extent of the provided independent health care by non-physicians is not known. Therefore, the non-physician workforce was excluded to specifically address the issue of accessing GPs. It has to be noted that the English Department of Transport regularly issues the “Journey Time Statistics,” which includes GP accessibility data (English Department of Transport 2015). For 2014, the Department of Transport reported an average minimum travel time to reach the nearest GP by car of 7.9 minutes, including 5 minutes parking time. Accounting for parking time, our results showed high congruencies with these data (7.9 vs. 7.2 minutes), indicating its high reliability.

In our conceptualization of access, we explicitly excluded non-spatial factors of access as described above. Still, since there are distinct health inequities shown between the least and the most socially deprived areas in England, the non-spatial factors of access to GPs should be regularly re-evaluated to achieve and sustain universal access (Newton et al. 2015; Asaria et al. 2016). Focusing on the populations health status, a link between disability and accessibility was recently shown in a study where adults with physical disabilities were more likely to have an unmet need to see a doctor due to difficulties getting to the practice and entering the building (Popplewell, Rechel, and Abel 2014). Furthermore, less mobile patients were reported to be less likely interested to choose a practice outside their neighborhood (Lagarde, Erens, and Mays 2015). In this regard, our study did not support a positive correlation of disability and accessibility. However, a positive correlation of disability translating into demand of care and GP accessibility (supply of care) would be preferable, since long-term illness (as an indicator of disability) represents a strong predictor of higher use of health services (Horner-Johnson et al. 2014). To improve GP accessibility for patients with disabilities, workforce planner should therefore consider the geographic variation of disability prevalence.

In our study, spatial GP accessibility was significantly lower in rural areas than in urban areas. Such a global gradient of the GP workforce between rural and urban administrative areas is supported by the literature (Kringos et al. 2015). For England, Todd et al. reported substantial geographic differences with a higher GP accessibility in urban areas: 94.2 percent of urban households versus 19.4 percent of rural households with access (Todd et al. 2015). Although we also found large differences between urban and rural areas, we did not document such striking differences in GP access since we used a continuous accessibility measurement rather than a dichotomous measurement. Furthermore, as previously described, a low socioeconomic status is known to be associated with negative health outcomes (Mackenbach et al. 2008; Elgar et al. 2015). Focusing on the relationship of GP accessibility and social deprivation, our results did not support the hypothesis that social deprivation is related to a lower GP accessibility. Instead, slightly higher GP accessibilities were revealed in socially deprived areas. Therefore, non-spatial factors are more likely to contribute to health inequities compared to spatial factors described in our study. Hence, Marshall et al. reported that increased levels of conventional risk factors among the socially deprived population accounted for half of the health inequities regarding strokes (Marshall et al. 2015).

Besides the socioeconomic status, the insurance status has substantial effects on GP accessibility. For the United States, accessibility in terms of

appointment availability varied significantly between privately insured and publicly insured patients with higher appointment rates for privately insured patients (84.7 percent vs. 57.9 percent) (Rhodes et al. 2014). This relationship has been further demonstrated for different health care systems and specialties (Olah, Gaisano, and Hwang 2013; Kim et al. 2015). For England, these aspects of access to GPs are regularly evaluated within the GP Patient Survey on behalf of the NHS England (Ipsos MORI 2016). In the January 2016 publication, 74.7 percent of patients in England were able to make an appointment with a GP last time they tried. Using data of the GP Patient Survey for measuring GP access, Cowling et al. (2013) demonstrated that timely access to GPs not only improved patient satisfaction, but also reduced emergency department utilization.

Varying GP accessibility could also be due to a differing quality of health care services with the implication being higher quality of care is associated with lower accessibility. However, defining health care quality using objective parameters is difficult. There has been a lot of effort put into quality measurements in the hospital sector in Germany. Starting from mid-2016 every hospital has to report 351 quality indicators to measure quality. In England, the NHS Quality and Outcomes Framework represents an annual reward and incentive program for GP practices. Within this framework, the level of achievement of each GP practice is measured by 77 indicators. However, so far the participation is voluntary. Both examples underline the difficulty of any quality measurement: Due to its multidimensional structure, defining thresholds of high and low quality of care remains difficult. In this context, it has to be noted that the overall performance of primary care in the United Kingdom was deemed favorable by the WHO compared to other European countries (Kringos et al. 2015). Still, the efforts being made regarding quality measurement represent an important step toward a more efficient and higher quality of care.

UNANSWERED QUESTIONS AND FUTURE RESEARCH

Commuting is a major issue for all parts of England. Although this study did not support a high impact of commuting on GP accessibility in the NHS, considering commuting behavior to quantify spatial GP accessibility is theoretically sound (Fransen et al. 2015). Therefore, further research should focus on commuting effects (such as location or travel mode) on GP accessibility. The presented discrete-choice framework would benefit from the incorporation of

patient contact frequencies. Such data have already been included in a demand forecast summary tool developed by NHS Monitor (Monitor 2015). However, this specific tool was designed to forecast demand for NHS foundation trusts and is not applicable for GP practices in particular. Finally, certain parameters used in the iFCA method (namely distance decay and catchment area) need further empirical validation. Therefore, travel behavior of patients within health care systems (means of transportation, willingness to travel) should be specifically addressed in future research.

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CONTRIBUTORSHIP STATEMENT

JB designed the study, monitored data collection, cleaned and analyzed the data, and drafted and revised the paper. RM, DB, and DAG analyzed the data, and drafted and revised the paper.

ETHICS APPROVAL OF RESEARCH

Ethics approval was not required.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the supporting information tab for this article:

Appendix SA1: Author Matrix.

Appendix SA2: Detailed Result (Accessibility) on Lower Layer Super Output Area (LSOA) Level.

Appendix SA3: Detailed Result (Accessibility) on NHS Clinical Commissioning Group (CCG) Level.

Appendix SA4: Detailed Result (Accessibility) for Developed Land Use Areas in England.