4 A method to estimate health care services access and costs

This chapter estimates health service location demand and costs using a method based on data for England. After reviewing the determinants of health care demand, it describes the method to estimate health services potential demand and access. The chapter then highlights the difficulties of predicting health care costs and examines preliminary evidence on health care costs for England. Finally, the chapter presents the method estimating differences in cardiology and maternity and obstetrics (M&O) services costs and access across geographical areas.

Main takeaways

- Due to data limitations, the analysis distinguishes between locations offering a given service but not among different facilities offering a service in the same location, or facilities offering multiple services, and focuses on cardiology and maternity and obstetrics (M&O) services.
- Evidence on "compression of morbidity" shows that individuals increasingly compress ill-health into the final years of life and that chronic diseases begin to present later in life at a rate faster than increases in life expectancy. Consequently, measures of expected future morbidity or time-to-death are of more use than age in predicting present and future health demand and costs.
- The simulation of health service location uses expected local deaths to approximate demand for cardiology and local birth rates to approximate demand for obstetrics and gynaecology services. It estimates demand at each location, the origin and destination of health service trips and the distances that users travel to reach a location.
- Data for England shows that users in sparse rural areas travel on average 10 km more than users in cities to access cardiology services and about 14 km more to M&O services.
- As most health service locations serve a largely diverse population in terms of geographical origin, comparing geographical cost differences should be based on the place of residency of users instead of the precise location of service location.
- Although there are many factors that can involve the costs of providing health services, this chapter considers only cost differences due to varying scales of operation of health service locations.
- The estimations show a negative and significant coefficient of population in catchment areas for both services and indicate reduced costs with increasing demand: for cardiology, a 1% increase in population in the catchment area of the average service location is associated with reducing costs per head in that service location by 0.57%.

Introduction

This chapter presents a method to estimate a selected number of health service costs from underlying catchment area population characteristics. Due to data limitations, the analysis focuses on health service locations in England, using estimates of individual service cost and location. The benchmark predicts costs of specific health services that are then aggregated at different geographical levels. This allows estimating present and future population values. Chapter 5 further examines the results of these estimates.

This chapter focuses on two specific services: cardiology and maternity and obstetrics (M&O). The proposed method allocates service locations based on local demand, approximated local death rates for the case of cardiology and birth rates for the case of M&O services. From local demand, the method estimates users in each location catchment area. Finally, the cost estimation aims to capture differences in costs per user purely driven by the size and composition of the service location catchment areas. This means that the costs estimated in this chapter do not aim to capture cost efficiencies arising from either economies of scale in facilities or scope across proximate facilities (Lorenzoni and Marino, 2017[1]).

The chapter first sets the scene in terms of the constraints within which the proposed method has been developed. It then presents a literature review on the determinants of health care demand and the chosen method of measuring demand. Subsequently, a literature review describes the measurement of accessibility and utilisation of health services that support the method choices used to predict health care supply and accessibility. A method to estimate variation in health care costs due to differences in numbers of users is presented together with a reflection on the limitations of the method. Finally, the last section concludes and the annexes provide additional technical details.

Estimating health services demand and access

Where are health services offered and how many people use them? This section tackles this question from an empirical point of view using actual health care data for England (see Annex 4.A for details on the data). The question of supply and demand of services can be seen from two different perspectives. The first is the perspective of health facilities that can vary in size and level of complexity in the services they offer. The offering of, for instance, cardiology services, can happen in both large hospitals or primary care facilities depending on patient needs and the organisation of the health care system.

A proper estimation of supply and demand in such a setting would require the availability of the volume of services offered in each facility linked to the usage of the service (e.g. as measured by admissions or visits). The next question on estimating demand would be what the relationship between facility choice and user characteristics is– in particular, how much distance determines the choice for a facility from the point of view of users.

Unfortunately, such level of detail is not available in the observed data, so the analysis in this chapter has to make a number of simplifications that limit the scope of the estimations. The first simplification is that the analysis distinguishes between locations offering a given service, but not among different facilities offering a service in the same location, or facilities offering multiple services. In this sense, the approach proposed here does not aim to capture the role of facility-specific determinants of supply and efficiency of service provision (Lorenzoni and Marino, 2017[1]) or the role of competition or complementarity between proximate locations in the offering of a service.

The second simplification is that the analysis focuses only on cardiology and maternity and obstetrics (M&O) services because these services have available data for relatively many locations, giving enough geographical variation for the analysis. Specifically, the analysis considers data for England for cardiology services in 188 facilities offering Cardiac Surgery Service (NHS specialty code 172), Paediatric Cardiac Surgery Service (code 221), Cardiology Service (code 320), Paediatric Cardiology Service (code 321), and

Congenital Heart Disease Service (code 331); and maternity and obstetrics (M&O) services in 219 facilities offering Obstetrics and Gynaecology (code 500), Obstetrics (code 501) and Midwifery Service (560).

This section starts with a review of the literature on measuring health services demand, access and costs. It then outlines an approach to estimate potential demand at every service location.

What determines health care demand?

A substantial body of literature has been dedicated to the accurate estimation of health care demand using both individual and population-level characteristics. This has most importantly incorporated a focus on the merits or otherwise of age and life expectancy, or remaining lifetime (often termed "time-to-death") in explaining demand.

Formal interest in such predictions, and increasing concern about the potential role of demographic factors in future changes in health care demand and expenditures, can be traced back to at least (Heller et al., 1986[2]), an International Monetary Fund report pointing to cross-sectional relationships between age and health care expenditures. Importantly, however, these relationships were not estimated longitudinally, nor did they attempt to control for morbidity. Even as late as 2000, the OECD report *Fiscal Implications of Ageing* expressed concerns that demographic changes would lead to expenditures on age-related social expenditures such as those on health care to rise by over a third as a percentage of GDP by 2050 (Dang, Antolin and Oxley, 2001[3]).

Uncertainty around such predictions, and the unsatisfactory nature of modelling such relationships in the cross-section, has given rise to a strand of academic literature arguing that age is a "red herring" in explaining health care demand and expenditures. Beginning with (Zweifel, Felder and Meiers, 1999[4]), successive papers have argued that while age is undoubtedly correlated with health care costs in the cross-section, such a relationship does not explain the true data-generating process – i.e. that age itself is an unsatisfactory explanatory cause of health care costs. Much of this literature (Werblow, Felder and Zweifel, 2007[5]; Zweifel, Felder and Werblow, 2004[6]; Zweifel, Felder and Meiers, 1999[4]) has focused on replacing, or augmenting, use of age as an explanatory factor with time-to-death, and finding that doing so removes the vast majority of explanatory power of ageing. Reviewing OECD projections for 2050 in the light of early such publications, (Gray, 2004[7]) remarks that age "is not a particularly good predictor of health expenditure, and simple projections based on age-specific health expenditure will therefore be misleading."

While more recent research has argued that time-to-death is itself a red herring in explaining health care costs (Howdon and Rice, 2018[8]), being itself a proxy for morbidity, it is generally accepted that time-to-death provides greater explanatory power than age. This has substantial implications for the prediction of future health care costs: the use of parameter estimates associated with age in *ceteris paribus* predictions of future health care demand and costs is likely to be inappropriate, and the use of measures of expected future morbidity or time-to-death would be of more use. Indeed, this has been repeatedly evidenced theoretically and empirically in a "compression of morbidity" strand of literature beginning with (Fries, 1980[9]). This thesis broadly argues that individuals increasingly compress ill-health into the final years of life, rather than having a consistent and immutable decline in overall health over their lifetime, and that chronic diseases begin to present later in life at a rate faster than increases in life expectancy.

What determines health service accessibility and utilisation?

The number of health accessibility studies has recently increased due to both the wider use of geographic information systems (GIS) and availability of spatially disaggregated data, and the growing importance of adequate and equitable accessibility concerns among policy makers (Neutens, 2015[10]). The literature spans several subjects: accessibility to emergency medical services (Shin and Lee, 2018[11]), accessibility to heart-related hospital services (Hare and Barcus, 2007[12]), accessibility to primary health care (McGrail and Humphreys, 2014[13]; Guagliardo, 2004[14]), accessibility, equality and health care (Goddard and Smith, 2001[15]), impacts of hospital closures in rural areas (Vaughan and Edwards, 2020[16]) and change in hospital accessibility inequalities over time. These various strands have provided convincing evidence that spatial barriers between service provider and user contribute to lower health care utilisation and decreased uptake of preventive services.

Access to a particular location does not guarantee utilisation (Hare and Barcus, 2007[12]) because there can be individual socio-economic characteristics and preferences, and consumer's ability to pay for services plays an important role in health service utilisation. Still, proximity to appropriate services is considered as the main determinant of health service utilisation, particularly in rural areas (Cromley and McLafferty, 2002[17]; Meade and Earickson, 2000[18]).

Health service accessibility is usually modelled based on the catchment areas where health care service utilisation is realised. Two factors to consider in the modelling catchment areas are the type of health service delivered and how far users are prepared to travel. Travel distance becomes particularly important for primary health care services, where most residents prefer to stay within their immediate neighbourhood (McGrail and Humphreys, 2014[13]).

Measuring health service accessibility has been done in several ways:

- Using travel distance or time to the nearest facility or to a certain number of closest facilities (see for example (Pilkington et al., 2017[19]) and (Lovett et al., 2002[20]). However, such a measurement does not consider capacity of the service provider or size of the population.
- Gravity models provide an alternative to include also population, where both accessibility and availability (i.e. capacity) are considered and attractiveness of a service diminishes with increasing distance (Guagliardo, 2004[14]).
- Population-to-provider ratios give a picture of both supply and demand for health care services. However, they usually do not use any spatial movement or separation (McGrail and Humphreys, 2014[13]).

Among various methods, the two-step floating catchment area (2SFCA) method proposed by (Luo and Qi, 2009[21]) and (Wang, 2012[22]) is one of the most widely used methods in measuring health service accessibility. It is a special form of gravity model combined with population-to-provider ratios. In the first step of the 2SFCA method, a physician-to-population ratio is calculated for each service within a floating catchment area or a window, in a second step, all the physician-to-population ratios are summed up for each location within the catchment area and used as the accessibility of that location. In each step, a distance or travel time threshold is used to define the catchment area (Pan et al., 2018[23]). The 2SFCA method, considers not only the distance decay (transferability) but also the interactions between supply and demand (complementarity) which overcomes the limitations of traditional place-based accessibility measures where the demand for service is largely overlooked (Chen and Jia, 2019[24]).[1]

A method to estimate health service demand and access

As in the school allocation procedures, this chapter measures demand for local communities that are defined as regularly latticed 1 km^2 node in a network. In the school simulations, educational demand per community is estimated through local student populations, which are straightforward to define for schools using age groups. Estimating current and future demand for health services based on age distributions is not as straightforward. As explained before, time-to-death, rather than age, is the most accurate predictor of demand for many health services. For the case of maternity and obstetrics, the number of births could serve as a reasonable approximation for demand for this type of services. Consequently, uses expected local deaths to approximate demand for cardiology and local birth rates to approximate demand for obstetrics and gynaecology services. Box 4.1 provides detail on the estimation of these rates at the local level.

Box 4.1. Estimating local mortality and birth rates

Estimating local expected deaths

Local-level estimates or proxies of morbidity are usually not available and they need to be estimated. Small area level estimates or proxies of morbidity – such as life expectancy – were not available on a consistently estimated basis at the level of the hospital's catchment area as in the approach of (Howdon and Rice, 2018[8]) who use local estimates of mortality patterns as instrumental variables for time-to-death on an individual basis.

The construction of a local-expected mortality involves the combination of the age distribution of the hospital's likely catchment population by five year age grouping[2] and actuarial tables by age in years at TL2-level as of 2020. This requires assumptions regarding the construction of each age group. It is clearly incorrect to assume that each five-year age group has the same weight in terms of sex: for instance, the age group 80-84 is composed of 56% women and 44% men, with a distribution that due to mortality skews towards lower ages within this group Office for National Statistics (2020[25]; 2019[26]). A more suitable approach is to assume that each age group is composed of proportions reflecting the national age distribution, so that a weighted average according to the population distribution within our age groups can be applied to the estimated mortality risk arising in the next year for individuals of each age.

Estimating local expected births

For each age, births are estimated as the weighted average of the sum of year fertility rates according to the female population distribution within age groups. As with mortality-related measures, local births are estimated as the sum of this for all age groups in the estimated hospital catchment population. This measure gives the total estimated number of expected births within the hospital's catchment area for the forthcoming year. As with mortality-related measures, the extent to which this proxies for actual births is limited by the need to impose TL2-level fertility estimates by age for each hospital's catchment area. Despite this, however, fertility rates on a local basis are likely to differ substantially less than those related to mortality.

To estimate health service locations, the chapter adopts the location-allocation simulation used for schools, as outlined in Chapter 2. Under this approach, health service locations are simulated based on local demand and travel distances. The potential users of a health service location are estimated using so-called floating catchments (Pereira et al., 2021[27]), in which the size of a location's catchment area depends on simulated choice behaviour and the sum of all allocated location users equals the sum of the total population. The method aims to:

- estimate absolute location utilisation, rather than a relative burden on service locations
- estimate the distances that users travel to reach a location, rather than a relative service accessibility indicator.

In addition, the method assumes that simulated health service locations have practically boundless capacity because expected location capacities are, contrary to the case of schools in Chapter 3, unknown for health service locations. As a consequence, in the method the difference in distances to locations is the only determinant of user allocation. This implies that, if a community has for instance a choice set of five service locations at equal distance, all locations obtain equal users from that community.

As is done for schools, the simulation of health service locations across the EU27+UK relies on grid search values. Grid searches allow obtaining the set of thresholds that best describe the geographical distribution of cardiology and maternity and obstetrics services in England[3] (see Annex 4.B). The obtained thresholds represent a societally acceptable balance between service access and service efficiency. The results show that health service locations have a much larger geographical scale than primary or secondary schools. As the thresholds are similar for both services, both cardiology and M&O services are of a similar geographical scale.

For England, catchment areas for cardiology services vary from 0.04% to 2.1% of the total population, with a mean of 0.42%, and for M&O services they vary from 0.04% to 3% with a mean of 0.38%. Table 4.1 summarises the travel distance for cardiology and M&O service users in the actual and modelled health service locations. In both cases, the modelled results capture differences across degree of urbanisation levels for both services. According to the results, users in sparse rural areas travel on average 10 km more than users in cities for cardiology services and about 14 km more in M&O services.

Table 4.1. Comparison of travelled distance per cardiology and maternity and obstetrics user in actual and modelled locations by degree of urbanisation, England

Degree of urbanisation	Travelled distance per user (km)	
(source locations)	Observed	Modelled/modelled
Cardiology		
Sparse rural	17.2	18.1
Villages	17.3	16.6
Towns and suburbs	12.2	10.0
Cities	7.4	5.9
Maternity and obstetrics		
Sparse rural	28.6	18.7
Villages	24.7	16.7
Towns and suburbs	15.8	10.3
Cities	4.3	4.3

Note: Modelled facilities are UK-wide results; observed facilities are England only.
Source: Authors' estimations based on (Goujon et al., 2021[28]; NHS Digital, 2020[29]; NHS England, 2020[30]; NHS Improvement, 2020[31]; Jacobs-Crisioni et al., n.d.[32]).

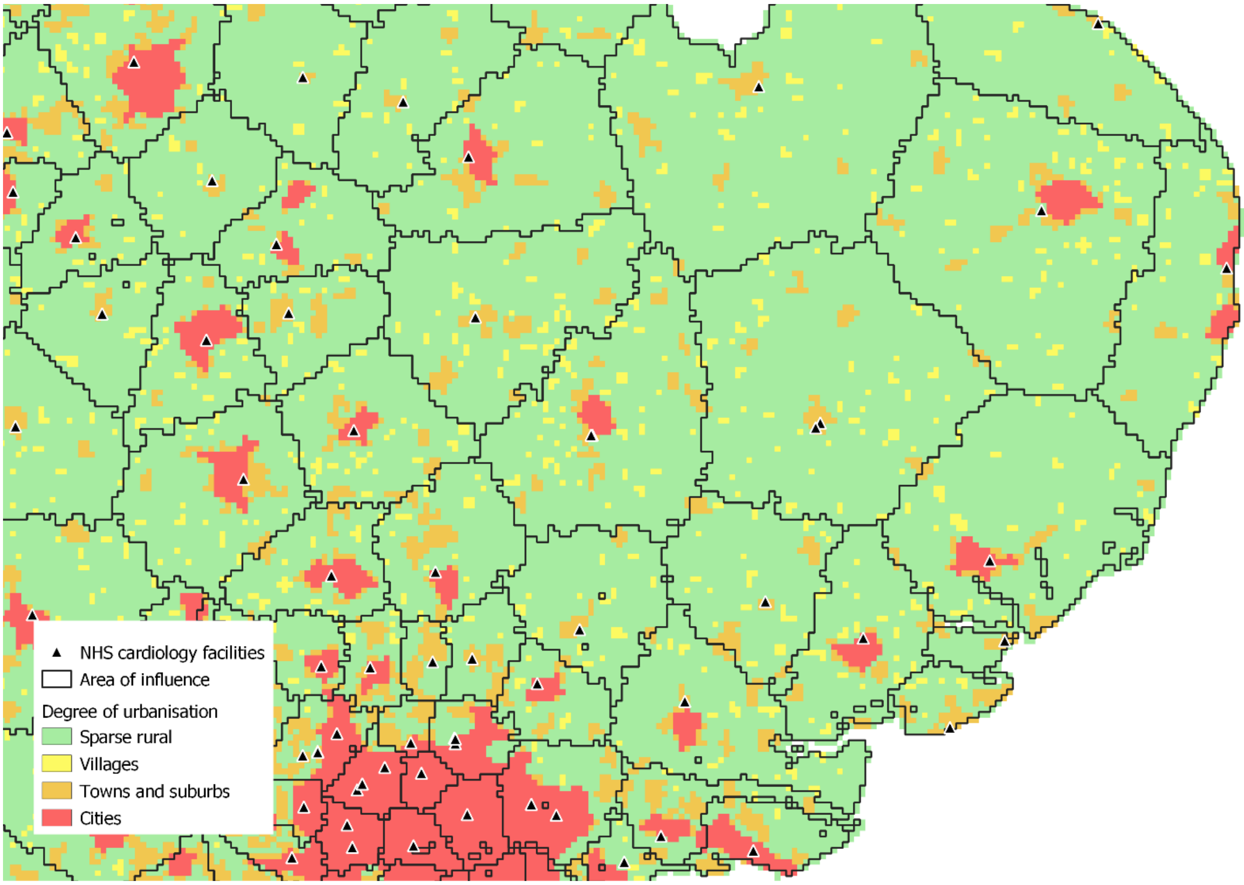
Results from the potential user simulation are subsequently used to assess:

1. total population in the catchment area of health service locations
2. average distances travelled by each community in order to reach these locations
3. retrieving which communities use which location, which in turn is relevant for the geographic distribution of where health care costs are borne.

Average travelled distances per community are computed as a usage-weighted average travel distance from the community to all health service locations in the choice set.

Figure 4.1 shows an example of the area covered by catchment areas for actual locations in England offering cardiology services, calculated following the procedure described above. While some service locations located in city catchment areas fall entirely within city areas, this is not the case for the majority of locations. As Table 4.2 shows, for both cardiology and M&O services, health service locations located in different degrees of urbanisation serve a mix of population coming from different areas. Comparing cost differences across degrees of urbanisation based on the precise location of the location would therefore be misleading, as it would hide the fact that most locations serve a largely diverse population in terms of their place of residency.

Figure 4.1. Example of catchment areas around actual hospital locations offering cardiology services, England



Source: Authors' estimations based on (Goujon et al., 2021[28]; NHS Digital, 2020[29]; NHS England, 2020[30]; Jacobs-Crisioni et al., n.d.[32]).

Table 4.2. Composition of catchment areas of service locations offering cardiology and maternity and obstetrics services by degree of urbanisation

Location by degree of urbanisation	Population in catchment area living in sparse rural areas (%)	Population in catchment area living in villages (%)	Population in catchment area living in towns and suburbs (%)	Population in catchment area living in cities (%)
Cardiology				
Sparse rural	14.2	12.5	33.3	40.5
Villages	13.6	15.4	31.6	39.4
Towns and suburbs	14.7	11.3	52.3	21.8
Cities	4.3	3.2	18.4	73.8
Maternity and obstetrics				
Sparse rural	11.4	10.5	30.4	46.3
Villages	24.8	23.3	38.0	34.2
Towns and suburbs	15.5	11.7	53.6	25.3
Cities	3.8	2.9	16.9	73.9

Source: Authors' estimations based on (Goujon et al., 2021[28]; NHS Digital, 2020[29]; NHS England, 2020[30]; Jacobs-Crisioni et al., n.d.[32]).

Estimation of health services costs

Conventional microeconomic theory of the firm suggests that the average cost of production is unlikely to be invariant with the quantity produced (e.g. the number of patients treated). In the case of hospitals, (Giancotti, Guglielmo and Mauro, 2017[33]) in a systematic review indeed find evidence of potential economies and diseconomies of scale. A 2012 review for NHS England looking at evidence for individual services, while reporting “no clear message on economies of scale”, found evidence of such scale economies in obstetrics and cardiovascular services, among other services (Monitor, 2012[34]).

Predicting present and future costs and access to health care services in a comprehensive and comparative manner entails a number of added considerations in comparison with predictions on schooling services (see Chapter 3):

- While basic education involves a relatively distinct and uniform set of services, this is not the case for health care provision. Health care costs in hospitals are incurred for a variety of different reasons connected to the provision of a wide set of health services of different levels of complexity.
- While simple demographic characteristics are undoubtedly useful in the prediction of hospital costs, health care use is both more difficult to predict and likely to exhibit within-age group variation in a way that education is not. Unlike the case of education, unobservable characteristics play an important role in determining health care use, implying that, for instance, individuals aged 70 in one area are likely to differ substantially from those aged 70 in another.
- A service like cardiology, just to give one example, can include both highly complex and costly health services such as heart surgery, and simpler procedures that do not require specialised facilities. Moreover, the provision of services of different degrees of complexity can happen both in highly specialised small facilities or in very large hospitals, and salaries can vary widely across staff. In the case of education, while there may be highly specialised (mainly private) schools, the overwhelming majority of schools provide services of similar complexity and intra-school salary disparities are not as wide.

Thus, although there are many factors that can involve the costs of providing health services, this chapter considers only cost differences due to varying scales of operation of health service locations. This section starts with some preliminary evidence for England and an explanation of the method used to estimate the relationship between costs per head and demand for cardiology and M&O services.

Preliminary evidence for England

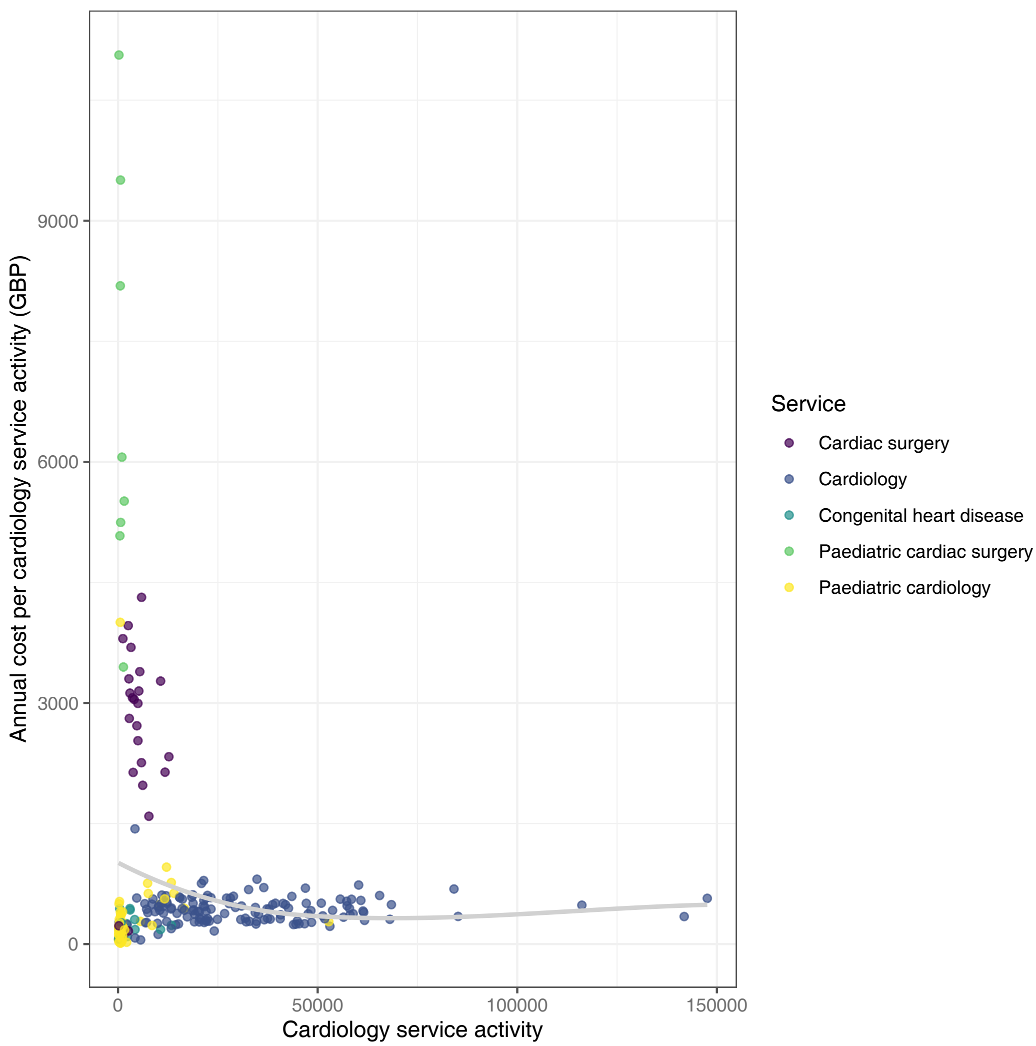
Table 4.3 shows the costs per service activity for each subcategory and the number of trusts offering the service. For cardiology, the annual costs per activity vary from almost GBP 6 000 (around EUR 7 000) for paediatric cardiac surgery to GBP 245 (around EUR 280) for congenital heart disease services. For M&O services, they are around 3 times higher for obstetrics than for relatively less complex midwifery services. As shown in Figure 4.2 and Figure 4.3, the activities with the lowest activity and the highest costs are relatively complex, so that part of the reduction in costs per activity as the number of users increases comes from the larger presence of less complex services.

Table 4.3. Cardiology and maternity and obstetrics services offer and average annual costs, England

Service name	Number of trusts offering the service	Annual costs per service activity (GBP)
Cardiology		
Cardiac surgery services	33	2 693
Cardiology services	142	434
Congenital heart disease services	15	245
Paediatric cardiac surgery services	10	5 923
Paediatric cardiology	92	426
Maternity and obstetrics		
Midwifery service	112	190
Obstetrics	129	552

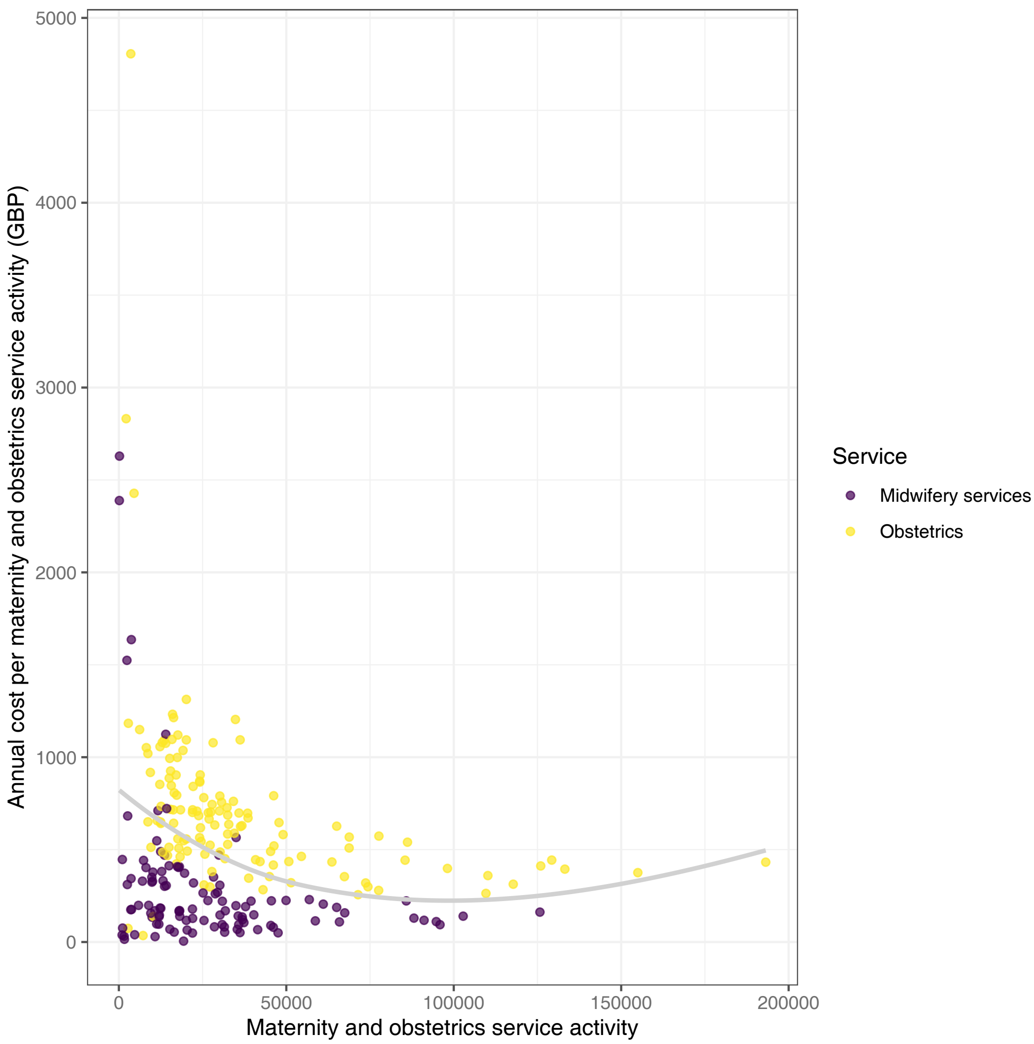
Source: Authors' calculations based on (NHS Digital, 2020[29]; NHS England, 2020[30]).

Figure 4.2. Service activity versus annual cost per activity for cardiology services, England



Source: Authors' elaboration based on (NHS Digital, 2020[29]; NHS England, 2020[30]; NHS Improvement, 2020[31]).

Figure 4.3. Service activity versus annual cost per activity for maternity and obstetrics services, England



Source: Authors' elaboration based on (NHS Digital, 2020[29]; NHS England, 2020[30]; NHS Improvement, 2020[31]).

The information of costs by trust that distinguishes among services at a disaggregated level cannot be readily used for predicting costs at the service location level because there are multiple service locations within most trusts, and many of these locations are not proximate to each other. The analysis first obtains geographical information on service locations, and then it assigns trust-level service costs for the aggregated categories of cardiology and M&O services to each service location. Annex 4.A describes the processing of mapping trust-level estimates to service locations. These location-level measures of costs form the basis of the dependent variable in a regression aiming to predict service costs on the demand for the service estimated via each service location catchment area. The next section describes the estimation of catchment areas.

Proposed cost estimation method

To estimate the cost per head of a given service, the first step is estimating the potential demand for the service, as that a larger candidate population will be strongly associated with the operating scale of the service location. The second step is obtaining an estimate of actual users, to assign the estimated costs to the pool of more likely users instead of the population as a whole. This is useful for both services since the number of admissions of cardiology services increases with age and is higher in males (62% of admissions related to cardiology services in England were males), and those of M&O correspond to women of reproductive age (98% of admissions related to obstetrics and gynaecology services in England were females) (Table 4.4).

Table 4.4. Cardiology and obstetrics admissions by age range, England

2019

Age range	Cardiology admissions by age (%)	Obstetrics and gynaecology admissions by age (%)
0-4	0.05	2.84
5-9	0.02	0.01
10-14	0.03	0.07
15-19	0.46	3.51
20-24	0.84	14.74
25-29	1.01	25.66
30-34	1.23	28.48
35-39	1.66	17.12
40-44	2.33	4.47
45-49	4.36	1.01
50-54	6.61	0.63
55-59	8.70	0.41
60-64	10.15	0.26
65-69	11.51	0.23
70-74	14.47	0.22
75-79	13.49	0.15
80-84	11.89	0.11
85+	11.19	0.07

Source: NHS Digital (2021[35]), "Hospital Episode Statistics for England - Admitted Patient Care statistics, 2018-19", https://digital.nhs.uk/data-and-information/publications/statistical/hospital-admitted-patient-care-activity/2018-19.

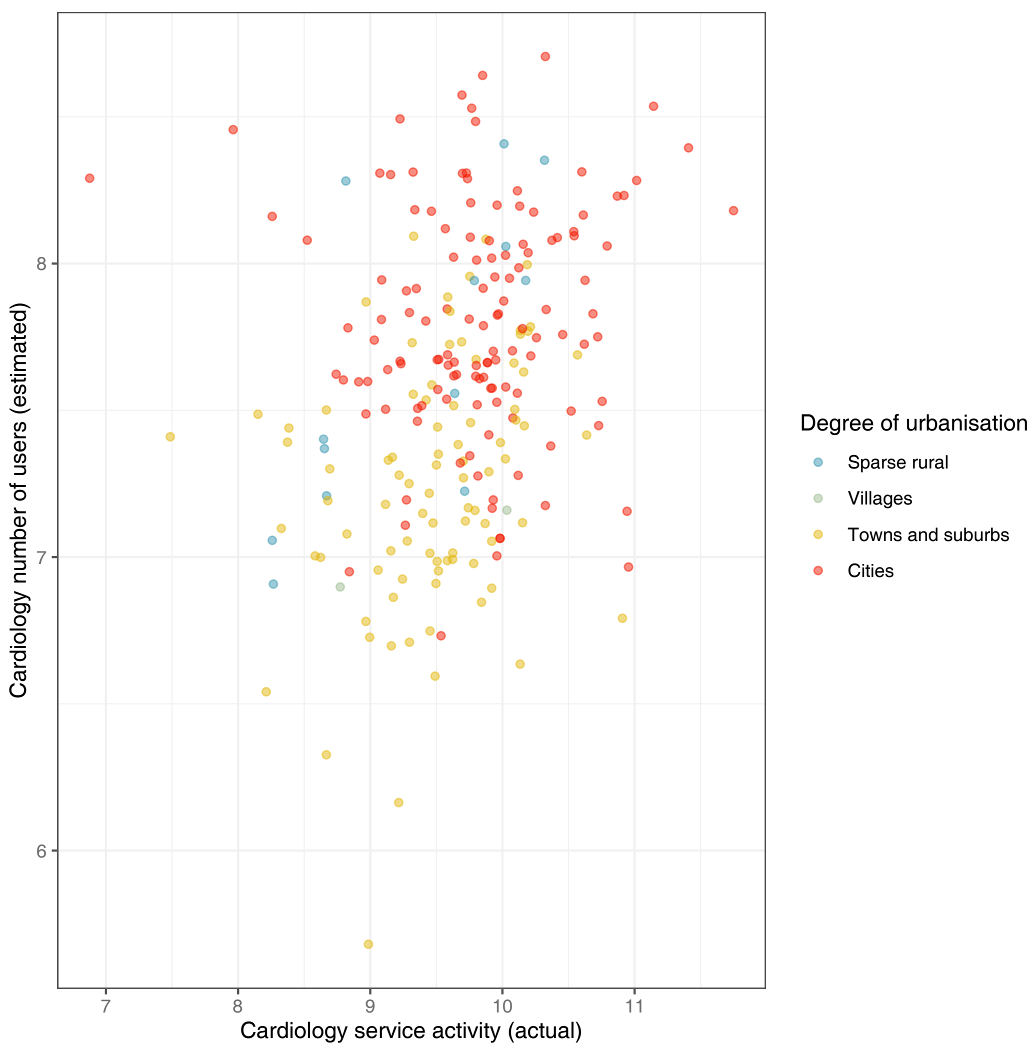
To this end, the approach uses NHS visits statistics for both services, by sex and age group, to estimate usage per catchment area, so that a catchment area with many expected users is allocated a relatively large share of the costs of a service location, compared to catchment area with few expected users.

The comparisons of the estimated annual costs per head per service are done based on costs per user at their place of residency, so when summarising by degree of urbanisation, the average represents the cost for a user living a given degree of urbanisation regardless of where the service location they potentially attend is located. Costs at place of residency are obtained through the process of 'cost porting' described in Box 3.2, Chapter 3. This ensures a consistent comparison of geographical differences in accessibility and costs, as a comparison based on service location would not truthfully capture location-specific scale economies, which likely depend on many other factors besides the scale of the potential user pool. Moreover, these facility-based estimates would give the wrong impression that for instance services located in sparse rural areas serve only users from those areas - in fact, as data for England shows, they serve a balanced mix of users from all areas, including cities.

Figure 4.4 and Figure 4.5 compare for service locations in England the (log) estimated users with (log) service activity, which records all service-related activity for the set of services included in cardiology and M&O services. Generally, the proposed approach to estimate number of users reproduces the scale of operation in service locations in different locations: compared to NHS admissions data by speciality for 2018 (NHS Digital, 2021[35]), the approach predicts 521 764 users in observed Cardiology locations against 450 173 actual cardiology admissions, and 613 707 users of M&O services, close to 720 809 obstetrics admissions.

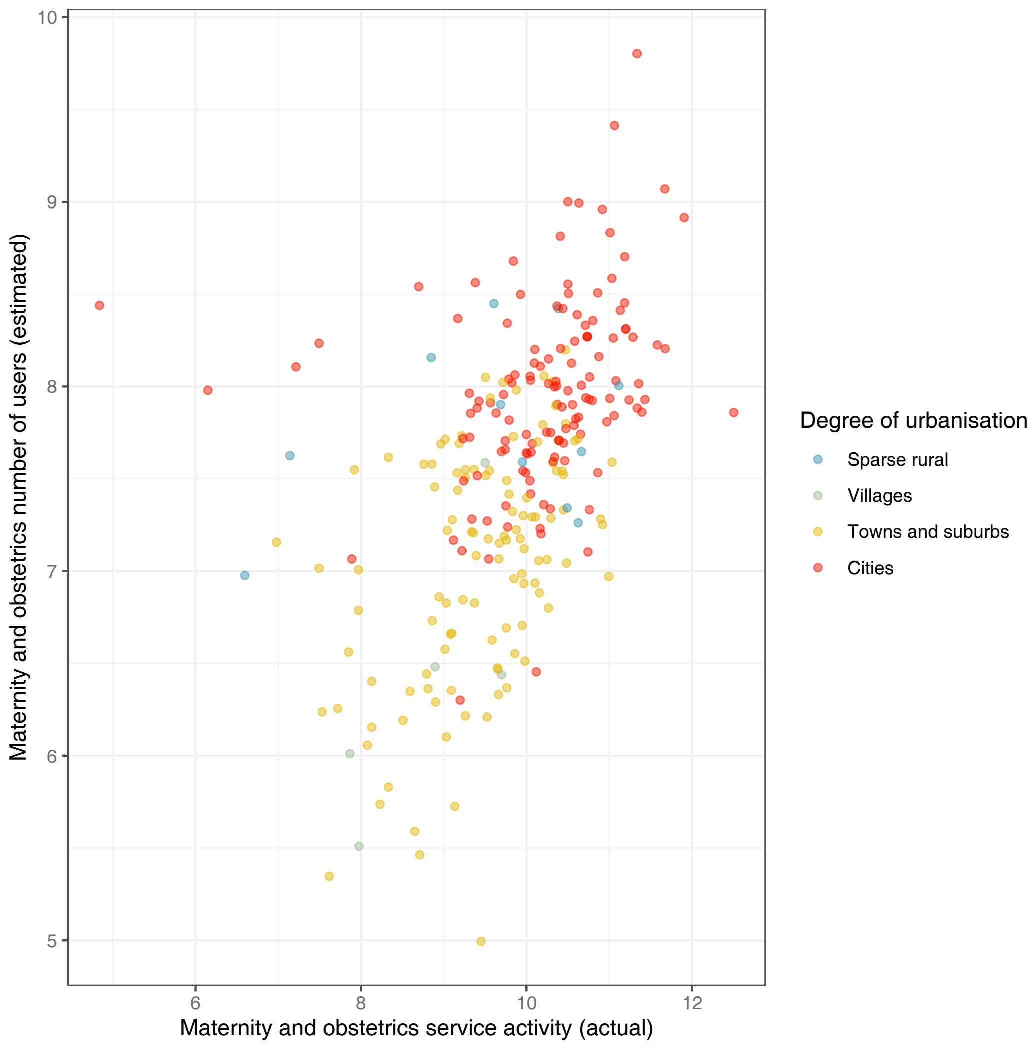
The comparison also confirms that in both actual and simulated data, service locations located in sparse rural areas may have a large scale of activity and services located in towns and suburbs have on average smaller scales. The largest differences between the estimated and actual measures of scale of services are observed for services located in cities and are possibly due to different levels of specialisation in actual urban service locations that cannot be captured with the approach proposed in this analysis.

Figure 4.4. Estimated users versus actual service activity at cardiology service locations, England



Note: Both variables are in logs.
Source: Authors' estimations based on (Goujon et al., 2021[28]; NHS Digital, 2020[29]; NHS England, 2020[30]; NHS Improvement, 2020[31]; Jacobs-Crisioni et al., n.d.[32]).

Figure 4.5. Estimated users versus actual service activity at maternity and obstetrics service locations, England



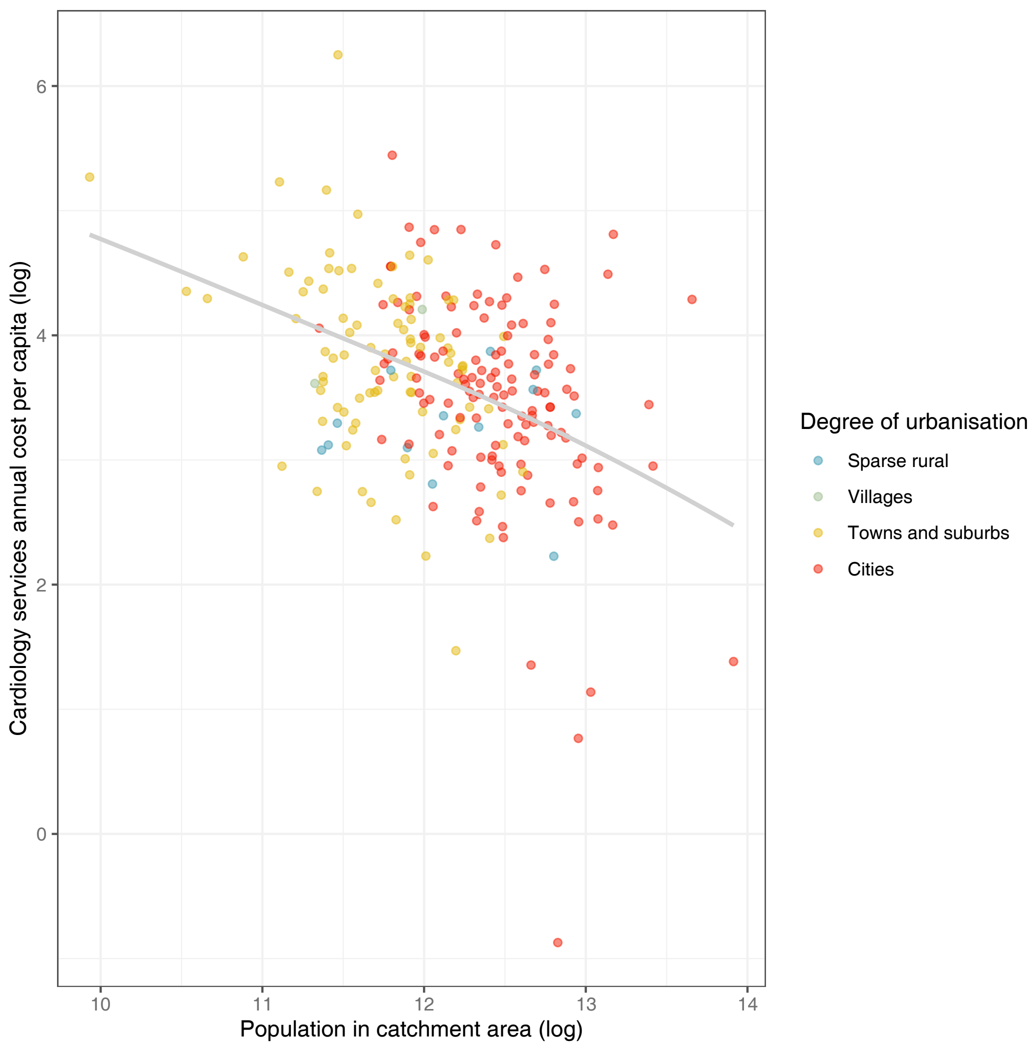
Note: Both variables are in logs.
Source: Authors' estimations based on (Goujon et al., 2021[28]; NHS Digital, 2020[29]; NHS England, 2020[30]; NHS Improvement, 2020[31]; Jacobs-Crisioni et al., n.d.[32]).

For cardiology services, the approach first considers the expected number of deaths in the service location's catchment area for the forthcoming year. However, there is a strong correlation between the number of deaths and population in the catchment area (correlation coefficient = 0.89). Separate regressions of these determinants show that population in the catchment area has higher explanatory power than deaths. Consequently, the approach uses this proxy for local demand in the regression analysis. In alternative regressions considering the effect of average mortality rates together with the effect of population, the effect of average mortality rates turned out to be not statistically significant.

For M&O services, the regression analysis also aims at estimating the effect of potential demand on costs per head, this time approximating demand by the number of expected births in the catchment area (see Box 4.1 for an explanation of how local expected births are obtained). As in the case of cardiology, while there is a strong correlation between births and population (correlation coefficient = 0.89), the regression fit favoured the use of population as a proxy for demand. Figure 4.6 and Figure 4.7 show that (log) population in catchment area has a negative relationship with (log) costs per capita for both services.

Figure 4.6. Population in catchment area versus annual costs per capita for cardiology services (estimated), England

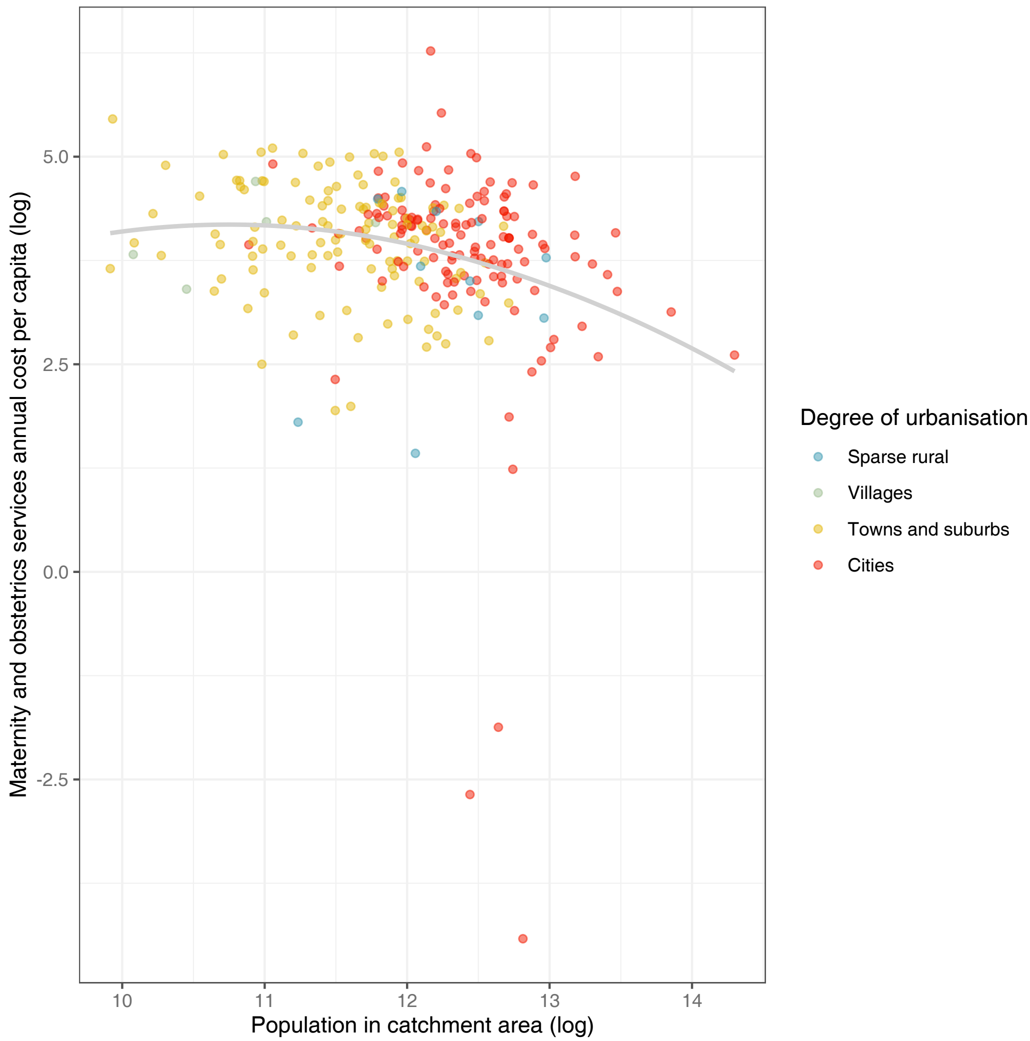
2011



Source: Authors' estimations based on (Goujon et al., 2021[28]; NHS Digital, 2020[29]; NHS England, 2020[30]; NHS Improvement, 2020[31]; Jacobs-Crisioni et al., n.d.[32]).

Figure 4.7. Population in catchment area versus annual costs per capita for maternity and obstetrics services (estimated), England

2011



Source: Authors' estimations based on (Goujon et al., 2021[28]; NHS Digital, 2020[29]; NHS England, 2020[30]; NHS Improvement, 2020[31]; Jacobs-Crisioni et al., n.d.[32]).

Thus, the (log) cost of service per capita for hospitals $i = 1 \ldots n$ as is estimated on the (log) of population of catchment area using linear regression:

$$HCC_i = \beta_0 + \beta_{1is} N_i + \varepsilon_i \qquad (1)$$

where HCC_{is} are services costs per capita at hospital i (i.e. total costs of the service in service location i divided by the population in the catchment area of service location i), N_i is the estimated population of catchment area around service location i, and ε_i is an idiosyncratic error term. β_{1i} can be interpreted as an average marginal effect of one percentage point of catchment area population on per capita costs. The same regression is run separately for cardiology and M&O services.

Table 4.5 shows the regression results. According to the estimations, the negative and significant coefficient of population in catchment areas in both regressions indicate reduced costs with increasing demand. For cardiology, a 1% increase in population in the catchment area of the average service location is associated with reducing costs per head in that service location by 0.57%. For M&O services, the elasticity of cost per head to catchment area population is 0.33%.

Table 4.5. Cardiology and maternity and obstetrics service annual costs estimation results

Dependent variable: Annual costs per head (log)

term	estimate	std. error	statistic	p- value
Cardiology (n=233; Adjusted R-square=0.16)				
Intercept	10.482	1.034	10.138	0.000
log(Pop)	-0.565	0.085	-6.657	0.000
Maternity and obstetrics (n=259; Adjusted R-square=0.052)				
(Intercept)	7.775	1.043	7.454	0.000
log(Pop)	-0.325	0.087	-3.745	0.000

Note: Pop=Population in catchment area.
Source: Authors' estimations based on (NHS Digital, 2020[29]; NHS England, 2020[30]; NHS Improvement, 2020[31]).

Table 4.6 shows the results of observed versus modelled annual costs per user at place of residency by degree of urbanisation. When indexing to cities - the degree of urbanisation category with the lowest costs per user - the results for both cardiology and M&O services show that, compared to cities, the modelled costs per user are higher in sparse rural areas and villages and lower in towns and suburbs. The observed costs exhibit a similar pattern, although with larger differences across categories.

Table 4.6. Comparison of actual versus modelled annual cost per user (at place of residency), England

Degree of urbanisation	Annual cost per user (GBP)			Relative costs per user (cities = 100)		
	Observed/ observed	Observed/ modelled	Modelled/ modelled	Observed/ observed	Observed/ modelled	Modelled/ modelled
Cardiology						
Sparse rural	4 257	3 570	4 180	105.2	114.0	116.2
Villages	4 095	3 548	4 182	101.2	113.3	116.3
Towns and suburbs	4 126	3 464	4 016	102.0	110.6	111.7
Cities	4 046	3 131	3 596	100.0	100.0	100.0
Maternity and obstetrics						
Sparse rural	6 102	4 736	4 894	230.3	146.8	124.8
Villages	5 738	4 622	4 975	216.5	143.2	126.9
Towns and suburbs	4 705	4 323	4 754	177.5	134.0	121.2
Cities	2 650	3 227	3 921	100.0	100.0	100.0

Note: Modelled service locations are UK-wide results; observed service locations are England only. All costs are based on porting using expected admissions.
Source: Authors' estimations based on (Goujon et al., 2021[28]; NHS Digital, 2020[29]; NHS England, 2020[30]; NHS Improvement, 2020[31]; Jacobs-Crisioni et al., n.d.[32]).

Conclusions

This chapter has presented a method to estimate service location demand and costs from aggregate data on actual service location costs. Chapter 5 uses these figures to obtain estimations in EU27+UK countries. The method presented in this chapter benchmarks data for England. The benchmarking employs service locations' own estimates of the cost of per capita provision of various healthcare activities, grouped by two service types: cardiology and maternity and obstetrics.

Following the current literature on the topic, the approach uses local death rates, rather than size of age classes, as predictor of demand for cardiology services, and local birth rates as a predictor of demand for maternity and obstetrics services. This demand determines the need for a new service location, so the number of health service locations allocated to a country depends on both the level of demand for the services and its geographical distribution: in sparsely populated areas, service locations are expected to have very large catchment areas, while in cities catchment areas can be relatively small.

To apply the demand and access estimation method presented in this chapter to EU27+UK countries, it is necessary to establish first the possible location of cardiology and maternity and obstetrics services. This chapter explains how the location of actual service locations in England can be used to benchmark the location of service locations elsewhere, using a grid search approach and assuming distances to service locations are the only determinant of user allocation.

The regression analysis used to determine the relationship between costs per head in service locations and demand in their catchment areas finds a negative relationship between the size of the population in the service locations' catchment areas and per capita health care costs for both cardiology and maternity and obstetrics. The results generally suggest the presence of scale returns that imply lower average costs for larger populations in a catchment area.

Annex 4.A. Data processing

Data sources and data processing

This annex describes the process to generate a dataset containing for each relevant health service location: i) estimated catchment areas of the service it provides; and ii) an estimate of the accounted annual costs incurred for health service provision at that facility.

The estimations of costs at location and service level rely on data from NHS England Reference Costs (NHS Improvement, 2020[31]). Reference Costs are published on a yearly basis as an estimate of the actual costs of provision of hospital services in England, with each provider returning an estimate on a full absorption basis (i.e. including a share of any relevant overheads) for services categorised by Healthcare Resource Groups (HRGs), grouping types of hospital activity that are similarly resource-intensive. While the primary aim of the collation of such cost data is to inform the following year's NHS Tariff – the rate at which hospitals are reimbursed for activity – the use of such administrative costs has been common in analysing patterns and changes in hospital activity, with a view to explaining relevant factors in their determination (Aragón, Chalkley and Rice, 2016[36]). While such activity is assigned to an HRG in order to inform reimbursement, it can also be categorised into the broader category service groups, largely at the level of clinical speciality: this is the categorisation employed in this analysis.

In order to map trust cost estimates to service locations, the approach first derives a comprehensive list of data on hospitals in England provided on the NHS website (NHS England, 2020[30]). From this list, data is scraped on the location of the service location (as determined by the midpoint of the location's postcode), as well as a list of all services provided by this service location, usually by clinical specialty. After cleaning for service locations listed as providing no services (from checking a sample of ten on this, all were now-defunct hospitals) and service locations geographically outside England (one located in Jersey), this yielded a dataset of 990 locations providing a mean of 16.06 services (median 9, interquartile range 3 to 24, max 86), the vast majority of which ultimately provided no services of relevance to the analysis. While in many cases this list of services maps on a one-to-one obvious basis to a specialty code grouping included in reference costs (NHS Digital, 2020[29]), this is not true in all cases. As a result, some judgement must be introduced at this stage: for each of the two services to be considered, specialty codes that are judged as best mapping onto these service descriptions are included. The final set does not contain private service locations contained on the list, service locations where it was not possible to match a hospital trust code to the locations' postcodes, and cases where missing data for hospitals within a trust entailed costs that were implausibly high being assigned to one small location.

For most combinations of trusts and services, activity takes place at a single site, and for such cases, the assignment of trust-level costs to locations is clear and straightforward. On occasion, however, services may be provided at multiple sites within the same trust, leaving the problem of assigning trust-level costs to individual locations in such cases.

Combining trust costs and service location catchments

A number of limitations are relevant for the data generation process.

- Catchment sizes are defined at the service location level.
- Whether a service is provided at a location is broadly indicated, e.g. indicating the presence of "cardiology".
- Costs are accounted for at the trust level.
- Trust-level costs are accounted for in detail, e.g. discerning costs in general cardiology consultation, cardiac surgery, and other cardiology-related treatments.
- Trusts typically operate multiple service locations.
- Multiple trusts can be present at the same location.

The particular nature of the available data imposed that the data generation process is based on a number of assumptions, which in turn affect the final distribution of costs over service locations, and subsequently the health cost regression results used in this report.

- The only feasibly identifiable link between service locations and the trusts that operate them, is when a trust has a location where the service is offered.
- Although, across service locations, there is presumably variance in the depth of health services offered, when defining the catchment sizes, all service locations were expected to compete on an equal footing.
- Service locations that offer more services are generally larger, have more capacity and possibly also offer more complex services. Service-specific costs are therefore downscaled from trusts to service locations proportionally to the number of services offered at a location, relative to the total number of services offered by the trust.

Given the limitations and assumptions involved in the endeavour, the process to ensure that costs are attributed to the right catchments is complex. The process by which the data is generated is outlined in the remainder of this annex. Descriptive statistics relevant for the data joining process are given in Annex Table 4.A.1.

Annex Table 4.A.1. Descriptive statistics of the inputs used to generate datasets

	Cardiology	Obstetrics and gynaecology
NHS location data		
Number of locations	238	257
Average catchment size (pop)	221 164	204 813
Min / mean / max number of trusts at location	0 / 2.91 / 7	0 / 2.51 / 6
NHS trust data		
Relevant service codes	172, 221, 320, 321, 331	500, 501, 560
Min / mean / max number of services	1 / 1.97 / 5	1 / 1.87 / 2
Cost accounts	292	241
Trusts with cost accounts	148	129
Min / mean / max number of locations	0 / 4.68 / 17	0 / 4.99 / 19
Spatial relation		
Service locations without known trusts	7	1
Trusts without known locations	7	5
Percentage costs not allocated	10%	5.5%

Preparation

First, verified service locations were stored in databases that separately describe the spatial distributions of both services. Subsequently, using the spatial interaction modelling procedure outlined in Chapters 2 and 4, floating catchment sizes are defined for the two services. All service locations were assumed to be perfectly equal. The result is a detailed account of the demography of a location's catchment, including breakdown of the location's catchment population by age group and expected number of births and deaths. The sum of total catchment populations for all service locations is always equal to the total population size of the study area.

Relevant trust cost accounts were identified as well. To do so, cost accounts for services described in Table 4.3 were maintained. This selection leaves a reduced list of cost accounts, which are reported by a limited number of trusts. Finally, for the selected services, lists are compiled that indicate total costs and total service activity for every relevant trust.

Linking trusts and facilities

Known locations and their catchments are linked to trusts through spatial location. Elementary here is a lookup table that indicates, per row, trust name and postcode of a specific site of the trust. The process to spatially link trusts and service locations for each service are:

- Create a data file with unique service locations (as sites are sometimes expected at the exactly same location).
- Create a data file with unique postcode locations, as in some cases those are in the same location as well.
- Link unique postcode locations to unique service locations by selecting the service location that is geographically closest to all postcodes accounted for.
- Link lookup table sites to postcode locations, and subsequently to service locations.
- Select, from the lookup table, only records of service locations that:
    - Belong to a trust that offers cardiology or obstetrics and gynaecology.
    - Are linked to a location at which cardiology or obstetrics and gynaecology services are offered.
    - Have, as an outcome of the spatial linking process, a less than 1 000 metres separation between the site's postcode location and health service location.
    - Identify unique combinations of trusts and locations. This is necessary because, in the lookup table, multiple administrative sites in a trust may be in the same location.
    - Compute weighted service count: sum total number of broad services offered at any selected health service location, and divide that sum by the number of trusts present at the location.
    - Distribute total costs per trust over the trust’s locations, proportional by weighted service count.
    - Sum total costs per trust per location to total costs per location.
    - Distribute total costs per location over the sites at the location, proportional by the number of services offered by the health service, relative to total services offered at the location.

Annex 4.B. Placement thresholds calibration

This annex describes the procedure to calibrate the thresholds that are used in the placement simulation.

The valuation of imputed threshold values was done through a grid search that aimed at most accurately reproducing observed service location distributions in England. The adopted location-allocation approach is meant to reproduce observed service location placement patterns accurately, under the assumption that the real-world placement patterns yield a societally acceptable balance between service location cost (as a function of its size) and travel costs.

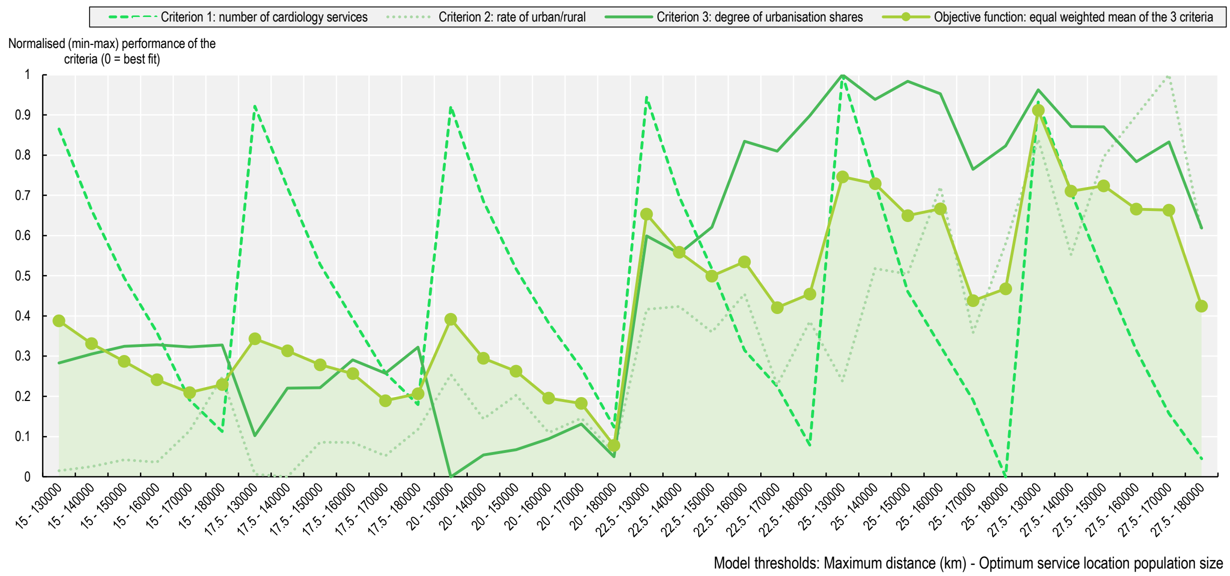
The grid search was performed by adapting values related to maximum distance, minimum size, optimal size and accessibility weighting. A composite objective function was computed to measure model accuracy given the imputed values. That function was composed of three criteria, namely percentage difference between modelled and observed nationwide number of service locations; the difference between modelled and observed rates of number of urban vs rural service locations; and the mean squared error of percentage points for shares of number of service locations by degree of urbanisation (see Box 1.2 in Chapter 1).

Annex Table 4.B.1 shows the thresholds that yield the most accurate results in England. These threshold values have therefore been selected as baseline values for allocation of birth services throughout Europe (Annex Figure 4.B.1 and Annex Figure 4.B.2). The calibration exercise also showed that some parameters have a much more substantial impact on allocation outcomes than others. In particular, the maximum catchment area distance and the facility's optimal size, which both come into play in the service location placement stage of the modelling procedure, have a considerable impact on service location distribution.

Annex Table 4.B.1. Selected threshold values

	Cardiology	Maternity and obstetrics
(1) Maximum catchment area (km)	20	20
(2) Minimum size (deaths or births as proxy for demand)	750	750
(3) Optimal size (deaths or births as proxy for demand)	1 800	1 800

Annex Figure 4.B.1. Results of adapting maximum distance and optimal size in allocation procedure for cardiology service locations, England



Note: Criterion 1: number of observed and modelled locations (% difference in modelled vs observed total number of service locations). Criterion 2: urban/rural rate (% difference between modelled and observed urban/rural rate in number of service locations). Criterion 3: degree of urbanisation shares (mean squared error of percentage points for degree of urbanisation shares of number of service locations). Objective function: Equal weighted mean of the 3 criteria. Best fitting model thresholds: 20 km maximum distance and 180 000 optimum population size.
Source: Authors' estimations based on (Goujon et al., 2021[28]; NHS Digital, 2020[29]; NHS England, 2020[30]; Jacobs-Crisioni et al., n.d.[32]).

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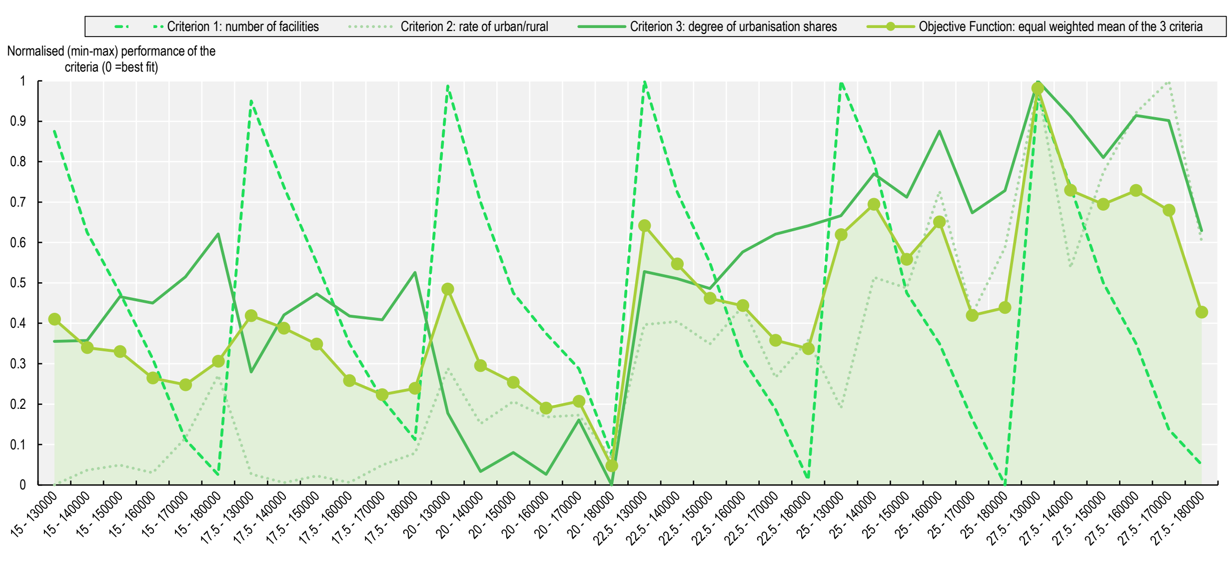
Annex Figure 4.B.2. Results of adapting maximum distance and optimal size in allocation procedure for maternity and obstetrics service locations, England



Note: Criterion 1: number of observed and modelled locations (% difference in modelled vs observed total number of service locations). Criterion 2: urban/rural rate (% difference between modelled and observed urban/rural rate in number of service locations). Criterion 3: degree of urbanisation shares (mean squared error of percentage points for degree of urbanisation shares of number of service locations). Objective function: Equal weighted mean of the 3 criteria. Best fitting model thresholds: 20 km maximum distance and 180 000 optimum population size.
Source: Authors' estimations based on (Goujon et al., 2021[28]; NHS Digital, 2020[29]; NHS England, 2020[30]; Jacobs-Crisioni et al., n.d.[32]).

StatLink https://doi.org/10.1787/888934246526

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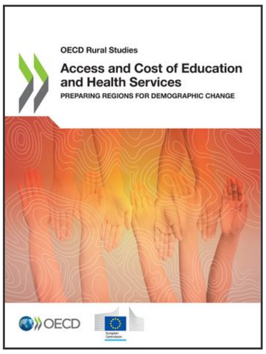
Notes

[1] See (Luo and Qi, 2009[21]), (Wang, 2012[22]) and (Kim, Byon and Yeo, 2018[37]) for further detail on the 2SFCA method together with varying applications of health service accessibility.

[2] These groupings are 0-4 years, 5-9 years… up to a single grouping of all individuals aged 85+.

[3] The service categories are aggregated differently by hospital locations so obstetrics and gynaecology is an approximation to M&O services.



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