# Mapping hospital demand: demographics, spatial variation, and the risk of "hospital deserts" during COVID-19 in England and Wales

Mark D. Verhagen,[1]* David M. Brazel,[1] Jennifer Beam Dowd,[1] Ilya Kashnitsky,[2,3] Melinda C. Mills[1]*

[1]Leverhulme Centre for Demographic Science, University of Oxford & Nuffield College, UK

[2]Interdisciplinary Centre on Population Dynamics, University of Southern Denmark

[3]National Research University Higher School of Economics, Moscow, Russia

*corresponding authors: mark.verhagen@nuffield.ox.ac.uk and melinda.mills@nuffield.ox.ac.uk

**Abstract.** COVID-19 poses one of the most profound public health crises for a hundred years. As of late March 2020, almost 15,000 deaths and over a quarter of a million confirmed cases have been registered across almost 170 countries or regions. The virus will still infect a sizeable proportion of the world's population, leading to unprecedented pressures on health care systems. Although national estimates of hospital bed capacity are available, these may obscure important differences at local and regional levels. COVID-19 appears especially dangerous for the oldest age groups and those with serious comorbidities. This makes it crucial to understand how health system capacity matches spatial variation in the underlying population risk. Using England and Wales where the outbreak is currently growing, we illustrate how the interaction of local demography, a high burden of COVID-19 morbidity and mortality at older ages, and regional variation in hospital resources culminates in "hospital deserts" with too few resources to cope with the coming wave of critical cases. Through a stylised example, we demonstrate how local capacity could rapidly become overwhelmed. Understanding more fine-grained local differences in hospitalization capacity supply versus demand can aid in predicting needs for shifting capacity and rapid redistribution of resources.

## Excess Demand and hospital deserts

COVID-19 is one of the most serious respiratory pandemics of the past 100 years, its rapid global spread already overwhelming hospitals and local communities in China, Italy, Iran, and Spain and beyond. As of March 22, 2020, almost 15,000 deaths have been reported with almost 400,000 confirmed cases across almost 170 countries or regions.[1] Thus far, considerable attention has been focused on understanding basic crude fatality rates (CFRs) and reproductive rates ($R_0$) of the infection and their variation by age, sex and underlying medical conditions.[2,3] Given the high demand for hospitalization and critical care for COVID-19 seen thus far in Wuhan and Italy, concerns have been raised about the capacity of other countries to cope.

The UK and US are at earlier stages of the outbreak and have only 2.5 and 2.8 hospital beds per 1,000 population, considerably lower than countries such as Italy (3.2), Germany (8.0) or South Korea (12.3).[4] Furthermore, the impact of demographic age-structure on hospitalization means that evaluating health capacity at a national level may overlook large regional and local variations in both the supply and demand of health capacity of general and critical care beds. These spatial variations, especially given low overall capacity, will be key to effective strategic planning by local government authorities in addressing the pandemic until a vaccine becomes available.

We focus on England and Wales since the closure of schools, public places and social distancing policies were implemented comparatively late to other European countries and the number of recorded deaths are currently increasing rapidly.[1] To examine whether the health system can sustain COVID-19 pressures, we study the regions at a more granular level by the number of general hospital and critical care beds. We see that the aggregated national average of 2.5 hospital beds per 1,000 is unequally distributed at both the Administrative Region (Fig 1), Ceremonial County (CC) (Fig S1) and Clinical Commissioning Group (CCG) level (Fig S2). Hospitalization, critical care and fatality rates for COVID-19 are all strongly associated with age and underlying comorbidities.[2] Using recently estimated pandemic modelling in the UK,[5] hospitalization rates for those under 40 are expected to be below 3.5%, but rise sharply for older ages, reaching 27.3% for those 80+. Applying these estimated hospitalization rates and assuming an illustrative cumulative infection rate of 10% (See Methods Supp Info) across England and Wales, we show that regional demographic variation will lead to stark spatial variation in expected hospitalization rates at the county (Fig 2) and CCG (Fig S3) level. For example, we observe very high pressures in the county of Powys (Wales) and the Isle of Wight (England), which is even more serious for critical care beds.

We also estimate potential "hospital deserts" where COVID-19 demand is likely to outstrip supply (Fig 3 and Fig S4). This includes once again Powys (Wales) which has a high expected hospitalization rate, combined with a low bed capacity, but also Northumberland, Rutland, Isle of Wight, and Suffolk in England. To illustrate this point further, we geo-coded and visualised all hospitals in Wales together with their general and critical care bed capacity as well as the expected hospitalization rates at a more fine-grained level (Fig S5). Hospital capacity is the highest in Cardiff and along the coast, which also have the highest levels of population density. Yet it reveals a demographically vulnerable middle rural region of Wales, consisting of an ageing population relatively far away from hospital and particularly critical care.  Conversely, there is a higher ratio of critical care beds to expected demand in London, partly due its young population structure as well as a relatively high supply of IC beds, yet given the concentration of COVID-19 first in urban areas, it will still place overwhelming pressures on the capital.

To further visualise the nationwide disparities in spatial risk, we calculated the potential "tipping point" of the hypothetical infection rate at which maximum hospital capacity would be reached (Fig 4 and S6). In fact, it takes about 2.5% of the population to become infected to cause of shortage of beds in most areas, and this assumes that all beds are given to COVID-19 patients. Given its younger age structure, areas such as London could support a higher infection rate for general hospital beds (4.7%) compared to areas such as Cornwall (1.5%). Notably, critical care bed capacity is exceeded at much lower levels of infection prevalence than overall hospital beds. Given the uncertainty in the timing of the epidemic and length of hospitalizations required, we note that this is a stylized illustration of overall infection levels relative to overall capacity. Governments have already announced the release of additional beds and alternative plans (e.g., hotels), although these must also be matched with appropriate levels of staffing and resources (e.g., mechanical ventilation, personal protective equipment). In general, COVID-19 related health care demand will depend on government policy and will be unequally spread over time and space, with the true path of the pandemic unclear. However, mean hospitalization durations are currently estimated at 10.4 days[5] and most hospitals currently have little excess capacity even when deferring elective procedures, meaning our estimates are likely conservative.[6] More importantly, our aim is to highlight local areas that may be at a particularly high risk for excess demand, even at relatively low levels of infection prevalence. As Fig 4 shows, there is considerable variation in the overall excess demand threshold for hospitalization, with the East Midland and Eastern England exceeding capacity at relatively low infection rates whereas for instance areas in Wales (Swansea, Cardiff) and Greater London would be doing comparatively better.

Taking our estimates of expected hospitalization to a more granular level, we see that even within London there are clear disparities in the estimated rates of hospitalization due to local demographics (Fig 5). Looking at the area of Harrow, for instance, we see that it already has a comparatively older population and thus already more hospital capacity in comparison to Newham, which has a comparatively younger population. Our estimates show that whereas Newham will likely experience fewer hospital admissions due to demographics, hospitals near Harrow will become overburdened – in spite of their larger capacity. Our prediction was in fact already realized on March 19, when Northwick Park Hospital in Harrow was the first hospital in London to declare a 'critical incident' after running out of intensive care beds.[7] Whereas urban areas can more easily shift patients to other hospitals, this will be difficult in rural, sparsely populated and ageing areas that may also be experiencing an influx of individuals with second holiday homes. This detailed level of analysis provides indications of which areas can be expected to have disproportionate rates of hospitalization and thus which local hospitals might reach their breaking point sooner, but also which high-risk areas the government could already start to proactively shield and protect.

**Policy implications**

Our estimates and models illustrate the importance of examining the availability of hospital and critical care beds in direct relation to the specific risks posed by COVID-19 to local demographic compositions of the population. Combining hypothetical infection rates with actual local level data on population demographics, hospitalization rates and hospital capacity, we identified potential hospital "deserts" in England and Wales. These are extremely vulnerable areas due to a high number of older adults combined with low health system capacity. This spatial variation implies that infected individuals in certain areas may have to travel substantial distances for care, creating logistical in addition to medical challenges. Although the early outbreak of COVID-19 in the UK is currently concentrated in younger urban areas such as London, as it unfolds it will likely have a disproportionate impact on the 'left behind' and rural areas. Better attention to hospital resource supply and demand mismatch at administrative and county districts will allow more efficient planning and anticipation of better mobilization of resources to avoid devastation for already vulnerable areas and populations. The need for "surge" ICU capacity will likely vary strongly by region, affecting these logistics. Identifying high-risk areas at a more granular level can also inform the targeting of mitigation policies to better protect vulnerable areas from the epidemic's spread. In order to provide a flexible tool for policymakers and local planners, as a companion to this paper, we are creating an interactive dashboard with all relevant local demographic and hospital data to allow policy-makers to simulate different infection scenarios and assumptions, which will eventually also include additional countries.

**Author contributions.** All authors devised the idea jointly. MDV, DMB and IK produced the maps and wrote the code. MCM and JBD drafted the paper, which was revised and approved by all authors.

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The authors report no competing interests.

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**Figure 1. Regional Hospital bed Capacity (per 1,000) for General Hospitalization (A) and Critical Care (B). England & Wales**

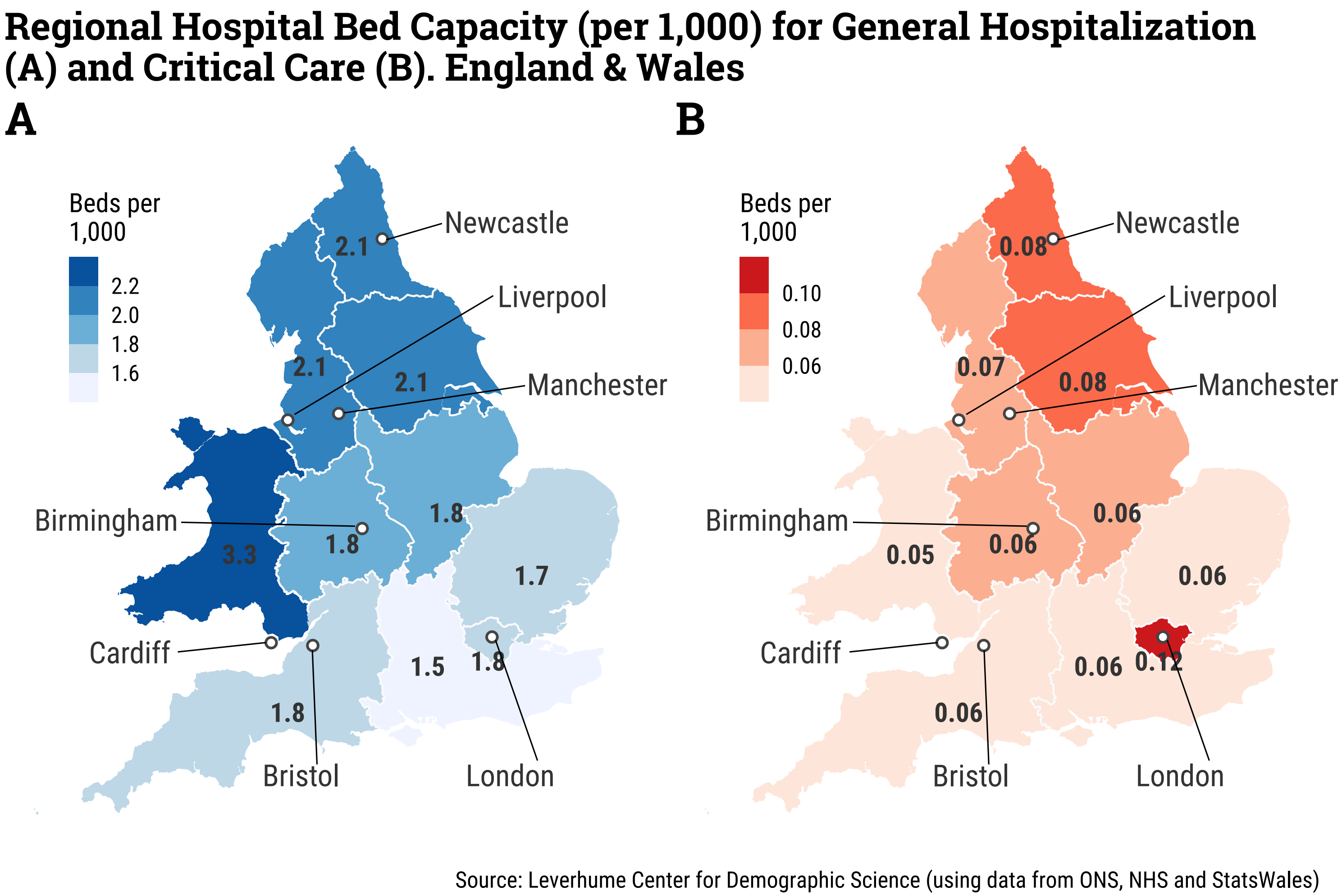


**Figure 2. County Expected Hospitalization (per 1,000) for General Hospitalization (A) and Critical Care (B). England & Wales**

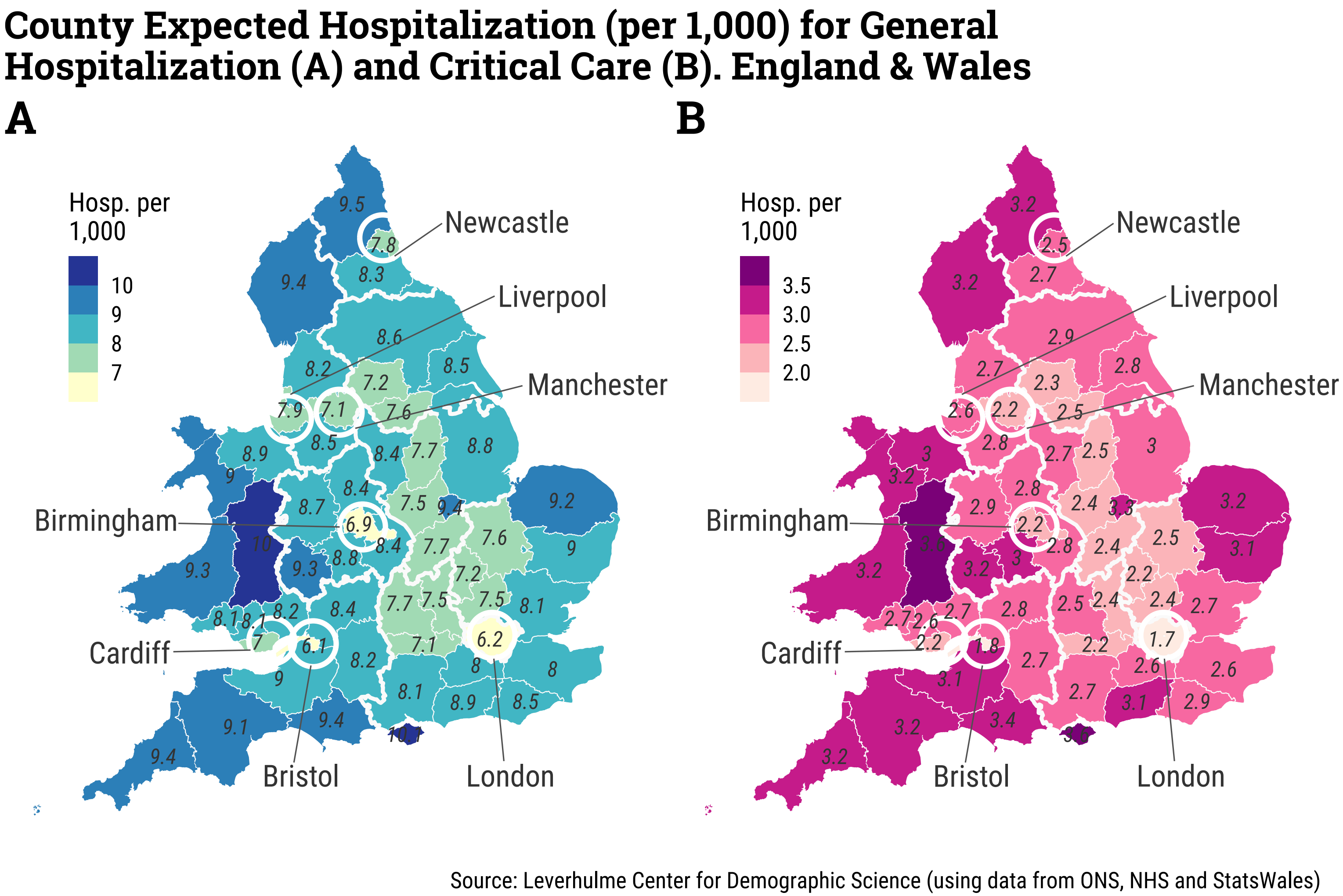


**Figure 3. County Excess Need for Hospital Beds (per 1,000) in Case of a 10% Nationwide Infection Rate for General Hospitalization (A) and Critical Care (B). England & Wales**

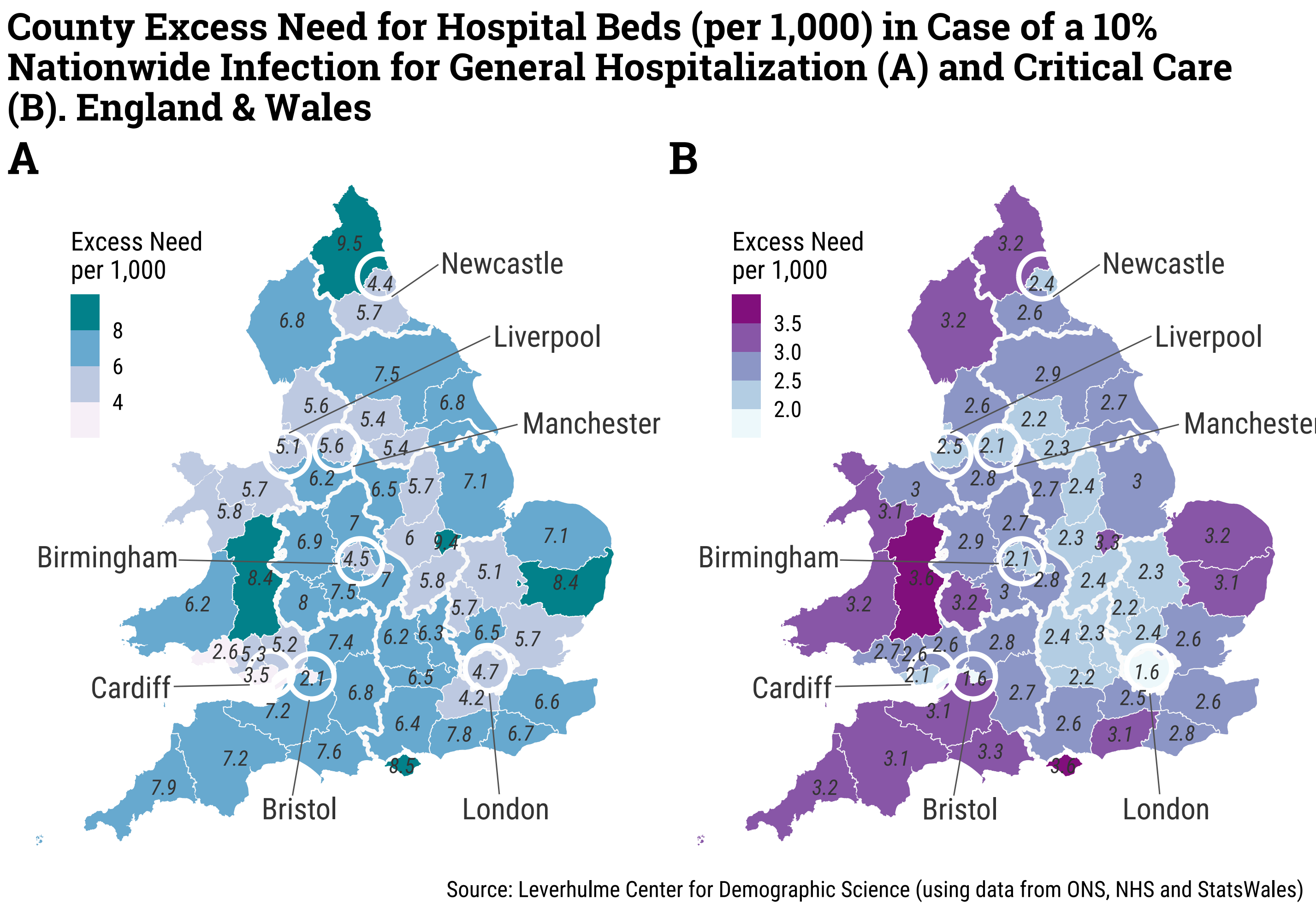
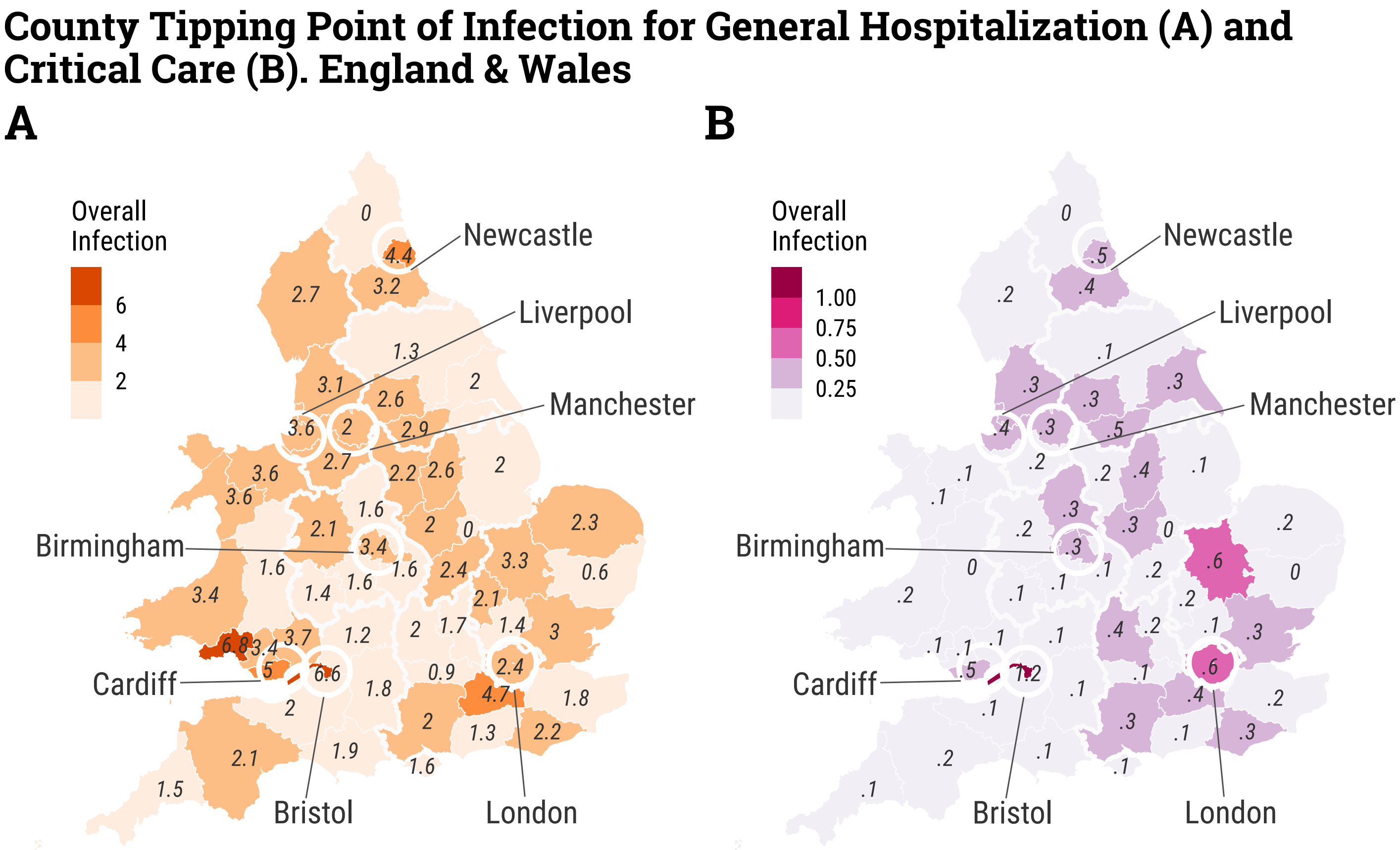
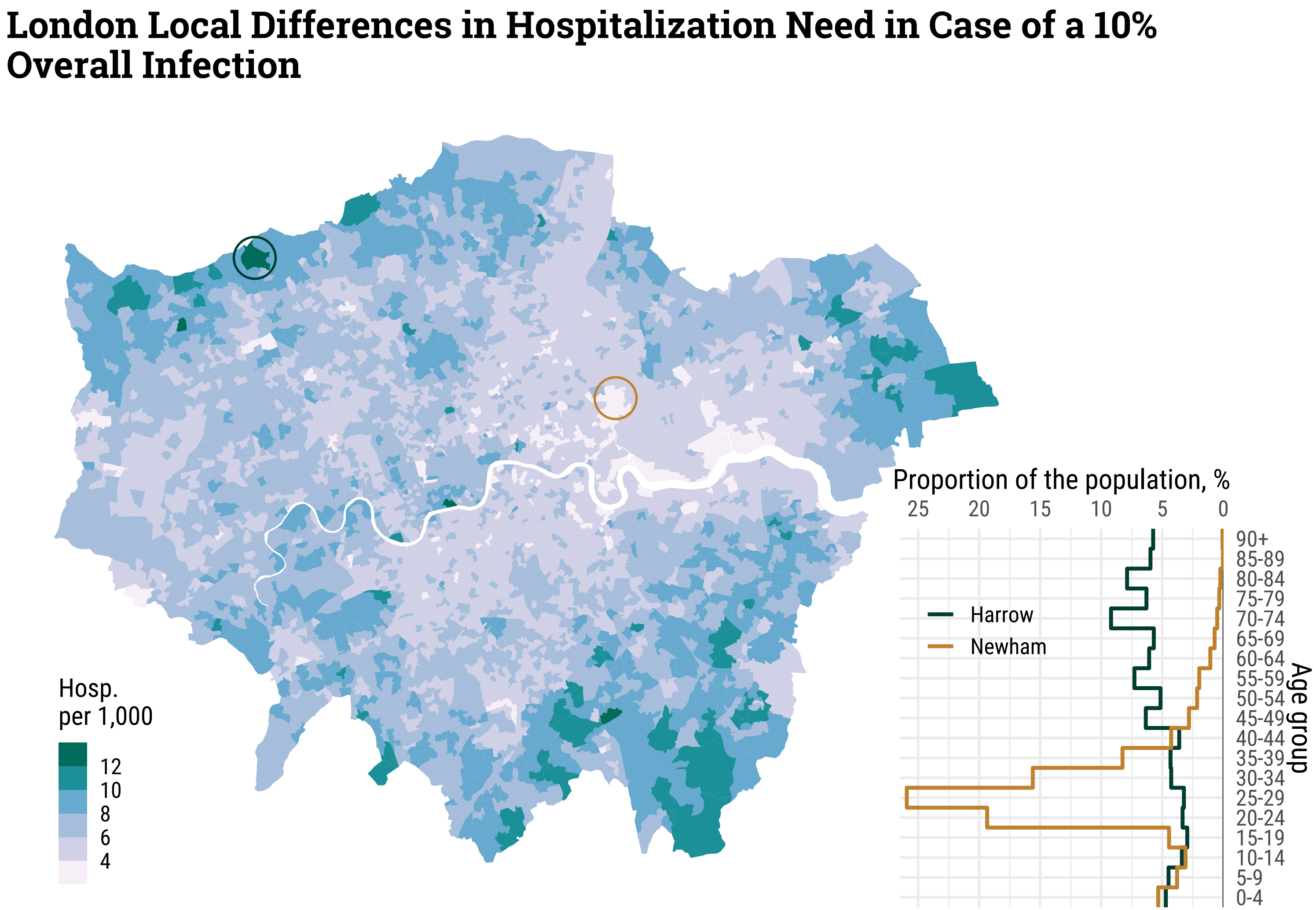


**Figure 4. County Tipping Point of Infection for General Hospitalization (A) and Critical Care (B). England & Wales**




Source: Leverhulme Center for Demographic Science (using data from ONS, NHS and StatsWales)

**Figure 5. London Local Differences in Hospitalization Need in Case of a 10% Overall Infection**




Source: Leverhulme Center for Demographic Science (using data from ONS, NHS and StatsWales)

## Supplementary information

# Mapping hospital demand: demographics, spatial variation, and the risk of "hospital deserts" during COVID-19 in England and Wales


Mark D. Verhagen,* David M. Brazel, Jennifer Beam Dowd, Ilya Kashnitsky,** Melinda C. Mills*

Leverhulme Centre for Demographic Science, University of Oxford & Nuffield College, UK

**Interdisciplinary Centre on Population Dynamics, University of Southern Denmark

*corresponding authors: mark.verhagen@nuffield.ox.ac.uk and melinda.mills@nuffield.ox.ac.uk


**Data**

For local population counts by age across England and Wales, we used the Mid-2018 census estimates on the Lower layer Super Output Area (LSOA) level, as estimated by the Office for National Statistics (ONS).[8] Hospital bed capacity for England was taken from NHS's SDCS data collection for both the general hospitalization bed capacity (collected December 2019) as well as the acute care bed capacity (collected January 2020).[9] Hospital bed capacity was available per NHS Trust and per Ceremonial County (CC). We geo-coded the postal codes of each NHS Trust into Lat-Lon coordinates to match NHS Trusts to Clinical Commissioning Groups as well. Hospital capacity and locations for Wales were obtained from Statistics for Wales and the NHS Wales Informatics Service.[10]

Shapefiles for England and Wales were obtained from the ONS' Open Geography Portal for the LSOA, CCG and Administrative Region level.[11] Shapefiles for the CC level were obtained from Ordnance Survey Digital Data.[6] Lookups between the LSOA and regional level were taken from ONS. Lookups between the LSOA and CC level were obtained by overlaying the shapefiles using the sf package in R. Shapefiles for Welsh Local Health Boards were obtained from the Lle Geo-Portal.[11]

**Methods**

We aggregated census data into five-year age-intervals starting at 0 until 89. We binned individuals 90 years and older into a single category, 90+. For each LSOA we calculated the number of individuals in every age category and multiplied this number with a fixed infection rate. By using a fixed infection rate across the population, we implicitly assume an equal risk of infection across age and geography. While this assumption is not likely to hold in practice, we are assuming low overall population infection rates relative to some estimates,[5] thus illustrating the strong spatial variation in risk across the country even at low levels of infection. Our aim is thus not to model the possible path of the pandemic but rather to show the strong spatial patterning of hospital capacity and hospitalization rates. We then used COVID-19 hospitalization estimates from Ferguson et al. 2020 to calculate the expected number of individuals in need of hospital care, as well as those in need of critical care (the rates will be updated as new estimates come in).[5] By aggregating up to the County and Region level, we estimated the total demand for hospital bed capacity on those aggregation levels given the assumed infection rate. Total hospital bed capacity was directly estimated at the County level by the NHS. Net demand for hospital beds was calculated by subtracting estimated demand from hospital capacity. We used General Hospital and Acute bed capacity to calculate excess demand for general hospitalization and used the Acute bed capacity in England and the intensive care capacity in Wales to calculate excess demand for critical care hospitalization.

**Data & Code availability**

All data and code are available on our GitHub repository (https://zenodo.org/record/3723556).[12] We also aim to launch an interactive dashboard that will allow policymakers to evaluate different thresholds of infection spreads, hospitalization rates and hospital bed capacity at the local level.

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The authors declare no competing interests.

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## Supplementary Information

**Figure S1. County Hospital Bed Capacity (per 1,000) for General Hospitalization (A) and Critical Care (B). England & Wales**

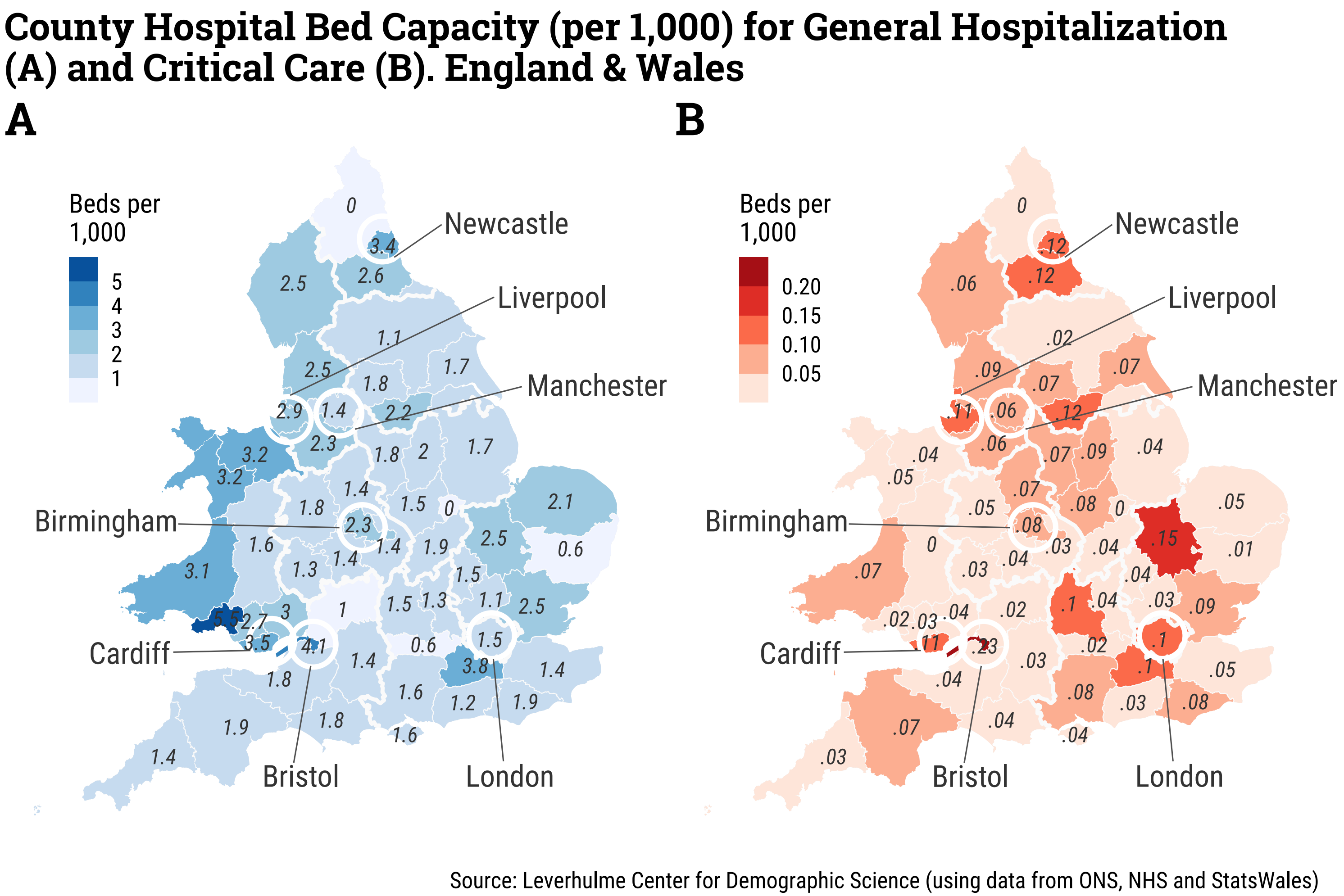

**Figure S2. CCG Hospital Bed Capacity (per 1,000) for General Hospitalization (A) and Critical Care (B). England**

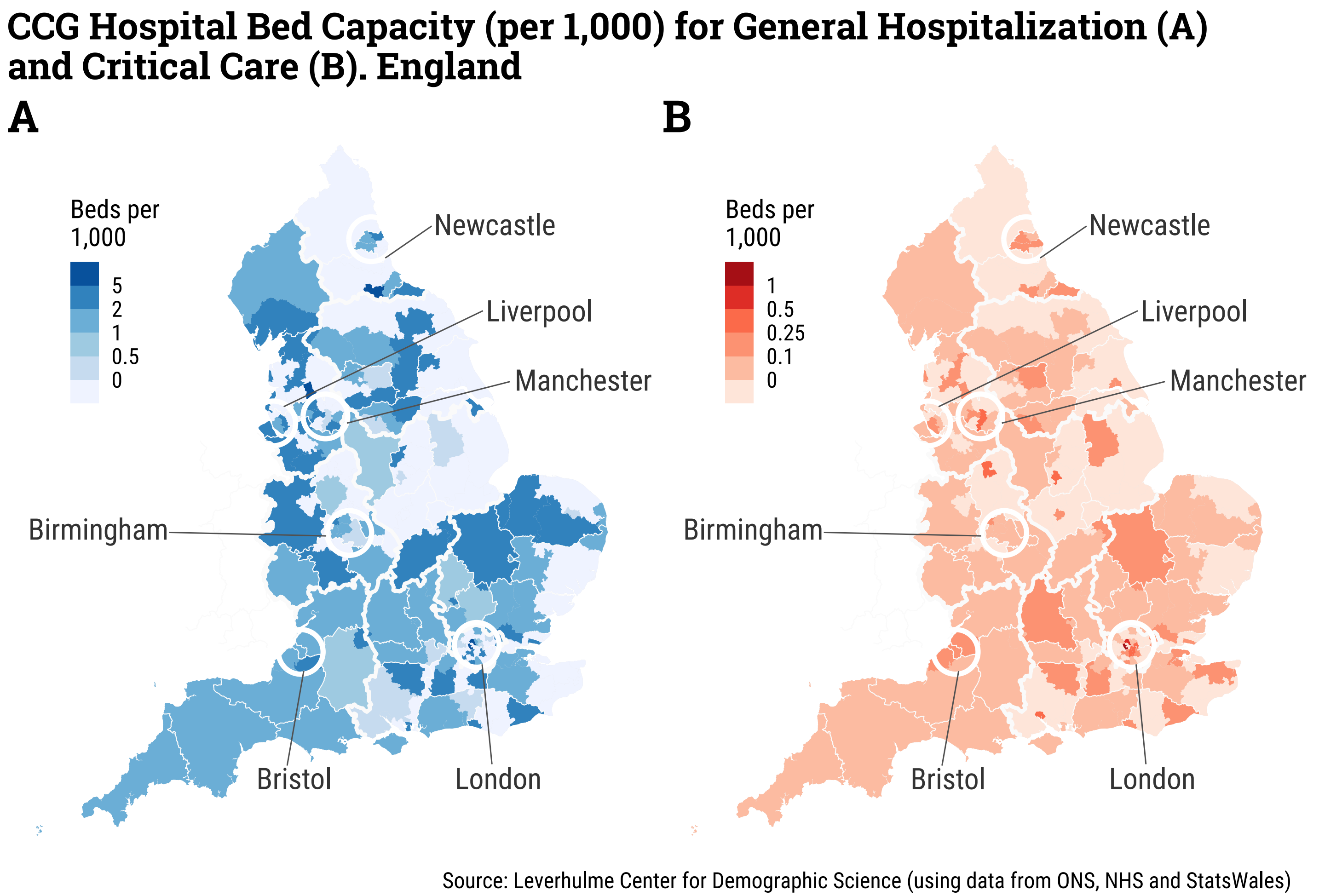

**Figure S3. CCG Expected Hospitalization (per 1,000) in Case of a 10% Nationwide Infection Rate for General Hospitalization (A) and Critical Care (B). England**

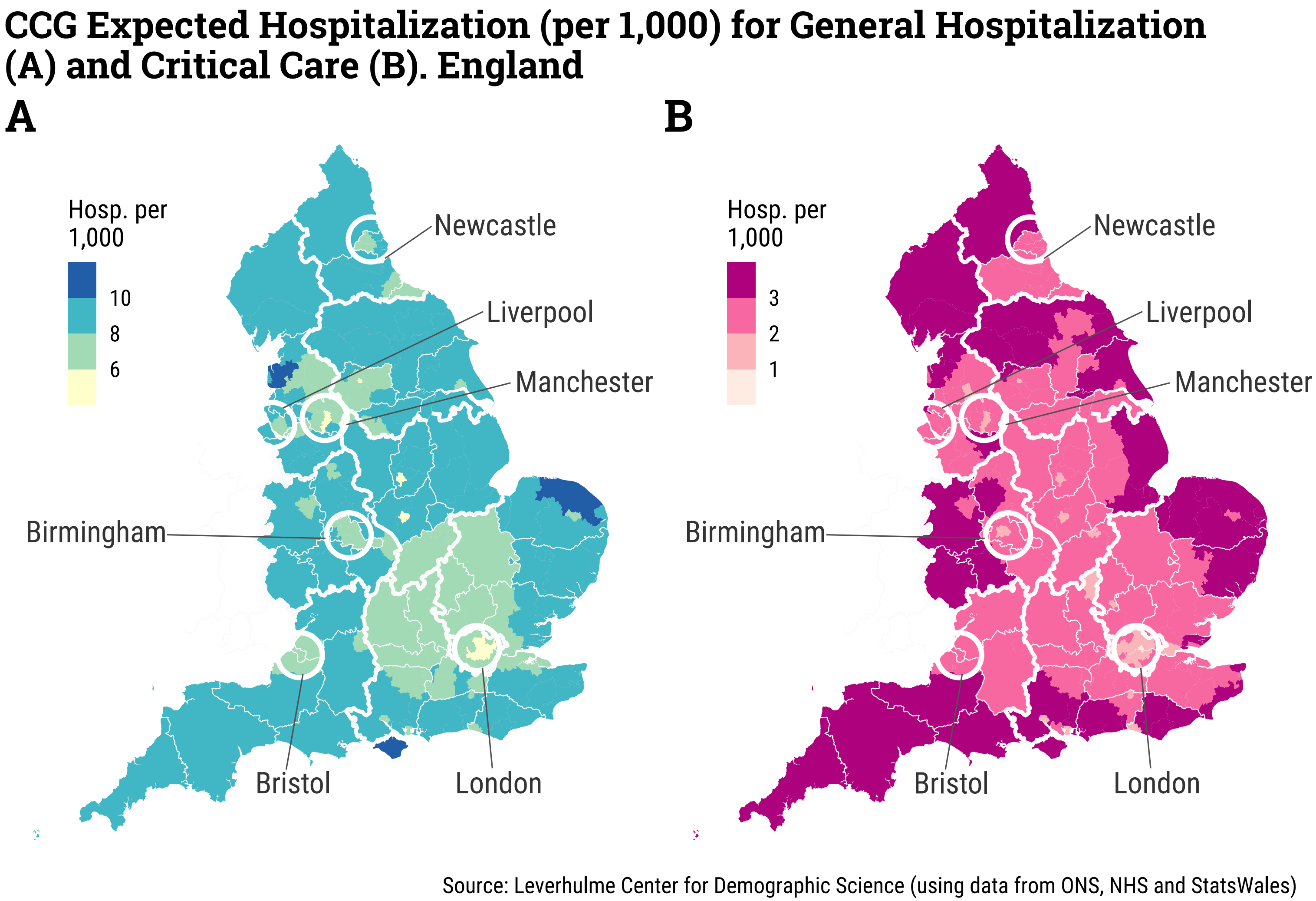

**Figure S4. CCG Excess Need for Hospital Beds (per 1,000) in Case of a 10% Nationwide Infection Rate for General Hospitalization (A) and Critical Care (B). England**

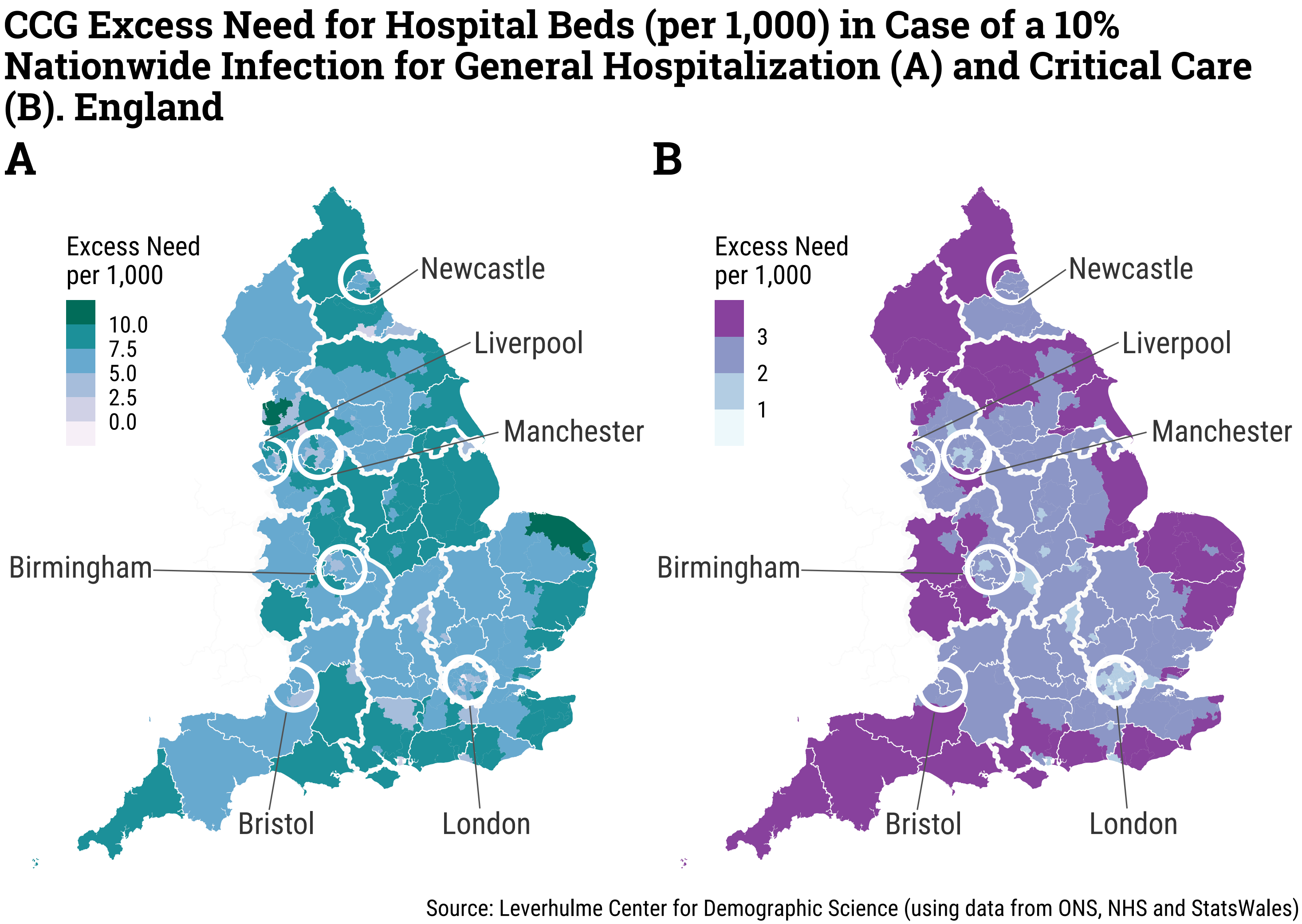

**Figure S5. Local Expected Hospitalization (per 1,000) and Hospital Capacity in Case of a 10% Nationwide Infection for General Hospitalization (A) and Critical Care (B) and Local Hospital Capacity. Wales**

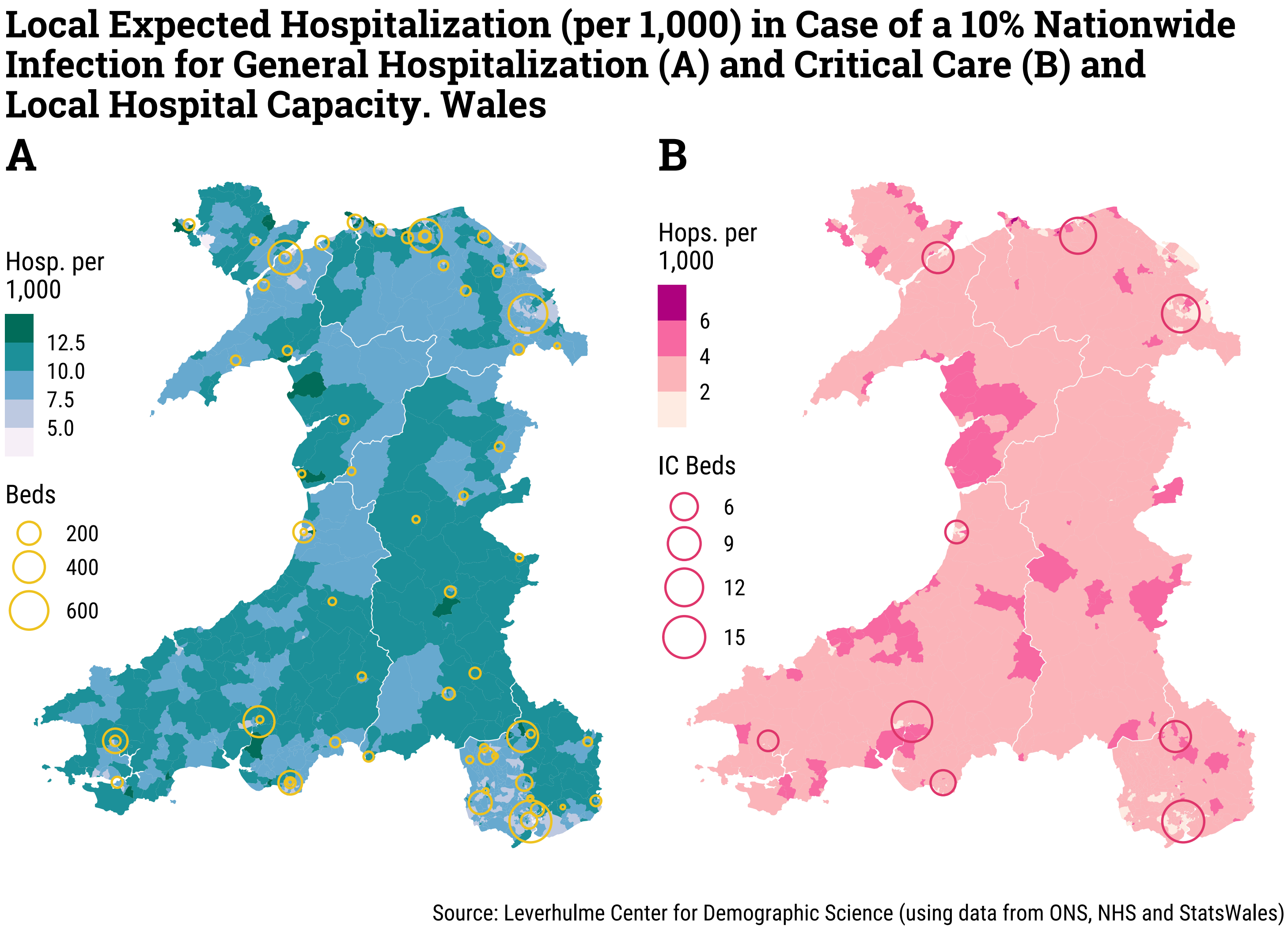

**Figure S6. CCG Tipping Point of Infection for General Hospitalization (A) and Critical Care (B). England & Wales**