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Multidisciplinary Insights into Health Care Financial Risk and Hospital Surge Capacity, Part 1

Nearness to Death, Infectious Outbreaks, and COVID-19

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Abstract

This series introduces epidemiological and medical concepts into understanding why health care costs and capacity pressures can be so volatile. COVID-19 is used as an example for many of the principles. The role of the nearness to death (NTD) effect in healthcare demand is discussed in relation to acute hospital bed utilization in U.S. states. The effect of the COVID-19 epidemic on international hospital capacity pressures is illustrated as the ratio of COVID-19 deaths per 1,000 hospital beds. Acute bed occupancy in U.S. states is compared using a new method for international bed comparison, revealing low bed occupancy relative to other developed countries. No relationship can be discerned between available nursing home beds and acute bed occupancy in U.S. states. COVID-19 deaths per 1,000 acute beds in U.S. states are also compared, along with a similar comparison with London in the UK. To illustrate the role of spatiotemporal granularity in infectious outbreaks the spread of COVID-19 through U.S. states is compared at county level. At the 16th October 2020, some 39% of U.S. counties have experienced less than a 2% increase in total deaths due to COVID-19, while just 15 cities (0.5% of counties) accounted for over 27% of COVID-19 deaths. By the 9th December, some 130 U.S. counties had not had a single COVID-19 death. The role of population density in the spread of epidemics is illustrated using COVID-19 and discussed in relation to both financial risk and hospital surge capacity. Los Angeles, a high population density city, implemented strict public health measures and initially reduced deaths by around 5- to 10-times compared to other similar high population density cities. Should health insurance policies be weighted according to small-area population density? This study raises questions, such as, does the health insurance underwriting cycle have a hidden infectious basis? Is the need for complex financial instruments in health care the outworking of our lack of fundamental understanding in this area? How big should an autonomous Health Authority or Health Insurer be to minimise financial risk? These and other issues will be discussed in the Parts 2 to 4 of this series.

Key Points

- The nearness to death effect has been recognized for over 40 years but has rarely been incorporated into health care demand and cost models, especially at local level
- Occupied acute and nursing home beds in U.S. states are compared using a new method of international bed comparison
- The surprisingly slow spread of COVID-19 through U.S. counties is demonstrated, with rapid spread occurring first in large cities and towns – as was observed for measles epidemics
- COVID-19 has demonstrated the key concept that any agent capable of killing people will also hospitalize many more who go on to recover
- A count of deaths can be used as an approximate measure of the interrelated morbidity/mortality issues in health care cost and capacity issues
- Population density is a key concept in infectious disease transmission, which increases costs and capacity pressures – however is a neglected variable in financial and capacity planning and associated volatility

Introduction

Over a 30-year career in health service capacity planning and associated demand and cost forecasting, I have been aware of the serious limitations of current models and have sought to find alternatives which work in the real world. Health care is a complex system often described as comprised of "wicked problems" (Lindsey 2018, Keijser et al 2020). In such a system, multidisciplinary insights are essential.

In this series of four studies, multidisciplinary insights into the interlinked issues of financial risk in healthcare costs and hospital size and surge capacity are presented. The COVID-19 pandemic is the ultimate example of the need for hospital surge capacity and of volatility in costs, however because of the spatial characteristics of infectious outbreaks the cost and capacity pressures are localized to different places at different times. The early work of DeLia and co-workers (DeLia 2005, Delia and Wood 2008) on hospital surge capacity is relevant.

Firstly, we will look at issues of hospital size and then issues of financial risk – which will also be covered in Part 2 where population density and infectious outbreaks are discussed in greater detail. Part 3 will investigate competition between pathogens and if outbreaks of a new type or kind of disease are concealed in the trends, while Part 4 will establish the size required in autonomous regions to achieve minimum financial risk.

Hospital Size

The current models for determining the size of a hospital can be manipulated to give almost any answer (Jones 2019a). This led to the development of a new tool for comparing intra- and inter-national bed numbers (Jones 2018, 2019b, 2020a,b, 2021a). This method relies on the operation of the nearness to death (NTD) effect in which up to 55% of an individual's bed occupancy occurs in the last year of life (Hanlon et al 1998) and is roughly independent of the age at death (Dixon et al 2004). Economists have recognised the NTD effect for over four decades (Payne et al 2007, Caley and Sidhu 2010), but it has never been incorporated into routine health care demand and capacity planning or to understanding local cost volatility.

Hence, the absolute number of deaths (rather than age-standardized mortality) is a key component of both demand forecasting and capacity planning. This component of demand can be visualized in the Y-axis of a graph as the ratio of the number of hospital beds (or nursing home beds) per 1,000 deaths. The new method also has a component of demand in the X-axis, which is sensitive to total population, however, this is represented as the ratio of deaths per 1,000 population which is commonly called the crude mortality rate. Older or more deprived populations will have a higher crude mortality rate and will therefore have a higher proportion of end-of-life care and vice versa.

This model successfully quantified a deficiency in beds in the state of Tasmania in Australia (Jones 2019a), has shed light on bed provision in U.S. states (Jones 2020a), and after adjustment for deprivation gives remarkable consistency between English Clinical Commissioning Groups (CCG) which cover a defined population somewhat like a Health Maintenance Organization (HMO) in the U.S.A. (Jones 2021a).

The ability of such a simple model to perform so well in the real world immediately leads to the question why? The explanation seems to lie in a related observation that periods of unexplained higher deaths are always associated with periods of unexplained higher medical admissions (Jones 2020b), i.e., mortality is also acting as a wider indicator of morbidity. The mortality/morbidity pyramid is a well-recognized concept (Duckett 2001) which is exemplified by infectious outbreaks of both influenza and COVID-19. In both instances many people are infected and experience varying degrees of symptoms without the need for hospitalization, some require hospitalization, and a smaller proportion die (Troeger et al 2019, Wang et al 2020). This is investigated in greater detail in Part 4.

This study will illustrate the usefulness of the ratio of COVID-19 deaths per 1,000 hospital beds to compare hospital capacity pressures between countries, update the comparison between U.S. states in the light of the more recent surge in COVID-19 infections, and investigate potential capacity pressures using U.S. county-level data. Finally, implications to future medical group capacity planning will be discussed.

Financial Risk

At the same time, I have also grappled with the related issue of financial risk in healthcare costs/income, and especially why income/costs and admissions are so volatile. It seems that the NTD effect and wider associated morbidity is largely responsible for this volatility (Part 4). This volatility also reflects in the hospital occupancy margin and surge capacity during epidemics (Jones 2011b,c). The key point is that volatility is both size and location specific.

To explain location-specific volatility, we must consider epidemiological concepts such as infectious granularity, i.e., unequal spread in time and space, and the consequences of traveling infectious waves and spatial hierarchies. Small-area population density is a key concept. Before returning to financial risk, I will use the role of the NTD effect to compare capacity pressures between countries and locations arising from the COVID-19 pandemic.

International Comparison

Widely reported COVID-19 deaths per 1,000 population is an entirely misleading statistic since the risk of death and hospitalization shows a logarithmic increase with age (Promislow 2020). See Appendix 1 for the percentage of excess COVID-19 deaths relative to 2020 forecast deaths in the absence of COVID-19. This is the way in which COVID-19 deaths should be reported for accurate statistical analysis and comparison between regions. Data will be an underestimate.

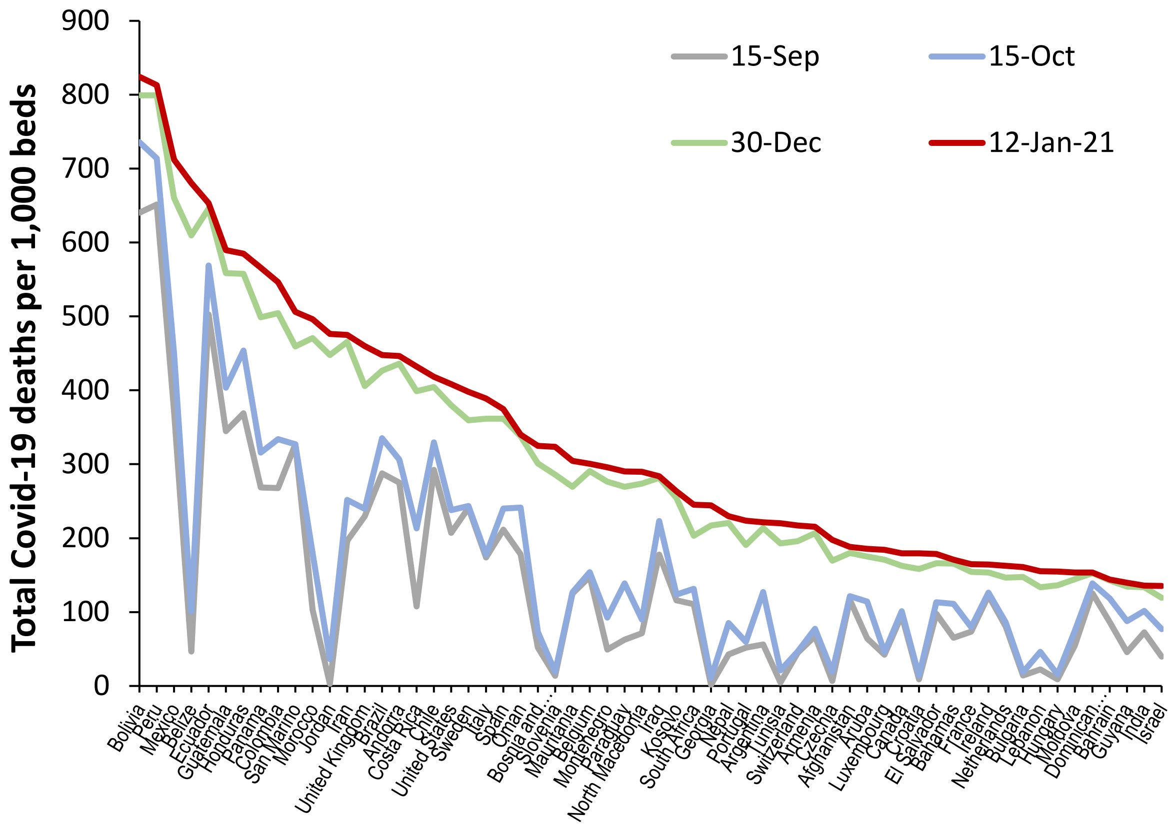
Using a similar approach to relevant ratios, COVID-19 deaths are a good proxy for hospital capacity pressures. In the absence of international data relating to the number of persons hospitalized due to COVID-19 plus the wide availability of COVID-19 deaths mean that health care capacity pressures must be approximated by the ratio of deaths per 1,000 beds. While such a comparison is not perfect it is pragmatic.

Figure 1 presents a comparison for the 50 countries with the highest ratio of COVID-19 deaths per 1,000 total beds. COVID-19 total deaths were those reported on 17th October 2020 via Bing.com, while total beds in each country were calculated from available data (Jones 2018) prior to the COVID-19 outbreak. Total beds include mental health, maternity, and acute beds simply because these figures are available on an international basis.

South American countries have the highest deaths per 1,000 hospital beds. The presence of San Marino and Andorra are special cases. San Marino is a micro-State with a population of just 34,000 which is surrounded by Italy (Expatfinder.com 2020). Wider health care will be provided in nearby Italian hospitals and the ratio of deaths per 1,000 hospital beds will therefore be an over-statement of the real situation. Andorra is another micro-state with a population of just 77,000 bordered by France and Spain. As with San Marino, wider healthcare will be provided in nearby hospitals in Toulouse and Barcelona (Andorra Guides 2020).

African countries are conspicuously absent from Figure 1 simply because they have young populations. Hence while COVID-19 infections may be high, hospitalization and death will be lower than in Western countries with older populations. This is because the risk of hospitalization and deaths due to COVID-19 rises logarithmically with age (Promislow 2020).

Figure 1: Official cumulative COVID-19 deaths per 1,000 hospital beds (acute + mental health + maternity) at various dates through to January 2021. Top 60 countries.

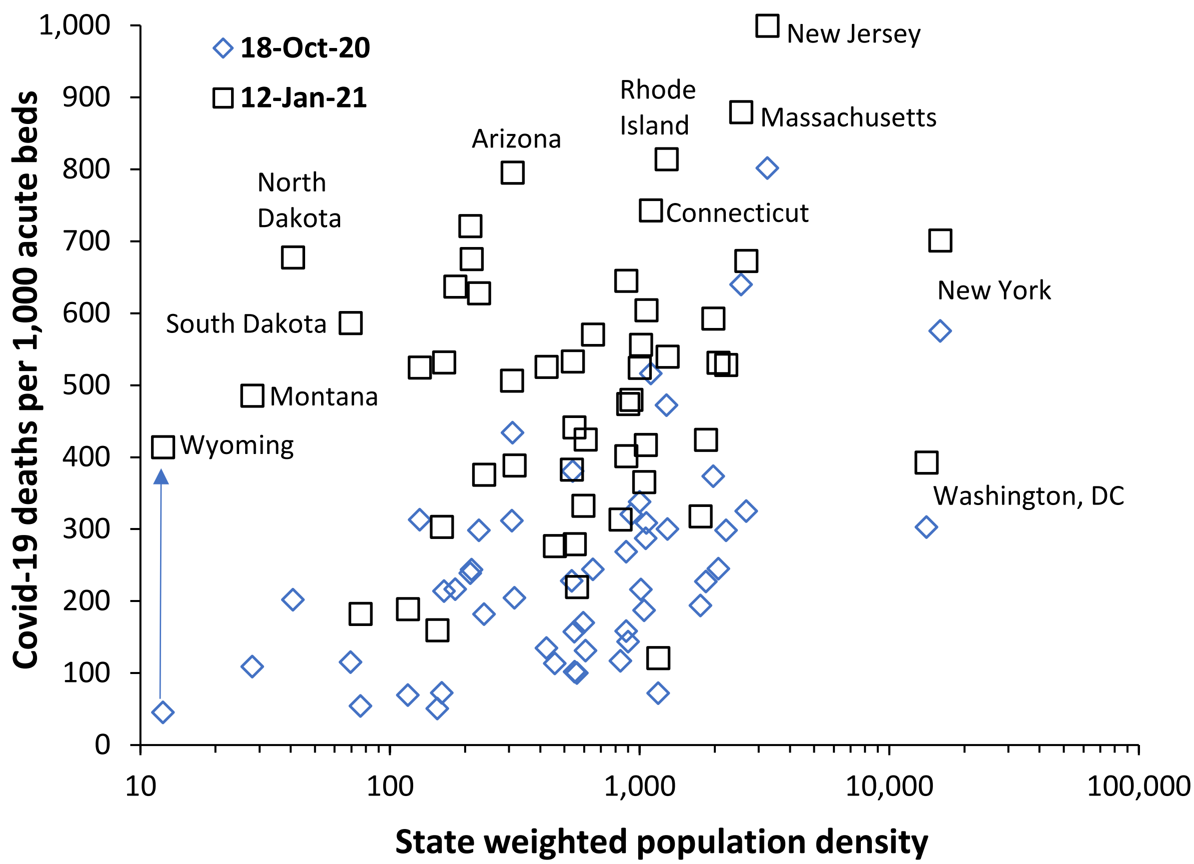


The highest European country is the United Kingdom where deaths are concentrated in London (high population density). A national lockdown was imposed by the government on the 24th of March 2020. Capacity pressures in London were far higher than for the UK average. In the UK, all routine surgery ceased, and some 2 million operations were cancelled from mid-April to June (Matthews 2020). Sweden now lies after the United States. Sweden was notable for its early relaxed approach to the state imposition of protective measures (Savage 2020). High COVID-19 deaths in care homes is an international problem (Comas-Herrera et al 2020). The international average is that 46% of total COVID-19 deaths have occurred in care homes. This illustrates the important role of frailty and NTD.

Which U.S. states have faced highest capacity pressures?

The international comparison in Figure 1 can be repeated for U.S. states and this is given in Figure 2. Figure 2 uses acute hospital bed numbers rather than total hospital bed numbers in Figure 1 and total COVID-19 deaths on 18th October 2020 and 12th January 2021. Since deaths escalate in an exponential or explosive manner as the outbreaks gains hold the count of total deaths is a good approximation to the capacity pressures at the peak death rate in each state. Available acute beds are for 2019 before the COVID-19 epidemic. Clearly, bed capacity was subsequently hastily increased, however, the comparison is useful. See an earlier publication regarding weighted population density (Jones 2020a) and later sections regarding the wider role of population density. As can be seen these capacity pressures change over time as COVID-19 takes hold in different counties in each State and will manifest at county level.

Figure 2: Acute hospital capacity pressures as COVID-19 deaths per 1,000 acute beds versus state weighted population density (18th October 2020 and 12th January 2021)



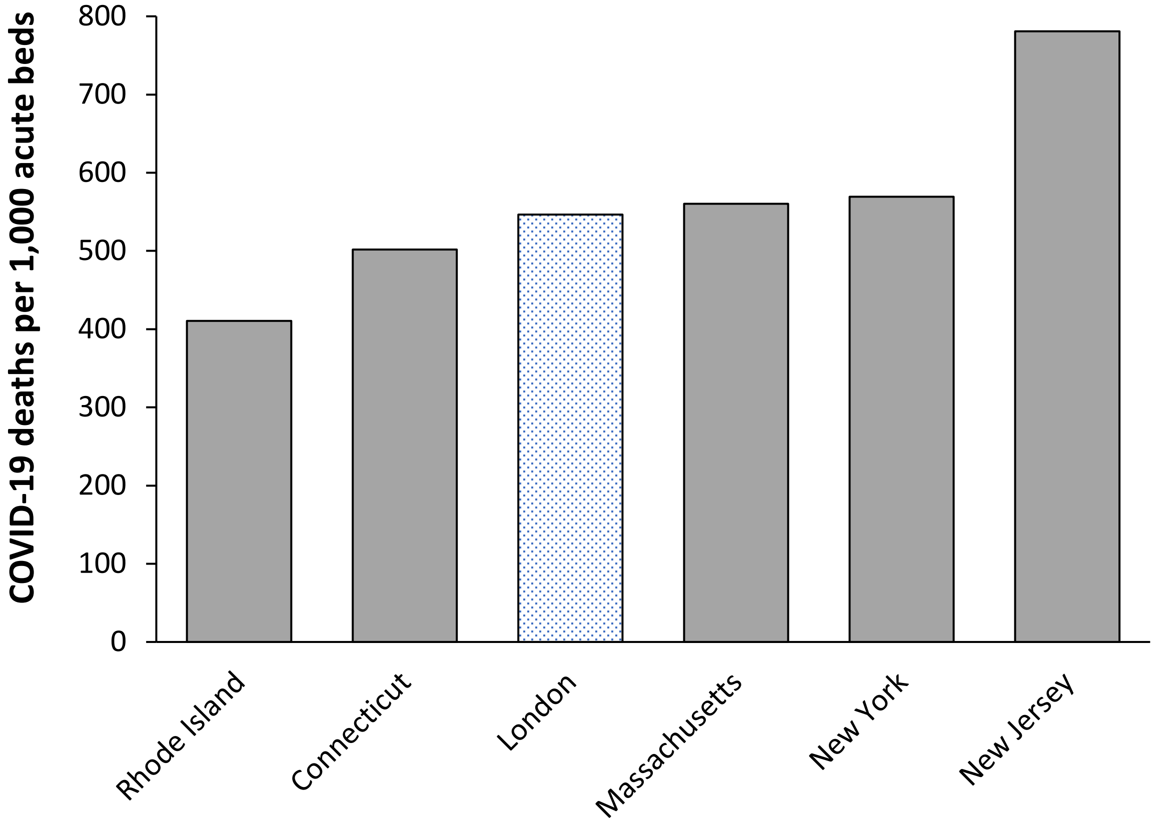
Washington DC does not experience large capacity pressures since it has access to tertiary acute beds which can be diverted to deal with its own population. While New York hit the headlines due early total deaths, it was New Jersey which experienced the greatest capacity pressures. Some of the least populated states have shown the greatest growth since October.

Highest capacity pressure, London versus the USA

This raises the interesting question as to whether London fared worse than U.S. states. In this comparison, a count of the number of available acute beds is for London and U.S. states before the arrival of COVID-19, and Figure 3, therefore, uses the ratio of COVID-19 reported deaths per 1,000 acute beds as a proxy for capacity pressure.

As can be seen, New Jersey was the worst affected U.S. state followed by New York, Massachusetts and then London. In this instance, the capacity shock for London was lessened due to its role as a tertiary center for most of the south of England and hence it has a disproportionate number of both acute and critical care beds. Note the small differences between Figures 2 and 3 due to the earlier date for Figure 2.

Figure 3: Cumulative COVID-19 deaths per 1,000 *acute* beds for London and the five worst affected U.S. states in the early stages of the epidemic on 26th July 2020.



Informal discussion with health service managers based in London was that ventilator and critical care capacity in London hospitals was rapidly expanded. A capacity disaster was narrowly averted by virtue of unprecedented measures which required £6.6 billion of special government funding for the UK NHS to achieve this outcome (Discombe 2020). The more recent January 2021 surge has now overwhelmed London capacity.

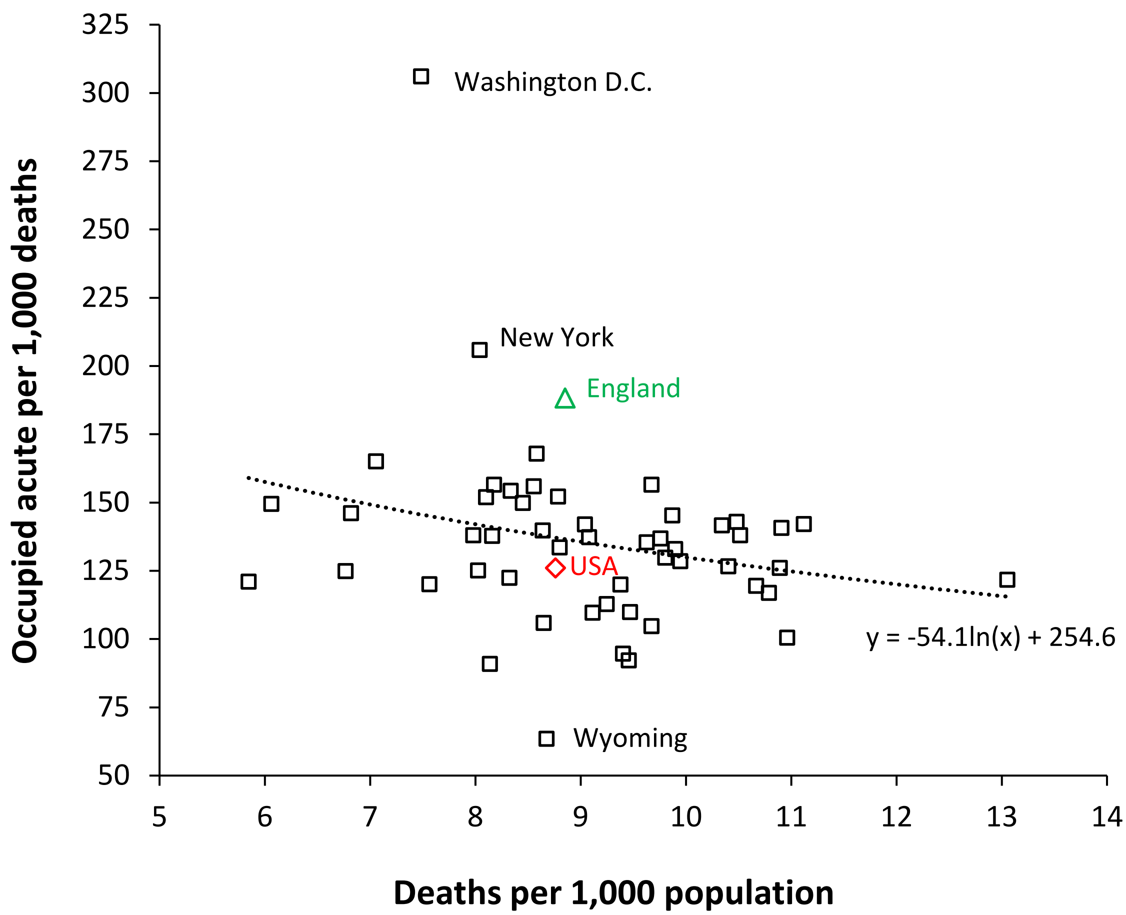
Bed capacity (occupancy) in the U.S. revisited

Earlier analysis of total available beds in U.S. states showed extremely wide variation, however, actual occupied acute beds is a better measure of the expressed demand for acute beds rather than wider bed availability which is greatly influenced by the average occupancy margin. In addition, COVID-19 patients are unlikely to be accommodated in Mental Health or Maternity beds. Data specific to occupied acute beds is available for U.S. states and is presented in Figure 4 for the period before the COVID-19 epidemic.

Figure 4 shows that the use of occupied acute beds rather than total available beds acts to reduce the huge disparity between states which occurs when available total beds are used as the measure of bed supply.

The situation for Washington DC is somewhat like London in that this small administrative territory acts as a major tertiary center for surrounding states (DOC Health 2020), and hence occupied beds include a significant number of beds occupied by non-residents. As can also be seen, New York had a high level of occupied beds per 1,000 deaths prior to the arrival of COVID-19, possibly due to wider poor health in districts of New York such as the Bronx with extremely high population density, poverty, and household crowding, plus associated air pollution. Average bed occupancy was also high (American Hospital Directory 2020), and these factors partly explain why capacity pressures were so pressing when COVID-19 arrived.

Figure 4: Occupied acute beds in American states compared to England, prior to COVID-19



Data for England is also included in Figure 4 to give a comparison with a publicly funded universal healthcare system which is highly bed-efficient (Jones 2018). Occupied acute beds in the U.S. are therefore low, which reflects the fact that the U.S. does not offer universal health care to its citizens.

Do nursing home beds substitute for acute beds?

It has been claimed that nursing home beds can substitute for acute beds. Demand for nursing home beds escalates toward the end of life hence nursing home beds per 1,000 deaths is the relevant indicator. In 2016 the USA had 616 certified nursing home beds per 1,000 deaths, the state median was 517 with a range of 1,071 in Iowa down to 154 in Alaska (National Center for Health Statistics 2020). This is broadly comparable with international levels of nursing home beds (Jones 2021a).

Neither available nursing home beds versus available acute beds per 1,000 deaths or occupied nursing home beds versus occupied acute beds per 1,000 deaths show any correlation (R^2 0.06 and 0.02 respectively). See Appendix 2.

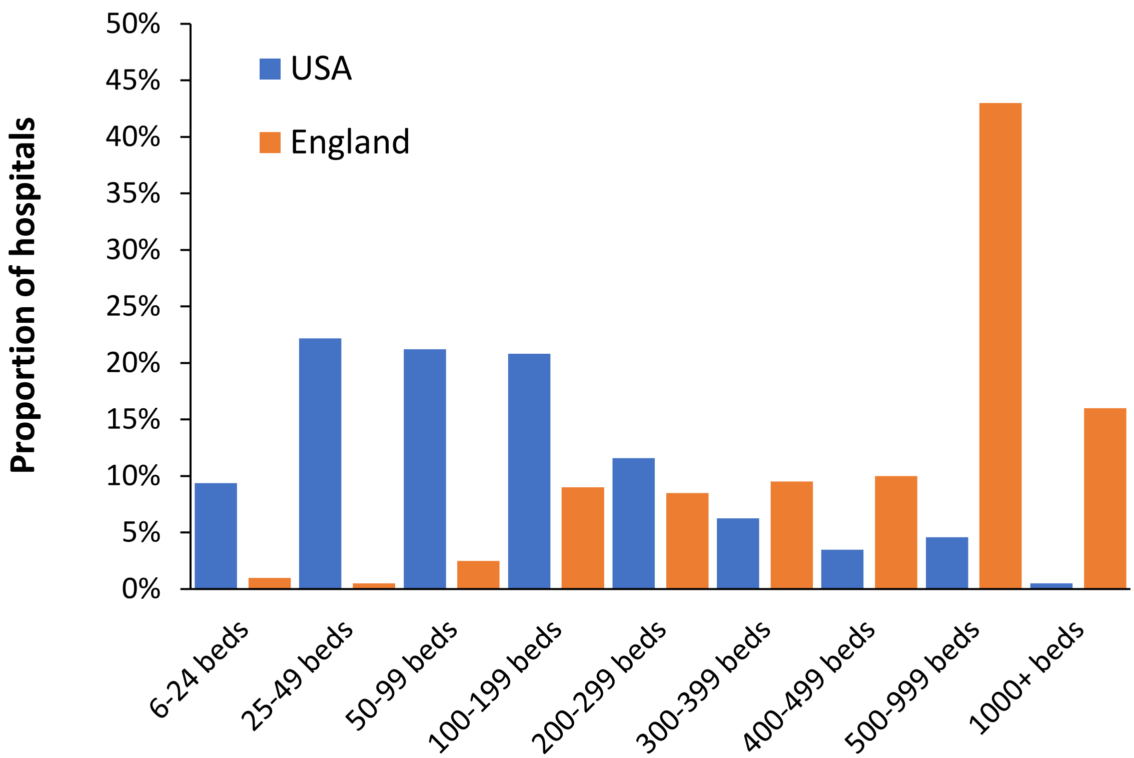
It is perfectly feasible to have more than 1 available nursing home bed per death, as in Iowa, since surplus beds are needed to ensure a bed is available for the next arriving resident. In this respect, the U.S. average for the nursing home occupancy rate is 80%, state median is 82% with a range of 65% in Indiana to 91% in South Dakota (National Center for Health Statistics 2020).

From the available state data, there is no evidence that nursing home beds substitute for acute beds in the USA, and this cannot explain the low bed numbers in some states.

Roles for population density in hospital size and occupancy margin

The U.S. is a large country with relatively low raw population density compared to England (Jones 2013a). High population density implies larger hospitals. Figure 5 shows the relative size of all hospitals (acute and mental health) in the U.S. versus England (adapted from Jones 2011a, 2013a,b). As can be seen, 53% of U.S. hospitals are below 100 beds, while only 4% are below this size in England. Just 5% of hospitals are above 500 beds in the U.S. compared to 59% in England.

Figure 5: Comparison of the size of U.S. versus English hospitals

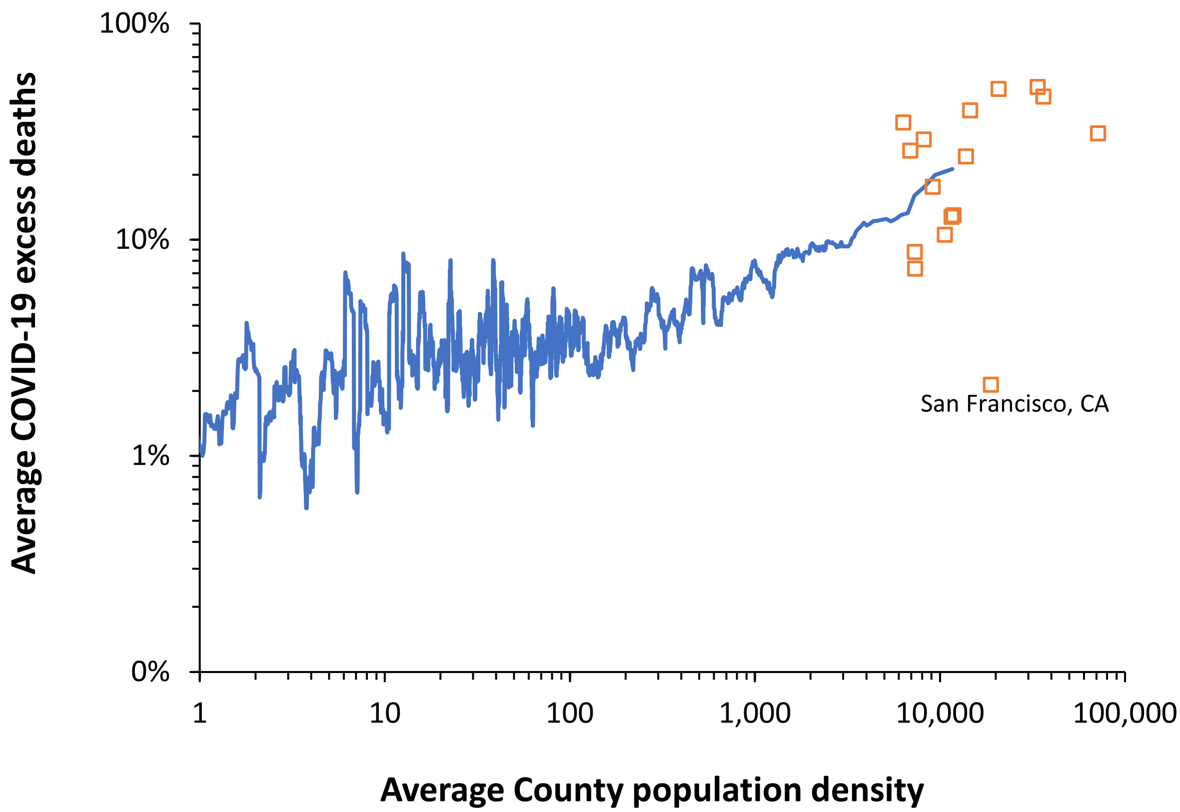


Due to high population density, English hospitals can reap the benefits of economy of scale, while U.S. hospitals cannot (Jones 2013c). The sustainable average bed occupancy margin rises rapidly with size. Hence, assuming all beds are equally accessible, a 50-bed hospital can operate at 65% average occupancy, 75% for 100 beds, 83% for 200 beds, 89% for 500 beds, and 93% for 1,000 beds (Jones 2011a, Kakad et al 2019, Proudlove 2020). Clearly, subdivision of beds into specialty pools limits these occupancies, however, the point is that for the vast majority of U.S. hospitals small size imposes higher capital costs per patient, plus higher staff costs per patient (Jones 2013c). For these and other reasons rural and remote hospitals in England have fared the worst financially during the COVID-19 epidemic, despite lower levels of infection (Palmer and Rolewicz 2020).

Wider roles for weighted population density

Infectious outbreaks rely on person-to-person transmission which will occur more frequently in crowded locations. Small-area population density is, therefore, a good proxy for the frequency of person-to-person transmission. This reality is illustrated in Figure 6 where data for over 3,100 U.S. counties has been used to create a rolling average (comprising 30 counties), with counties ranked by raw population density (population divided by county land surface area). While raw population density underestimates weighted population density (R-bloggers 2017), this is still a useful comparison.

Figure 6: Average COVID-19 excess deaths in U.S. counties versus the average population density (rolling average of 30 counties ranked by population density) up to 16th October 2020



As can be seen, excess deaths due to COVID-19 rise slowly from an average of 1% at 1 person per square mile up to 3% to 4% at 100 persons per square mile, and then rapidly increasing to an average of 20% excess deaths at 10,000 persons per square mile, etc.

The reason that the 30-county rolling average is volatile is that high COVID-19 deaths occur in some less populated counties due to the chance presence/arrival of an infected person at community events such as weddings or other social gatherings and/or to the presence of large nursing homes (Comas-Herrera et al 2020). In this respect note that as of 16th October 2020 some 416 counties had yet to report any COVID-19 deaths, while a further 285 had reported only 1 COVID-19 death. Some 723 (23%) of counties had less than 1% excess deaths from COVID-19, and 1,206 (39%) had less than 2% excess deaths, i.e., large parts of the USA have been so far relatively unaffected by COVID-19. Just 15 counties (cities) account for over 27% of total COVID-19 deaths.

Small-area population density has also been demonstrated to play an important role in COVID-19 transmission in Japan (Rashed et al 2020), the United Kingdom (Jones 2020), and crowded micro-spaces such as cruise ships (Rocklov and Sjogin 2020). Clearly population density is only a part of wider social, economic, and political factors (Carozzi et al 2020).

The reason that San Francisco in California is an apparent outlier, while Los Angeles also in California is not, is discussed in the next section.

Traveling infectious waves and spatial hierarchies

The National Press and scientists are constantly indicating that a large second wave is coming. The seminal paper by Grenfell et al (2001) "Traveling waves and spatial hierarchies in measles epidemics" gives a perfect description of the international spread of COVID-19, and a potential answer to the question as to whether we will all be engulfed in the 'second' wave.

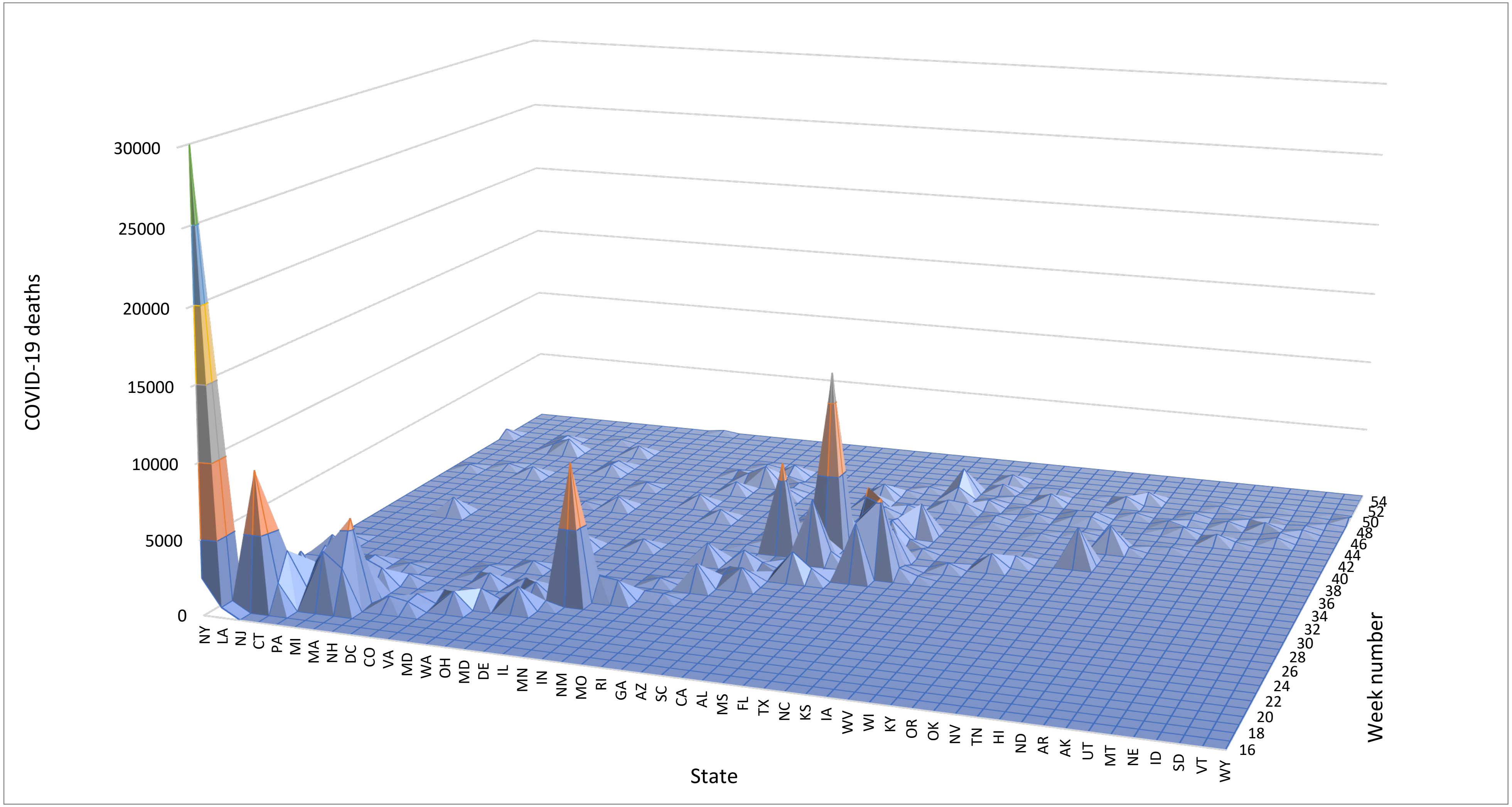
No epidemic arrives in all places simultaneously and when it does arrive there is considerable granularity with one area seemingly affected far worse than those nearby. This is due to chance and spatial population structures (Yang et al 2016). Hence measles epidemics were observed to affect large cities first followed by smaller towns, etc (Grenfell et al 2001). Figure 7 investigates this spatiotemporal (space-time) behaviour of COVID-19 using cumulative COVID-19 deaths data for U.S. counties on 11th January 2021.

COVID-19 outbreaks generally follow a sigmoidal shaped pattern of cumulative deaths. The mid-point in the sigmoidal relationship usually occurs close to the exponential or explosive part of outbreak. Data in Figure 7 was up to the 11th January 2021, hence, at this point Kings county in New York had 7,540 cumulative COVID-19 deaths. The mid-point is therefore 3,770 deaths which occurred on the 19th April 2020. The first death was reported on the 14th of March. This is repeated across all counties, although the data in Figure 7 is restricted to either the largest 5 counties in each state, or counties with over 200 COVID-19 deaths for the larger states.

Figure 7 is designed to illustrate a single moving wave as it travels throughout the USA. As can be seen in Figure 7 deaths are dominated by outbreaks in large cities, especially so by early and large outbreaks in the high population density counties of New York and the Orleans and Jefferson parishes in Louisiana. A large outbreak occurs in Cook County, Illinois at a mid-point on 14th May (week 20), a larger outbreak with a mid-point of 1st July (week 27) occurs in Los Angeles, California, etc. A significant later cluster occurs in the states of California, Florida, Texas, North Carolina, etc around August. Outbreaks occur in Utah and Montana (week 44), Nebraska and Idaho (week 45) and South Dakota (week 46) Kansas, Nebraska, South Dakota and finally in Vermont and Wyoming (weeks 49 and 50). The larger cities are usually, but not always first

Recall from the section above that a significant proportion of counties only had minimal levels of COVID-19 deaths at mid-October. See Appendix 3 for a similar chart with earlier data up to mid-October. The data in Appendix 3 extends down to counties with fewer than 200 COVID-19 deaths.

Figure 7: Date for the mid-point of COVID-19 cumulative deaths in U.S. counties, grouped by state and week when explosive growth in deaths occurred (cumulative data to 11th January 2021)



Hence, strictly speaking there is no 'second wave' (except when artificially generated by lockdown) just the continuous spatiotemporal movement into new communities. From New York, there is no evidence that deaths are rising steeply in recent times, i.e., once a maximum amplitude wave has swept through there is no second wave. A seeming 'second' wave for the total USA is merely an artifact of the spread of the virus through larger cities and towns as observed in the measles epidemic study (Grenfell et al 2001) and seen in Figure 7 which are clustered around weeks 16 to 22 and weeks 28 to 34. After week 38 the explosive part of the outbreak has finally reached the lower population density states.

Returning to the issue of San Francisco in California as an outlier in Figure 6. San Francisco does not reach its mid-point until 27th August (week 35), but even on 11th January 2021 there are only a cumulative total of 233 reported COVID-19 deaths. However, the trend in deaths in San Francisco have been shaped by multiple lockdowns and strict safety precautions to prevent the spread of COVID-19. Due to these protective measures, there is the beginning of a first major outbreak with a mid-point at the 30th April 2020 (week 18). Had these measures not been implemented San Francisco could easily have had 5- to 10-times more deaths as demonstrated in other cities with similar population density in Figure 6.

Implications to financial risk and surge capacity

This study has demonstrated the important role of small-area population density on infectious disease transmission. It adds to the body of knowledge suggesting that both deaths and medical admissions show location-specific volatility (Jones 2010a-d, Jones 2012a-e, Jones 2019b,c). The medical group of specialties is especially volatile due to seasonal factors and infectious outbreaks (Jones 2011b,c, 2015). COVID-19 has been the ultimate example of such pressure on medical bed availability, including intensive care (Carenzo et al 2020).

Volatile admissions mean volatile costs and consequent financial risk to both hospital and commissioner/payer alike. Infectious transmission is amplified in high population density locations, hence, amplified volatility and location-specific volatility (Jones 2012a-e).

In England, the process for NHS hospitals to gain approval for a new build requires treasury approval based on 'affordability'. This process implies that hospitals are generally built smaller than before with medical bed numbers suffering the greatest reduction. This is the exact opposite of the real-world need dictated by infectious outbreaks.

There are also major implications to the financial risk inherent in the national funding formulae which are used to distribute funds to states, regions and individual commissioners. See the link to further studies regarding risk sharing just before the references. This issue is examined in greater detail in Part 4 and in a recent study relating to the funding formula for English commissioning groups (Jones 2021b).

In the post-COVID world hospitals need to be built with maximum flexibility in mind to balance capital costs with the need for more medical beds as contingency arises.

The health insurance underwriting cycle

Most will be aware of the health insurance underwriting cycle (Gabel et al 1991, Grossman and Ginsburg 2004, Rosenblatt 2004, Born and Santerre 2008). This cycle has never been adequately explained and may have unintended consequences along with the pricing regulations in the Affordable Care Act (Frech and Smith 2015). Few will be aware that a similar cycle operates in the English NHS where the vagaries of insurance are absent (Jones 2010a-d). Outbreaks of a new type or kind of infection, possibly due to a common virus, have been proposed as a likely source of the observed cycle (Jones 2010a-d, 2015). Do we really understand the full impact of infectious outbreaks, especially since many will be due to non-reportable pathogens, i.e., they are going under the radar of public health surveillance? Part 3 is relevant to a potential infectious basis for the health insurance underwriting cycle.

Conclusions

How many beds do we need for optimum efficiency has been the 'Holy Grail' of the healthcare industry for many years? A recent study has suggested ways in which the current models need to be adapted (Jones 2021b). There is also an additional need for surge capacity in the event of a major disaster or pandemic such as COVID-19 (DeLia 2005, Helman & Kollek 2020, Carenzo et al 2020, Rathnayke et al 2019). High population density is a source of amplified financial and capacity risk. Should health insurance policies or financial allocation formulae be weighted according to small-area population density? Is the need for complex financial instruments in healthcare the outworking of our lack of understanding in this area?

The specific issues of population density and the spatiotemporal granularity of infectious spread in relation to financial and operational risk will be discussed in more detail in Part 2. Part 3 will explore interactions between pathogens and how outbreaks of a new type or kind of disease lie hidden in the trends. Part 3 will discuss if evidence for outbreaks of a new type or kind of disease have laid hidden in health care trends while Part 4 will investigate the optimum size for an autonomous health district, HMO or similar.

Data sources

Most data sources are detailed in earlier studies (Jones 2018, 2019a-c, 2020a-c). Additional data sources unique to this study are mentioned in the text.

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Additional reading

The authors wider work on financial risk in healthcare and hospital capacity planning can be accessed via http://www.hcaf.biz/2010/Publications_Full.pdf. Further research on COVID-19 can be accessed at http://www.hcaf.biz/2020/Covid_Excess_Deaths.pdf

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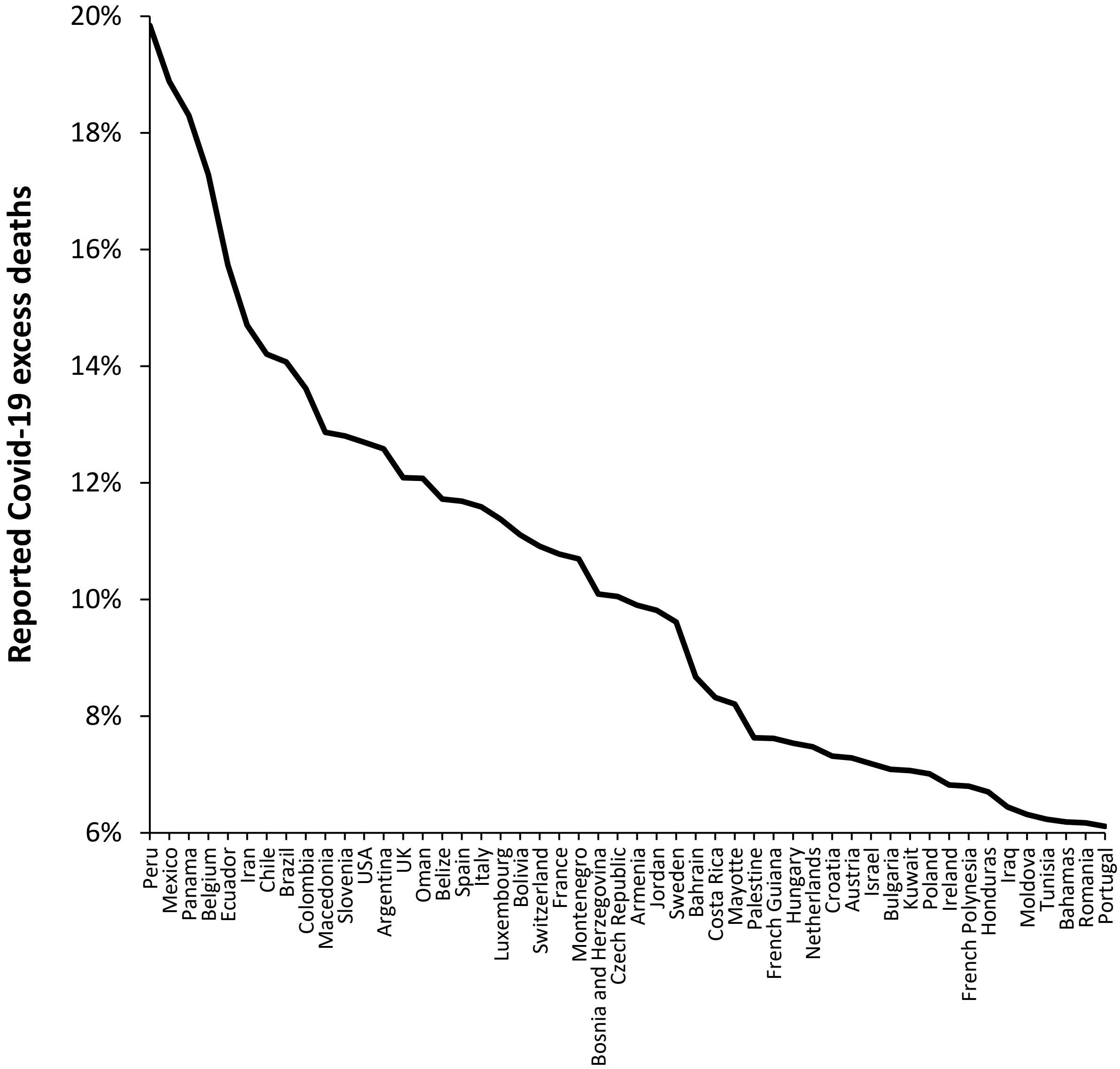
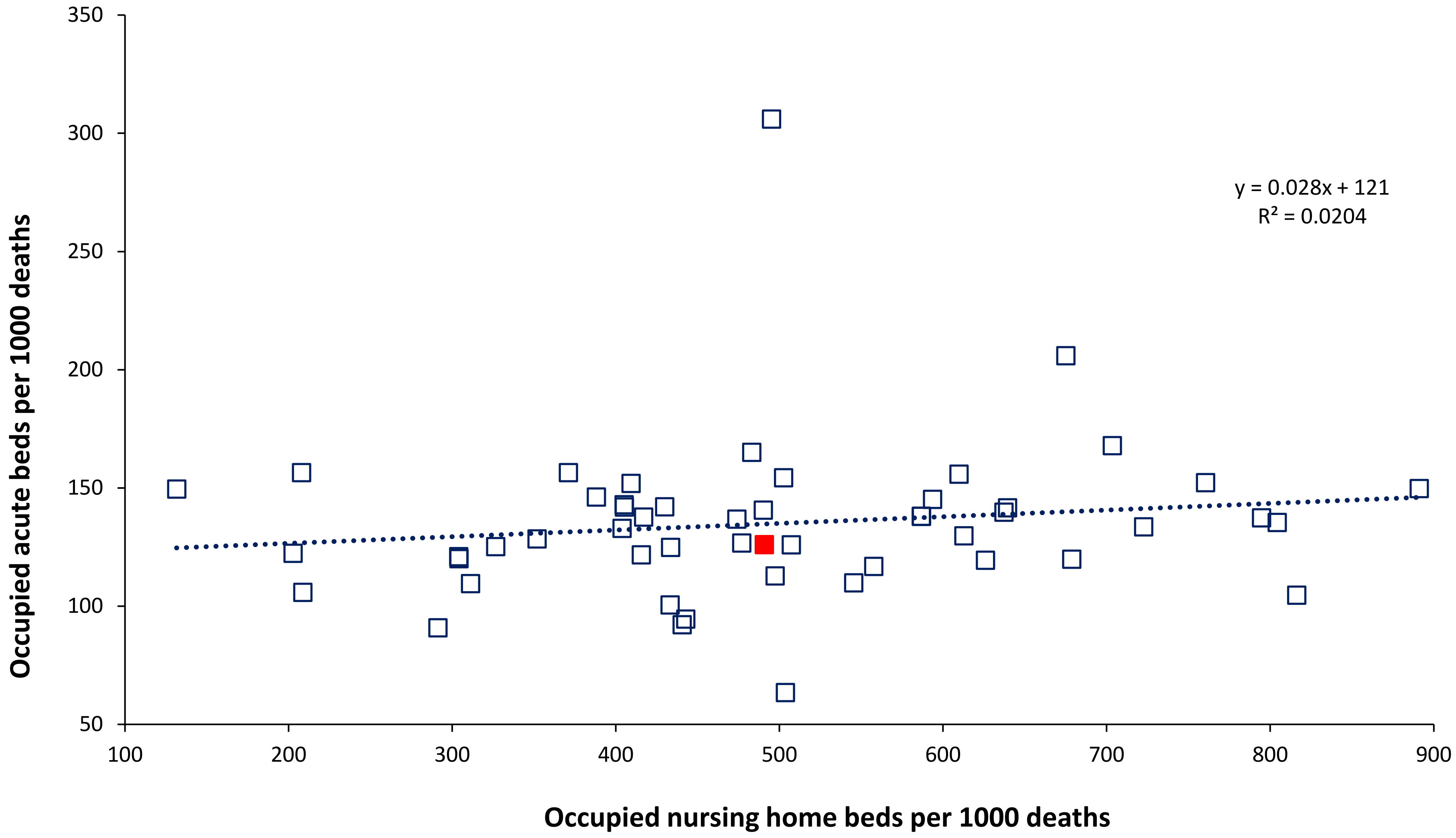
Appendix 1: Reported cumulative COVID-19 deaths as of 31st December as a percentage 'excess' deaths calculation. Baseline annual deaths are those forecast in 2019 in the absence of COVID-19. COVID-19 deaths from Coronavirus Update (Live): 83,842,646 Cases and 1,826,373 Deaths from COVID-19 Virus Pandemic - Worldometer (worldometers.info). Deaths in 2019 are from How many people die and how many are born each year? - Our World in Data



Note that Belgium is a European outlier, however, COVID-19 deaths in Peru, Mexico, Panama, Ecuador, Iran, Chile, etc are likely to be significantly underestimated. All-cause excess mortality is therefore a more reliable figure for the totality of the effects of COVID-19. See http://www.hcaf.biz/2020/Covid_Excess_Deaths.pdf

Appendix 2: No apparent relationship between occupied nursing home beds and occupied acute beds for U.S. states. The value of R squared is too low for the slight slope to have great significance. Red square is the USA average. The high value is Washington D.C.



Appendix 3: An earlier version of Figure 7 in the main text, up to mid-September. View is from behind the moving front. States at the far right have a later date due to the truncating effect of an earlier view of the spread. Data is at a daily level and includes smaller counties than in Figure 7. The moving front has reached half the states by June and then slows down as it reaches the least populated states.