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Geographical variation in COVID-19 mortality and its relationship to social care provision in England

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Exec summary

1. Older people living in care homes are at high risk from COVID-19, and in many countries this population has experienced high mortality rates during the pandemic. Policy responses have developed rapidly in this area. In England, they do so in the context of largely separate systems for long-term social care (LTC) and for NHS health care.
2. There are 11,000 registered care homes (for older people) and 129 acute NHS Trusts in England (as of March 2020). We see substantial variation in the ratio of care homes to Trusts beds across localities in England. For areas in the lowest quartile of this ratio, there are 2.2 care home beds for every General and Acute (GA) bed in the nearest Trust on average. In the upper quartile, there are 8.0 care home beds for every GA bed.
3. The overall aim is to explore the extent to which the need for treatment of (high-risk) COVID-19 patients in the hospital and LTC systems – as indicated by the respective number of COVID-19 deaths – is affected by the supply of care services (bed capacity) in each system (specifically, NHS acute hospitals and care homes), and how far the supply of beds between systems are interrelated in their effect. We also aim to consider how changes in COVID-19 infection rates locally would be projected to change the number of deaths expected in those localities.

Concepts and approach

4. Care homes residents are at high risk of COVID-19 infection and death. This risk could be higher for being in a care home rather than in another care setting (e.g. receiving care at home) – because co-habitation and contact with a higher number of different staff increases the chances for infection. People using social care are at risk due to their underlying health conditions and frailty, and those in care homes are especially so for this reason. On the other hand, being in a care home rather than at home might have a (relatively greater) preventative effect as regards COVID-19 hospital admissions, particularly for people receiving nursing care, thus reducing the relative risk of admission.
5. Overall, it is the *difference* in risk for a resident compared to a similarly frail person living in the community that affects the impact on admissions and deaths of an increase in care home capacity in a locality. On balance, the net effect of additional care home places – that results in fewer frail people in the community – on admissions and deaths could be quite small. At the same time, an increase in the infection rate for the care home population (e.g. the proportion of care homes with outbreaks in a locality) should unambiguously imply a greater number of admissions and associated deaths from COVID-19.
6. Another relevant consideration is the (inter-dependent) capacity effect of care home supply on the availability and use of hospital beds, particularly with regard to the timely transfer of patients who are fit for hospital discharge. Localities with more care homes places might facilitate a higher rate of hospital discharge, other things equal, than localities with fewer care home places, allowing in turn higher hospital admissions. This situation would matter where a Trust was nearing capacity.
7. Overall, although we cannot be definitive, we expect that localities with more care home places will experience greater COVID-19 admissions and hospital deaths than localities with fewer care homes, although the effect could be quite small, and less significant than the impact of an increase in care home COVID-19 outbreak rates in one locality compared to another.
8. Turning to the expected effects of NHS Trust capacity, clearly larger Trusts – as indicated by the number of their GA beds – will be able to admit more COVID-19 patients, other things equal. Deaths in hospital from COVID-19 will be directly related to the number of COVID-19 admissions.

9. Regarding the total number of COVID-19 related deaths of residents *in care homes* in a locality, this will be directly related to the size of the at-risk care home population, which is closely linked to the number of care home beds in that area and to the rate of COVID-19 outbreaks in care homes in the locality. Furthermore, because there are options about where to support people with COVID-19, and in particular a choice between the NHS and the care home sector, in theory it is possible that localities with a high number of GA beds could accommodate earlier admissions of care home residents, and so have fewer COVID-19 deaths in care homes. Nonetheless, Trusts have some option to adjust the capacity that is available for COVID-19 admissions (including those from care home populations), potentially mitigating any such effect.

10. We explored these hypothesised effects by estimating (by Generalised Linear Modelling) the relationship between the (cumulative) number of COVID-19 deaths up to 8 May 2020 (i.e. focusing on the first wave), in both NHS Trusts and care homes, and: (a) the number of (older people's) care home beds and the number of Trust GA beds in the locality (pre-pandemic bed count, as of March 2020); (b) associated infection/outbreak rates; and (c) other control factors.

11. For the hospital Trust COVID-19 deaths analysis, 129 localities were defined where care home supply was linked to each acute Trust in England by summing all care home beds for which the Trust was the nearest in distance (travel-time adjusted). For COVID-19 deaths in care homes, each local authority district (316 LADs) defined the locality, summing care home beds in the LAD. Trust beds capacity was associated on a pro-rata basis to LADs within range (20km) of the Trust, allowing that Trusts can operate across LAD boundaries (with this expressed as a rate per head of LAD population).

12. We assessed deaths until 8 May to coincide with the pandemic's first wave. According to analysis of Public Health England data by the Health Foundation, around the 8 May we saw a flattening off of the cumulative percentage of care homes reporting an outbreak. NHS England reported 22,818 COVID-19 deaths for the 129 Acute Trusts to that time. Care home COVID-19 deaths notified to the Care Quality Commission totalled 8,314 between 10 April and 8 May 2020 for England.

Results

13. The analysis showed, as expected, that the outbreak rate (i.e. the total number of care homes with outbreaks per total care homes (for older people) in the locality) was a significant predictor of COVID-19 deaths in hospital (p-value < 0.05).

14. The overall association between care home beds and hospital COVID-19 deaths, although positive, was not found to be statistically significant at the margin (i.e. for small changes in beds from the England mean). There was some tentative indication that the *average* change in hospital deaths between localities with very low care home beds and those with very high care home beds was significant, but this finding is sensitive to what constitutes 'low' and 'high' (and so to outlier effects). Overall, this result is consistent with there being offsetting factors affecting the relationship, as noted above.

15. We found that the size of the (marginal) effect between hospital deaths and care home outbreaks was affected (positively) by the number of care home beds in the locality (p-value < 0.01, *log-interaction model*). In other words, an increase in the outbreaks rate was associated with a higher (absolute) number of hospital COVIDV-19 deaths in a locality with a high number of care home places compared with a locality with a low number of care home places.

16. Not surprisingly there was a strong positive association between total hospital COVID-19 deaths and the number of Trust GA beds in that locality. There was also some suggestion in the data that the

size of this effect was greater in areas with a high number of care home beds compared to areas with a low number of care home beds (p-value = 0.075). This finding supports the hypothesised inter-relationship of care home and hospital beds in affecting (hospital) COVID-19 deaths. For example, this result would be consistent with arguments that Trusts in localities with a high number of care home places would have on average a higher discharge rate and, therefore, would be able to admit more patients.

17. The range of control variables for population characteristics were highly significant (jointly), indicating strong need effects in addition to supply/capacity effects (e.g. p-value < 0.01 in the main estimation). There was little indication that any remaining variation in hospital COVID-19 mortality rates was systematically correlated at regional level.

18. Turning to COVID-19 deaths in care homes, the analysis also showed that the outbreaks rate was a significant predictor of those COVID-19 deaths of care home residents (p-value < 0.01 for both main models). As expected, care home COVID-19 reported deaths were strongly positively related to the number of care home beds in the locality (p-value < 0.01). This result is equivalent to there being 1 extra COVID-19 related death in care homes in a locality with 55 care home beds greater than the average, other things being equal.

19. In addition, as with deaths in hospital, the positive relationship between care home COVID-19 deaths and care home outbreaks was further increased in effect size in localities with a relatively high number of care home beds (p-value = 0.023). In other words, an increase in the outbreaks rate is associated with a higher (absolute) number of care home COVID-19 deaths in a locality with a high number of care home places compared with a locality with a low number.

20. The estimation showed that the number of COVID-19 related deaths in care homes was not significantly related to the number of GA beds per capita (we found a negative coefficient, but not significant, with p-value > 0.1).

21. The results were used to project COVID-19 deaths in different regions of England on the basis of a change in outbreak rates. Reflecting differences in the number of care home beds and outbreak rates, for example, the South West would be projected to have considerably more deaths associated with care home populations if outbreak rates were at England mean levels rather than at observed regional mean levels. London, by contrast, would be projected to have far fewer deaths in that case.

Discussion and policy implications

22. In this analysis we identified associations between COVID-19 deaths and supply levels. Without being able to fully account for differences in the underlying frailty, risk and infection rates between localities, there are limits on how far we can infer *causal* effects. A number of specific limitations were noted, including: small sample sizes (needed because we use pre-pandemic beds capacity to avoid reverse causation); needing to make assumptions about patient movement between the systems (we linked supply using straight line distance, average speed adjusted, noting the lack of definition of Trust catchment areas); and the potential for differences in the values of key variables, depending on the dataset source (and definitions) being used.

23. The main implications of this analysis are twofold. The first concerns 'need' effects. The number of hospital COVID-19 deaths is positively related to the proportion of care homes with outbreaks, and indeed the size of this effect is greater in localities with a large supply of care home places compared with those with a low supply. Accordingly, we predict that extra demand on hospital beds from an increase in outbreak rates will be greater (in absolute number) in areas with more care home places than areas with a low number, which is to be expected.

24. However, the results were not clear that there is a specific care home supply effect on deaths; that is, where comparatively more people are resident in a care home in a locality – rather than receiving other forms of social care, e.g. home care – we did not find a significantly greater number of hospital deaths, other things equal, at least at the margin (and after factoring out differences in care home outbreaks rates between localities).

25. This result is consistent with the theory that areas with fewer care home places use more of other forms of social care (e.g. home care and informal care), and that the population using these other forms is still at high-risk of severe COVID-19. There may be a difference in both the infection rate and the hospital admission rate between different forms of social care – e.g. higher infection risk in care homes – but this comparative effect on the number of deaths would be less important than an increase in underlying infection rates, which would affect people using all forms of social care.

26. Notwithstanding this point about care home supply specific effects, it is still clear that we need to account for the number of care homes in the area, at least in combination with the rate of care home outbreak rates, as a predictor of hospital admissions and deaths for COVID-19 (and indeed other infections).

27. Second, the results support the hypothesised inter-dependence between care home and Trust capacity (beds) in affecting the number of COVID-19 admissions and deaths – the number of deaths (and so admissions) per NHS Trust bed (at the margin) was greater in areas with a higher number of care home places than in areas with a lower number.

28. Although we can speculate as to the nature of the interdependency e.g. as regards the relative rate of hospital admissions from and (timely/delayed) transfers back to care homes, more specific data on patient flows would be needed to provide greater clarity on this point.

29. Nonetheless, this overall finding has the important implication that capacity choices in both the care home and hospital sectors longer-term should account for supply in the other sector. There are a number of particular implications in this regard. For example: that funding allocations to the NHS and social care recognise and allow for (own and cross-) supply effects in their development and use. Also, that in managing of local care markets, any influence on supply by public authorities should again account for the local ratio of Trust capacity to existing care home (and wider social care) supply. More generally, these results support the current policy drive to create closer coordination between NHS and local authority commissioners and providers.

30. In conclusion, this paper has showed the importance of recognising supply factors and the variation in supply in England, and noting, in particular, the substantially varying ratio of (nearest) care home beds to acute NHS Trusts bed numbers.

31. The results are tentative given the availability of data for this study. Further analysis is needed to isolate the specific effects, and control for underlying need, and population infection rates. A multi-level analysis, with supply measured at the organisational/locality level and flows of patients/care home residents measured at the individual person level, would be ideally suited but this would require comprehensive health and social care linked datasets and these are not currently available. It is recommended that such a dataset be developed.

32. This paper contributes to our understanding of social care supply effects. Given the numbers of people that use care homes (and other forms of social care), and the interdependent use of care home (social care) and hospital care for these populations, especially as regards the impact of COVID-19, this is a priority area for research.

Introduction

Older people living in care homes are at high risk from COVID-19, and in many countries this population has experienced high mortality rates during the pandemic (Comas-Herrera, Zalakaín et al. 2020). Policy responses have developed rapidly in this area. In England, they do so in the context of a separate system for long-term social care (LTC) and for health care, the former mainly a local government and private responsibility and the latter being organised as the National Health Service (NHS). There have been significant strides in recent years in policies to promote greater joint working and coordination between the systems, recognising the interdependencies. In this regard, we expect the experience of the COVID-19 pandemic to further confirm the importance of partnership working and coordination between the health and social care systems.

The overall aim of this paper is to explore the extent to which the need for treatment of (high-risk) COVID-19 patients in both the hospital and LTC systems – as indicated by the respective number of COVID-19 deaths of people needing care – is affected by the supply of care services (bed capacity) in each system (specifically, NHS acute hospitals and care homes), and how far the supply of beds between systems are interrelated in their effect. We also aim to consider how changes in COVID-19 infection rates locally would be estimated to change the number of deaths expected in those localities.

In considering this question, an important observation is that care homes are not uniformly located across England and the number of beds in those homes closest to each acute NHS Trust differs across the country.

There is now well-documented evidence that people with high-level care needs, such as people in care homes, are at significantly higher risk that a COVID-19 infection will be severe, with an increased risk of death (Bell, Comas-Herrera et al. 2020). These patients will potentially need hospital level treatment, and there is evidence about those patterns of hospital admissions and discharge by care home residents during the pandemic (Hodgson, Grimm et al. 2020). The main contribution of this analysis is to estimate the links with local care home supply. The findings can help in accounting for the interdependency between the systems. In particular, the potential number of patients at risk of hospitalisation, as influenced by the supply of care home beds in the locality, need not coincide with the existing (pre-COVID) levels of hospital bed supply. Hospital supply can and was adjusted in a number of ways, such as the suspension of elective care, adjustments to bed numbers etc., capacity projects such as Nightingale hospitals, and more generally, funding and capital allocations and infrastructure can be adapted to change local capacity. Estimates of the scale of this care home supply effect can inform decisions about these adjustments.

An indicator of the number of 'high-risk' patients in any locality is the number of people who have had a COVID-19-related death[1]. We hypothesise that numbers of COVID-related deaths in each locality in England – in hospitals and in care homes – will be affected by the respective supply of beds in both systems and the rate of infections locally.

There are just over 11,000 care homes in England registered with the regulator, the Care Quality Commission (CQC) (as of March 2020) with older people as the primary resident group. Together they provide 412,000 care home places for older people. In this analysis, we focus on the 129 acute NHS Trusts in England (as of March 2020).

[1] Notwithstanding issues with the consistent definition and measurement of COVID-related deaths.

We explore these hypothesised effects in two analyses. First, we assessed whether the number of care home beds (pre-pandemic) is significantly associated with the number of COVID-19 deaths in each NHS (acute) Trust, after accounting for Trust bed numbers, infection/outbreak rates and a range of control factors. Second, we assessed whether Trust bed capacity (pre-pandemic) is significantly associated with the number of COVID-19 deaths in care homes, after accounting for care home bed numbers and a range of control factors.

This paper is structured as follows. In the next section we outline the conceptual framework, defining and developing the key concepts for this analysis. Section three describes the corresponding empirical specification. Section four outlines the data used. Section five reports the results of the analysis. The final section has the discussion and policy implications.

Conceptual framework

People with COVID-19 in the care home population

We hypothesise that in any given locality, k, the number of people with COVID-19 in the care home population, y_k^c, will vary according to the size of the care home population in that area, $\sum_{i\in k} p_{ik}^c$ and the infection rate in care homes, r^c, according to the function:

$$y_k^c = \sum_{i\in k} p_{ik}^c(\sigma_k) r_{ik}^c(x_{ik}^c, \sigma_k, r_k) = \sum_{i\in k} w_{ik}^c x_{ik}^c r_{ik}^c \tag{1}$$

with each care home in locality k indexed by i. The superscript c denotes the care home sector. In this function, x_{ik}^c, is the number of beds (capacity) of the care home. The infection rate in care homes in locality k, r_{ik}^c, will depend on the characteristics of the home and also of the rate of infection in the community overall in which the care home is located, r_k. We assume that the underlying level of frailty in the population, denoted σ_k, will drive both the size of the care home population and population susceptibility to COVID-19 infection. In turn, the size of the care home population will depend on occupancy rates of care homes in locality k, as denoted w_{ik}^c.

We can make further assumptions about this relationship: that each home in locality k has (approximately) the same rate of infection, $r_{ik}^c = \bar{r}_k^c = \frac{1}{X_k}\sum_{i\in k} r_{ik}^c$ for all i and that this average rate is given by the number of homes with outbreaks, B_k^c, in locality k over the number of homes, X_k^c, in that locality. As such, $\bar{r}_k^c \sum_{i\in k} x_{ik}^c = \bar{r}_k^c x_k^c = \frac{B_k^c}{X_k^c} x_k^c = B_k^c \frac{x_k^c}{X_k^c}$, where $x_k^c = \sum_{i\in k} x_{ik}^c$ is the total number of care home beds in the locality. This is equivalent to the total number of infected residents for locality k being the number of homes with an outbreak, weighted by the average number of beds in each home (x_k^c / X_k^c). Using the average occupancy rate in the locality, $\bar{w}_k^c$, we have:

$$y_k^c = \bar{w}_k^c \sum_{i\in k} r_{ik}^c x_{ik}^c = \bar{w}_k^c \bar{r}_k^c \sum_{i\in k} x_{ik}^c = \bar{w}_k^c \bar{r}_k^c x_k^c \tag{2}$$

COVID-19 deaths in hospitals

Infected populations are at risk of needing a hospital admission and of death. The specific Trust for which the admission referral is made will depend on the catchment area of local Trusts, and the (available) bed capacity. In general, we assume that operating procedures with regard to catchment areas, population referrals etc., will be aligned with the relative capacity of the Trusts in the region. Trusts with large bed capacity will be serving larger populations compared to smaller Trusts.

In assessing the relative mortality risk from COVID-19 in different areas in England, we need to account for the effects of hospital capacity, since their capacity (beds) to take referrals will differ and this existing capacity need not reflect the distribution of COVID-19 cases between areas. For example, through adjustment to referral processes, Trusts with relatively high bed capacity but relatively few COVID-19 cases in their usual operating population-area can take relatively more COVID-19 patients than Trusts in the region with lower capacity but potentially higher COVID-19 case numbers. Without accounting for this supply/capacity effect, we might otherwise infer a higher-mortality rate in that area, other things equal.

The cumulative number of COVID-19 deaths in each Trust will be directly related to the (cumulative) number of admissions of COVID-19 patients. In turn, numbers of admissions will be affected by hospital bed and care home capacity in the locality, as well as by the number of COVID-19 cases in the local population (including the care home population). Further details of these relationships are outlined in Annex 1; in particular, Trust admission capacity is directly affected by rates of patient discharge that occur in the Trust, including discharge back to the care sector.

Bringing these elements together, the total number of COVID-19 deaths in hospital to date is:

$$m_k^h = m_k^{hc} + m_k^{hw} = \phi y_k^h \left(x_k^h, x_{-k}^h, x_k^c(\sigma_k), \bar{r}_k^c(\sigma_k, r_k), \bar{w}_k\left(m_k^{cc}, m_k^{hc}\right), y_k^w\left(x_k^h, \sigma_k, r_k^w\right)\right) \tag{3}$$

where m_k^{hc} and m_k^{cc} are respectively deaths of care home residents in hospital and in care homes. Also, m_k^{hw} and y_k^w are respectively hospital deaths and numbers of COVID-19 admissions from the community (rather than from the care homes population), and x_k^h is hospital bed capacity.

Occupancy rates in care homes will be endogenous and a negative function of (cumulative) mortality and also potentially of the outbreak rate if new residents coming into a home are deterred by high outbreak rates in the home $\bar{w}_k(m_k^{cc}, \bar{r}_k^c)$.

As regards deaths of care home residents in the care home, the same logic applies, with both a direct need effect (number of COVID-19 cases) and, potentially, an indirect capacity effect: $m_k^{cc} = m_k^{cc}\left(\bar{r}_k^c, x_k^c, \bar{w}_k\left(m_k^{cc}, m_k^{hc}\right), x_k^h, y_k^w\left(x_k^h, \sigma_k, r_k^w\right), \sigma_k\right)$. Using (3) and this function, we can solve for m_k^{cc} and m_k^{hc} to give partial reduced-forms:

$$m_k^h = m_k^h\left(x_k^h, x_{-k}^h, x_k^c(\sigma_k), \bar{r}_k^c(\sigma_k, r_k), y_k^w\left(x_k^h, \sigma_k\right), \sigma_k, r_k\right) \tag{4}$$

In this analysis of hospital COVID-19 deaths, the locality is tied to the acute Trust (i.e. the Trust's catchment area).

Care home capacity and hospital COVID-19 deaths

In order to frame and guide the empirical analysis we can hypothesise about the relationship between hospital COVID-19 deaths and care home beds, $\frac{\partial m_k^h}{\partial x_k^c}$. The following sets of arguments apply – see Annex 1 for derivations. First, we can hypothesise that there is a care home specific (need) effect, an effect from a frail person being in a care home setting (rather than another care setting) – and in addition to any capacity effects. We might expect a potential for higher infection rates in care homes, other things equal, because co-habitation increases the chances for transmission (e.g. compared with the same person living at home). By contrast, being in a care home rather than at home for a person with high frailty/care need might have a preventative effect as regards COVID-19 hospital admissions, particularly for people in nursing homes.

An example can illustrate this effect. A linear form of (3) is:

$$m_k^h = \phi\theta_k^c\bar{r}_k^c p_k^c + \phi\theta_k^w\bar{r}_k^w p_k^w \qquad (5)$$

which is the sum of hospital admissions from care homes and from the community. Here θ_k^c and θ_k^w are the relative propensity for hospital COVID-19 admissions from the care home and community populations, respectively (and where the care home population is $p_k^c = \bar{w}_k^c x_k^c$). To begin with, we can start with the case where there are no capacity effects (i.e. $\frac{\partial\theta_k^c}{\partial x_k^c} = 0$ and $\frac{\partial\theta_k^w}{\partial x_k^c} = 0$). Differentiating with respect to care home capacity gives:

$$\left.\frac{\partial m_k^h}{\partial x_k^c}\right|_{\theta_k,\bar{r}_k} = \phi\theta_k^c\bar{r}_k^c\frac{\partial p_k^c}{\partial x_k^c} + \phi\theta_k^w\bar{r}_k^w\frac{\partial p_k^w}{\partial p_k^c}\frac{\partial p_k^c}{\partial x_k^c} = \phi\bar{w}_k^c\left(\theta_k^c\bar{r}_k^c + \theta_k^w\bar{r}_k^w\frac{\partial p_k^w}{\partial p_k^c}\right) \qquad (6)$$

The differential $\frac{\partial p_k^w}{\partial p_k^c}$ is the change in the community population from a change in the care home population in the area. We might assume that one more person in a care home means one less person in the community (in locality k) i.e. $\frac{\partial p_k^w}{\partial p_k^c} = -1$. With this assumption $\left.\frac{\partial m_k^h}{\partial x_k^c}\right|_{\theta_k} = \phi\bar{w}_k^c(\theta_k^c\bar{r}_k^c - \theta_k^w\bar{r}_k^w)$. This differential could be positive or negative, because although we hypothesise infection rates in care homes might be higher than in the community (i.e. $\bar{r}_k^c > \bar{r}_k^w$), it might also be the case that $0 < \theta_k^c < \theta_k^w$.[2] Moreover, if the difference in the respective rates between care home and community populations is small i.e. $\theta_k^c\bar{r}_k^c \cong \theta_k^w\bar{r}_k^w$, then the effect will be near zero i.e. $\frac{\partial m_k^h}{\partial x_k^c} \cong 0$. At the same time, we would still expect $\frac{\partial m_k^h}{\partial \bar{r}_k^c} = \phi\theta_k^c\bar{w}_k^c x_k^c > 0$ and $\frac{\partial^2 m_k^h}{\partial\bar{r}_k^c\partial x_k^c} = \phi\theta_k^c\bar{w}_k^c > 0$ (assuming also no change in occupancy rates, see also below).

Second, with regard to the capacity effects outlined above, localities with more care homes can facilitate a higher rate of hospital discharge, other things equal, than localities with few care home places. This would matter where a Trust was nearing capacity and patients would otherwise be more likely to be admitted to other Trusts. This effect, which would be a positive influence, would depend also on the availability and suitability of other forms of care that hospital patients could be discharged to; the effect would be small if other, suitable options existed (e.g. discharge to people's own homes). With regard to the linear case in (5) this capacity effect means $\left.\frac{\partial m_k^h}{\partial x_k^c}\right|_{p_k} = \phi\bar{r}_k^c p_k^c\frac{\partial\theta_k^c}{\partial x_k^c} + \phi\bar{r}_k^w p_k^w\frac{\partial\theta_k^w}{\partial x_k^c} \geq 0$ as both $\frac{\partial\theta_k^c}{\partial x_k^c} \geq 0$ and $\frac{\partial\theta_k^w}{\partial x_k^c} \geq 0$ in this case (and with no need effect, i.e. $\frac{\partial p_k^c}{\partial x_k^c} = 0$). The interaction of Trust and care home sector capacity will be important; in particular, the number of admissions (including COVID-19 admissions) that can be made for each Trust bed will be increased if there are more care home beds available to facilitate timely discharge, i.e. we expect $\left.\frac{\partial^2 m_k^h}{\partial x_k^h\partial x_k^c}\right|_{p_k} > 0$ as $\left.\frac{\partial^2\theta_k^h}{\partial x_k^h\partial x_k^c}\right|_{p_k} > 0$ and $\left.\frac{\partial^2\theta_k^c}{\partial x_k^h\partial x_k^c}\right|_{p_k} > 0$.

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[2] This result assumes no change in the locality's total population i.e. that $\frac{\partial p_k^w}{\partial p_k^c} = -1$, but it is possible that any increase in care home supply draws people to move into the locality, such that $\frac{\partial p_k^w}{\partial p_k^c} > -1$. This would make the effect in (6) more likely to be positive (indeed in the limit case where $\frac{\partial p_k^w}{\partial p_k^c} = 0$, (6) becomes $\frac{\partial m_k^h}{\partial x_k^c} = \phi w_k^c\theta_k^c\bar{r}_k^c > 0$). Furthermore, this relationship would change if we assume that the number of care home places in a locality also affects the outbreak rate i.e. $\frac{\partial\bar{r}_k^c}{\partial x_k^c} \neq 0$.

Hospital capacity and hospital COVID-19 deaths

Turning to the effects of hospital beds capacity on deaths, we would also expect a positive relationship. As outlined above, larger Trusts can admit more COVID-19 patients, other things equal; hence $\frac{\partial m_k^h}{\partial x_k^h} > 0$.

We also expect $\frac{\partial m_k^h}{\partial \bar{r}_k^c} > 0$ other things equal (see Annex 1, and above for the linear case) – localities with higher infection rates, given bed numbers, will have a greater number of the care home population being infected compared to localities with lower infection.[3]

COVID-19 deaths in care homes

The reduced-form function for COVID-19 deaths of care home residents in care homes is:

$$m_j^{cc} = \phi y_j^{cc}\left(x_j^c, \bar{r}_j^c, x_j^h, y_k^w\left(x_k^h, \sigma_k, r_k\right), \sigma_k, r_k\right) \tag{7}$$

In this case, as we are considering residents with COVID-19 who remain in the care home, the 'locality' is not specifically tied to Trusts, and could be defined by each care home or by an area that is linked directly to the operation (commissioning, regulation etc.) of care homes, such as the local authority. We use the notation j to distinguish the different definition of locality. As above, (7) is found by also solving for m_j^{cc} and m_j^{hc} – in this case for locality j – to remove the dependence on occupancy.

We expect a positive relationship between care home beds and the number of care home deaths in care homes, $\frac{\partial m_j^{cc}}{\partial x_j^c} > 0$, through the size of need effect.

Available capacity in the nearest Trust could constraint the decision to admit a care home resident to that Trust. For example, if the Trust is at capacity and an admission to an alternative Trust is offered, the decision to admit by the resident and family might be deferred. As such, we hypothesise that localities with a high level of GA beds per capita would be less likely to be constrained, other things equal, and so we might expect a positive relationship between Trust capacity and hospital admissions. In theory therefore, if capacity constraints are significant in a locality, this would mean a negative relationship with decisions to manage the case in the care home; otherwise, with no capacity constraints there would be no effect. As such, we might expect $\frac{\partial m_j^{cc}}{\partial x_j^h} \leq 0$. More generally, we might expect localities with a relatively high level of GA beds to operate with somewhat different admission thresholds/policies than areas with fewer GA beds per capita. Clearly, there are many factors that influence admission rates, GA bed capacity being only one, and so any effect on decisions to manage the residents with COVID-19 in the care home, and in turn mortality rates, will be small.

[3] Potentially localities with high infection rates may see reductions in occupancy rates where new entrants are deterred. This would offset the effect on the size of the care homes population to some extent over time. Nonetheless, because this effect is lagged and the normal rate of care home admission is relatively small (so the potential rate of reduction of admissions from the deterrence effect is small), we hypothesise overall that there will be a positive relationship between infection rates and deaths. In the linear case we have $\frac{\partial m_k^h}{\partial \bar{r}_k^c} = \phi \theta_k^c x_k^c \left(\bar{w}_k^c + \bar{r}_k^c \frac{\partial \bar{w}_k^c}{\partial \bar{r}_k^c}\right)$ where $-1 < \frac{\partial \bar{w}_k^c}{\partial \bar{r}_k^c} \leq 0$, in which case this differential is positive where $\bar{w}_k^c \geq \bar{r}_k^c$ (anecdotally, occupancy rates are 0.8 or more; on average infection rates observed – see below).

Empirical specification

COVID-19 mortality

Hospital deaths

An empirical counterpart to the hospital COVID-19 deaths model (4) above (specified in log-form) is:

$$\ln\left(m_k^h\right) = \beta_0 + \beta_1 \ln x_k^c + \beta_2 \ln \bar{r}_k^c + \beta_3 \ln(\bar{r}_k^c) \ln(x_k^c) + \beta_4 \ln x_k^h + \beta_5 \eta_k + \beta_6 G_k + \epsilon_k \qquad (8)$$

In this specification, the locality k is defined around each acute NHS Trust, for which there were 129 at the time of analysis. The variables are defined as follows:

- m_k^h is the (cumulative) total number of COVID-19 deaths in NHS Trust k.
- x_k^c is the total number of care home beds in homes for which Trust k is the nearest acute Trust (see below).
- $\bar{r}_k^c$ is the care home (average) infection rate indicator linked to homes nearest to Trust k (see below), namely: the number of care homes that have had an outbreak, deflated by the total number of care homes (for older people) in the corresponding local authority.
- x_k^h is the total number of GA beds in Trust k.
- $\eta_k(\sigma_k)$ are other needs-related and scale indicators.
    - The intention is to account for factors that could influence COVID-19 deaths in hospital trust areas. To account for non-care home social care support in the area, including domiciliary care, we use the total number of Attendance Allowance (AA) claimants[4] in the locality. The total population over 65 is used to account for the size of locality, noting that the analysis is in levels (see below). Also included is population density and the proportion of the population 65 and over that is over 85, as controls. These variables are available at MSOA level, and we map the effects to locality k in the same way as with care homes beds: for each MSOA we calculate the nearest Trust, and then sum up (or average over) the corresponding indicator value for all those MSOAs for which Trust k is the closest.
    - We also use risk and scaling factors for hospital mortality of COVID-19 patients that are linked to the Trust via (straight-line) distance:
        - Proportion of females aged 85+ living within 20km of each Trust;
        - Proportion of males aged 85+ living within 20km of each Trust;
        - Total population (all ages) of people living within 20km of each Trust;
        - Total population (all ages) of people living within 50km of each Trust.
    - In addition, to account for the scale of hospital bed availability in the vicinity of Trust k, which indicates the potential for diversion of patients, we include the total number of GA beds in other Trusts within 50km of Trust k.
- G_k is the Government office region in which Trust k is located. We include these dummies to capture any outstanding differences in infection and outbreak rates.

In line with the main aim to explore the effects of care home provision on the variation of hospital deaths of care home residents with COVID-19, the unit of analysis is at the organisation level;

[4] AA rates are a strong predictor of home care use – and are used in the adult social care relative needs formula Vadean, F. and J. Forder (2018). The revision of the Relative Needs Formulae for adult social care funding and new allocation formulae for funding Care Act reforms: Final report. Canterbury, University of Kent. Publicly-funded care home residents are not entitled to claim AA, although this does not apply for privately/self-funded residents. As such there may be some co-linearity between the care home need indicators (particularly care home beds) and AA numbers, potentially reducing implied effect sizes from the former. However, this is likely to be a minor issue as beds is a much more direct indicator.

specifically, locality k is defined by the pairing of NHS Trusts and care home provision. Since NHS Trust operating areas in relation to care homes is not defined, we link care homes to Trusts as based on their geographical location.

For each care home, the nearest Acute NHS Trust was calculated using straight-line distance, adjusted for average road speeds in the corresponding local authority. For each NHS Trust, the total number of beds in all care homes for which the Trust was the closest, were summed:

$$x_k^c = \sum_i \gamma_{ik}(\vec{d}_{ji}) x_i^c \tag{9}$$

where d_{ji} is the matrix of the adjusted straight-line distance[5] between each NHS Trust j and each care home i in England. The function γ_{ik} takes a value of 1 if Trust $j = k$ is the nearest to care home i, or 0 if not, for each care home i and NHS Trust j pair in England.

The relationship between care home beds and COVID-19 mortality in hospital is mediated by the (cumulative) total number of residents who are infected. For this we use data on number of care homes with outbreaks to date. We map outbreaks in care homes to NHS Trust localities, k, in the same way that care home beds are associated with Trusts, i.e.:

$$\bar{r}_k^c = \frac{\sum_i \bar{r}_{i\in l}^c \gamma_{ik}(\vec{d}_{ji})}{\sum_i \gamma_{ik}(\vec{d}_{ji})} \tag{10}$$

where $\bar{r}_{i\in l}^c = \frac{B_l}{X_l}$ is number of homes with an outbreak in local authority district (LAD) l in which the home is located, B_l, over the number of care homes (for older people), X_l, in the LAD.

We use a log specification for (8) to account for the distribution of the dependent variable. This specification also accounts for the expected shape of the relationship between total care home beds and hospital COVID-19 mortality – in particularly, that second order effects are expected to be negative (see Annex 1).

We estimate this model in levels (rather than say rates per head of population) because catchment populations for NHS Trusts are undefined. By including population levels in log specification models we address some of the scaling issues (as well as having other key variables in levels).

A number of alternative specifications were also estimated that include linear as well as log terms for care home beds and for the total number of homes with outbreaks over total (older people) homes – see the results section below.

We also use a version that uses the testing data on infection rates in the population as a whole – although we note its limitations, as discussed below. We add this variable, denoted $\tilde{\sigma}_{k\in l}$, to test for robustness of the results in the main model, and to help with the interpretation of the main results – see also below.

All models were estimated using GLM to account for re-transformation issue with log functional forms (Manning, 1988). Both gamma and Poisson distribution models were estimated.

[5] Straight line distance was adjusted by proportionately multiplying by an inverse of average road speeds in the LAD – as a proxy for road infrastructure and relative travelling population density – see Annex 3 for data sources.

Care home deaths

The empirical counterpart to (7) for total COVID-19 care home deaths is:

$$\ln\left(m_j^{cc}\right) = \alpha_0 + \alpha_1 \ln\left(\bar{r}_j^c x_j^c + \mu_1\right) + \alpha_2 \ln\left(\bar{r}_j^c \bar{x}_j^c + \mu_2\right) + \alpha_3 \bar{r}_j^c x_j^c + \alpha_4 \bar{r}_j^c \bar{x}_j^c + \alpha_5 x_j^c + \alpha_6 \bar{r}_j^c + \alpha_7 \bar{x}_j^h + \alpha_8 \eta_j^c + \alpha_9 G_j + \epsilon_j \quad (11)$$

This model is estimated where the locality j is one of the 316 local authority districts (LADs) (lower tier LAs) in England.[6] The relationship between total care home beds and total COVID-19 deaths in care homes in the LAD is mediated by the (cumulative) resident infection rate, and as above we use the number of homes with outbreaks over the total number of older person care homes in the corresponding local authority district, $\bar{r}_j^c = \frac{B_j}{X_j}$.

The variables are:

- m_j^{cc} is the total number of COVID-19 care home deaths in the local authority district.
- $\bar{r}_j^c$ is the set of (average) infection rate indicators, as above.
- x_j^c is the total number of care home beds in LAD j.
- $\bar{x}_j^c$ is the mean number of care home beds per home in LAD j (being x_j^c divided by the total number of homes in j).
- x_j^h is the LAD-mean number of hospital GA beds per capita (see below).
- η_j^c is total population over 65, used to account for the different size of populations in each LAD (population 65+ is used as more relevant to care homes).
- G_j is the Government office region in which LAD j is located.
- μ is to allow for zero values of $\bar{r}_j^c x_j^c$ and $\bar{r}_j^c \bar{x}_j^c$ in our log specification (being the smallest positive value of the variable).

To model the relationship between Trust capacity and COVID-19 mortality at the LAD level, we associated Trust beds capacity on a pro-rata basis to LADs within range of the Trust, noting that Trusts can operate across LAD boundaries, and expressed this as a rate per head of LAD population (as LADs differ in population size). This derivation of $\bar{x}_j^h$ is detailed in Annex 2.

Another empirical counterpart to (7) is:

$$\ln\left(m_j^{cc}\right) = \alpha_0 + \alpha_1 \ln\left(x_j^c\right)\bar{r}_j^c + \alpha_2 \ln\left(x_j^c\right)\bar{r}_j^{c\,2} + \alpha_3 \ln\left(\bar{x}_j^c\right)\bar{r}_j^c + \alpha_4 \ln\left(\bar{x}_j^c\right)\bar{r}_j^{c\,2} + \alpha_5 \bar{r}_j^c x_j^c + \alpha_6 \bar{r}_j^c \bar{x}_j^c + \alpha_7 x_j^c + \alpha_8 \bar{r}_j^c + \alpha_9 \bar{r}_j^{c\,2} + \alpha_{01} \bar{x}_j^h + \alpha_{11} \eta_j^c + \alpha_{12} G_j + \epsilon_j \quad (12)$$

which uses a quadratic function of the infection rate.

The models were estimated using GLM at the LAD level (again with both gamma and Poisson distributions). We weighted the estimation according to the relative number of care homes in each LAD since we are modelling deaths in care homes and so should give LADs with a relatively higher number of care homes more importance than those with fewer care homes. As outlined below, deaths in care home data is available at the upper-tier LA level, and therefore we also estimated models with standard errors clustered at upper-tier LA level (and also versions without clustering).

[6] As is conventionally the case, City of London is omitted because it has no care homes and highly distinctive population characteristics.

Marginal effects and differences in mortality effects between regions

Differences in COVID-19 deaths of care home residents between areas are $m^h_{k\in G} - m^h_{k\in G'}$. The estimation results can be used, as outlined above, to project/infer differences in mortality in different circumstances.

Three projection scenarios were considered. The first was to project the number of COVID-19 related deaths in hospital of care home residents at the observed outbreak rate, accounting for the number of care home beds in the locality, but treating all other factors as constant. In the second scenario we projected the number of deaths of care home residents where the care home outbreak rates was taken to be the same for all regions. The third scenario had the number of deaths in Trusts of care home residents where the care home outbreak rates was taken to be at the level observed for the region with the highest rate.

Underpinning calculations are provided in Annex 4.

Data

The characteristics and location of care homes and NHS Trusts in England were sourced from Care Quality Commission (CQC) data. We selected care homes for older people (OP) using the March 2020 CQC registration database, which gave 11,047 care homes. These homes were located using their address (ONS coordinates). CQC registration data includes the number of care home beds for each care home. The 11,047 care homes included in the analysis accounted for 411,678 beds, or around 37 beds per home on average (but varying significantly between homes).

Acute - non-specialist - Trusts were selected for this analysis, of which there were 129 in England in March 2020. Specialist, mental health and community Trusts were excluded. This selection was made to focus on the location of urgent care and intensive care unit (ICU) capacity. Trusts were located by the address of the Trust headquarters.

Data on deaths, outbreaks and infections was sourced online from ONS. We used a census data of 8 May 2020 for the analysis, a date chosen as it coincides with the first wave of the pandemic. According to analysis of Public Health England (PHE) data by the Health Foundation, around 8 May we saw a flattening off of the cumulative percentage of care homes reporting an outbreak (see Hodgson, Grimm et al. 2020, Figure 1). Specifically, for NHS Trust deaths, this was the cumulative number of deaths of patients who have died in hospitals in England and had tested positive for COVID-19 up until 8 May. It stood at 23497 at that date for all Trusts and 22818 for 129 Acute Trusts used in the sample (97.1% of the total).

For care home deaths, information on deaths notified to the CQCwas used. This is the number of deaths involving COVID-19 occurring in care homes, by Local Authority (upper tier) and day of notification, between 10 April to 8 May 2020, for England. Care home deaths were not published by CQC before 10 April. Between these dates, 8,314 deaths were recorded (where address of death was known).

The ONS published an *analysis of deaths involving COVID-19 within the care sector*[7] using provisional counts of the (total) number of deaths registered in England for care home residents, with deaths involving coronavirus (COVID-19) based on any mention of COVID-19 on the death certificate, unless stated otherwise. Data were available for COVID-19 deaths of care home residents registered from 2

[7] See Annex 3 source 6.

March until 8 May 2020, and recorded 10,479 deaths of care home residents in the care home and 3,854 deaths of care home residents in hospital. Extrapolating CQC data for the period 2 March to 9 April, gives around 10,500 care home resident deaths in care homes and 3,500 residents deaths in hospital for the period 2 March to 8 May. These figures suggest around a quarter of care home resident COVID-19 deaths were in hospital, and around 17% of all hospital COVID-19 deaths were care home residents.

Care home outbreaks data were sourced from PHE management information. These data record the number of homes with a suspected or confirmed COVID-19 outbreak by week, starting from 2 March 2020. Cumulative totals were recorded up to and including the week commencing 4 May. Data were available at LAD (i.e. lower tier LA) level. At that time, 5,546 care homes[8] had reported an outbreak in the period.

The number of lab-confirmed cases were sourced from the UK Government Coronavirus (COVID-19) data dashboard. Data on the rate per 100,000 resident population were used in the analysis, up until 8 May.[9] At that point, the case rate stood at an average of 232 cases per 100,000 for English LADs. Testing at that time was mainly focused on hospital and care home patients and so we have not used this variable in the main models, but rather tested it as a variant.

Details for the source for the above data are in Annex 3.

NHS Trust hospitals analysis

Descriptive statistics for the variables described above are reported in Table 1. On average there were 177 COVID-19 deaths in each NHS Trust in the period. Those Trusts averaged just over 750 General and Acute (GA) overnight beds and about 3,200 beds in the care homes for which the Trust headquarter was the nearest.

Table 1. Descriptive statistics for main variables in NHS Trust analysis, values per locality (NHS Acute Trust)

Variable	**Mean**	**Std. Dev.**	**Min**	**Max**
COVID-19 deaths (8 May) in NHS Acute Trusts	176.884	122.447	3	830
Total (Trust nearest) care home (CH) beds	3191.302	1301.526	63	6687
Number of Trust GA beds[10]	750.479	381.697	226	2568.652
Total number of GA beds in other Trusts within 50km	8549.545	6748.470	0	20964.280
Total (Trust nearest) care homes - number	85.636	38.344	1	193
Total (Trust nearest) CH beds × prop. of homes w/ an outbreak	1190.874	526.471	43.313	2609.479
No. of care home outbreaks per care home for older people	0.389	0.118	0.134	0.76
Proportion of homes that are clustered (58+ homes w/in 10km)	0.438	0.367	0	1
Proportion of homes that are nursing homes	0.386	0.114	0.150	1
Cumulative lab confirmed case rate in corresponding LAD	237.499	87.977	87.6	477.5
Proportion of females aged 75+ living within 20km of each Trust	0.048	0.010	0.029	0.074
Proportion of males aged 75+ living within 20km of each Trust	0.035	0.008	0.021	0.058
Total population (all ages) living within 20km of each Trust	1738033	2187546	45200	8186867
Total population (all ages) living within 50km of each Trust	5560668	4328974	276752	1.38E+07

N = 129

[8] Of the total of 15,514 care homes of all types in England.
[9] Where no new cases were reported in a small number of LADs for that day, the nearest day with new data was used.
[10] Average daily number of available beds open overnight, October to December 2019. Note, as available bed numbers can change over the period October to December 2019, this number need not be an integer.

There is considerable variation in this number of care home beds between Trusts, and also in the number of GA beds in Trusts, which can be seen in Figure 1. Due to the different size of localities, there was a positive correlation between the number of care home beds and GA beds of these Trust (0.24). However, when account was made of population size of the locality, a negative relationship was found. Figure 2 shows the ratio of (Trust-nearest) care home beds to Trust GA beds, which varies considerably between Trust localities.

Figure 1. Variation in numbers of care home beds (in homes for which the Trust is nearest) across NHS Trusts and numbers of GA beds per Trust

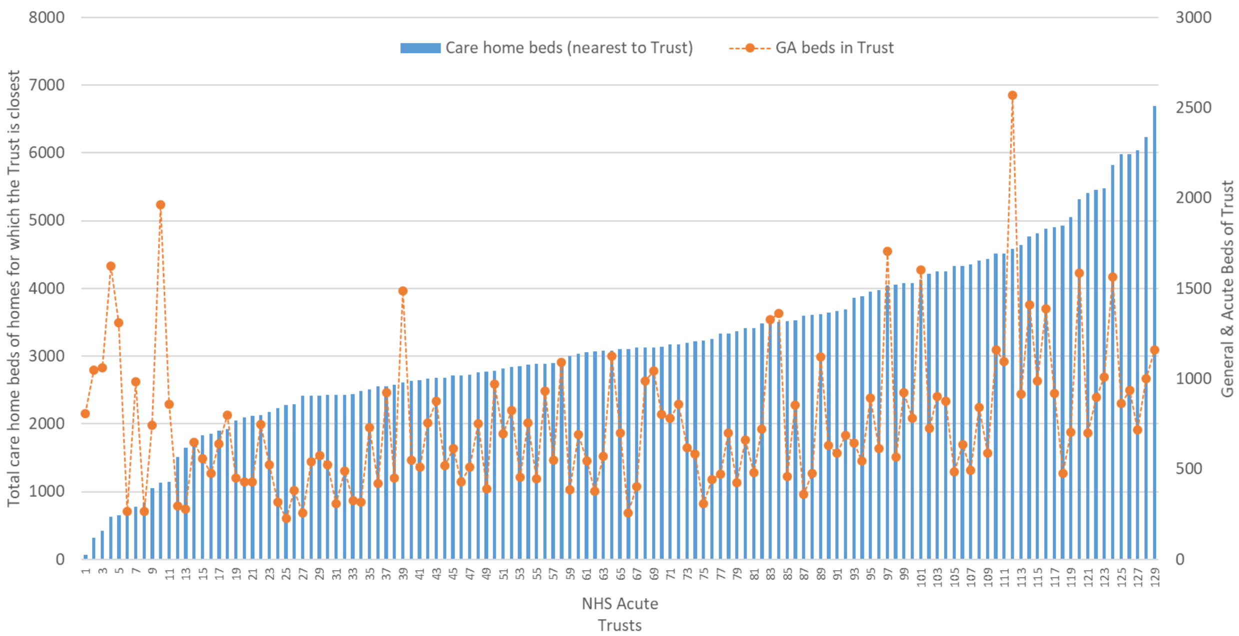
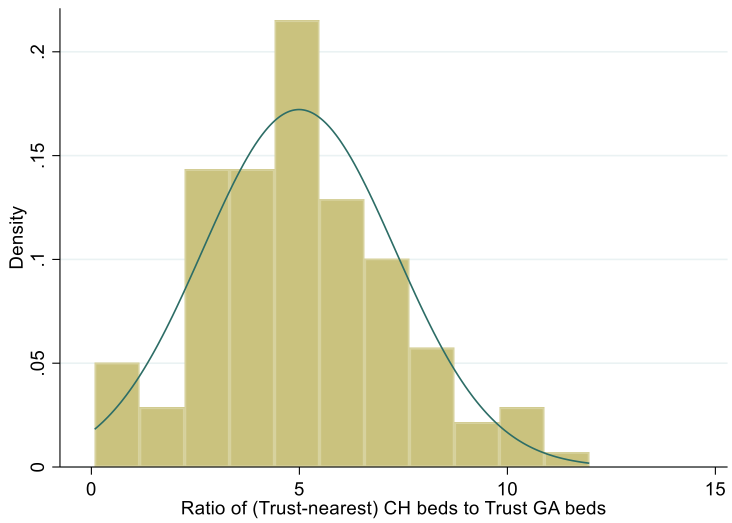


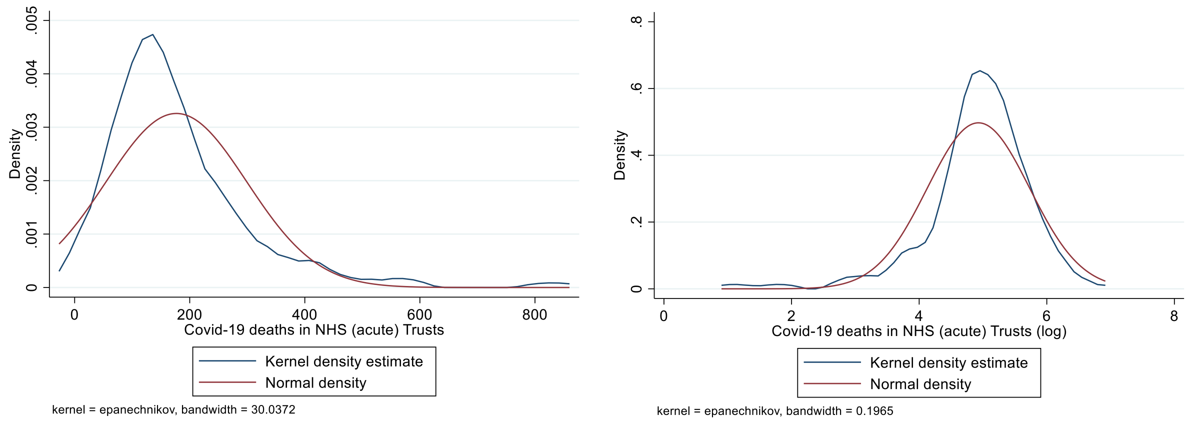
Figure 2. Histogram – ratio of (Trust-nearest) care home beds to Trust GA beds



Trusts experienced very different levels of COVID-19 mortality, ranging from 3 deaths in one Trust (Weston Area Health NHS Trust) to 830 deaths in another (University Hospitals Birmingham NHS

Foundation Trust). Figure 3 shows this variation, and the skewed and leptokurtic nature of the distribution. A log transformation brings the distribution closer to the normal.

Figure 3. Kernel density plots - COVID-19 deaths (8 May) in NHS Acute Trusts, linear and log functions



Care home deaths analysis

Descriptive statistics for the main variables in the model are reported in Table 2. The values are for each of the 316 local authority districts (LAD). These data are weighted by the number of care homes for older people in each LAD as described above. Weights were re-scaled to ensure that the total number of COVID-19 deaths in care homes corresponded to the observed national total (8,314).

Table 2. Descriptive statistics for main variables in care homes analysis; values per LAD, weighted for number of care homes per LAD

	Mean	Std. Dev.	Min	Max
COVID-19 related deaths in care homes (cumulative total until 8 May 2020)	36.399	34.303	0	170
Care home for older people beds (total)	1874.395	1230.120	14	6269
Care homes for older people per locality (total)	51.576	34.538	1	183
No. of care home outbreaks per care home for older people[11]	0.501	0.181	0	1.172
Population aged 65+	44351.510	29211.520	576	147944
Population all ages (care home no. weighted)	8464.360	824.154	2242	11959.31
Population density	1617.701	1990.983	24.683	16093.54
Population of AA claimants (higher rate)	3327.067	2364.650	24	14553

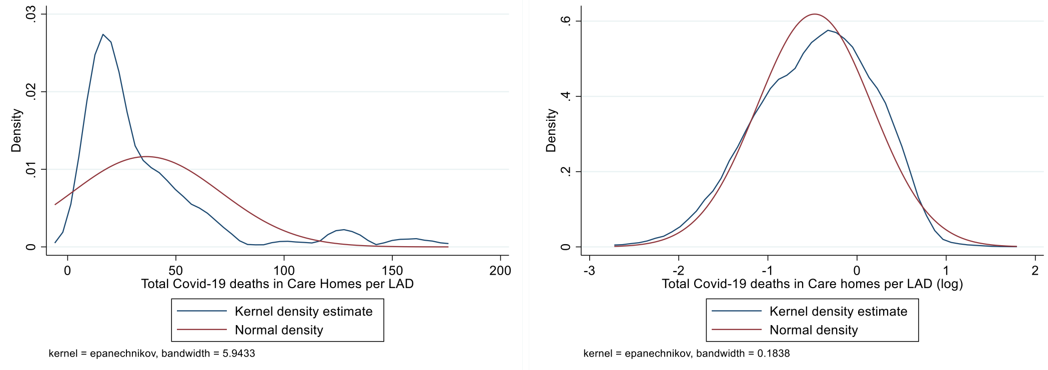
N = 316; Weighted observations = 228.4

The number of homes (all types) with an outbreak (any since recording started) was available at LAD level. In the analysis we divided this by the number of older people care homes. Care homes for older people were used as denominator because this was a better fit for the analysis.

As above, the dependent variable, COVID-19 related deaths in care homes, showed a rightward skew and high kurtosis. A log transformation produced a distribution that corresponds closely with the normal distribution (see Figure 4).

[11] The denominator is care homes for older people – data on outbreaks did not distinguish primarily client group, so all types of homes with outbreaks were used – see also below.

Figure 4. Kernel density plots – Total cumulative COVID-19 deaths (up to 8 May) in care homes per LAD; linear and log functions



Results

NHS Trust hospitals

The results of the estimation of COVID-19 deaths in hospital – function (8) and variants – are reported below.

Table 3 reports three variant models, with log, linear and interaction terms. As regard the first model in the table, the marginal effect of an increase in care home beds at the sample mean, other things equal, $\frac{\partial m_k^h}{\partial x_k^c}$, was positive at 0.0065 (where this number is the equivalent of 6.5 additional deaths per extra 1,000 care home beds in a locality) but was not significant (p-value = 0.530). The marginal effect of an increase in the number of outbreaks per total homes in the locality, $\frac{\partial m_k^h}{\partial \bar{r}_k}$, was significant, with a point estimate of 84.2 (p-value = 0.0495, with a confidence interval range of 13.7 to 154.7), other things equal.

A linear extrapolation using this marginal effect result (point estimate), going from a zero number of homes with outbreaks to the sample average of 0.54 outbreaks per (older person) homes would correspond to about 45.5 deaths of care home residents in each Trust, or around 5,870 for all 129 Trusts. This number is higher than the recorded national level of 3,854 (from ONS analysis, see data section above), but note the confidence interval range. We would also expect some association between outbreaks in care homes and the rate of infection in the community ($\bar{r}_k^w$), where the latter drives admissions (and deaths) in hospital from people admitted from the community. We do not have a good indicator of the latter, but when the (imperfect) measure of the cumulative rate of test-confirmed infections is used in the estimation[12], the estimated marginal effect $\frac{\partial m_k^h}{\partial \bar{r}_k}$ is reduced; the estimated total number associated with home outbreaks reduces to around 4,500 in that case, which is close to reported number of 3,854.

[12] Not reported but available upon request

Table 3. COVID-19 deaths in hospital – logged and linear interaction models (log GLM, by distribution)

	Log and linear CH beds		Log interaction with additional log terms		Log and linear interaction with log and linear terms	
	Coefficient	Z	Coefficient	Z	Coefficient	Z
CH beds-related effects						
Total (Trust nearest) care home (CH) beds, log	0.308***	3.57	0.283***	3.46	0.258***	2.69
No. of home outbreaks per OP home, log	0.987**	2.15	-1.477	-1.56	3.375	1.10
Total (Trust near.) CH beds, log × no. of CH outbreaks per OP CH, log			0.222*	1.81	-0.298	-0.84
Total (Trust nearest) care home beds	-5.950E-05	-0.99			-2.339E-04	-1.11
No. of home outbreaks per OP home	-1.349*	-1.78			-2.208	-1.53
Total (Trust nearest) CH beds × no. of CH outbreaks per OP CH					2.637E-04	0.90
Hospital-beds related effects						
Total number of GA beds, log	0.708***	10.75	0.715***	10.69	0.708***	10.77
Total number of GA beds per pop living 20km of Trust	54.921**	2.50	51.425**	2.27	53.835**	2.41
Total number of GA beds in other Trusts within 50km	7.190E-05**	2.46	7.190E-05**	2.49	7.090E-05**	2.41
Total number of GA beds in other Trusts within 50km, sq.	-2.410E-09*	-1.78	-2.430E-09*	-1.83	-2.400E-09*	-1.76
Needs-related effects						
Total population over 65 in Trust nearest MSOAs	2.340E-06	0.98	2.060E-06	1.03	2.150E-06	0.93
Total AA claimants per pop 65+ in Trust nearest MSOAs	1.409	0.60	0.927	0.39	1.270	0.51
Total pop 85+ per pop 65+ in Trust nearest MSOAs	-1.815	-0.50	-2.067	-0.60	-2.041	-0.55
Pop density in Trust nearest MSOAs	3.770E-05	1.05	3.860E-05	1.07	4.690E-05	1.21
Total pop (all ages) of people living within 20km of each Trust	1.330E-07	1.51	1.300E-07	1.46	1.140E-07	1.28
Total pop (all ages) of people living within 20km of each Trust, sq.	-7.630E-15	-0.80	-9.720E-15	-0.99	-4.940E-15	-0.49
Total female pop 85+ per total pop living within 20km of each Trust	43.305	0.73	53.173	0.90	42.613	0.71
Total male pop 85+ per total pop living within 20km of each Trust	-81.734	-0.79	-101.735	-0.99	-82.195	-0.80
Region (North East is ref cat)						
North West	-0.026	-0.15	-6.167E-03	-0.04	-0.027	-0.16
Yorkshire and The Humber	-0.121	-0.74	-0.139	-0.85	-0.131	-0.81
East Midlands	0.023	0.12	0.032	0.17	0.025	0.13
West Midlands	0.224	1.27	0.250	1.47	0.217	1.21
East of England	0.325	1.63	0.342*	1.82	0.330*	1.65
London	0.123	0.53	0.199	0.98	0.109	0.45
South East	-1.446E-03	-0.01	9.673E-03	0.05	5.016E-03	0.02
South West	-0.320	-1.37	-0.340	-1.54	-0.333	-1.45
Constant	-1.197	-1.05	-2.266***	-4.00	-0.141	-0.08
N	129		129		129	
Log pseudolikelihood	-1111.30		-1120.04		-1107.02	
Joint significance (CH beds related effects), $chi^2(n)$	12.75***		25.07***		16.10***	

This model, and those below, use a Poisson distributions in the GLM estimation.[13]

The second model reported in Table 3 used an interaction term with logged care home beds and outbreaks per home. The interaction term was significant and positively signed, as expected. The marginal effects are similar to those above, with $\frac{\partial m_k^h}{\partial x_k^c}$ being 0.0075 at the point estimate, but again not significantly different from zero. The association with outbreaks, $\frac{\partial m_k^h}{\partial \bar{r}_k}$, was significant at 94.22 (p-value = 0.032).

The third model reported in Table 3 used both a log and linear interaction with log and linear other terms. The marginal effects are similar to those above, with $\frac{\partial m_k^h}{\partial x_k^c}$ being 0.0092 at the point estimate, but also not significantly different from zero. The association with outbreaks, $\frac{\partial m_k^h}{\partial \bar{r}_k}$, was significant at 87.48 (p-value = 0.047).

These results are consistent with hypothesised effects (see conceptual framework section) where we expect a positive association between care home beds and hospital mortality, but that it could be nearer to zero in theory. By contrast, we hypothesised a significant positive association between outbreaks per home and deaths, and this was evident.

Table 4 reports the estimation results using the product of care home beds and numbers of homes with outbreaks per total (OP) homes as an interaction term, in line with the theoretical specification in (2), i.e. with the product $x_k^c \bar{r}_k^c$, which approximates the number of care home residents with COVID-19. The first variant is with the square root of this product, with additional squared root terms. The marginal effect of the association between care home beds and hospital mortality is 0.009 (p-value = 0.385) and between outbreaks and hospital mortality it is 100.17 (p-value = 0.031). The second variant used a specification with the log of the product of care home beds and the number of homes with outbreaks per total OP homes in the locality. In both cases the product term was highly significant.

[13] Table 10 in Annex 5 has Pregibon link/Park test results which support the use of this distribution where other distribution choices are rejected by the test (Jones 2010). There was, nonetheless, little qualitative difference between the gamma and Poisson distribution results.

Table 4. COVID-19 deaths in hospital – square root and log product models (log GLM, by distribution)

	Root product		Log product with additional linear terms	
	Coefficient	Z	Coefficient	Z
CH beds-related effects				
Total (Trust nearest) care home (CH) beds, sqrt	-0.030**	-2.11		
No. of home outbreaks per OP home, sqrt	-1.920**	-2.41		
Tot (Trust near.) CH beds × no. of CH outbreaks per OP CH, product sqrt	0.049***	3.18		
Total (Trust nearest) care home beds			-8.380E-05	-1.41
No. of home outbreaks per OP home			-0.255	-1.00
Tot (Trust near.) CH beds × no. of CH outbreaks per OP CH, product log'd			0.366***	4.75
Hospital-beds related effects				
Total number of GA beds, log	0.723***	10.59	0.711***	10.62
Total number of GA beds per pop living 20km of Trust	49.095**	2.11	53.771**	2.36
Total number of GA beds in other Trusts within 50km	7.460E-05**	2.59	7.520E-05**	2.57
Total number of GA beds in other Trusts within 50km, sq.	-2.610E-09*	-1.94	-2.530E-09*	-1.87
Needs-related effects				
Total population over 65 in Trust nearest MSOAs	2.050E-06	0.82	2.600E-06	1.06
Total AA claimants per pop 65+ in Trust nearest MSOAs	0.405	0.16	1.566	0.67
Total pop 85+ per pop 65+ in Trust nearest MSOAs	-2.300	-0.63	-1.240	-0.35
Pop density in Trust nearest MSOAs	3.970E-05	1.04	4.100E-05	1.16
Total pop (all ages) of people living within 20km of each Trust	1.190E-07	1.33	1.310E-07	1.45
Total pop (all ages) of people living within 20km of each Trust, sq.	-8.380E-15	-0.85	-8.430E-15	-0.87
Total female pop 85+ per total pop living within 20km of each Trust	55.539	0.94	36.533	0.62
Total male pop 85+ per total pop living within 20km of each Trust	-106.519	-1.02	-76.442	-0.75
Region (North East is ref cat)				
North West	-1.880E-04	0.00	-0.042	-0.25
Yorkshire and The Humber	-0.156	-0.95	-0.150	-0.93
East Midlands	0.024	0.12	8.263E-03	0.04
West Midlands	0.245	1.42	0.208	1.18
East of England	0.344*	1.76	0.312	1.57
London	0.231	1.09	0.094	0.41
South East	0.012	0.06	-0.020	-0.10
South West	-0.361	-1.59	-0.368	-1.59
Constant	0.952	1.03	-2.645***	-3.92
N	129		129	
Log pseudolikelihood	-1131.49		-1120.10	
Joint significance (CH beds related effects), chi²(n)	12.21***		22.79***	

Joint significant tests for all the relevant variables under *CH beds-related effects* in the above tables were all significant.

The two interaction models (second and third variants in Table 3) and the product models (Table 4) could be used to explore the second order effects of being in a locality with a greater or lesser number of care home beds (compared to the average) on the marginal effect of the association between deaths and the number of homes with outbreaks per total OP homes, i.e. $\frac{\partial^2 m_k^h}{\partial \bar{r}_k^c \partial x_k^c}$ (see also conceptual section above). For the log interaction model, this estimate was positive and significant at: 0.027 (p-value = 0.008). A lower value was estimated for the log and linear interactions model, at 0.021 (p-value = 0.465) using the point estimates. We estimated a higher value for this differential of 0.057 (p-value = 0.001) for the square root product model. This number is the change in the association between deaths and the number of homes with outbreaks per total OP homes for every 1 bed difference between localities from the sample mean. These results are in keeping with the hypothesised association.

The results also show that the number of GA beds in the Trust is highly significantly correlated with the number of deaths – as outlined above, we expect larger Trusts to have the capacity for greater admissions of COVID-19 patients and in turn, greater numbers of deaths. Furthermore, the terms estimated for GA beds in other Trusts within 50km were significant individually, helping to control for spillover effects between the localities that could confound the results above.

Overall, the other control variables for population characteristics were not individually significant, but they were highly significant jointly (e.g. chi^2(8) = 40.84, p-value < 0.001, using the first model variant as reported above). We should also note that these variables are correlated regionally, and had a higher joint significance test result when the models were estimated with regional dummies: chi^2(8) = 53.67, p-value < 0.001. Moreover, all regional dummies were insignificantly different from the reference case (the North East) except for the East of England in one variant above.

To explore the functional form of the estimated relationship between care home beds and deaths in hospital, we estimated a cubic polynomial specification. The results are reported in the first column of Table 5. Figure 5 also shows the estimated relationship between care home beds (for which the Trust is nearest) and COVID-19 mortality in that Trust for these specifications. In addition, the figure shows a simulated linear relationship between the number of care home beds and hospital mortality – the dashed line. This simulation assumes that 17% of COVID-19 deaths in hospital are care home residents at the mean number of care home beds (3,854). Around the mean, we can see that the results are very similar.

The estimation using the cubic polynomial specification is largely consistent with the estimations in Table 3, although it showed a smaller marginal association at the mean. There was some indication, nonetheless, that the associated *average* change in hospital deaths from localities with very low care home beds (at the 1st percentile) to those with very high care home beds (at the 99th percentile), other things equal, was significant using the cubic specification (p-value = 0.095), as indicated by the dotted line in the figure, but this result is sensitive to the function form assumption and the choice of comparison points.

Table 5 also reports an estimation of the log and linear model (as in column 1 of Table 3) with an additional set of interaction terms between care home beds and Trust GA beds. This specification allows an estimate of the mediating effects of care home beds in the locality on the association between hospital beds and COVID-19 deaths in hospital, $\frac{\partial^2 m_k^h}{\partial x_k^h \partial x_k^c}$, which was also positive and significant (p-value = 0.075). Similarly, we can calculate the mediating effect of Trust GA beds on the association between hospital COVID-19 deaths and care home beds, that is of $\frac{\partial^2 m_k^h}{\partial x_k^c \partial x_k^h}$. We estimate this effect to be positive and significant (p-value = 0.069).

Table 5. COVID-19 deaths in hospital – Cubic polynomial and GA beds interaction models (log GLM, Poisson distribution)

	Cubic polynomial		Log and linear CH beds w/ GA beds interaction	
	Coefficient	Z	Coefficient	Z
CH beds-related effects				
Total (Trust nearest) care home beds, cube root	0.196***	4.13		
Total (Trust nearest) care home beds	-3.286E-04**	-2.55	-1.444E-03*	-1.79
Total (Trust nearest) care home beds, cubed	1.410E-12	0.98		
No. of home outbreaks per OP home	0.274**	2.03	-1.259*	-1.67
Total (Trust nearest) care home beds, log			2.450	1.49
No. of home outbreaks per OP home, log			0.922**	2.03
Total (Trust nearest) care home beds x Total number of GA beds, log			2.024E-04*	1.67
Total (Trust nearest) care home beds, log x Total number of GA beds, log			-0.316	-1.28
Hospital-beds related effects				
Total number of GA beds, log	0.719***	10.67	2.574	1.62
Total number of GA beds per pop living 20km of Trust	50.943**	2.20	56.841***	2.68
Total number of GA beds in other Trusts within 50km	7.190E-05**	2.43	7.350E-05***	2.66
Total number of GA beds in other Trusts within 50km, sq.	-2.350E-09*	-1.71	-2.320E-09*	-1.81
Needs-related effects				
Total population over 65 in Trust nearest MSOAs	2.650E-06	1.07	2.790E-06	1.17
Total AA claimants per pop 65+ in Trust nearest MOSAs	1.856	0.78	2.031	0.84
Total pop 85+ per pop 65+ in Trust nearest MOSAs	-1.483	-0.41	-1.837	-0.51
Pop density in Trust nearest MSOAs	3.930E-05	1.07	3.870E-05	1.07
Total pop (all ages) of people living within 20km of each Trust	1.270E-07	1.40	1.370E-07*	1.66
Total pop (all ages) of people living within 20km of each Trust, sq.	-8.270E-15	-0.81	-8.010E-15	-0.88
Total female pop 85+ per total pop living within 20km of each Trust	42.987	0.72	35.098	0.60
Total male pop 85+ per total pop living within 20km of each Trust	-86.222	-0.83	-68.050	-0.67
Region (North East is ref cat)				
North West	-0.026	-0.15	-0.081	-0.50
Yorkshire and The Humber	-0.137	-0.82	-0.162	-1.03
East Midlands	0.032	0.16	-0.079	-0.39
West Midlands	0.233	1.31	0.153	0.94
East of England	0.323	1.59	0.251	1.32
London	0.107	0.46	0.012	0.05
South East	-1.323E-03	-0.01	-0.042	-0.22
South West	-0.348	-1.45	-0.357	-1.56
Constant	-2.105***	-3.62	-14.000	-1.32
N	129		129	
Log pseudolikelihood	-1121.78		-1089.18	

Figure 5. Relationship between care home beds (for which the Trust is nearest) and COVID-19 mortality in that Trust – various specifications

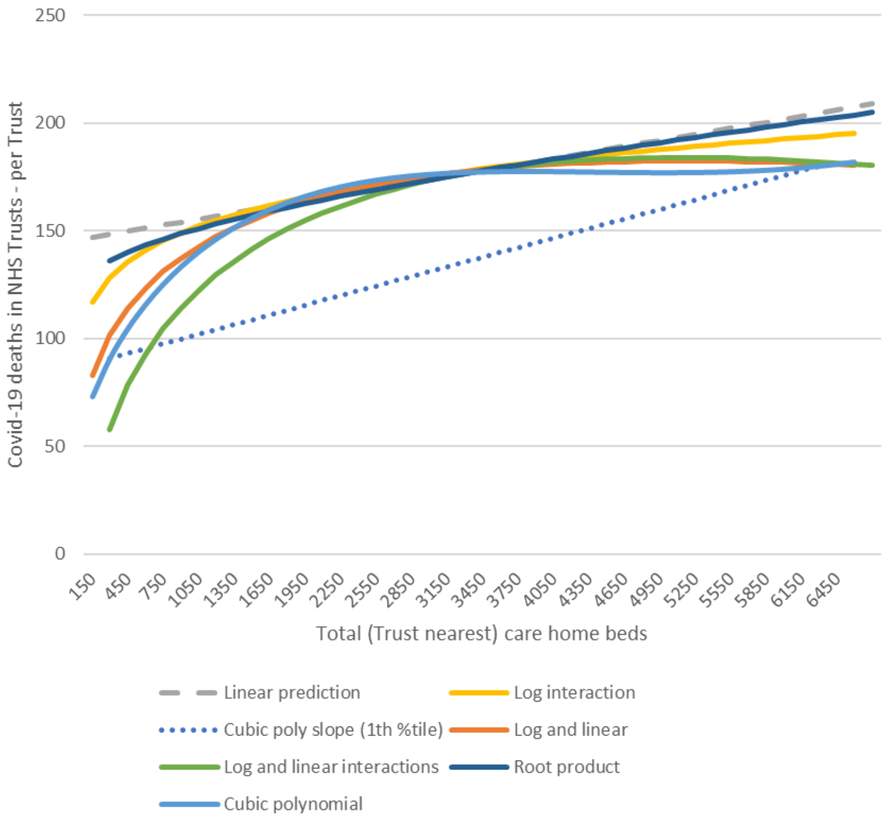


Figure 6 below has the equivalent relationship between outbreak rates and deaths. To note, as above, that the cubic polynomial is defined with regard to care home beds (not outbreaks), where the outbreaks per OP home are specified as a log in the estimation. Accordingly the distribution corresponds closely with the log interaction model version. The two specifications with log and linear numbers of outbreaks per older people homes in the locality show some diminishing effect away from the mean.

Figure 6. Relationship between numbers of outbreaks per total homes (for which the Trust is nearest) and COVID-19 mortality in that Trust – various specifications

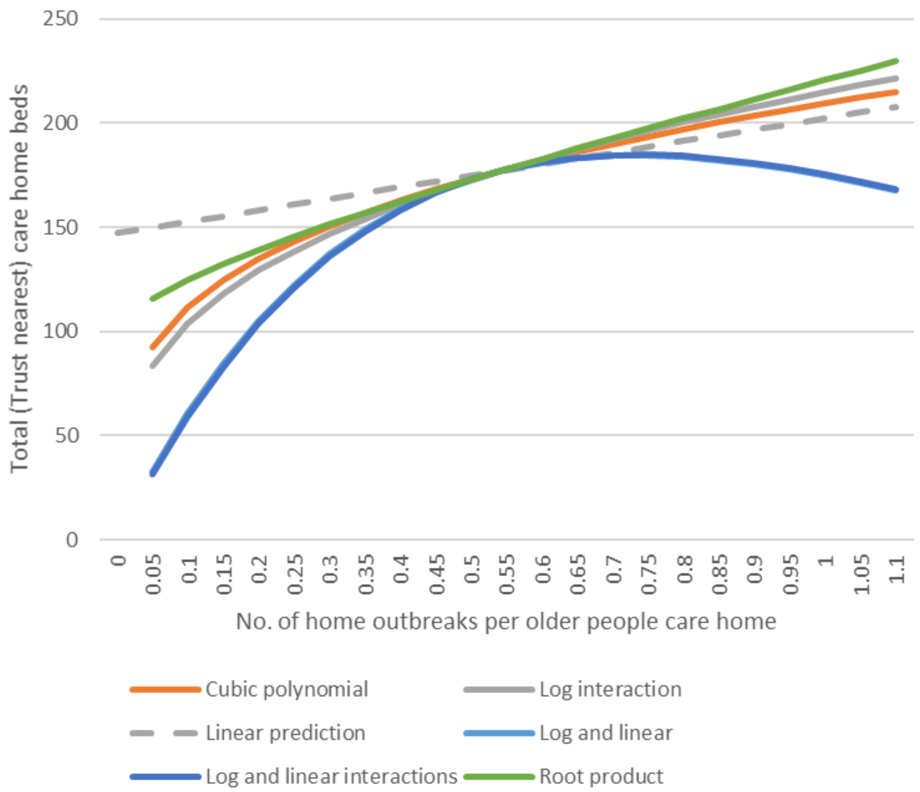


Table 6 reports the projected number of COVID-19 related deaths in hospital associated with the care home population, using extrapolations from the estimation results (the point estimates). Regions vary according to the rate of care homes with outbreaks, as shown, and also as to the numbers of care home beds. Overall, around 17% of hospital COVID-19 deaths (as reported at the time) were of care home residents. Other things equal, the number of projected deaths at the outbreak rate for each locality differs substantially from the 17% share of region observed total hospital deaths. For example, although London Trusts are in localities with higher than average care home COVID-19 outbreaks, the numbers of care home beds is much lower than average. On this basis alone, projected deaths of care home residents in those Trusts would be projected to total 521 deaths (rather than 933). If we also allowed for the high outbreak rate observed in London, and instead assumed that London had the national average rate (of 0.54), deaths would be lower still at a projected 366. By contrast, in the South West, the outbreak rate was much lower at the time, so projected deaths in hospital of care home residents would be higher.

Increases in infection rates that in turn increase the number of OP care homes with outbreaks (over total homes) would lead to increased numbers of deaths if all other factors remained unchanged. For example, in the South West, an increase from the observed outbreak rate of 0.37 to the national average of 0.54 would be projected to mean an additional 159 deaths in the care homes population.

Finally, we can project the number of additional deaths if the outbreak rate was at the (highest) London mean value of 0.77 OP homes per total homes in the area. In total for England, this is projected to increase deaths by 1,748, again using the point estimates and on the basis of the infection and admission rates at the time.

Projections using other values in the confidence interval range of these estimations would give different results. Also, we have assumed linear extrapolations in this case; this might be an over-estimate given the models have reducing marginal effects – see Figure 6 (but note that the sample is too small to be confident about functional forms in this regard).

Overall, we see substantial variation between the regions that stems both from differences in the number of care home places per Trust and from the different level of outbreaks per homes in the associated locality.

Table 6. Projected deaths in hospital associated with care home populations – different scenarios

	Actual deaths	17% of all (actual) deaths	Projected deaths of CH population (linear approx. w/ observed outbreak rates)	Projected CH pop deaths at sample-mean outbreak rate	Difference: projected deaths of CH pop at observed cf. sample outbreak rate	Projected CH pop deaths at max obs outbreak rate	Difference: projected deaths of CH pop at observed cf. max outbreak rate	No. of OP CHs with outbreaks over total homes
North East	1,179	200	279	243	-37	346	67	0.62
North West	3,641	619	572	571	-1	813	242	0.54
Yorkshire & The Humber	1,923	327	408	416	8	592	184	0.53
East Midlands	1,570	267	257	302	45	431	174	0.46
West Midlands	2,860	486	391	415	24	591	200	0.51
East of England	2,504	426	425	459	33	653	228	0.50
London	5,489	933	521	366	-155	521	0	0.77
South East	2,690	457	663	665	2	948	284	0.54
South West	962	164	337	496	159	707	370	0.37
Total	22,818	3,879	3,854	3,932	78	5,602	1,748	0.54

Care homes

The results of the estimation of (11), the logged interaction model, and (12), the quadratic outbreak rate interaction model, are reported in Table 7 and Table 8, respectively. In both cases we also report variant estimations. As to the former, models were estimated with both gamma and Poisson distributions.[14] Joint significance tests of the care home need-related factors in Table 7 for the logged interaction model showed these variables to be highly significant together ($Chi^2(6) = 89.75$, p-value <0.0001 for the gamma model and $Chi^2(6) = 122.09$, p-value <0.0001 for the Poisson model).

[14] Pregibon link/Park tests (Table 11 in

Annex 5) did not reject either specification but as this is a count (of deaths) analysis we opted to use the Poisson models.

Table 7. COVID-19 deaths in care homes – Logged interaction models (Log GLM, by distribution)

	Logged interaction (Gamma)		Logged interaction (Poisson)	
	Coefficient	Z	Coefficient	Z
CH need-related factors:				
Total CH beds × no. of home outbreaks per OP home, product log'd	0.230	1.54	0.425***	3.30
Total CH beds per CH × no. of home outbreaks per OP home, product log'd	0.562**	2.19	0.676**	2.11
Total care home beds × no. of home outbreaks per OP home	4.880E-04***	3.30	4.963E-04***	3.97
Total care home beds per CH × no. of home outbreaks per OP home	-5.830E-03	-0.55	-0.011	-0.71
No. of home outbreaks per OP home	-0.901	-1.49	-1.151*	-1.74
Total care home beds	-2.600E-04	-1.55	-2.845E-04*	-1.81
Hospital (GA) beds per capita - average over MSOAs w/in 20km, CH num weighted	-52.626	-1.45	-63.059	-1.15
Control factors				
Population aged 65+, by LAD	1.250E-05*	1.89	1.000E-05*	1.73
Population density - by LAD	1.471E-04***	4.89	1.200E-04***	3.24
Population density - by LAD, sq.	-1.090E-08***	-4.16	-9.970E-09***	-2.67
Population of AA claimants (higher rate)	-1.020E-05	-0.15	-2.160E-05	-0.47
Population all ages (care home num weighted)	2.070E-05	0.69	1.690E-05	0.54
Region (East Midlands is ref cat)				
East of England	-0.124	-0.89	-0.256**	-2.14
London	-0.132	-0.78	-0.123	-0.76
North East	0.455***	2.95	0.376***	2.85
North West	0.363**	2.09	0.382***	2.67
South East	0.272**	2.10	0.153	1.35
South West	0.425**	2.24	0.487***	2.91
West Midlands	0.192	1.45	0.061	0.46
Yorkshire and The Humber	0.298*	1.87	0.201	1.47
Constant	-0.197	-0.26	-1.277	-1.54
N	316		316	
Log pseudolikelihood	-991.93		-1010.28	

Table 8. COVID-19 deaths in care homes – Interaction models with quadratic outbreak rate (Log GLM, Poisson distribution)

	Squared outbreak rate interaction I		Squared outbreak rate interaction II		Squared outbreak rate interaction I (no clustering)	
	Coefficient	Z	Coefficient	Z	Coefficient	Z
CH need-related factors:						
Total CH beds (log) × no. of home outbreaks per OP home	1.844***	2.90	0.725***	3.37	1.844***	3.10
Total CH beds (log) × no. of home outbreaks per OP home (sq.)	-1.539*	-1.84			-1.539*	-1.88
Total CH beds per tot CHs (log) × no. of CH outbreaks per OP home	2.427	1.19	4.341	1.55	2.427	1.15
Total CH beds per tot CHs (log) × no. of CH outbreaks per OP CH (sq.)	-2.588	-1.34			-2.588	-1.35
Total CH beds × no. of home outbreaks per OP home	4.302E-04*	1.71	1.233E-04	0.70	4.302E-04*	1.80
Total care home beds per CH × no. of home outbreaks per OP home	-3.324E-03	-0.06	-0.101	-1.42	-3.324E-03	-0.05
Total care home beds	-2.764E-04	-1.59	-2.770E-05	-0.18	-2.764E-04*	-1.73
No. of home outbreaks per OP home	-19.719**	-2.35	-15.998**	-2.07	-19.719**	-2.42
No. of home outbreaks per OP home (sq.)	19.099*	1.92			19.099*	1.95
Hosp (GA) beds per capita (over MSOAs w/in 20km), CH num weighted	-66.821	-1.19	-48.740	-0.91	-66.821	-1.18
Control factors						
Population aged 65+, by LAD	1.110E-05**	2.07	8.970E-06	1.37	1.110E-05**	2.12
Population density - by LAD	1.227E-04***	3.25	1.310E-04***	3.41	1.227E-04***	3.33
Population density - by LAD, sq.	-1.050E-08***	-2.93	-1.060E-08***	-2.83	-1.050E-08***	-2.94
Population of AA claimants (hgher rate)	-3.650E-05	-0.81	-2.810E-05	-0.60	-3.650E-05	-0.83
Population all ages (care home num weighted)	2.720E-05	0.85	1.470E-05	0.46	2.720E-05	0.90
Region (East Midlands is ref cat)						
East of England	-0.265**	-2.09	-0.184	-1.33	-0.265***	-2.67
London	-0.148	-0.86	-0.181	-1.01	-0.148	-0.96
North East	0.362***	2.62	0.419***	2.85	0.362***	3.30
North West	0.370**	2.56	0.407**	2.54	0.370***	3.50
South East	0.148	1.25	0.133	1.05	0.148	1.59
South West	0.466***	2.71	0.415**	2.23	0.466***	3.24
West Midlands	0.063	0.46	0.088	0.60	0.063	0.56
Yorkshire and The Humber	0.183	1.28	0.215	1.42	0.183	1.52
Constant	1.890***	4.12	2.016***	5.62	1.890***	4.87
N	316		316		316	
Log pseudolikelihood	-1,007.874		-1,035.48		-1,007.874	

As expected, numbers of care home COVID-19 deaths in the period were highly correlated with the number of care home beds in the local authority. The marginal effect of an increase in care home beds at the sample mean other things equal, $\frac{\partial m_k^{cc}}{\partial x_k^c}$, was 0.0156 ($p$-value = 0.002, 95% CIs 0.0055 to 0.0256) using the logged interaction (Poisson) results (Table 7, col. 2). In other words, using the point estimates, we would expect 15.6 extra deaths for each additional 1,000 care home beds in a locality. Equivalently, the total predicted deaths is 6,675 for England. The marginal effect results from the squared outbreak rate interaction model I (Table 8, col 1) was 0.0181 (p-value = 0.001, 95% CIs 0.0076 to 0.0285), that is, 18.1 extra deaths for each additional 1,000 care home beds in a locality at the point estimate. In both cases, the confidence interval range estimated encompass the observed number of deaths. Figure 7 shows this relationship for the two sets of results, showing a generally linear form.

The marginal effects of an increase in the number of homes with outbreaks per total homes, $\frac{\partial m_k^{cc}}{\partial \bar{r}_k^c}$, was also positive and significant. For the logged interaction (Poisson) estimation, this marginal effect was estimated at 55.15 (p-value < 0.001, 95% CIs 36.40 to 73.89). For the squared outbreak rate interaction model I, the marginal effect was 62.77 (p-value < 0.001, 95% CIs 40.77 to 84.78). These relationships are shown in Figure 8, again having a largely linear form.

As noted above, we estimated models with standard errors adjusted for clustering at upper tier LA level (150 LAs). Without clustering – e.g. see Table 8, last col. – the estimated standard errors on the marginal effects were (slightly) smaller than with clustering.

Figure 7. Relationship between care home beds in the locality and COVID-19 mortality in care homes – various specifications

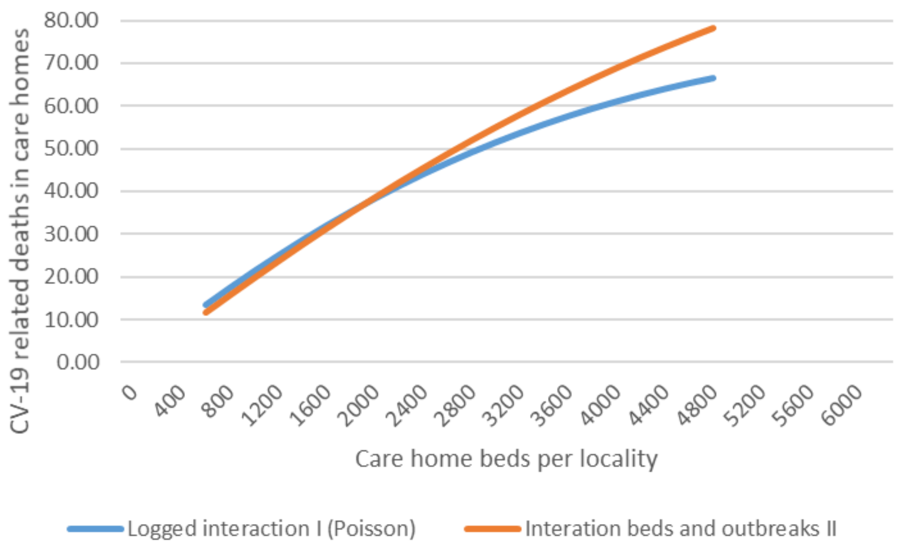
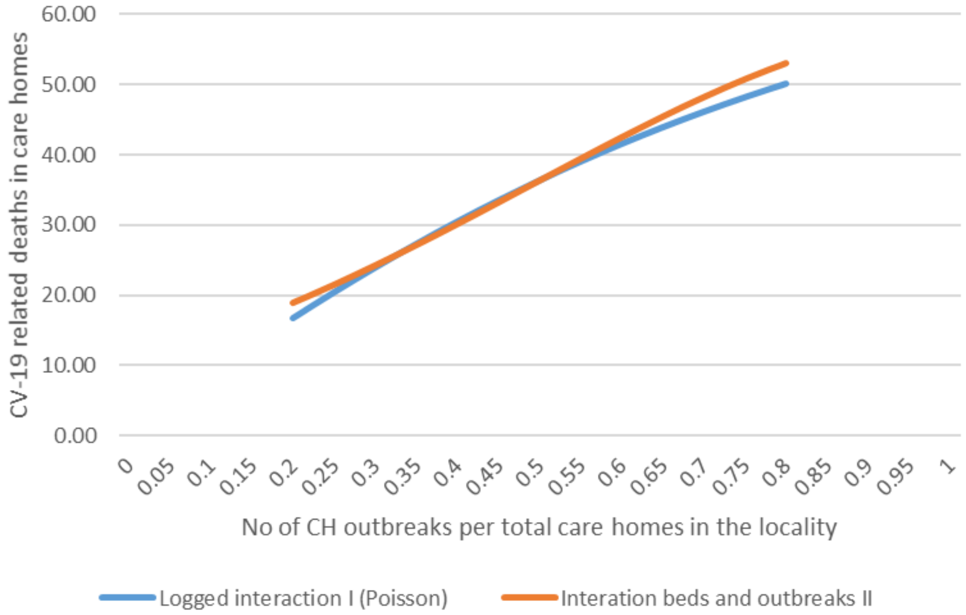


Figure 8. Relationship between the number of care home outbreaks per total care homes in the locality and COVID-19 mortality in care homes – various specifications



The interaction between outbreaks and care home beds is also significant. For example, from the squared outbreaks interaction model, the marginal effect of an increase in the rate of care home outbreaks is strongly increasing with the number of care home beds in the locality. The second order effect, $\frac{\partial^2 m_k^{cc}}{\partial \bar{r}_k^c \partial x_k^c}$ was 0.047 (p-value = 0.023). In other words, an increase in the outbreak rate in areas with a higher number of care home beds is associated with a higher number of extra COVID-19 deaths compared with areas that have a lower number of beds.

The estimation showed that the number of COVID-19 related deaths was negatively related to the number of Trust GA beds per capita, but this relationship was not significant (p-value > 0.1).

The estimation results were used to project the number of COVID-19 related deaths at regional level under three scenarios – see Table 9. The first is where the number of deaths is only determined by care home beds and outbreak rates in the locality (and all other factors in the estimations are held constant, i.e. the same for each region) – see col. 2, Table 9. In general, the projected number of deaths in this case are not markedly different from the actual number, underlining the importance of these two variables.

The second case is where all localities have the same (sample mean) care home outbreak rate, so that the projected number of deaths is only determined by differences in the number of care home beds between homes in different regions (col. 3). In this scenario, Northern regions and London would have expected fewer care home deaths, whilst the number would be higher in the South West, noting the difference in observed outbreak rates (last col.).

The final case is where outbreak rates in all localities are at the highest regional mean value (which is London) such that projected deaths in London in the scenario are the same as in the observed outbreak rate case (col. 5). In this case, we would see a projected additional 3,371 deaths in total in England, with a substantial increase in the South West.

Table 9. Expected COVID-19 related deaths of care home residents in care homes

	Actual deaths	Projected deaths of CH pop at observed outbreak rate (linear approx.)	Projected CH pop deaths at sample-mean outbreak rate	Difference: projected deaths of CH pop at observed vs. sample outbreak rate	Projected CH pop deaths at max obs outbreak rate	Difference: projected deaths of CH pop at observed vs. max outbreak rate	No. of OP CHs with outbreaks over total homes
North East	828	834	650	-183	925	91	0.62
North West	1,459	1,304	1,167	-137	1,659	355	0.52
Yorkshire & The Humber	1,359	1,549	1,376	-173	1,956	407	0.52
East Midlands	412	361	409	48	582	221	0.44
West Midlands	1,111	1,270	1,207	-63	1,715	445	0.51
East of England	410	492	505	13	717	225	0.51
London	490	463	326	-137	463	0	0.70
South East	995	864	906	42	1,288	424	0.50
South West	1,251	1,177	1,675	498	2,380	1,203	0.35
Total	8,314	8,314	8,222	-92	11,685	3,371	

Discussion

The COVID-19 pandemic has significantly affected both the NHS and social care systems in England. Policy concerning the management of COVID-19 has had to respond rapidly as the pandemic unfolded. There is a significant degree of interdependency between the NHS (acute) system and the care home sector (for older people) in England (Forder 2009; Gaughan, Gravelle et al. 2015; Gaughan, Gravelle et al. 2017). Accordingly, we expect that outcomes for older people with COVID-19 are affected by this interdependency, with interaction between the systems in the care and support of people with COVID-19, particularly frail older people who might be care home residents.

Focusing on NHS Acute Trust general and acute (GA) beds and care home capacity (supply of beds), we see substantial variation in their ratio between localities in England. For the lowest quartile of the ratio, there are 2.2 care home beds for every GA bed in the nearest Trust on average. In the upper quartile, there are 8.0 care home beds for every GA bed.

As regards the contribution of this paper, the aim was to identify the effects of care home supply on COVID-19 mortality. In particular, in the analysis we sought to explore the degree to which care home supply and hospital (NHS Trust) supply of beds are interrelated in their effect.

In theory, supply of care home and hospital beds is not fixed – and potentially influenced by the progression of the disease (e.g. the Nightingale hospitals) – but the analysis is able to account for this (endogeneity) by using supply levels that pre-date the pandemic. To note, endogeneity due to omitted variables (especially underlying need) remains a challenge, and the potential implications are discussed in the paper.

The analysis was undertaken at locality level to explore supply effects as they pertain to 'market' operation. Care home and NHS Trust supply was linked using a (travel-time adjusted) nearest distance method. This approach, as opposed to using administrative boundaries (such as LA boundaries), recognises that NHS Trust and care home 'operating or catchment areas' need not align or respect these administrative boundaries.

Hypotheses

Care homes residents are at high risk of COVID-19 infection and death due to their underlying health conditions and frailty, although this population group would also be at high risk if they were in another care setting or living in their own home, and became infected. A central question is whether being in a care home increases (a) the risk of infection and (b) the risks of hospitalisation and death if infected.

We might expect that the risk of infection for this population sub-group could be higher for being in a care home, other things equal – because co-habitation increases the chances for transmission and due to contact with a higher number of different staff members. Nonetheless, it is the *difference* in infection risk compared to a similarly frail person living in the community that affects the expected impact on admissions and deaths of an increase in care home capacity in a locality. Moreover, being in a care home rather than at home for a person with high frailty/care need might have a (relatively greater) preventative effect as regards COVID-19 hospital admissions, particularly for people in nursing homes, reducing the relative risk of admission. These arguments mean that the impact of additional care home places (that result in fewer frail people in the community) on admissions and deaths could be quite small. At the same time, an increase in the infection rate for the care home population (e.g. the proportion of care homes with outbreaks in a locality) should unambiguously imply a greater number of admissions and associated deaths from COVID-19.

Another relevant consideration is the (inter-dependent) capacity effect of care home supply on the availability and use of hospital beds, particularly with regard to the timely transfer of patients who are fit for hospital discharge. Localities with additional care homes might facilitate a higher rate of hospital discharge, other things equal, than localities with fewer care home places, allowing in turn higher hospital admissions. This situation would matter where a Trust was nearing capacity.

On balance, although we cannot be definitive, we hypothesise that localities with more care home places will experience greater hospital admissions and deaths than localities with fewer care homes, although the effect could be quite small, and indeed, less significant than the impact of an increase in care home COVID-19 outbreak rates in one locality compared to another.

Turning to the expected effects of NHS Trust capacity, clearly larger Trusts – as indicated by the number of their General and Acute (GA) beds – will be able to admit more COVID-19 patients, other things equal. Deaths from COVID-19 will be directly related to the number of admissions for the condition.

Regarding the total number of COVID-19 related deaths of residents *in care homes* in a locality, this will be directly related to the size of the at-risk care home population, which is closely linked to the number of care home beds in that area. Because there are options about where to support people with COVID-19, and in particular a choice between the NHS and the care home sector, in theory it is possible that localities with a high number of GA beds (relative to population health needs) could accommodate earlier admissions of care home residents, and so fewer COVID-19 deaths in care homes.

The relationship between COVID-19 deaths and care home bed capacity is affected by the rate of infection outbreaks in care homes. Jointly therefore, (average) outbreak rates and numbers of care homes beds in a locality are important determinants of the numbers of deaths of people with COVID-19.

We explored these hypothesised effects by estimating the relationship between COVID-19 deaths, in both hospital (NHS Trusts) and in care homes, and: the number of care home beds in the locality; the number of Trust GA beds in the locality; associated infection/outbreak rates; and a range of control factors.

The estimations in the analysis identified associations between COVID-19 deaths and supply levels, but without being able to fully account for differences in the underlying frailty, risk and infection rates between localities. There are, therefore, limits on how far we can infer *causal* effects.

Results

The analysis showed, as expected, that the outbreaks rate – the total number of care homes with outbreaks per total care homes in the locality – was a significant predictor of COVID-19 deaths in hospital (p-value < 0.05, depending on the model). The overall association between care home places and hospital COVID-19 deaths, although positive, was not found to be statistically significantly different from zero, at least at the margin. There was some indication, nonetheless, that the associated *average* change in hospital deaths from localities with very low care home beds to those with very high care home beds was significant. This result is consistent with there being offsetting factors that affect the overall relationship, as hypothesised.

We found that the relationship between hospital deaths and care home outbreaks was (positively) affected by the number of care home beds in the locality (p-value = 0.008 in the log-interaction model). In other words, an increase in the outbreaks rate is associated with a higher (absolute) number of hospital COVID-19 deaths in a locality with a high number of care home places compared with a locality with a low number of care home places.

Not surprisingly there was a strong positive association between total hospital COVID-19 deaths and the number of Trust GA beds in that locality. There was also some suggestion in the data that the size of this effect was greater in areas with a high number of care home beds compared to areas with a low number of care home beds (p-value = 0.075). This finding supports the hypothesised integrated effect of care home and hospital beds in affecting (hospital) COVID-19 deaths. For example, this result would be consistent with arguments that hospital Trusts in localities with a comparatively high number of care home places would have for each admission a lower average length of stay (earlier transfer of care) and, therefore, would be able to admit more patients per hospital bed.

The range of control variables for population characteristics were highly significant (jointly), indicating strong need effects separate to supply/capacity effects (e.g. $chi^2(8) = 40.84$, p-value < 0.001, using the first model reported above). There was little indication that any remaining variation in hospital COVID-19 mortality rates was systematically correlated at regional level (all regional dummies were insignificantly different from the North East reference case except for the East of England in one estimation variant).

Turning to COVID-19 deaths in care homes, the analysis also showed that the outbreaks rate was a significant predictor of those COVID-19 deaths of care home residents (p-value < 0.01 for both main models). There was also significant support, as expected, for care home COVID-19 reported deaths being strongly positively related to the number of care home beds in the locality (p-value = 0.001). This result is equivalent to 1 extra COVID-19 related death in care homes in a locality with 55 more care home beds than the average, other things being equal. Put another way, a locality with 10% more care home beds than average would have nearly 9.3% more COVID-19 related deaths in care homes. Indeed, in as far as we can extrapolate in the data, this estimated relationship appeared to be consistent with deaths being a linear proportional function of care home beds.

In addition, as with deaths in hospital, the positive relationship between care home COVID-19 deaths and care home outbreaks was further increased in localities with a relatively high number of care home beds (p-value = 0.023). This finding means that an increase in the outbreaks rate is associated with a higher (absolute) number of care home COVID-19 deaths in a locality with a high number of care home places compared with a locality with a low number.

In theory, the number of COVID-19 deaths in care homes could be influenced by the availability of GA beds in the Trust(s) in the locality. However, although the estimation showed that the number of COVID-19 related deaths in care homes was negatively related to the number of GA beds per capita, this relationship was not significant (p-value > 0.1).

The results were used to project COVID-19 deaths in different regions of England on the basis of a change in outbreak rates. Reflecting differences in the number of care home beds and outbreak rates, for example, the South West would be projected to have considerably more deaths associated with care home populations if outbreak rates were at England mean levels rather than at the observed regional mean levels. London, by contrast, would be projected to have far fewer deaths in that case.

Limitations

There are a number of limitations of this analysis. First, as noted above, because the analysis concerns supply effects, it was conducted at an organisation/market level. This necessarily restricted the number of observations to be the population of NHS Trusts and local authority districts (with associated issues of statistical precision). Moreover, in order to control for problems of endogenous response (by using pre-pandemic care home beds and hospital supply), this also meant that we could not use a panel data design in the analysis.

In theory, a multi-level approach might have been adopted, whereby individual patients and care home residents were followed as they moved between systems and providers, and where their characteristics and outcomes were known and used in the analysis. Currently, individual level linked datasets are not available (at least not for a sufficient number of organisational units so as to be able to assess supply effects).

Second, following from the previous point, we needed to make assumptions about *potential* patient movement between the systems. In this regard, the association of care home beds to NHS Trusts was made on the basis of straight line distance (average speed adjusted) between the care home and the NHS Trust headquarters (usually the primarily acute hospital).

Third, (parametric) statistical models were used to adjust for population characteristics; different specification of such models will give different results. We did estimate the models in levels (total numbers of beds and deaths), with scale factors (e.g. population) as independent variables. This gave the estimation some flexibility in being able to account for scale effects, by using a number of scaling factors (rather than a single population size denominator for the dependent variable in a model of deaths per capita). The (natural) log specification used in the analysis allowed for proportional scaling in a more flexible way.

Fourth, we used data from up until 8 May (as it coincides with the first wave of the pandemic). Clearly the pandemic continues to develop over time and changing the period of the analysis would have some effect on the results.

Fifth, this analysis used a mix of datasets that were and are developing over time and potentially subject to error or revision. A particular issue is the classification of deaths as being due to COVID-19 (rather than using an excess deaths classification).

Sixth, as noted above, we might not be able to account for all (underlying) risk factors for COVID-19 mortality – other than capacity and outbreak rates – which limits inferences about the causality of care home supply. In theory, an empirical analysis should fully account for the distribution of (underlying) ill health and frailty in a locality's population as a driver of COVID-19 mortality risk. Otherwise, the number of care home beds in a locality may appear to be associated with hospital admissions and death rates, but this would not be a *causal* effect, rather a result of the underlying correlation between a person's ill health/frailty and being in a care home. On the other hand, it is important not to adjust for differences in population levels of ill health and frailty that *result from* differences in care home supply between localities (where people's move into a care home is influenced by supply). In our selection of 'control' factors we were mindful of these issues, but these biases cannot be fully ruled out.

Policy implications

The main implications of this analysis are twofold. The first concerns 'need' effects. The number of hospital COVID-19 deaths is positively related to the number of care homes with outbreaks, and indeed the size of this effect is greater in localities with a large supply of care home places compared with an area with a low supply. Accordingly, we predict that the extra demand on hospital beds from an increase in outbreak rates will be greater (in absolute number) in areas with more care home places than areas with a low number, which is to be expected.

The results were not clear that there is a specific care home supply effect on deaths; that is, where comparatively more people are resident in a care home in a locality – rather than receiving other forms of social care, e.g. home care – there was not a significantly greater effect on deaths (at least at the margin, and after factoring out differences in care home outbreaks rates between localities).

The insignificant size of the relationship at the margin is consistent with the theory that areas with fewer care home places use more of other forms of social care (e.g. home care and informal care), and the population using these other forms of care is still at high-risk of severe COVID-19. There may be a difference in both the infection rate and the hospital admission rate between different forms of social care – e.g. higher infection risk in care homes – but this comparative effect on the number of deaths would be less important than an increase in underlying infection rates, which would affect people using all forms of social care.

Notwithstanding this point about care home specific effects, it is still clear that we need to account for the number of care homes in the area (at least in combination with the rate of care home outbreak rates) as a predictor of COVID-19 hospital admissions and deaths.

Second, the results support our hypothesis of inter-dependent effects between care home and Trust capacity (beds) in affecting the number of COVID-19 admissions and deaths, albeit somewhat tentatively. Localities with a high number of hospital beds had a greater number of hospital COVID-19 deaths (and admissions) *associated with each additional care home bed* than areas with a lower number of hospital beds. Equivalently, the number of deaths (and so admissions) per NHS Trust bed (at the margin) was greater in areas with a higher number of care home places than in areas with a lower number.

Although we can speculate as to the nature of the interdependency, e.g. as regards the relative rate of hospital admissions from and (timely) transfers back to care homes, more specific data on patient flows would be needed to provide greater clarity on this point. Nonetheless, in finding evidence for any form of interdependency, as we do, this has an important general implication: that longer-term capacity choices in both the care home and hospital sectors should account for supply in the other sector. A particular implication is for funding allocation formulae to recognise and allow for (own and cross-) supply effects in their development and use. Another implication in this regard concerns the management of local social care markets by commissioners and regulators. Notwithstanding that the vast majority of care homes are non-public, with few restrictions on where they can locate, any influence on this supply by public authorities should again account for the local ratio of Trust capacity to existing care home (and wider social care) supply.

More generally, these results support the current policy drive to create closer coordination between NHS and local authority commissioners and care providers. Indeed, we can expect this coordination to be facilitated by the implementation of Integrated Care Systems (ICSs).

In conclusion, this paper has tentatively showed the significance of care home supply in affecting the need for high-levels of COVID-19 care, and also of the interdependence between hospitals/NHS acute Trusts and the care home sector. Our experience of the COVID-19 pandemic has emphasised the importance of recognising this interdependence (we would also expect the same arguments to apply for the support of frail populations with other infectious, and indeed, long-term conditions). As regards the focus on supply, this matters because across localities in England we see a substantially varying ratio of (nearest) care home beds to acute NHS Trusts bed numbers.

The results are tentative given the availability of data for this study. Further analysis is needed to isolate the different effects, and control for underlying need, and population infection rates. A multi-level analysis, with supply measured at the organisational/locality level and flows of patients/care home residents measured at the individual person level, would be ideally suited but this would require comprehensive health and social care linked datasets and these are not currently available. It is recommended that such a dataset be developed.

This paper contributes to our understanding of social care supply effects. Given the numbers of people that use care homes (and other forms of social care), and the interdependent use of care home (social care) and hospital care for these populations, especially as regards the impact of COVID-19, this is a priority area for research.

Annex 1. Care system capacity

On average, the flow of patients into the hospital must be balanced by the flow out of hospital, that is admissions are equal to discharge during any given time period (with short-term adjustments to capacity allowing for some fluctuation at any given time). In this way, admissions rates will be determined according to the required rate of discharge. With no constraints on discharges, hospitals can operate at full capacity with admissions determined as follows:

$$A_k^H = D_k^H + M_k = D_k^H + \phi A_k^H \tag{13}$$

where D_k^H is the number of patients requiring discharge in steady state and M_k is mortality, including COVID-19 deaths (i.e. $M_k = m_k + m_k^0$ with m_k^0 being other deaths). Hospital mortality of admitted patients is ϕA. On average (in steady state) the discharge rate will be number of occupied beds (x_k^h) divided by length of stay (l_k^h). As such, (13) is:

$$A_k^H = \frac{D_k^h}{1-\phi} = \frac{x_k^h}{l_k^h}\frac{1}{1-\phi} \tag{14}$$

It may not be possible, for a whole range of reasons, to discharge all patients who are fit for discharge at any given time. One potential delay may be due to care home capacity, but other delays may arise in the hospital or in the process of discharging people back to the community. To consider the care homes capacity case, we distinguish two types of discharge. In this case, admissions to hospital will be constrained accordingly – to a level denoted as A_k^D:

$$A_k^D = D_k^c + D_k^w + M_k \tag{15}$$

where D_k^c is the level of discharge to care homes, D_k^w is the level of discharge to the community. Suppose that patients discharged either require a care home placement, at a proportion α, or go back to the community, at a rate $1-\alpha$. As such:

$$A_k^D = D_k^c + (1-\phi)(1-\alpha)A_k^D + \phi A_k^D \tag{16}$$

Solving for A_k^D gives:

$$A_k^D = \frac{D_k^c}{(1-\phi)\alpha} \tag{17}$$

In a steady state, with full occupancy, hospital discharges to care homes must equal care home admissions, which in turn must equal care home discharge levels. With average length of stay in care homes of l_k^c, we have $D_k^c = \frac{x_k^c}{l_k^c}$, so that[15]:

$$A_k^D = \frac{x_k^c}{l_k^c}\frac{1}{(1-\phi)\alpha} \tag{18}$$

In other words, when the availability of care home beds is restricted, hospital discharge rates will be determined by care home bed numbers, not hospital bed capacity – at a rate of $\frac{1}{(1-\phi)\alpha l_k^c}$ care home beds.

[15] Note that length of stay is likely to be a function of mortality rates in practice, although it can be convenient to think of lengths of stay as being the same regardless of outcome (mortality or discharge), without loss of generality, noting that this rate cancels out at the optimal (see below).

It may also be the case that actual admissions fall below the capacity to admit, such as where the level of referrals (need) at any given time is low. As such, admissions rates are determined at the level of COVID-19 referrals from both the care homes population:

$$\begin{aligned} A_k^N &= A_k^{Nc}(y_k^c(\sigma_k, r_k), \sigma_k) + A_k^{Nw}(y_k^w(\sigma_k, r_k), \sigma_k) \\ &= A_k^{Nc}(p_k^c(\sigma_k)\bar{r}_k^c(\sigma_k, r_k), \sigma_k) + A_k^{Nw}(p_k^w(\sigma_k)\bar{r}_k^w(\sigma_k, r_k), \sigma_k) \end{aligned} \tag{19}$$

Where σ_k stands for the underlying level of frailty in the population, r_k for rate of infection in the population overall, p_k^c for sizer of the care home population, $\bar{r}_k^c$ for the average rate of infection in care homes, p_k^w for size of the population living in the community, $\bar{r}_k^w$ for the average rate of infections in the community (i.e. outside care homes), and the size of the care home population is positively correlated to the total number of beds ($\frac{\partial p_k^c}{\partial x_k^c} > 0$). Here, $y_k^c = x_k^c \bar{w}_k^c \bar{r}_k^c = p_k^c \bar{r}_k^c$ from (2).

Actual admission rates will be the determined such that: $A_k = A_k^N \leq A_k^H \leq A_k^D$.

Admission need is a positive function of the level of frailty in the population, σ_k as this affects both the infection rate and the severity of the infection (likelihood of needing an admission). Holding constant the relative size of the care home and community populations, we have:

$$\left.\frac{\partial A_k^N}{\partial \sigma_k}\right|_{p_k^c, p_k^w} = \left.\frac{\partial A_k^{Nc}}{\partial \sigma_k}\right|_{\bar{r}_k^c} + p_k^c \frac{\partial A_k^{Nc}}{\partial \bar{r}_k^c}\frac{\partial \bar{r}_k^c}{\partial \sigma_k} + \left.\frac{\partial A_k^{Nw}}{\partial \sigma_k}\right|_{\bar{r}_k^w} + p_k^w \frac{\partial A_k^{Nw}}{\partial \bar{r}_k^w}\frac{\partial \bar{r}_k^w}{\partial \sigma_k} > 0 \tag{20}$$

But holding constant the level of frailty (and care home outbreak rates), the effect of a change in the size of the care home population is:

$$\begin{aligned} \left.\frac{\partial A_k^N}{\partial p_k^c}\right|_{\sigma_k, \bar{r}_k^c} &= \left.\frac{\partial A_k^{Nc}}{\partial y_k^c}\right|_{\sigma_k, \bar{r}_k^c} \frac{\partial y_k^c}{\partial p_k^c} + \left.\frac{\partial A_k^{Nw}}{\partial y_k^w}\right|_{\sigma_k} \frac{\partial y_k^w}{\partial p_k^w} = \left.\frac{\partial A_k^{Nc}}{\partial y_k^c}\right|_{\sigma_k, \bar{r}_k^c} \bar{r}_k^c + \left.\frac{\partial A_k^{Nw}}{\partial y_k^w}\right|_{\sigma_k, \bar{r}_k^c} \bar{r}_k^w \frac{\partial p_k^w}{\partial p_k^c} \\ &= \left.\frac{\partial A_k^{Nc}}{\partial y_k^c}\right|_{\sigma_k, \bar{r}_k^c} \bar{r}_k^c - \left.\frac{\partial A_k^{Nw}}{\partial y_k^w}\right|_{\sigma_k, \bar{r}_k^c} \bar{r}_k^w \end{aligned} \tag{21}$$

given that we can assume that $\frac{\partial p_k^w}{\partial p_k^c} = -1$; for a given total population size, people can be in care homes or in the community (assuming no care home supply effects from outside the locality – see also below). This expression might be positive or negatively signed. The term $\left.\frac{\partial A_k^{Nc}}{\partial y_k^c}\right|_{\sigma_k, \bar{r}_k^c}$ is the propensity for a person in a care home to be admitted if they have COVID-19, and similarly, $\left.\frac{\partial A_k^{Nw}}{\partial y_k^w}\right|_{\sigma_k, \bar{r}_k^c}$ for people in the community. In general, without accounting for frailty, we would expect care home residents with COVID-19 to be admitted with greater likelihood than people in the community because they are frailer and more likely to suffer a severe disease. However, if we control for frailty that need not be the case – i.e. if we compare the likelihood of admission for a person with COVID-19 and of equal frailty living in a care home and the community, we might find that $0 < \left.\frac{\partial A_k^{Nc}}{\partial y_k^c}\right|_{\sigma_k, \bar{r}_k^c} < \left.\frac{\partial A_k^{Nw}}{\partial y_k^w}\right|_{\sigma_k, \bar{r}_k^c}$, which we might call a preventative effect (e.g. through better nursing support in a care home that reduces the risk of avoidable admissions at any given time, compared with support in the community). In this case, and if $\bar{r}_k^c = \bar{r}_k^w > 0$, then $\left.\frac{\partial A_k^N}{\partial p_k^c}\right|_{\sigma_k, \bar{r}_k^c} < 0$. On the other hand, if infection rates were not equal, and indeed we might expect them to be higher in care homes, i.e., $\bar{r}_k^c > \bar{r}_k^w > 0$, then the sign of $\left.\frac{\partial A_k^N}{\partial p_k^c}\right|_{\sigma_k, \bar{r}_k^c}$ could be positive or negative. The main point however, is that if we fully account for frailty in an estimation, it could be possible, theoretically, for there to be a negative relationship between the need for admissions and the number of people in care homes. Overall, we may not be able to say, *a priori*, what the expected sign of $\left.\frac{\partial A_k^N}{\partial x_k^c}\right|_{\sigma_k, \bar{r}_k^c} = \left.\frac{\partial A_k^N}{\partial p_k^c}\right|_{\sigma_k, \bar{r}_k^c} \frac{\partial p_k^c}{\partial x_k^c}$ would be, although if prevention effects are weak then we might reasonably expect $\left.\frac{\partial A_k^N}{\partial x_k^c}\right|_{\sigma_k, \bar{r}_k^c} > 0$; indeed, with COVID-19 we might expect the opportunities for preventative nursing to quite limited.

Generally speaking, the optimal deployment of beds between sectors – i.e. to maximise admissions given need – occurs where achievable admissions rates are equal: $A_k^H = A_k^D$.[16] Therefore the optimal allocation of capacity is where:

$$A_k^D = \frac{x_k^c}{l_k^c} \frac{1}{(1-\phi)\alpha} = A_k^H = \frac{x^h}{l_k^h} \frac{1}{1-\phi} \tag{22}$$

Or

$$\frac{x_k^c}{x_k^h} = \alpha \frac{l_k^c}{l_k^h} \tag{23}$$

Care home lengths of stay will in general be longer than (acute) hospital lengths of stay (although potentially falling as COVID-19 mortality increases), which means that CH bed capacity needs to be higher than (acute) hospital bed capacity to achieve equilibrium.

In practice, we assume that hospital Trust and the care home total capacity are exogenously determined for each area k and effectively fixed for the current time period. As such, in some areas $\frac{x_k^c}{x_k^h} > \alpha \frac{l_k^c}{l_k^h}$ which will mean no (systematic) delayed transfers (due to social care) and that admissions rates are determined in line with hospital bed capacity constraint, whilst in other areas, $\frac{x_k^c}{x_k^h} < \alpha \frac{l_k^c}{l_k^h}$, the converse case would apply. Likewise, with regard to need σ_k, although care home supply will be aligned with local need, it will also be determined by market factors, especially input prices for capital and other factors, such that $p_k^c = p_k^c(\sigma_k, x^c(x^{cS}, \sigma_k))$, where x^{cS} are market supply factors. We might expect $\left.\frac{\partial p_k^c}{\partial x_k^c} \frac{\partial x_k^c}{\partial x_k^{cS}}\right|_{\sigma_k} \neq 0$.

In the longer term, care system capacity is adjusted to be in line with likely referral rates as they differ between localities across the country. Accordingly, hospital beds by Trust/locality will be positively correlated with differences in expected referral rates between localities i.e. $x_k^h(l_k^h) = \hat{x}_k^h\left(\hat{A}_k(p_k^w, p_k^c)\right)$, with $\frac{\partial x_k^h}{\partial \hat{A}_k} > 0$.

Hospital mortality (in all populations) is $M_k = \phi A_k$. We can explore the marginal effects of additional CH bed capacity. Where $A_k = A_k^D$, then $\frac{\partial M_k}{\partial x_k^c} = \frac{1}{l_k^c} \frac{\phi}{(1-\phi)\alpha}$. Where $A_k = A_k^H$, then $\frac{\partial M_k}{\partial x_k^c} = 0$.

[16] Otherwise where this equality condition does not hold, the same total level resources could be re-allocated between sectors to change relative capacity and this would lead to an increase in admission rates.

We can also expect to see referrals stemming from the increasing need that COVID-19 presents in the population.

Taking the above together, at any given time:

$$A_k = \rho^D(x_k^c, x_k^h)A_k^D + \rho^H(x_k^c, x_k^h)A_k^H + (1-\rho^D-\rho^H)A_k^N \quad (24)$$
$$= \rho^D(x_k^c, x_k^h)\frac{x_k^c}{l_k^c}\frac{1}{(1-\phi)\alpha} + \rho^H(x_k^c, x_k^h)\frac{x^h}{l^h}\frac{1}{1-\phi} + (1-\rho^D-\rho^H)A_k^N(p_k^w, p_k^c(x_k^c))$$

where ρ^D is the probability that care home capacity is restricting discharge (i.e. that $A_k = A_k^D$) and ρ^H is the probability that hospitals are full capacity (i.e. that $A_k = A_k^H$). Differentiating:

$$\frac{\partial A_k}{\partial x_k^c} = \rho_{x^c}^D A_k^D + \frac{\partial A_k^D}{\partial x_k^c}\rho^D + \rho_{x^c}^H A_k^H + \frac{\partial A_k^N}{\partial x_k^c}(1-\rho^D-\rho^H) - (\rho_{x^c}^D + \rho_{x^c}^H)A_k^N \quad (25)$$

If referrals are below capacity thresholds, then $\rho^D = 0$ and $\rho^H = 0$, and $\rho_{x^c}^D$ and $\rho_{x^c}^H$ are zero. In this case, $\frac{\partial A_k}{\partial x_k^c} = \frac{\partial A_k^N}{\partial x_k^c}$. As noted above, if (hospital admission) prevention effects for care home residents are weak, as we assume, then $\frac{\partial A_k^N}{\partial x_k^c} \geq 0$. Where need is high so that the hospital and/or care sector are operating at full capacity, then $\rho^H = 1 - \rho^D$ and $\rho_{x^c}^D \leq 0$ and $\rho_{x^c}^H = -\rho_{x^c}^D \geq 0$; an increase in care home beds makes it less likely that there will be delayed transfers. In that case (25) becomes:

$$\frac{\partial A_k}{\partial x_k^c} = \rho_{x^c}^D\left(A_k^D - A_k^H\right) + \frac{\partial A_k^D}{\partial x_k^c}\rho^D \quad (26)$$

For low values of x_k^c, with care home capacity binding, $A_k^D - A_k^H < 0$, and first term is positive. For high values of x_k^c, then $A_k^D - A_k^H > 0$. However, at that point, $\rho_{x^c}^D = 0$ and so $\rho_{x^c}^D\left(A_k^D - A_k^H\right) = 0$. In this case there $\frac{\partial A_k}{\partial x_k^c} \geq 0$.

Overall, either with capacity constraints binding or not, we expect $\frac{\partial A_k}{\partial x_k^c} \geq 0$.

Summing over time, the total number of deaths of care home residents in hospital with COVID-19 over the period – denoted with the superscript, hc – will be a proportion of the total (cumulative) admissions:

$$\frac{\partial m_k^{hc}}{\partial x_k^c} = \phi\sum_t \frac{\partial A_{kt}}{\partial x_k^c}(x_k^c, x_k^h) \geq 0 \quad (27)$$

This expression is the basis for our empirical hypothesis.

Finally, COVID-19 deaths in hospital (all populations) will be positively correlated with hospital bed capacity, for two reasons. First, because $\frac{\partial x_k^h}{\partial \hat{Y}_k} = \frac{\partial x_k^h}{\partial \hat{Y}_k}\left(\frac{\partial \hat{Y}_k}{\partial p_k^w} + \frac{\partial \hat{Y}_k}{\partial p_k^c}\right) > 0$ (hospitals serving large populations have more capacity) and because $\frac{\partial y_k}{\partial p_k^w} > 0$ and $\frac{\partial y_k}{\partial p_k^c} > 0$ (numbers of COVID-19 cases are positively related to the numbers in the local population, other things equal). Second, because COVID-19 infections rates in any given locality can vary (and in an unplanned-for way historically), referral protocols might be adjusted to re-align catchment populations p_k between different Trusts, k, in the region so that $\frac{A_k^N(p_k)}{A_{-k}^N(p_{-k})} \to \frac{A_k^H(x_k^h)}{A_{-k}^H(x_{-k}^h)}$. In other words, some people in a local population with high rates of COVID-19 infection compared to existing Trust capacity normally served by Trust k

might instead be referred to Trust j. As such, given observed COVID-19 infection rates in the region, Trusts with higher capacity, other things equal, will have more referrals than Trusts with lower capacity.

Where exogenous need is increased, such as through an increase in infection rates, $\frac{\partial A_k^N}{\partial r_k^c} > 0$ in (19), we would expect hospital admission to rise, unless capacity is constrained. Accordingly, with analogy to the above case regarding beds, we expect $\frac{\partial m_k^{hc}}{\partial r_k^c} > 0$, other things equal.

Annex 2. Allocation of Trust capacity to LADs

The allocation was done in two steps. First, we calculated the number of MSOAs within a given range of each Trust (in this case within 20km) and apportioned the total number of GA beds of the kth Trust (x_k^h) to these MSOAs. This is repeated for all Trusts and beds are summed for MSOAs with more than one Trust in range. It gives the total proportioned GA beds associated with each MSOA m:

$$\bar{x}_m^h = \sum\nolimits_k \frac{\gamma_{mk}(\vec{d}_{km})}{\left(\sum_{m^n=1}^{m^n=6791} \gamma_{m^n k}(\vec{d}_{km})\right)} x_k^h \tag{28}$$

where $\gamma_{mk}(\vec{d}_{km})$ is a function that takes a value of 1 when Trust k is within a given range of MSOA m, using the matrix $\vec{d}_{km}$ of adjusted straight-line distances between all 129 acute Trusts and 6,791 MSOAs in England, and zero otherwise. For example, if Trust k has 10 MSOAs in range, then MSOA m is assumed to have one-tenth of its beds. In addition, MSOA m is allocated the share of other Trust's beds if they are in range (according to how many MSOAs are in range of Trust $k + 1$). We add up all allocated beds to MSOA m from all Trusts to give the total proportioned GA beds of all Trusts to that MOSA ($\bar{x}_m^h$).

The second step is to sum this number to LAD level and to account for differences in the sizes of population served (at MSOA or LAD level). We accounted for the different number of care homes in each LAD to weight the average GA beds per capita calculation:

$$\bar{x}_j^h = \frac{1}{\sum_m n_m^{i \in m}} \sum\nolimits_{m \in j} n_m^{i \in m} \frac{\bar{x}_m^h}{p_m} \tag{29}$$

where $n_m^{i \in m}$ is the number of care home in each MSOA.

Another option is to sum allocation GA beds over all MSOAs in LAD j and then divide by the population of LAD j i.e. $\frac{\sum_{m \in j} \bar{x}_m^h}{p_j}$, or use the average of beds per capita over all MSOAs in the LAD i.e. $\frac{1}{N_j^{m \in j}} \sum_{m \in j} \frac{\bar{x}_m^h}{p_m}$ where $N_j^{m \in j} = \sum_{m \in j} 1$ is the number of MSOAs in LAD j (which gives the same result if the population is the same for all MOSAs in j). Weighting by numbers of care homes as in (29) reflects that some LADs have many more homes than others, and so should have more importance given the conceptual unit of analysis is the care home. Nonetheless, if all LADs had an equal number of homes, (and the same populations) these different approaches would produce the same value for X_j^h.

Annex 3. Data sources

The number of COVID-19 deaths in care homes notified to the Care Quality Commission, England

(1) https://www.ons.gov.uk/file?uri=/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/datasets/numberofdeathsincarehomesnotifiedtothecarequalitycommissionengland/2020/previous/v3/20200510officialsensitivecoviddeathnotificationschdata20200508.xlsx

(2) and https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/datasets/numberofdeathsincarehomesnotifiedtothecarequalitycommissionengland/2020

Number of COVID-19 deaths in NHS Trusts

(3) https://www.england.nhs.uk/statistics/statistical-work-areas/covid-19-daily-deaths/

Data on registered care homes were sourced from CQC (as of March 2020):

(4) https://www.cqc.org.uk/about-us/transparency/using-cqc-data

Homes were selected with older people as the primary resident group.

Acute NHS Trust data was sourced from CQC and NHS Digital:

(5) https://digital.nhs.uk/services/organisation-data-service/data-downloads/other-nhs-organisations

Analysis of deaths involving COVID-19 within the care sector (ONS)

(6) https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/datasets/deathsinvolvingcovid19inthecaresectorenglandandwales (Table 6)

Outbreaks data are sourced from Public Health England (PHE):

(7) https://www.gov.uk/government/statistical-data-sets/covid-19-number-of-outbreaks-in-care-homes-management-information

This dataset includes management information describing the number of care homes reporting a suspected or confirmed outbreak of COVID-19 to PHE, together with the cumulative proportion of all care homes that have reported an outbreak. Figures are included for each week starting from 2 March 2020 by local authority, government office region and PHE centre.

Data on coronavirus (COVID-19) tested rates in the UK are sourced from the official UK Government website for data and insights on Coronavirus:

(8) https://coronavirus.data.gov.uk/

Data on Trust GA beds are from NHS England (NHS organisations in England, Quarter 3, 2019-20 (revised 19.11.2020):

(9) https://www.england.nhs.uk/statistics/wp-content/uploads/sites/2/2020/11/1920-Q3-Beds-Open-Overnight-Web_File-Final-DE5WC.xlsx

Data on average road speeds were sourced from the Department for Transport, using statistics on Average speed and delay on local ‘A’ roads (CGN05):

(10) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/940732/cgn0501.ods

Annex 4. Marginal effects

In the first scenario, we project the number of deaths associated with the (difference) between the sample mean outbreak rate and zero outbreaks ($\bar{r}_k^c$). As an approximation, we used marginal effects at whole-sample mean (denoted $\bar{\bar{r}}_k^c$) to calculate projected deaths were outbreak rates are zero for each locality.[17]

$$\widehat{m}_k^{h0} \cong \widehat{m}_k^h(\bar{\bar{r}}_k^c) + \frac{\partial m_k^h}{\partial \bar{r}_k}(\bar{\bar{r}}_k^c)(0 - \bar{r}_k^c) \tag{30}$$

An adjustment is made for localities with care home beds that differ from the mean, such that $\frac{\partial m_k^h}{\partial \bar{r}_k}(\bar{\bar{r}}_k^c) = \left.\frac{\partial m_k^h}{\partial \bar{r}^c{}_k}\right|_{\bar{x}_k} + \frac{\partial^2 m_k^h}{\partial \bar{r}_k \partial x_k^c}(x_{k\in G}^c - \bar{x}_k^c)$. The difference between predicted deaths at the mean and at zero outbreak rates is as follows, and this is equivalently the number of deaths associated with a change in outbreak rate of this amount:

$$\Delta\widehat{m}_k^{h0} \cong \gamma\left(\left.\frac{\partial m_k^h}{\partial \bar{r}_k}\right|_{\bar{x}_k} + \frac{\partial^2 m_k^h}{\partial \bar{r}_k \partial x_k^c}(x_{k\in G}^c - \bar{x}_k^c)\right)(-\bar{r}_k^c) \tag{31}$$

The first and second order differentials are derived in their application to (8) and (11), and their variants. We use the sample mean values for other variables in the calculation of the differentials.

An adjustment factor γ is applied such that the sum of projected deaths in each area add to the England total, m^h, i.e. $\sum \Delta\widehat{m}_k^h = m^h$.

As regards the second scenario, where care home outbreak rates are the same for all regions (i.e. $\bar{r}_k^c = \bar{\bar{r}}_{k\in G}^c$, the difference in the predicted number of deaths in each locality is similar:

$$\Delta\widehat{m}_k^{h\bar{\bar{r}}} \cong \Delta\widehat{m}_k^{h0} - \frac{\Delta\widehat{m}_k^{h0}}{\bar{r}_k^c}\bar{\bar{r}}_{k\in G}^c \tag{32}$$

In this case, the predicted number with whole-sample mean outbreaks is calculated as $\widehat{m}_k^h = \Delta\widehat{m}_k^{h\bar{\bar{r}}} + m_k^h(\bar{r}_k)$.

In the third scenario, $\bar{r}_k^c$ is set to the regional mean value of the region with the highest (mean) outbreak rate.

We can then compare regions: $\bar{\bar{m}}_{k\in G}^h - \bar{\bar{m}}_{k\in G'}^h$ by taking the mean values of $\widehat{m}_k^h$ for localities in regions G and G'.

[17] With a second-order adjustment using the regionally mean level of care home beds $x_{k\in G}^c$ as compared to the whole-sample mean, $\bar{x}_k^c$.

Annex 5. GLM distribution specification tests

Table 10. Pregibon link/Park tests – Hospital deaths

	Gamma distribution		Poisson distribution	
	Test Chi-sqrd	prob	Test Chi-sqrd	prob
log and linear model				
Gaussian	60.21	<0.001	23.16	<0.001
Poisson	8.13	0.004	1.33	0.248
Gamma	4.23	0.040	6.26	0.012
Inverse Gaussian	48.49	<0.001	37.94	<0.001
Log interaction model				
Gaussian	67.70	<0.001	27.83	<0.001
Poisson	9.14	0.003	1.63	0.202
Gamma	4.76	0.023	7.41	0.007
Inverse Gaussian	54.57	<0.001	45.16	<0.001

Table 11. Pregibon link/Park test – Care home deaths (logged interaction model)

	Gamma		Poisson	
	Test Chi-sqrd	prob	Test Chi-sqrd	prob
Gaussian	76.8	<0.001	18.71	<0.001
Poisson	13.91	<0.001	**0.02**	**0.879**
Gamma	**1.7**	**0.192**	21.45	<0.001
Inverse Gaussian	40.17	<0.001	82.99	<0.001

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