Insight for decision-making as lockdown is gradually lifted: simple proxy measures to indicate local rate of growth/ shrinkage in COVID-19

Working paper by Russell Cake (Director), Antonio Weiss (Director) and Henry Holms (Consultant) at 2020 Delivery Ltd, updated 12th May 2020

Executive summary

1. As government and scientific decision-makers consider releasing elements of the COVID-19 lockdown, three of the government's "five tests" relate to quantitative measures of infection rate. These three tests ask:
    i. Have we moved beyond the peak, with a consistent and daily fall in the death rate?
    ii. Do we know that the rate of infection is decreasing?
    iii. Do we risk a second peak?
2. In Germany, the Robert Koch Institute publishes a daily estimate for "R"[1], at a national level, helping to provide insight to decision-makers on these sorts of questions as they consider releasing lockdown
3. In the UK, R is referred to as a "critical indicator" informing the questions above, but in spite of this there is no regular publication of estimates of its value, either nationally or regionally. The recommendation of this paper is that the UK should publish quantitative measures, nationally and regionally, and regularly, to provide transparent insight on the three questions above.
4. As the Robert Koch Institute makes clear, estimation of R is not straightforward – their calculation methodology explains that it *"can only be estimated and not directly extracted from the notification system"* and that the estimate requires assumptions to be made, for example about the mean generation time of the infection
5. R is not the only measure that can be used to answer the questions above – indeed R is more complex than is required for this purpose, as R has a level of sophistication (not needed for this purpose) that allows it also to be used across different diseases to compare their relative reproduction characteristics.
6. This paper illustrates a simple growth index, G, which can be used to illustrate the rate of growth (or shrinkage) in COVID infections. Like R, G has value > 1.0 when infections are growing, and has value < 1.0 when infections are shrinking. The advantage of G compared to R is that it can be directly and simply calculated from published data, at local, regional and national level – and that it can be used to inform answers to the government's tests.
7. In this paper we use G to look at: (i) Growth index in the number of COVID infections using $G_{\text{-diagnosis}}$; (ii) Growth index in the number of COVID hospitalisations using $G_{\text{-hospitalisations}}$; and (iii) Growth index in the number of COVID deaths using $G_{\text{-deaths}}$
8. Both R and G need to be used with care, especially when there are changes to how COVID infections or deaths are being counted. This includes: (i) changes to the testing regime, as has happened in the UK during the last week of April, which will _temporarily_ mean that the change in the number of reported infections is different from the real underlying change in the number of infections; (ii) changes to how

[1] For the purposes of this paper, we define: (i) R_0 as the "basic reproduction number" of the Coronavirus infection, defined as the average number of secondary infections produced by a typical case of an infection, prior to mitigations being in place, and (ii) R as being the "reproduction number" of the Coronavirus infection in a real situation once mitigations are in place. When R is greater than one, the pandemic is growing, when it is less than one, it is shrinking.

COVID deaths are counted and coded, for instance in care homes, which may *temporarily* mean that the change in the number of reported COVID deaths is different from the real underlying changes in numbers of deaths

9. These confounding factors need to be managed carefully, especially in periods of transition when counting and coding approaches are changing. Nonetheless, we recommend that the UK should aim to have regular publication of metrics relating to the growth of COVID-19, available locally, regionally and nationally, by 15th May. The metrics could be based either on R or G, but should be published.

10. Given the confounding factors and the quality of the different datasets, we believe that $G_{\text{-hospitalisations}}$ is likely to be the growth index metric that shows the best combination of timeliness and reliability

11. The data is already available to allow us to produce and publish these metrics, and to update them regularly. Data is published that allows us to calculate each of $G_{\text{-diagnosis}}$, $G_{\text{-hospitalisations}}$, and $G_{\text{-deaths}}$ nationally, and we have done that in this document. Data is published that allows us to calculate $G_{\text{-diagnosis}}$, locally and regionally as well as nationally, and we have done that. Data exists (but is not published) that allows us to calculate $G_{\text{-hospitalisations}}$ and $G_{\text{-deaths}}$ regionally as well as nationally

12. Based on that data, at 12th May our emerging answers to the government's questions are as follows:

    i. Have we moved beyond the peak, with a **consistent and daily fall in the death rate**? *Answer - yes but with some caveats. Overall, we have definitely moved beyond the peak, with $G_{\text{-deaths}}$ at approximately 0.80 based on deaths up to and including 1st May, and with the trend in a good (downwards) direction. However, although the death rate is falling overall, the peak in the death rate for Care Homes came later than the peak in others settings, and there is also regional variation in trajectory since the peak*

    ii. Do we know that the **rate of infection is decreasing**? *Answer – yes but with some caveats, especially relating to data quality. Both $G_{\text{-diagnosis}}$ and $G_{\text{-hospitalisations}}$ indicate that the rate of infection is decreasing overall ($G_{\text{-diagnosis}}$ approximately 0.85, $G_{\text{-hospitalisations}}$ slightly higher at 0.94, but with hospitalisations in absolute terms now 60% below the peak of 9th April). However, while $G_{\text{-diagnosis}}$ has been decreasing fast in some parts of the country (e.g., London and the South East), the evidence is much more equivocal in other regions, for instance $G_{\text{-diagnosis}}$ does not yet indicate a sustained decrease in the East of England and Yorkshire & Humber, and the data quality on this metric is not strong, especially considering changes in testing practice since the last week of April. The data on $G_{\text{-hospitalisations}}$ should be seen as a much more reliable indicator of how the rate of infection is decreasing.*

    iii. Do we risk a **second peak**? *Answer – possibly. We have created significant headroom in hospital bed capacity, for example, and more headroom in some parts of the country (e.g., South West) than in others. But in absolute terms numbers of new infections are still several thousand per day, and we have not yet created the same headroom that countries such as Denmark, Germany, Austria and the Czech Republic have created as they begin to relax restrictions. Without significant headroom, our chances of a second peak would be relatively higher, and we would have relatively less time to react to an approaching second peak than would other countries.*

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Section 1: The approach of Germany and the Robert Koch Institute to estimating and publishing R daily

Since the 7th April 2020, the Robert Koch Institute has produced and published a daily estimate for R for COVID infections in Germany, as a section within its daily situation report. On 7th May the Robert Koch Institute estimated that R = 0.71 (95% confidence interval: 0.60 - 0.85), which indicates that the pandemic is currently shrinking in Germany. It highlighted supporting methodological detail at https://www.rki.de/DE/Content/Infekt/EpidBull/Archiv/2020/17/Art_02.html, and stated that *"R can only be estimated and not directly extracted from the notification system"* and that *"The case numbers presented do not fully reflect the progression of the number of cases of illness, as it takes varying lengths of time for a COVID-19 infection to be diagnosed, reported and transmitted to the Robert Koch Institute after the onset of illness. Therefore, an attempt is being made to model the actual course of the number of COVID-19 cases that have already occurred by means of a so-called nowcasting."*

The output of the Robert Koch Institute's modelling as at 3rd May are shown in the figure below, with the consistent downward slope of the graph in the latter part of April leading to the estimation that R is less than 1.0. Note that the modelling published on 3rd May only estimated values up to 28th April because "*The nowcasting and the R-estimate include all transmitted cases with onset of disease up to 3 days before data status. Cases with a more recent onset of the disease were not taken into account as they had not yet been transmitted in sufficient numbers and would lead to unstable estimates.*"

The Robert Koch Institute has progressively developed its methodology. Since 29th April, *"the RKI has been using a 4-day [rolling] average, which smooths the course of the bar chart to a certain extent"* and *"for a given day, this [R] value is now calculated as a simple quotient of the number of new cases for this day divided by the number of new cases 4 days before."* With the exception of the RKI's use of Nowcasting, that quotient methodology is extremely similar to what we propose for G in section 2 of this paper.

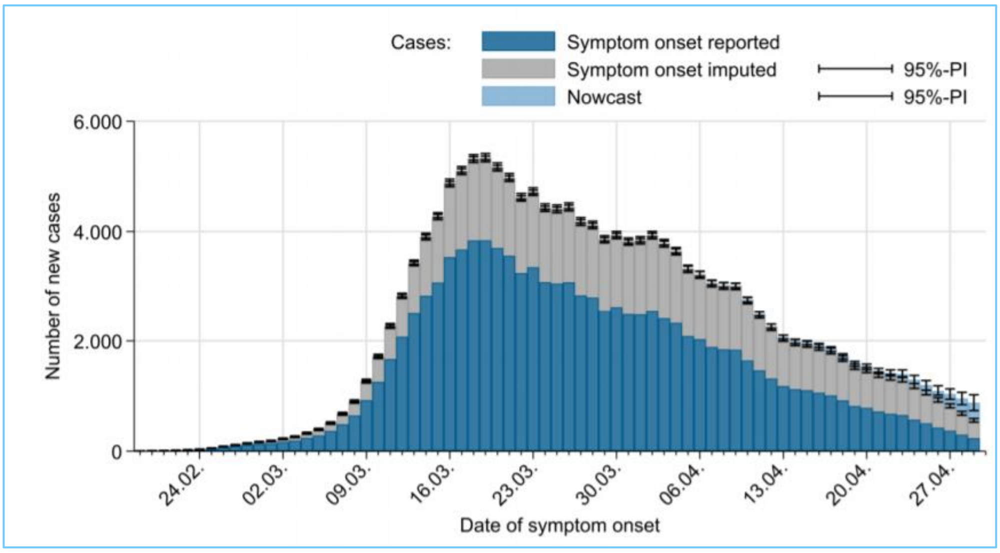


Figure: Extract from Robert Koch Institute on 3rd May 2020 showing number of daily new cases in Germany, and illustrating a continual sustained reduction in case numbers throughout April

Section 2: Methodology for a simple growth index measure G

Building on the Robert Koch Institute's approach, we have used the following definitions for the three metrics:

1. "$G_{diagnosis}$" = (7-day rolling average daily number of COVID-19 diagnoses) / (7-day rolling average daily number of COVID-19 diagnoses 4 days before)

2. "$G_{hospitalisations}$" = (7-day rolling average daily number of hospitalisations with a diagnosis of COVID-19) / (7-day rolling average daily number of hospitalisations with a diagnosis of COVID-19 4 days before)

3. "G_{deaths}" = (7-day rolling average daily number of deaths with a mention of COVID-19 on the death certificate) / (7-day rolling average daily number of deaths with a mention of COVID-19 on the death certificate 4 days before)

We have used 7-day rolling averages to take account of weekly periodicity in how COVID tests are performed, in how health services operate, and in how death registrations are processed and reported.

We have used a 4-day gap between the numerator and the denominator to mirror the time period[2] used by the Robert Koch Institute in its estimation methodology for R.

As for many countries, we know that there are limitations in the UK's data on COVID-19 diagnoses, and in the UK's coding of COVID-19 on death certificates. The metrics are designed to account for these as shown in the table below:

[2] The Robert Koch Institute says: "The current estimate… is based on … an assumed mean generation time of 4 days" and says ""for a given day, this [R] value is now calculated as a simple quotient of the number of new cases for this day divided by the number of new cases 4 days before."

Issue	How addressed
1. Many COVID-related data series show a weekly periodicity because diagnostic practices, health system practices and death registration practices differ by day of the week	Each metric uses a 7-day rolling average to avoid the risk of this weekly periodicity causing noise/ error in the results
2. Delays and incomplete data: for example, there is a delay between the date that a sample is taken, and the date that a diagnosis is registered	For diagnoses: the data on https://coronavirus.data.gov.uk/ includes a field for specimen date, which is what we have used. The data also shows the effect of delay between sample date and returns of result, with almost all samples reported within 5 days of sample date. Based on this, we have excluded data where the specimen date is within 5 days of the publication date (so today, 7th May, the latest data on specimen date is 6th May, and we have only "trusted" data up to and including 30th April as being reliable). This can be compared to the Robert Koch Institute's policy of ignoring the last 3 days of data For deaths: we use ONS data, and used the field for "date occurred" rather than "date registered". For hospitalisations: this data has a good combination of consistency and timelinesss
3. There are increasing numbers of diagnostic tests for COVID-19 being performed, and therefore a likelihood that previous under-diagnosis may be reducing	This is a known issue with the source data which cannot be addressed directly by this metric or other known metrics for R which are based on diagnoses. As a result, this proxy measure will slightly overestimate the real value of "$G_{diagnosis}$" if a country is increasing testing and reducing under-diagnosis – we know that this will be the case in the UK at the end of April and for the first two weeks of May, following the government's drive towards achieving 100,000 tests per day. This effect will reduce once testing policy has stabilised for approximately two weeks, and in the mean time we can mitigate this effect partially by triangulating across the three metrics of $G_{diagnosis}$, $G_{hospitalisations}$ and G_{deaths} $G_{hospitalisations}$ should be seen as having the best combination of timeliness and reliability
4. There can be random statistical variations in numbers of diagnoses,	We have included statistical confidence intervals in our charts to account for this

hospitalisations and deaths from day-to-day, separate from the underlying trend	

Section 3: What the metrics currently show for G for England – national, regionally and locally

3.1 Emerging results for "$G_{diagnosis}$":

- Currently has a value of approximately 0.85 for England as a whole. As this value is less than 1, it indicates slight shrinking of the pandemic in England. This value has oscillated only gradually for England as a whole, varying between values of 0.95 and 0.84 during the period 13/04/20 to 30/04/20 (see figure 1, below)
- Is lowest in London, where the value is approximately 0.75. The pandemic grew faster and earlier in London than it did in the rest of the country, and has been shrinking faster in London too. The value for $G_{diagnosis}$ has been lower in London than for the rest of the country throughout April (see figure 1, below)
- Is not consistently below 1.0 for every region in England. In particular, both the Yorkshire & Humber region and the East of England region have seen values oscillating just above and just below 1.00 in recent days (See figure 2, below)

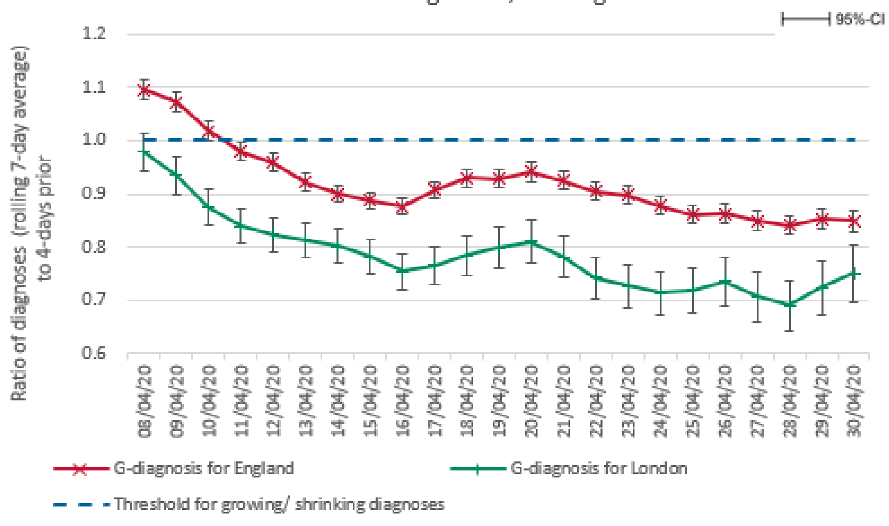
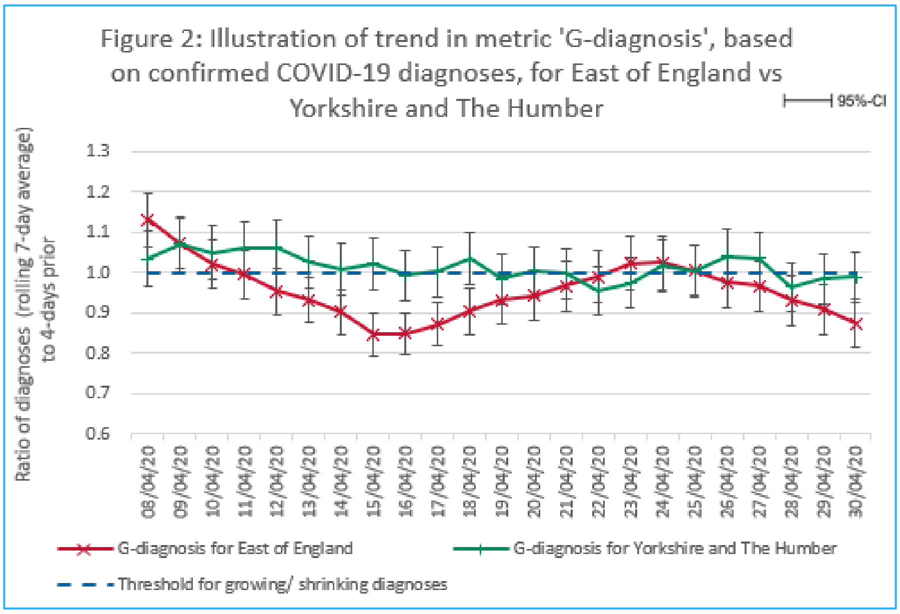
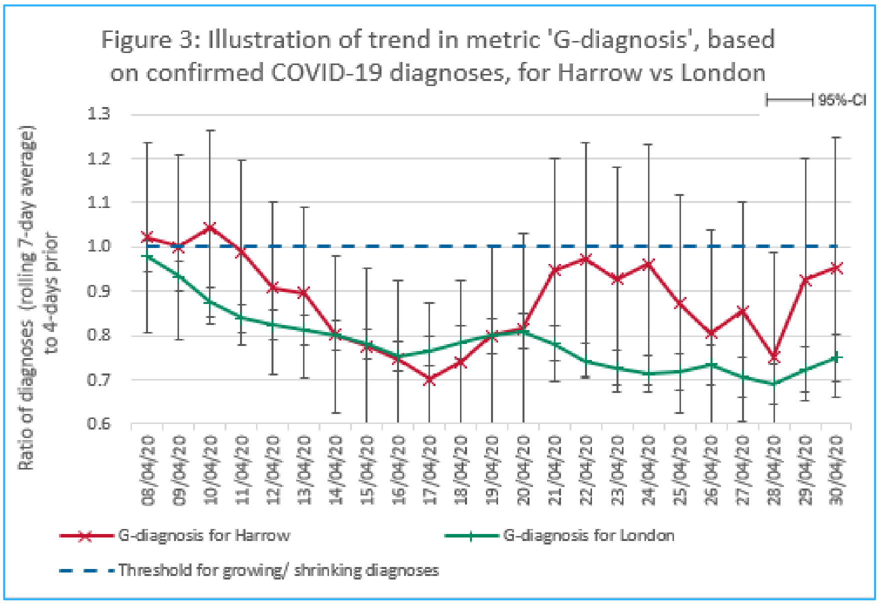


Figure 1: Illustration of trend in metric 'G-diagnosis', based on confirmed COVID-19 diagnoses, for England vs London

Note that the horizontal axis for this chart is based on the "sample date" for each patient, not the date that the positive test was reported (which can be up to 5 days after the sample date).



This data is available for every region in England, and for every local authority area. For instance, Figure 3 compares the situation in Harrow vs the situation in London as a whole. Note however that there is large statistical volatility once this metric is used at local authority level – as shown by the broader statistical confidence limits for Harrow in Figure 3. We conclude that the metric is useful at national and regional level, but not at local authority level.



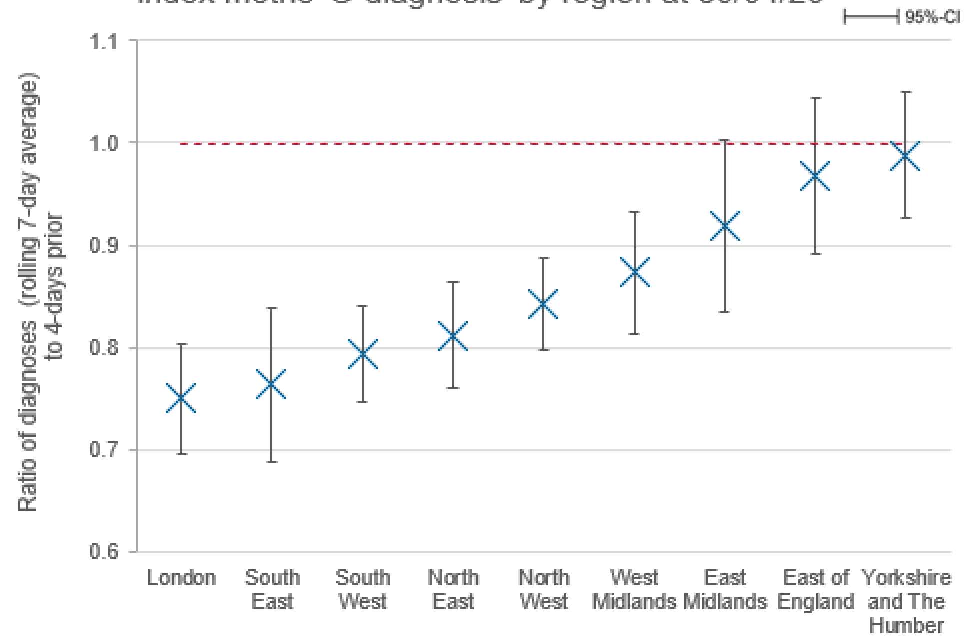
In assessing why the value of "G-$_{diagnosis}$" differs by region, there is further work to do to test:

- Is the difference associated with regional differences in the testing regime (e.g., was there previously a greater degree of under-testing in some regions than others, and is the picture impacted by a different degree of "catch-up" across regions?)

- Is the difference associated with differences relating to Care Homes? We know that the “peak” of infections associated with Care Homes is occurring significantly later than the peak for the population that is not resident in Care Homes – so could this be having an impact on values of “G-$_{diagnosis}$” by region
- Is the difference associated with other aspects of how social distancing and lockdown have worked from region to region?

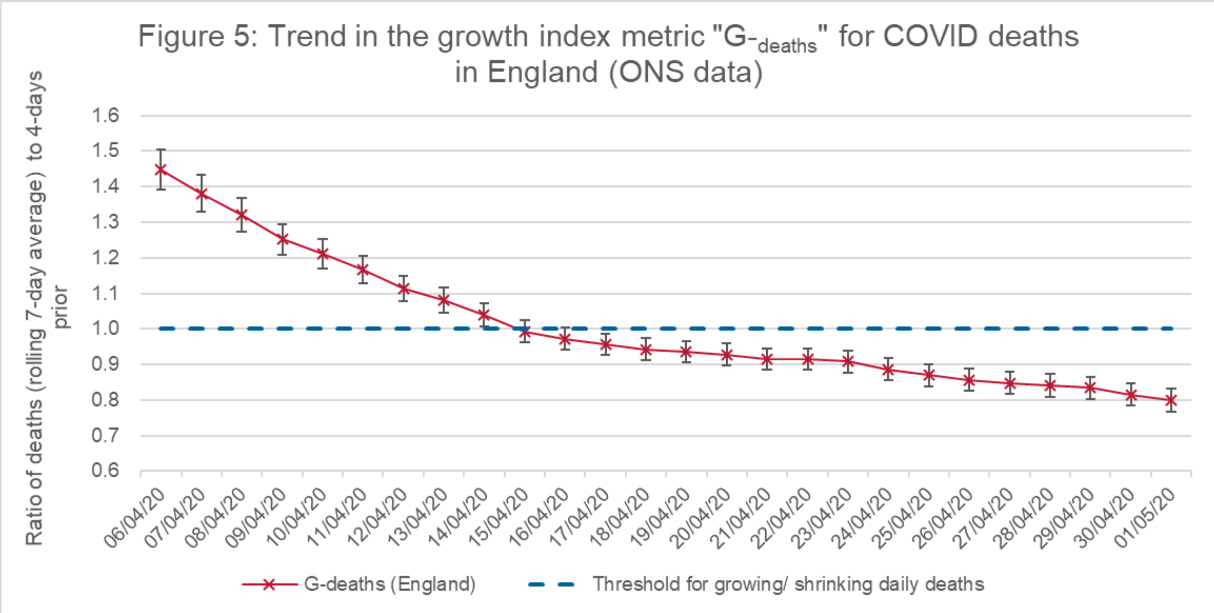
Figure 4 shows the difference in value of “G-$_{diagnosis}$” by regional area in England:

Figure 4: Illustration of the variation in the growth index metric 'G-diagnosis' by region at 30/04/20



3.2 Emerging results for “G-deaths”:

Using data that ONS publishes weekly on COVID deaths, and using their field for “date of death” rather than “date of registration”, we can calculate the growth index metric “G-deaths” for England as a whole. This is shown in Figure 5 below, and shows that the rolling 7-day average of COVID deaths was growing until 14th April, after which it has begun to fall. The data indicates a few days of time lag between the time when COVID-19 diagnoses started to fall and the time when COVID deaths have started to fall:



This analysis shows that total deaths were falling quite quickly by 24th April (R approximately 0.85), but within that there is a picture of Care Home deaths still being at the peak, while deaths in hospital are well beyond the peak and falling fast.

3.3 Emerging results for "G-$_{hospitalisations}$":

The number of patients being admitted to hospital for COVID has been falling since about the 9th April. At 3rd May, the number of hospitalisations continues to fall, but more slowly than before, such that G-$_{hospitalisation}$ is now approximately 0.94, as shown below. In absolute terms, the daily number of hospitalisations is at about 40% of the peak level reached on 9th April.

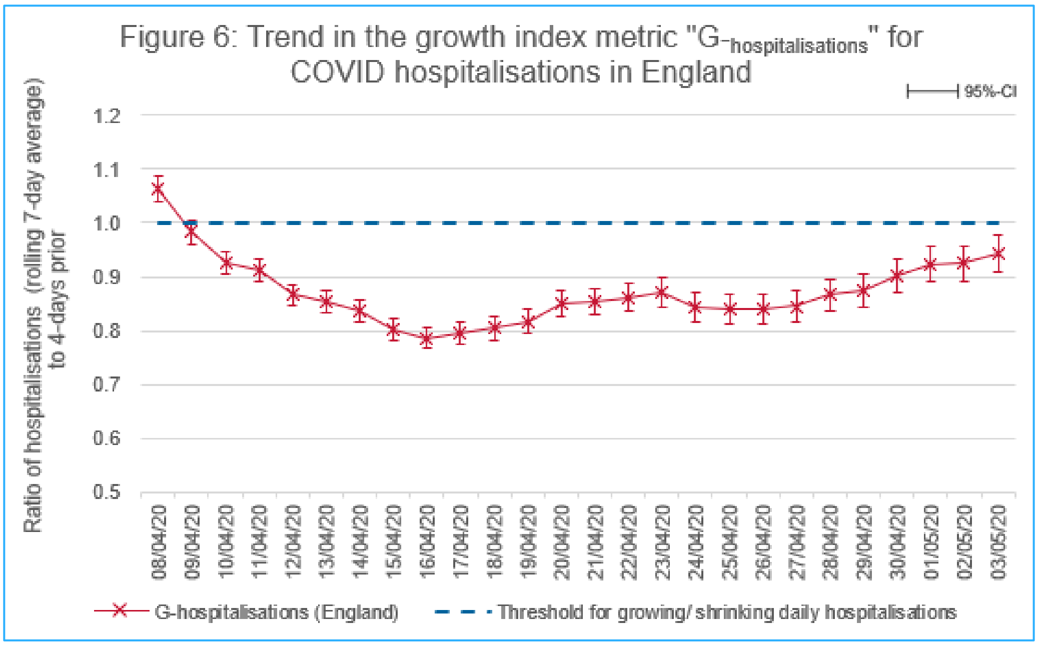


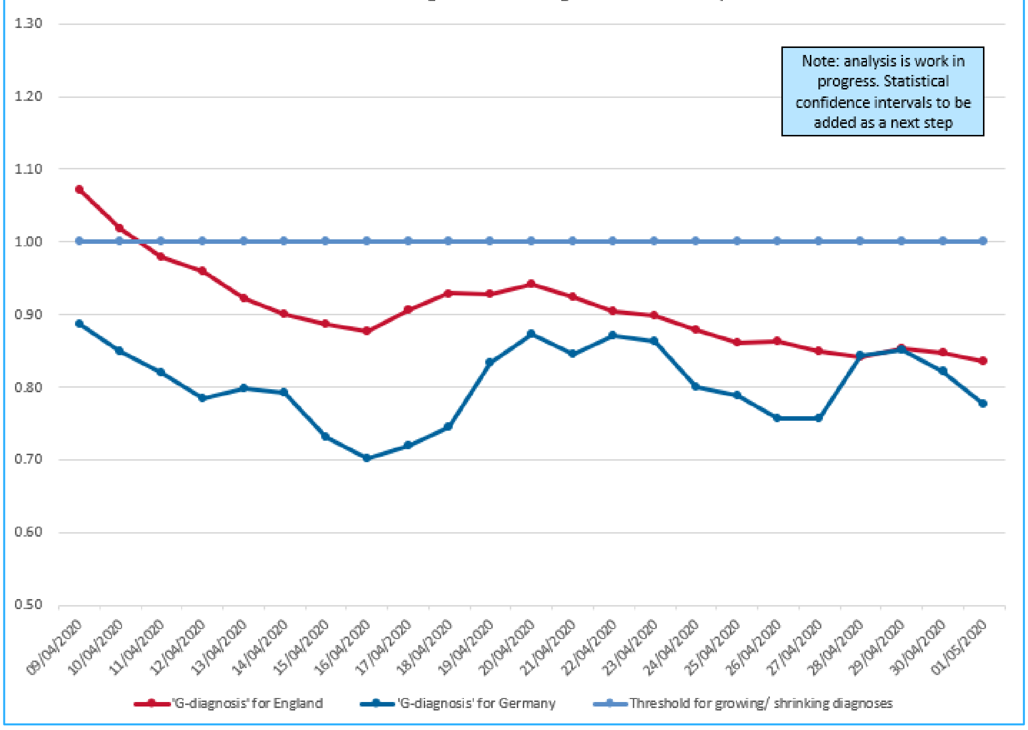
Figure 6: Trend in the growth index metric "G-$_{hospitalisations}$" for COVID hospitalisations in England

Section 4: International comparisons: comparing England vs selected European countries, and comparing R and G for Germany

Using data from the Coronavirus Worldometer (Johns Hopkins), we can add data for Germany, Spain, Italy and France, and compare growth index metrics “G-$_{diagnosis}$” across those countries and England.

Figure 7, below, compares “G-$_{diagnosis}$” for England and Germany during April 2020. The analysis shows that while both countries have values of “G-$_{diagnosis}$” at < 1.0 for every day since 11th April, Germany’s values have almost always been lower than England’s, indicating a faster rate of reduction of the pandemic in Germany.

Figure 7: Illustration of trend in growth index metric 'G-diagnosis', based on confirmed diagnoses, for England vs Germany



We have also compared the values of “G-$_{diagnosis}$” for Germany to those of R as published by the Robert Koch Institute. Under the methodology for R as revised by the Robert Koch Institute at 29th April, very similar values are obtained both for R and G-$_{diagnosis}$:

- Values for R as published between 29/04/20 and 07/05/20 inclusive, have averaged 0.74 and have varied between 0.65 to 0.79
- The value for G-$_{diagnosis}$ for Germany has averaged 0.75 between 29/04/20 and 07/05/20 inclusive, and has varied between 0.64 to 0.85 (similar average but with slightly more variation than there is in the Robert Koch Institute metric)

In figure 8 below, we compare “G-$_{diagnosis}$” for England with those for Germany, Spain, Italy and France. The analysis shows England approximately in the middle of the pack in terms of its current growth index:

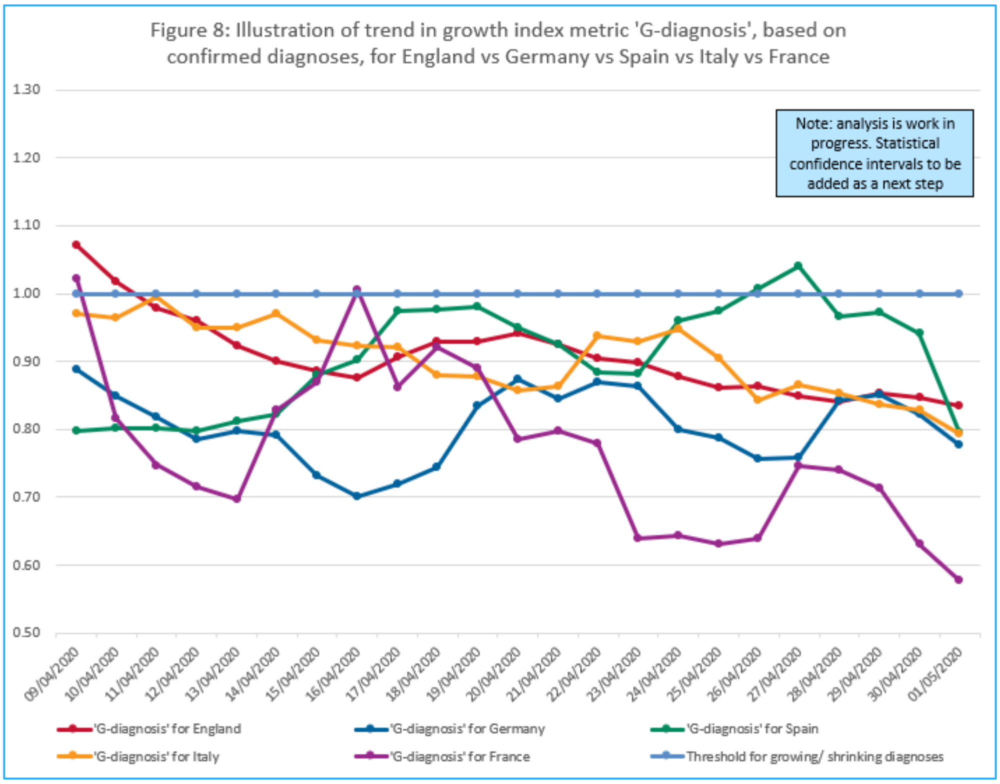


Figure 8: Illustration of trend in growth index metric 'G-diagnosis', based on confirmed diagnoses, for England vs Germany vs Spain vs Italy vs France
Note: analysis is work in progress. Statistical confidence intervals to be added as a next step
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
09/04/2020
10/04/2020
11/04/2020
12/04/2020
13/04/2020
14/04/2020
15/04/2020
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30/04/2020
01/05/2020
'G-diagnosis' for England
'G-diagnosis' for Germany
'G-diagnosis' for Spain
'G-diagnosis' for Italy
'G-diagnosis' for France
Threshold for growing/ shrinking diagnoses

Section 5: Next steps

We are keen to hear feedback from stakeholders as to how best to design and display metrics that address the government's "five tests", including feedback on how to triangulate across growth index measures relating to COVID admissions and COVID deaths, as well as COVID diagnoses.

We are keen to hear feedback from stakeholders about the usefulness of having a tool that can be automated and updated daily to show growth index metrics updated continuously as new data becomes available.

About 2020 Delivery, Russell Cake, Antonio Weiss and Henry Holms

2020 Delivery is a management consultancy company that specialises in supporting public organisations. Our mission is to help CEOs and senior leaders improve public services and health services, and to deliver lasting positive change for service users, patients and taxpayers.

Since we formed 2020 Delivery in 2006, we have developed a track record of exceptional impact through our range of strategy, performance improvement and capability building projects. We focus on being highly collaborative with our clients, and are recognised as such (for instance, we won the Health Service Journal "Consultancy Partnership of the Year 2019").

Find out more about 2020 Delivery at https://www.2020delivery.com/about-us/

Russell Cake co-founded 2020 Delivery in 2006 and leads our Strategy practice. He combines client service to government departments and healthcare organisations with research into healthcare system performance. Russell brings 20 years of experience to his work helping healthcare leaders to develop evidence-based responses to the strategic challenges facing the health service. Russell has a strong track record of providing clarity and insight into complex system challenges and engaging stakeholders in the delivery plans.

A keen analyst, Russell is widely recognised as providing thought-provoking and considered insights into the healthcare system. He has led 2020 Delivery's work on reconfiguration, including nationwide analyses of activity data, cost data and workforce data to provide quantitative evidence on the financial impacts of reconfiguration, and quantitative evidence on how changes in rotas can contribute to savings. He has led 2020 Delivery's three-year research initiative into emergency pathway performance and winter pressures analysis, which has helped people to understand how the system behaves and how to achieve the best outcomes for patients. He has published research on the drivers of the stalling of life expectancy improvements in the UK since 2011, published on 2020 Delivery's website and referenced in The Economist.

Find out more about Russell at https://www.2020delivery.com/our-people/russell/

Antonio Weiss is a Director of 2020 Delivery, who leads 2020 Delivery's our Digital Service Transformation Practice, advising senior clients on user-centred design, innovation thinking, and utilising technology to redesign public services to meet citizens' needs. He is a globally recognised and published thought-leader on business strategy and management.

Antonio has supported the Government Digital Service – the world's leading government digital unit – in the development of the cross-government vision of 'government as a platform', and a number of other UK public service agencies in their digital transformation plans, covering the fields of housing, foreign affairs, healthcare, driving services, licensing and grants funding. He also has extensive NHS and central government experience, and has worked with leading charities and third sector clients. Antonio joined 2020 Delivery in 2007.

Find out more about Antonio at https://www.2020delivery.com/our-people/antonio/

Henry Holms is a Consultant at 2020 Delivery. He is passionate about delivering efficient, effective, and user-centred public services. Henry is particular interested in applying data and quantitative analyses to better understand how public services are delivered in practice, and how they can be improved, and to understand the value and experience our services offer to the public. Henry has led the analytical work across various projects with UK Government and NHS, including comparative analyses of education funding and attainment across countries and level of education, forecasting of hospital activity and finances, and operational analysis for education and health services in the UK. Henry graduated from the University of Cambridge, with a degree in Natural Sciences, specialising in Physics.

Find out more about Henry at https://www.2020delivery.com/our-people/henry/

Appendix: Methodology for estimation of confidence intervals

There may be random statistical variations in numbers of diagnoses, hospitalisations and deaths from day-to-day, separate from the underlying trend. We have estimated this variation for $G_{diagnoses}$, $G_{hospitalisations}$, and G_{deaths}, and indicated the 95% confidence-interval for each growth metrics in our figures.

Statistical variation has been estimated by first estimating the standard deviation of published figures for daily number of diagnoses of COVID-19, hospitalisations of patients infected with COVID-19, and deaths from COVID-19. We have then extrapolated this uncertainty to estimate standard deviation of the growth metrics.

These confidence intervals indicate the level of statistical uncertainty in our estimates, but do not indicate the level of error introduced by systematic error in the input data, or potentially in our calculations. The confidence intervals indicate that the actual value of G will be within the indicated range 95% of the time, assuming that there is no systematic bias. As discussed in section 2 we believe that there are likely to be systematic errors in the reported data, particularly with the reported number of COVID-19 cases, which is dependent on testing capacity and coverage.

Example methodology: estimating 95% confidence interval for G_{deaths} on day n.

i. We model the number of daily COVID-19 deaths (by actual date of death) on a given day as a binomial distribution. On a given day, we assume that each person in the population (e.g. population of England) has a set probability, p, of dying from COVID-19. The number of deaths on day n, D_n is the expected value of this distribution, given by the probability, p, multiplied by the number of people in the population, N.

ii. Given N is very large*, and p is very small, we approximate the binomial distribution as a Poisson distribution.

iii. The variance of a Poisson distribution is equal to the expected value (mean) of the distribution. Standard deviation of the daily number of COVID-19 deaths, σ_{Dn}, is therefore given by $\sigma_{Dn} = \sqrt{D_n}$.

iv. We have averaged the number of deaths over a 7-day period to account for the strong weekly periodicity of the COVID-19 data. On day n, the average number of COVID-19 deaths over the last 7-days is given by D_{Wn}.

v. Standard deviation of 7-day average number of deaths is given by $\sigma_{DWn} = \frac{1}{7}\sqrt{\sum_1^7 {\sigma_{Dn}}^2}$

vi. G_{deaths} is calculated by dividing the 7-day average number of deaths on a given day by the same figure from 4-days prior. Therefore $G_{deaths} = D_{Wn}/D_{Wn-4}$

vii. Standard deviation of G_{deaths} on day n, σ_{Gn}, is given by $\sigma_{Gn} = G_n * \sqrt{(\frac{\sigma_{DWn}}{D_{Wn}})^2 + (\frac{\sigma_{DWn-4}}{D_{Wn-4}})^2}$

viii. The 95% confidence interval is then calculated as $G_n \pm (2 * \sigma_{Gn})$

This methodology has been applied similarly to each of the growth metrics. We believe it is a reasonable approach given the level of uncertainty in the underlying data.

*This is true for England, and the English regions, but may not be valid for all local authority areas, depending on their volume of COVID cases.