A previous version, version 1, of this paper analysed older PHE data and was presented to SAGE 69 on 19 November.

Soon after version 1 of this paper was finished, at SPI-M's request, PHE helpfully released a large amount of data including approximately 8 million negative test results not previously shared with SPI-M modellers.

This, version 2, of this paper presents the analysis of this more recent and reliable data.

Only the data from England are changed. The conclusions of the two papers are the same except that in version 1: (a) the patterns in England described here emerged 4 days earlier and (b) epidemics shrank in *all* English LTLAs under tier 3 restrictions. This paper was considered at SAGE 70 on 26 November.

The UK's Four Nations' Autumn Interventions

1. Introduction

In the autumn of 2020, all four nations of the United Kingdom faced a second rise in numbers of people with COVID-19 infection, with associated rises in morbidity and mortality. Each nation implemented its own interventions to slow the spread of infection, and those interventions changed as the autumn progressed. As a result, interventions to control the spread of COVID-19 across the UK were diverse in both time and place. That diversity of interventions offers both a challenge and an opportunity. A challenge, because so many different interventions were designed, named and implemented that it is hard to gain a complete overview of what has been put in place. But, also an opportunity, to learn more about the more successful approaches by comparing these different interventions, through time and across nations. The interventions were policy instruments designed to reduce the rate of contact, collectively known as non-pharmaceutical interventions (NPI). They included mixtures of regulation and guidance that influenced population behaviour in different ways. We do not seek to understand the mechanism of how different NPIs worked but to examine the outcome of different packages of NPIs.

This Task and Finish Group paper asks three questions. What interventions were made, where and when? How fast did epidemics shrink or grow before and after those interventions? And what can we learn from this autumn's efforts to control the spread of COVID-19 in the UK?

We are not analysing the outcome of experiments. The places where infections were initially most common and then growing fastest were subject to the most stringent interventions. There will be multiple other confounders, too many to list here. For this reason, we must take care that when we describe patterns and correlations, we do not infer processes and causality.

2. What interventions were made, where and when?

A rich vocabulary for naming interventions has arisen. England had pre-tiers until 12 October, tiers (or local COVID alert levels) until 5 November and then national restrictions after 5 November. We note that Tier 3 restrictions in England are heterogeneous, with most/all having additional restrictions above the minimum set of interventions for this tier. Wales had local interventions in place during September and early October, with additional measures in some local health protection areas, followed by a national firebreak from 23 October to 8 November. Northern Ireland had pre-restrictions until 16 October, including additional measures in Derry and Strabane from 6 October, followed by national restrictions from 16 October – 20 November. Scotland had pre-level restrictions until 2 Nov, with additional central belt restrictions in some areas from 9th October, followed by a national system of levels from the 2 November.

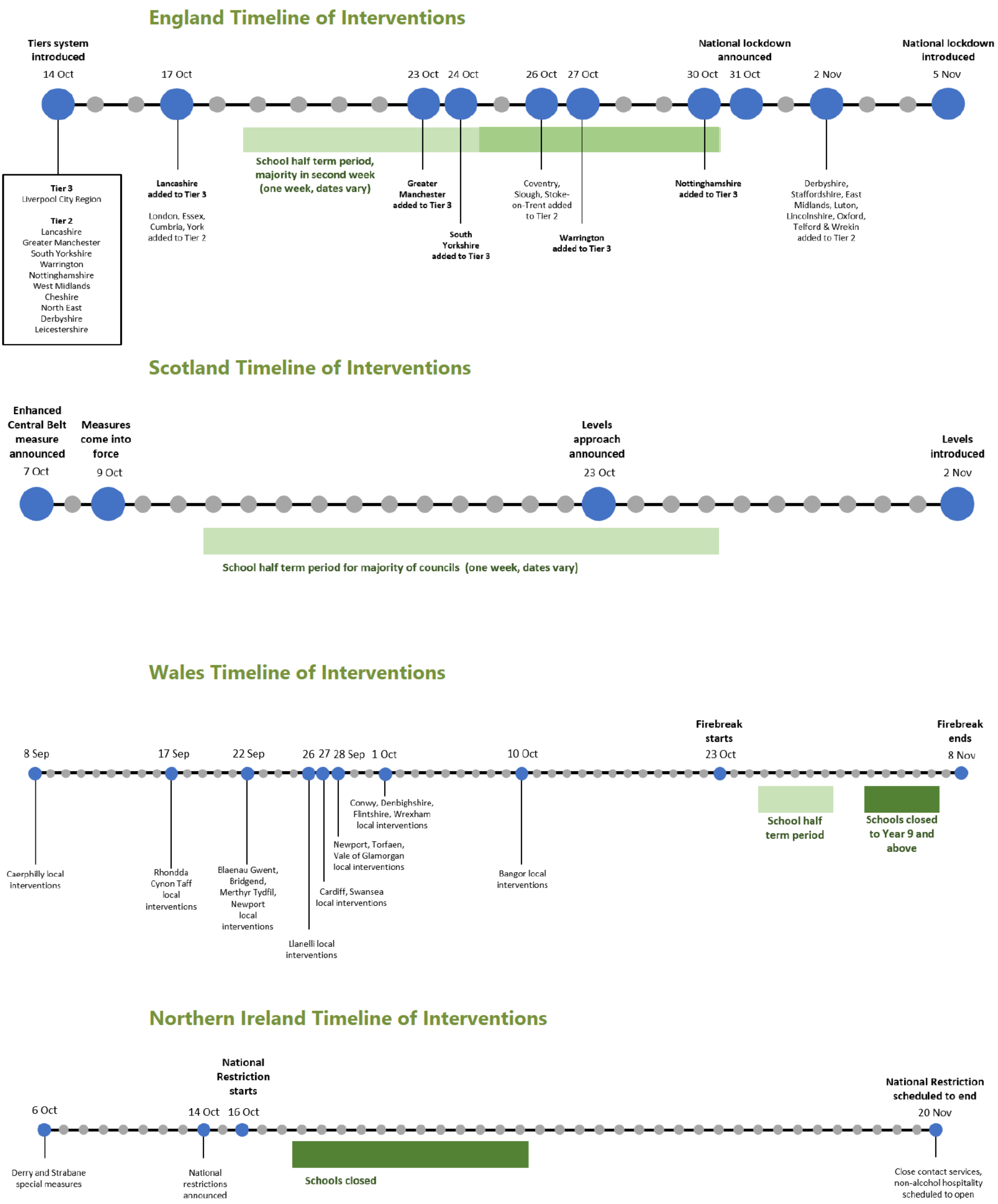
All nations have, at some time over autumn, applied interventions at a sub-national level. These interventions were applied at the level of local authorities, local health ‘Boards’, local health protection areas or local government districts within each nation. These split individual nations into areas with populations from a few 10s of thousands to a few hundred thousand. England has 317 Lower Tier Local Authorities (LTLA), Wales has 22 unitary authorities, Northern Ireland has 11 local government districts and Scotland has 14 territorial Health Boards and 32 local authorities. The population size distribution of these local authorities or districts is similar across the nations. **Table 1** describes the interventions as they were defined in each nation. **Figure 1** describes where, and when each type of intervention was applied in each nation and includes the timing of autumn half-term school holidays.

Table 1: Summary of regulations across the four Nations during October and November 2020. Information taken from public health websites and published legislation. Most severe regulations in a country are shaded in pink, least severe regulations are unshaded, regulations between these extremes are shaded in green.

	England					Wales			Northern Ireland		Scotland						
	Pre-tiers (until 11 Oct)	**Tier 1** (12 Oct – 5 Nov)	**Tier 2** (12 Oct – 5 Nov)	**Tier 3** (12 Oct – 5 Nov)	**National Restrictions** (5 Nov – 2 Dec)	**Pre-firebreak** (until 23 Oct)	**Local interventions** (at LTLA level as needed)	**Firebreak** (23 Oct – 8 Nov)	**Pre-restriction** (until 16 Oct)	**National Restrictions** (16 Oct – 20 Nov)	**Pre-levels** (until 2 Nov)	**Central belt restrictions**[1] (10 October until 2 Nov)	**Level 0** (2 Nov onwards)	**Level 1** (2 Nov onwards)	**Level 2** (2 Nov onwards)	**Level 3** (2 Nov onwards)	**Level 4** (2 Nov onwards)
Meeting in homes	6	6	No	No	No	6	No	No	No	No	No	No	8	No	No	No	No
Meeting in gardens	6	6	6	No	No	6	No	No	6	6	6	6	15	6	6	6	6
Meeting inside, public space	6	6	No	No	No	6	No	No	15	15	6	6	8	6	6	6	6
Meeting outside, public spaces	6	6	6	6	1	6	No	No	15	15	6	6	15	6	6	6	6
Support bubble/extended household mixing indoors	Yes	Yes	Support bubble only	Support bubble only	Support bubble only	Yes	Yes (single person)	Yes (single person)	Yes (10/2)	Yes (10/2)	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Pubs & bars	Close 2200	Close 2200	Close 2200	Closed	Closed	Open	Close 2200	Closed	Close 2300	Closed	Close 1800 (2200 outside)	Closed	Open	Close 2230	Close 2000, (outside 2230)	Close 1800	Closed
Restaurant	Close 2200	Close 2200	Close 2200	Close 2200	Closed	Open	Close 2200	Closed	Close 2300	Takeaway, Delivery only	Close 1800 (2200 outside)	Close 1800, no alcohol	Open	Close 2230	Close 2000 (outside 2230)	Close 1800, no alcohol	Closed
Non-essential shops	Open	Open	Open	Open	Closed	Open	Open	Closed	Open	Open	Open	Open	Open	Open	Open	Open	Closed
Close-contact retail (e.g. hairdressers)	Open	Open	Open	Open	Closed	Open	Open	Closed	Open	Closed	Open	Open	Open	Open	Open	Open	Closed
Nightclubs	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed	Closed
Visitor attractions	Open	Open	Open	Open	Closed	Open	Open	Closed	Open	Closed	Open	Open	Open	Open	Open	Open	Closed
Leisure and Entertainment	Open	Close 2200	Close 2200	Close 2220	Closed	Open	Open	Closed	Open	Closed	Open	Cinemas, libraries only	Open	Open	Cinema & bingo only	Closed	Closed
Holiday accommodation	Open	Open	Open	Open	Closed	Open	Open	Closed	Open	Closed	Open	Open	Open	Open	Open	Open	Closed
Driving lessons	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No	Yes	Open	Yes	Yes	Yes	Yes	No
Outdoor events/stadia	Open				Closed	Limited nos./stadia closed	Limited nos. /stadia closed	Closed	Open	Open	Open	Closed	Open	Open	Closed	Closed	Closed
Outdoor sports	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Elite – Yes Otherwise <15	Yes	Yes	Yes	Yes	Yes	Non-contact	Non-contact
Public buildings	Open	Open	Open	Open	Only libraries	Open	Open	Closed	Open	Community halls open	Open	Open	Open	Open	Open	Open	Closed
Places of worship	Open	Open	Open	Open	Individual prayer only	Open	Open	Closed	Open	Open for services of worship only	50	50	50	50	50	50	20
Weddings/funerals	30	15/30	15/30	15/30	15/30	Yes	Yes	Yes	Yes	25	20	20	50	20	20	20	15/20
Early learning	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open	Open
Schools	Open	Open	Open	Open	Open	Open	Open	Closed above year 8	Open	Closed for 2 weeks	Open	Open	Open	Open	Open	Open	Open
Universities	Open	Open	Open	Open	Open	Open	Open	Open	Open	Essential only	Open	Open	Blended	Blended	Blended	Restricted blended	Restricted blended
Workplaces	Work from home	Work from home	Work from home	Work from home	Work from home	Work from home	Work from home	Work from home	Work from home	Work from home	Work from home	Work from home	Work from home	Work from home	Work from home	Work from home	Work from home
Travel in/out of areas	Yes	Yes	Reduce	Essential/ work only	Essential/ work only	Yes	No	Essential only	Necessary only	Necessary only	Avoid travel to central belt	Essential, within area	No travel to Tiers 3 & 4	No travel to Tiers 3 & 4	No travel to Tiers 3 & 4	Essential, within area	Essential, within area

[1] The central belt is for these purposes defined as covering the health board regions of Lothian, Lanarkshire, Forth Valley, Ayrshire & Arran and Greater Glasgow & Clyde

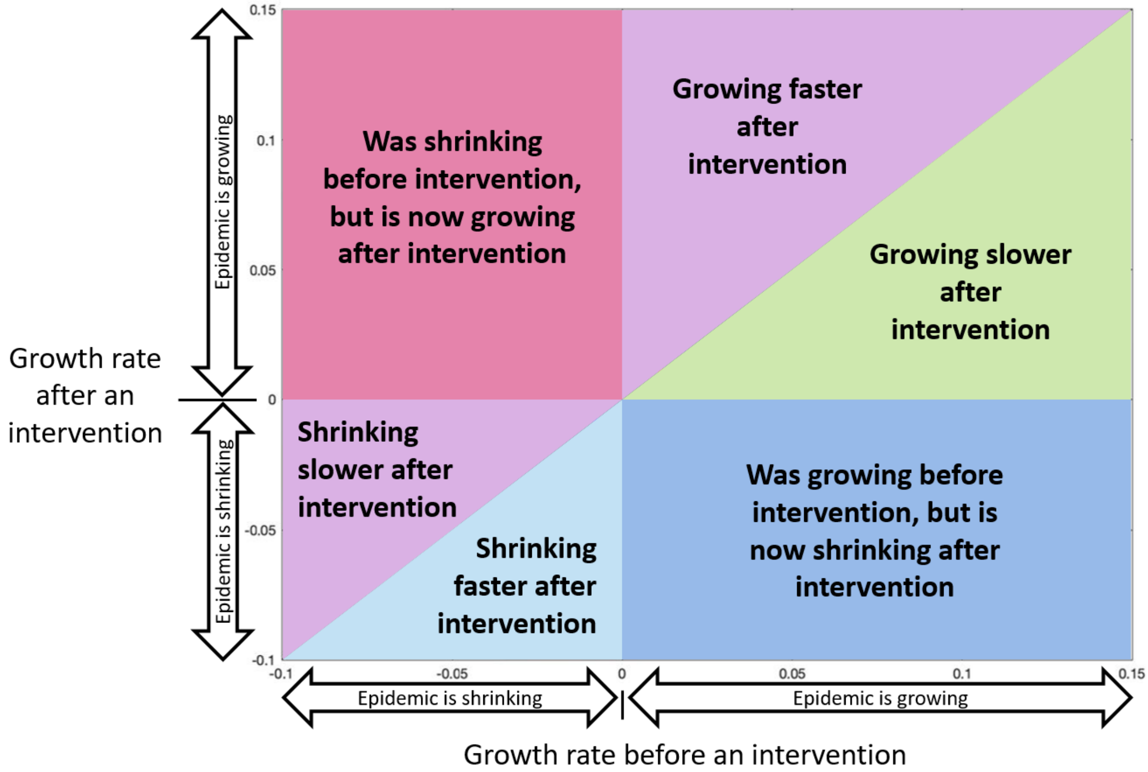
Figure 1. Timelines of interventions carried out in England, Scotland, Wales and Northern Ireland



3. How did growth rates compare before and after interventions?

We wish to ask, “what changed after each intervention?”. We have chosen to illustrate that change with a series of charts that plot local, exponential growth rates before and after each intervention. The comparison of growth rates before and after an intervention is consistent with our understanding that changing the pattern and rate of contact will lead to shifts in exponential growth rates. **Figure 2** shows how the different areas of the standard charts used in this paper show the difference in growth rates before and after an intervention. Detailed methodology is described in **Annex A**.

Figure 2. Understanding segments of a correlation plot. Correlation plots show the exponential growth rate of COVID-19 cases in areas before an intervention (x axis) and after an intervention (y axis). Each region studied is plotted on the chart based on these growth rates. A growth rate can be positive (growing) or negative (shrinking) before and after an intervention. The position of the region on the correlation plot shows what has changed after the intervention.



3a. Before and after the most recent intervention in each of the four nations.

We first ask, what was the impact of the most recent set of interventions? We address this question for the interventions for which enough time has passed that we might expect to see a change in growth rate in the number of confirmed cases. In every case we measure growth rate by fitting an exponential curve to the proportion of Pillar 2 swab tests that were positive during the relevant time period.

For England we explore changes after tiers were introduced on 12 October, shown in **Figures 3a-d**. In all figures, for LTLAs going into Tiers 1, 2, and 3 (coloured blue, green and red respectively) we show the growth rate before the start of tiers measured from Pillar 2 data from 3-16 October against the growth rate during tier measures calculated from Pillar 2 data from 28 October – 10 November. In these and all subsequent figures the oval clouds show our confidence in each growth rate, with the major and minor axis representing the interquartile range. In figure 3d, the data from all 3 tiers is combined; dots are positioned at the mean growth rate with their size indicating the percentage Pillar 2 tests that are positive before the start of the tier restrictions.

In **Figures 3a-c** we see that in England: during Tier 1 many LTLAs still had positive growth rates; during Tier 2 the epidemic in most LTLAs was growing more slowly than before the interventions and was shrinking in many, but many local epidemics were still growing; and that during Tier 3, epidemics in all LTLAs had a lower growth rate than before tiers were introduced and most were declining. **Figure 3d** further illustrates quite clearly that more stringent tiers were introduced to LTLAs with higher percentage prevalence. This can be seen in that all LTLAs that ended up in Tier 3 and many that ended up in Tier 2 started with high prevalence (all the red and orange symbols and many green symbols are squares whilst most blue symbols are dots or triangles).

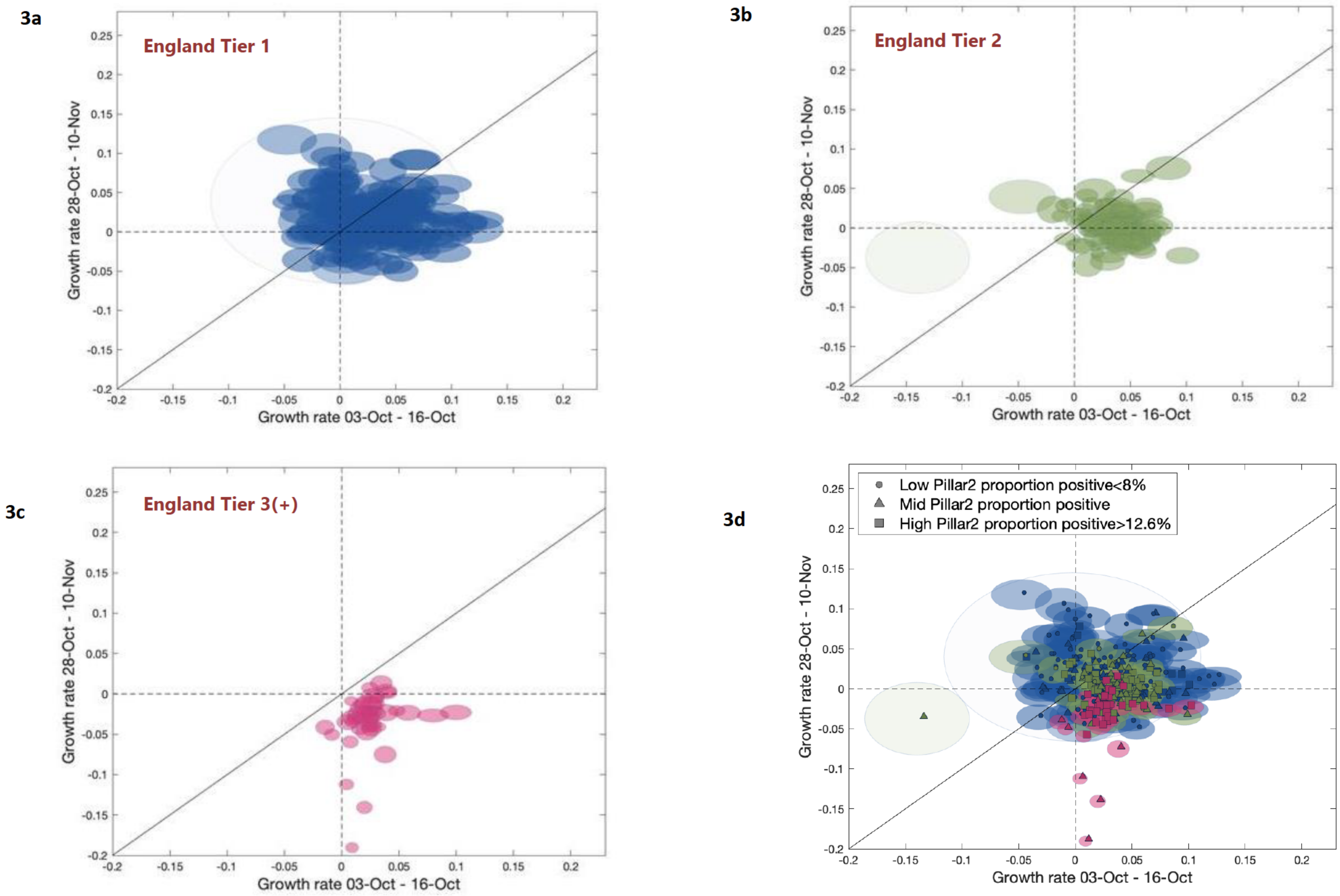
For Wales we plot growth rates before and after the start of the national firebreak on October 23 (**Figure 4**). We show the growth rate before the start of the firebreak measured from Pillar 2 data from 17-30 October against the growth rate during the firebreak calculated from Pillar 2 data from 4– 17 November. We see that, although epidemics were shrinking in many local authorities during and after the firebreak, the pattern is not universal. Many local epidemics continued to grow, and some grew faster than before the firebreak began. It is worth noting that the division between Pillar 1 and 2 testing in Wales may be more ambiguous than in other nations.

For Scotland we compare growth rates before and after central belt restrictions were introduced during October (**Figure 5**). We show the growth rate before the start of the restrictions measured from Pillar 2 data from 25 September - 8 October against the growth rate during the restrictions calculated from Pillar 2 data from 16– 29 October. The oval clouds are colour coded red and green for those LTLAs under central belt restrictions and not under these restrictions respectively. Most epidemics (both red and green shaded in Figure 5) grew more slowly or shrank after the restrictions than before, with one exception. Whilst several epidemics shrank after the restrictions, a few continued to grow, and many remained at about the same size.

For Northern Ireland we compare growth rates before and during the national restrictions introduced on 16 October (**Figure 6**). We show the growth rate before the start of national restrictions measured from Pillar 2 data from 3 -16 October against the growth rate during the restrictions calculated from Pillar 2 data from 23 October – 5 November. We see that, during national restrictions, epidemics in all 11 districts were shrinking, and shrinking faster than before national restrictions were introduced.

Summarising across all four nations we see that epidemics shrunk in every local area subject to national restrictions in Northern Ireland and most LTLAs subject to Tier 3 interventions in England. All other interventions were followed by a more mixed picture, and although the general trend is for a reduction in growth rates some local epidemics continued growing in the weeks following intervention.

Figures 3a-d: Impact of tiers on the growth rate in each LTLA of England. Figures 3a-c show changes in growth rates for LTLA areas placed into Tiers 1-3 respectively, and Figure 3d the data from all three tiers are combined, where dots are positioned at the mean growth rate with their size indicating the percentage Pillar 2 positives before the start of tier restrictions.



Figures 4, 5, 6, and Figure 2 (repeated): Impact of the national firebreak in Wales, central belt restrictions in Scotland, and national restricitons in Northern Ireland.

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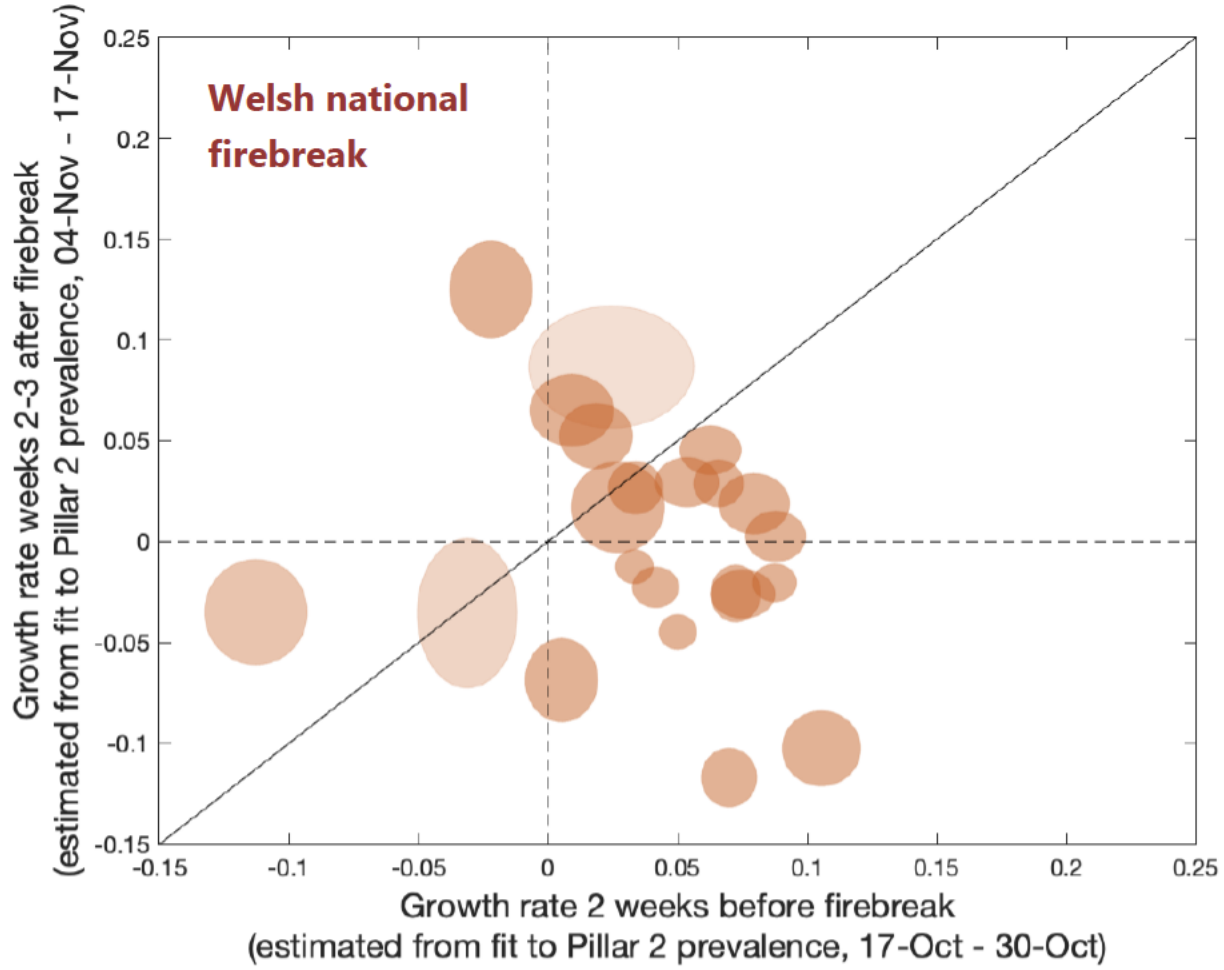

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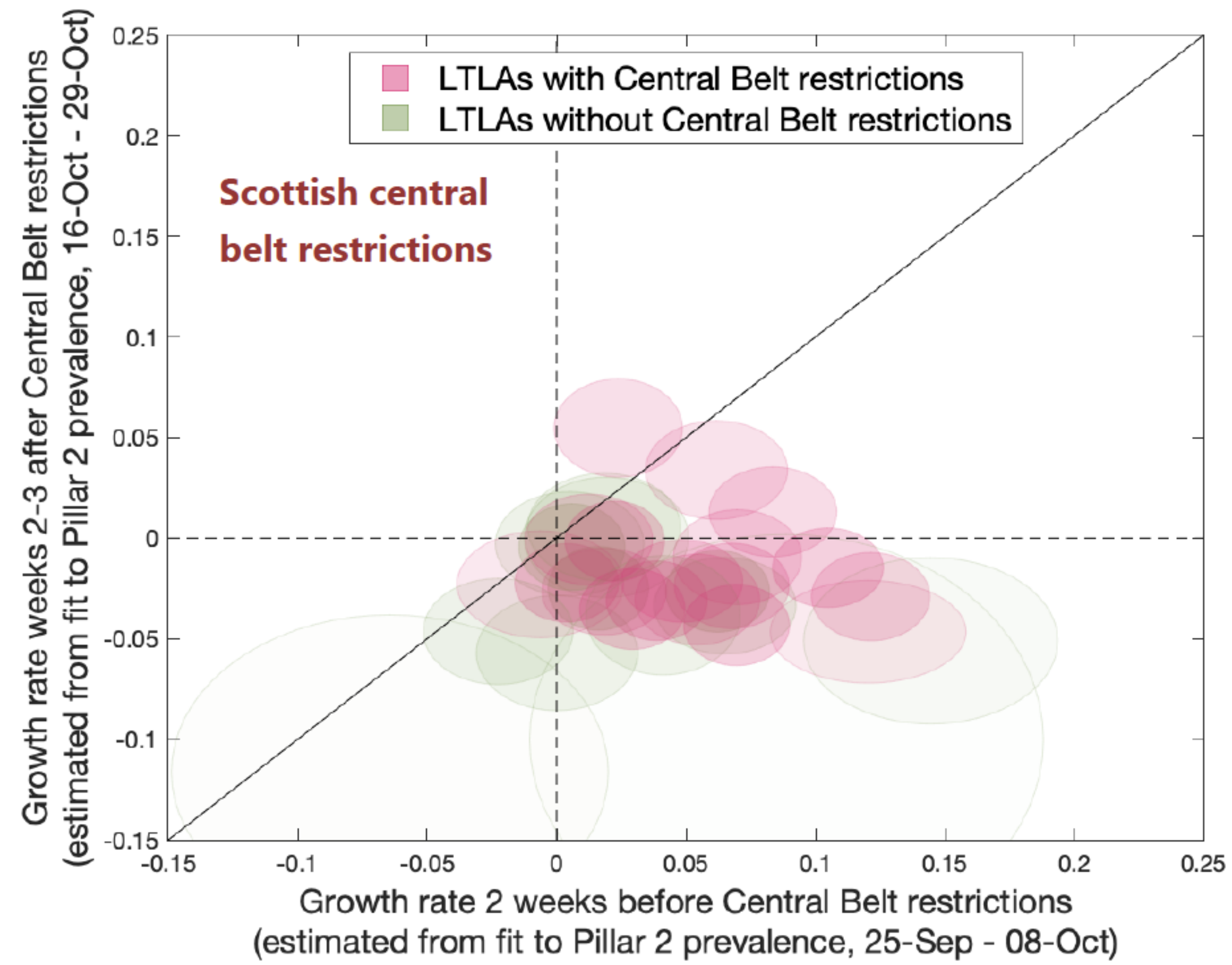

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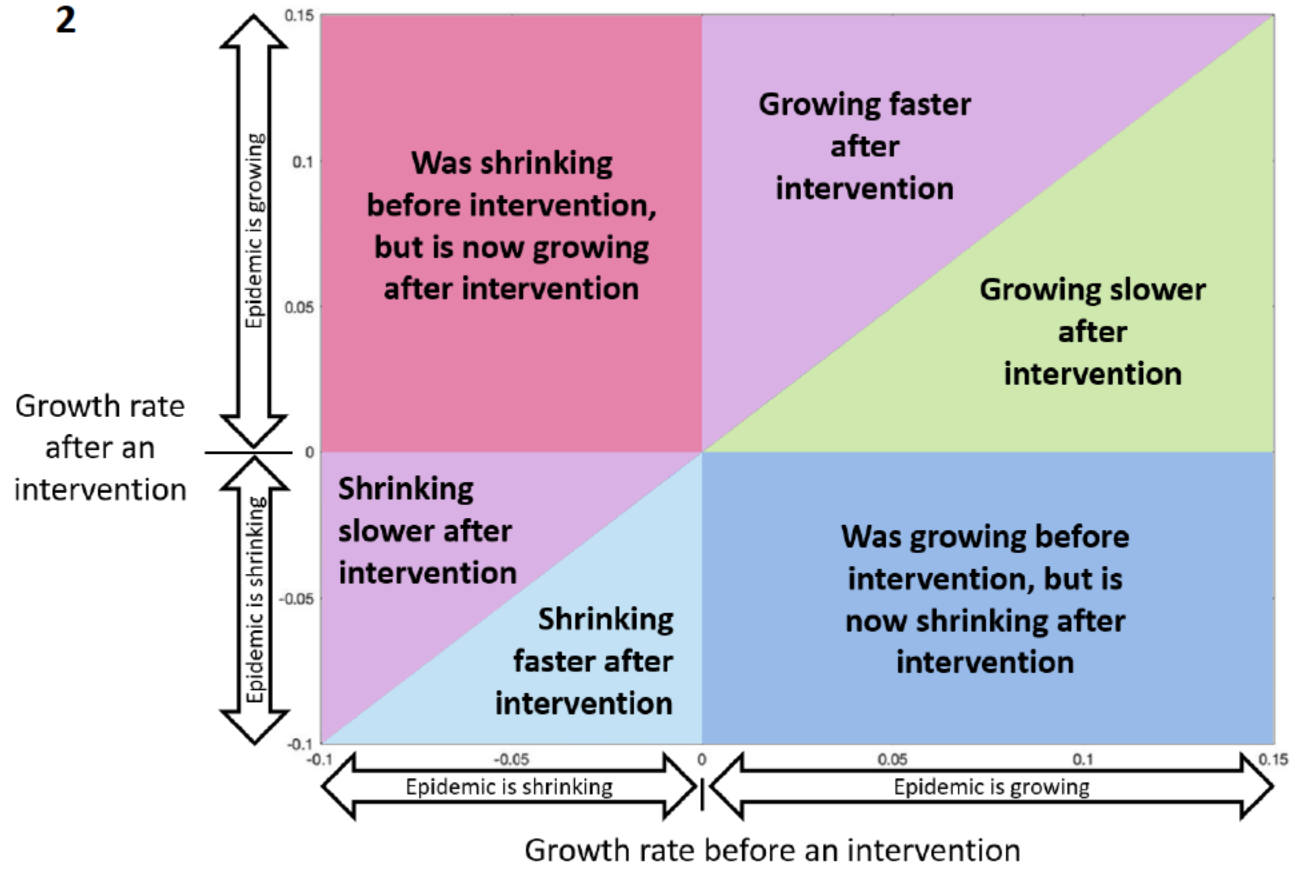


3b. Early gains did not always endure

For Wales, Northern Ireland and Scotland we can ask if changes in growth rates seen straight after an intervention endured in the following weeks. England introduced national restrictions less than 4 weeks after tiers so there is insufficient data to address this question.

For Wales, **Figures 7a and 7b** shows changes to the estimated growth rates for the 15 Welsh LTLAs that were under local restrictions before the firebreak. **7a** shows the immediate impact of the local restrictions, with the x-axis giving the growth rate estimated from the two weeks before local controls and the y-axis showing the estimated growth rate for weeks 2 and 3 following controls, thus measuring their short-term impact. In **Figure 7b** the y-axis now shows the growth rate for weeks 3 to 5 following local controls, but before the firebreak; the arrows indicated the change of each LTLA from their earlier growth rate in **Figure 7a**. As before dots are positioned at the mean growth rate with their size indicating the percentage Pillar 2 tests that are positive before the start of restrictions. There is a complex pattern of changes, although LTLAs with initially high percentage prevalence are all observed to increase their growth rate at later times in the restrictions.

For Scotland, **Figure 8** shows changes to the estimated growth rates for the 32 Scottish LTLAs, considering the longer-term impact of local central belt restrictions before the change to a system of levels; this contrasts with **Figure 5** which shows the immediate impact of the central belt restrictions. LTLAs are colour coded red for those LTLAs under central belt restrictions and green for those not under these restrictions. Here the y-axis now shows the growth rate for weeks 4 to 5 following central belt restrictions, measured from Pillar 2 data from 27 October - 9 November; the arrows indicated the change of each LTLA from their earlier growth rate in **Figure 5**. Although again a complex picture, there is a general trend towards slightly increased growth rates at later times compared with the growth rate straight after restrictions were introduced.

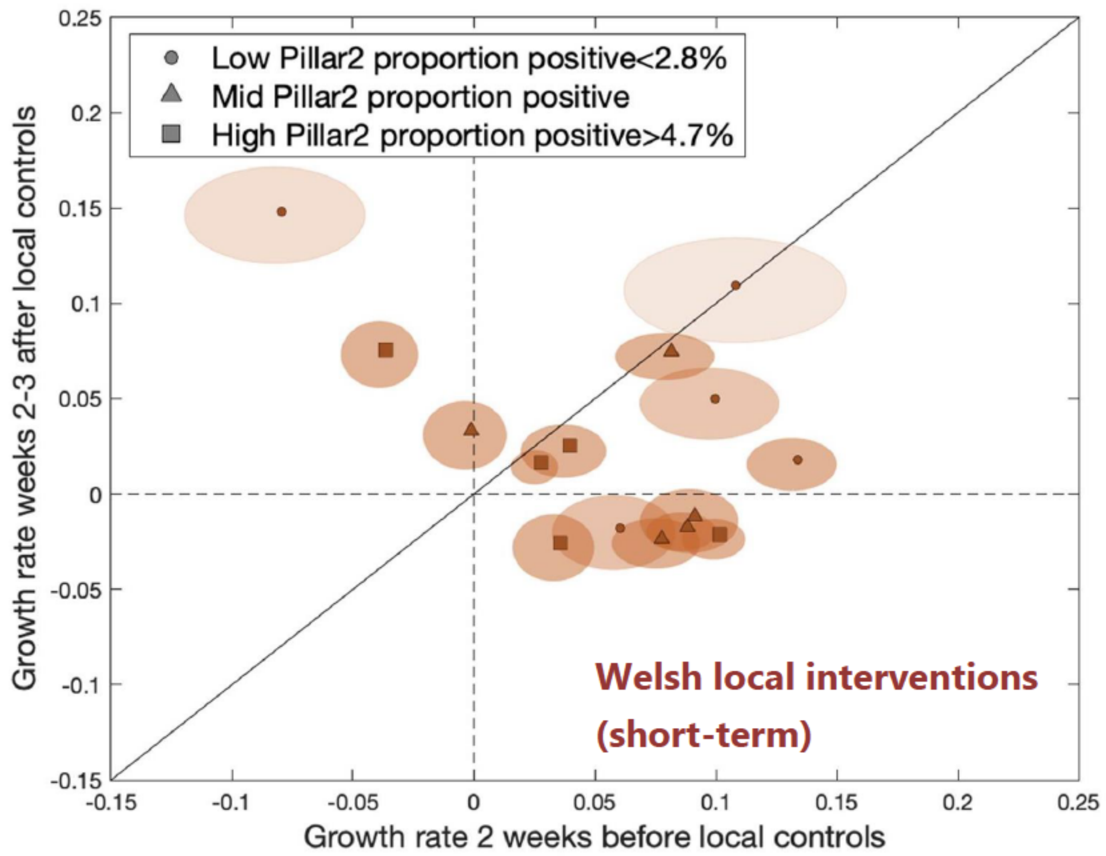
For Northern Ireland, **Figure 9** shows changes to the estimated growth rates for the 12 local government districts in Northern Ireland, considering the longer-term impact of national restrictions; this contrasts with **Figure 6** which shows the immediate impact of the national restrictions. Here the y-axis now shows the growth rate for weeks 4 to 5 following national restrictions, measured from Pillar 2 data from 2-15 November; the arrows indicated the change of each LTLA from their earlier growth rate in **Figure 6**. Once again there were shifts in growth rates later on during the restrictions, but every district bar one kept their epidemic stable, or shrinking.

No overwhelming message emerges of either deterioration or improvement in growth rates 3-5 weeks into an intervention. **Figures 7, 8 and 9** do, however, raise interesting hypotheses about the durability of change during interventions and what it is that allows some local areas to keep growth rates low, whilst others cannot.

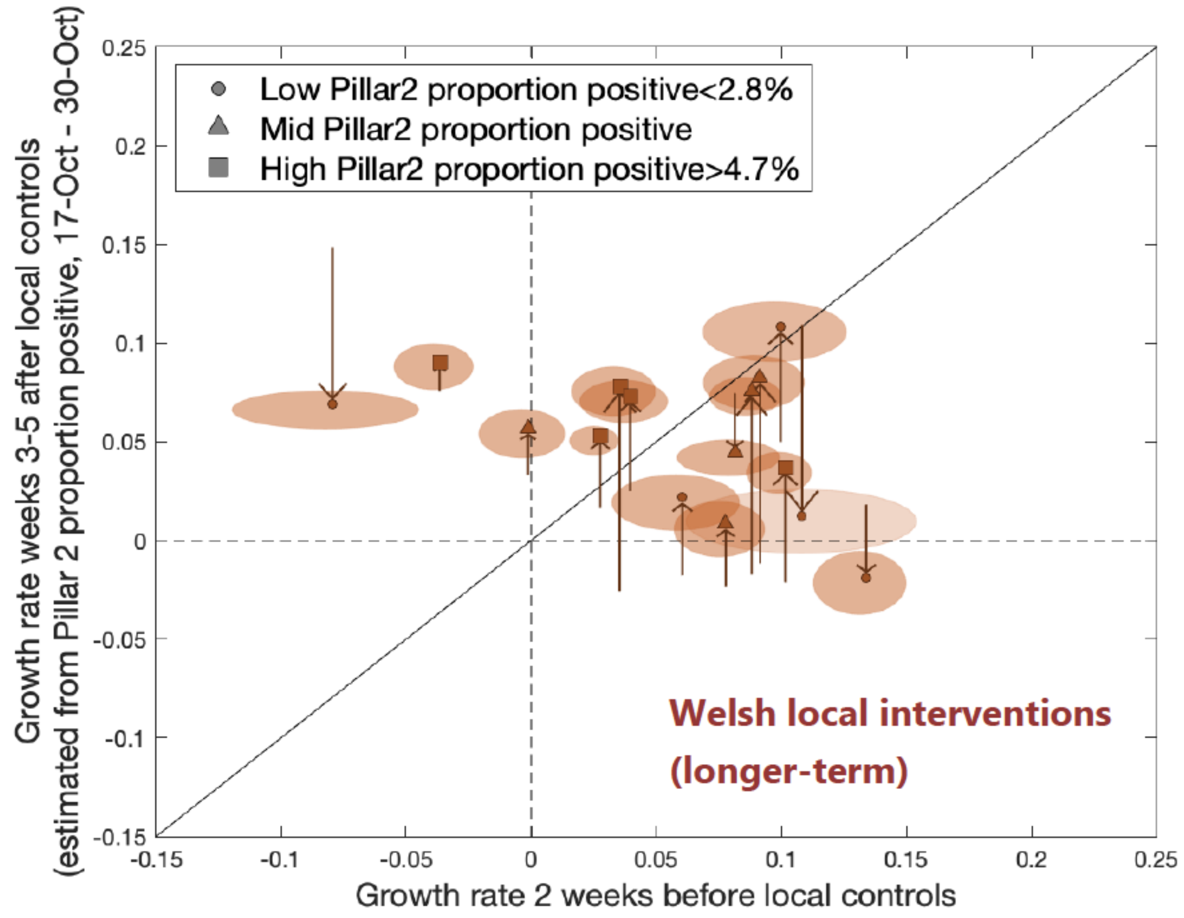
In **Figures 10a-c**, we further take the probability distribution for each LTLA and sum to provide a combined distribution of the growth rate before (red), immediately after (green, weeks 2 and 3) and some time later (blue, weeks 4 and 5) the imposition of restrictions. These correspond to the same data examined in **Figures 7, 8 and 9**, but we lose the behaviour of individual local authorities. Although in some nations the pattern is complex, in general we find that immediately following restrictions the distribution of the growth rate (r) has decreased, but this rises again (but remains below pre-restriction levels) in subsequent weeks. This is most clearly observed in Scotland and Northern Ireland, with a more mixed picture in Wales.

Figures 7a, 7b, 8 and 9: Plots comparing the short and longer-term impact of local interventions in Wales respectively, the longer-term impact of the central belt restrictions in Scotland, and longer-term impact of national restrictions in Northern Ireland.

7a



7b



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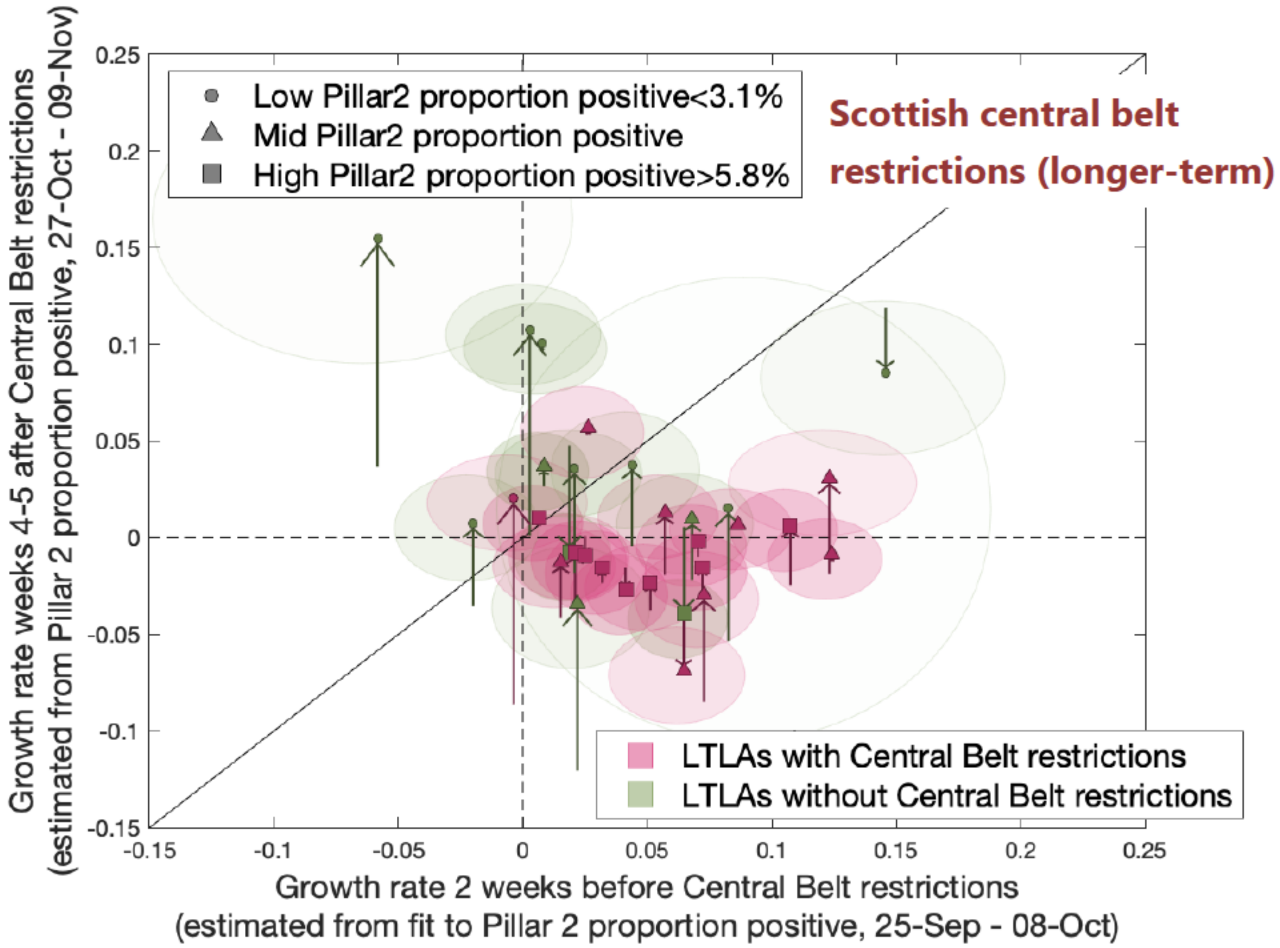

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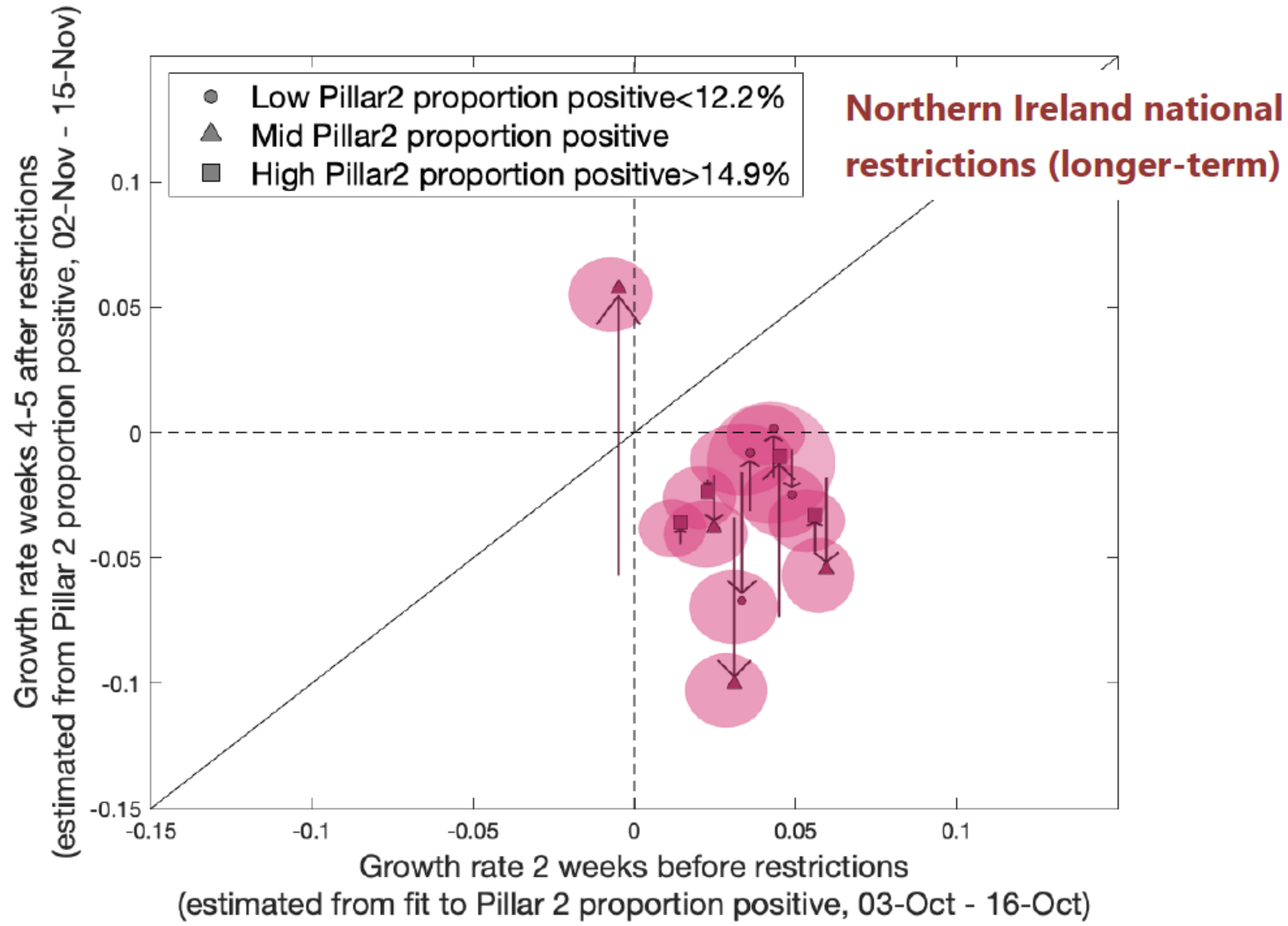
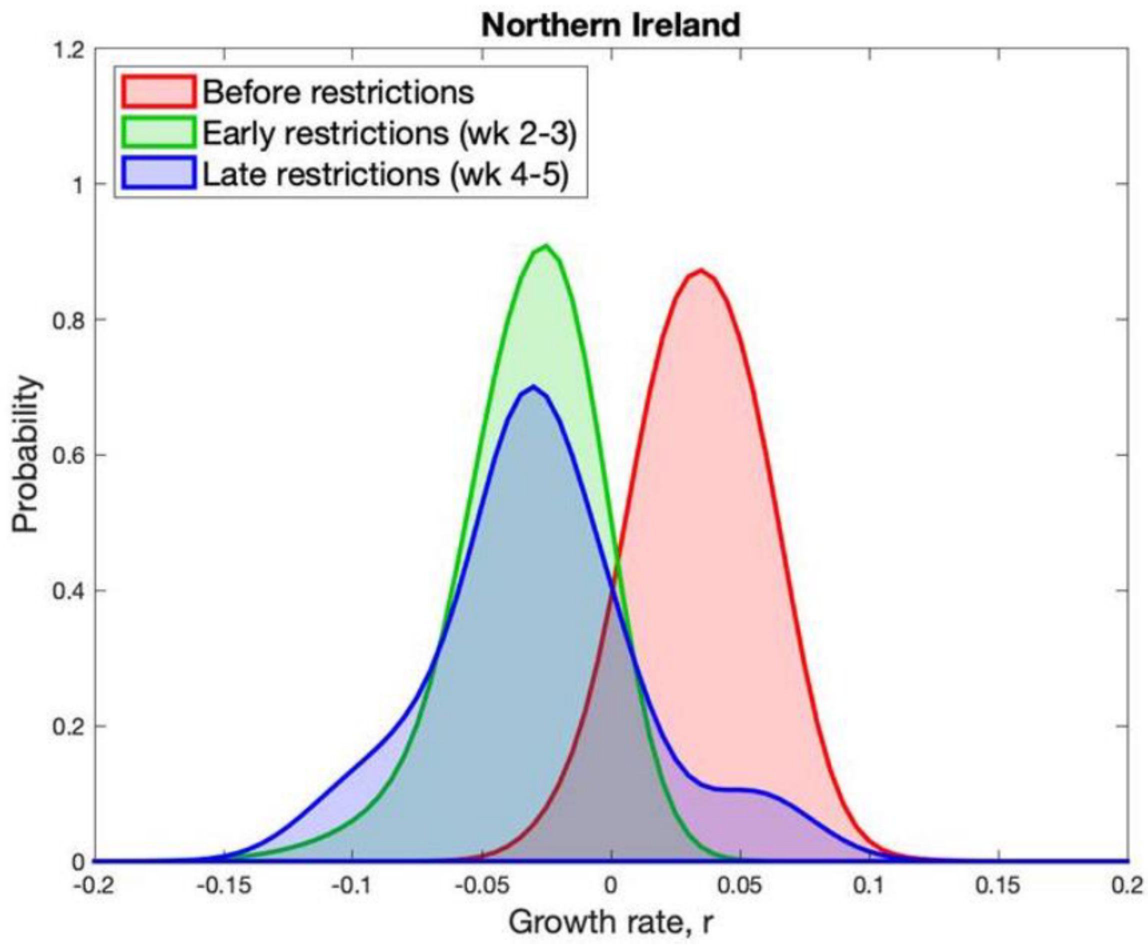
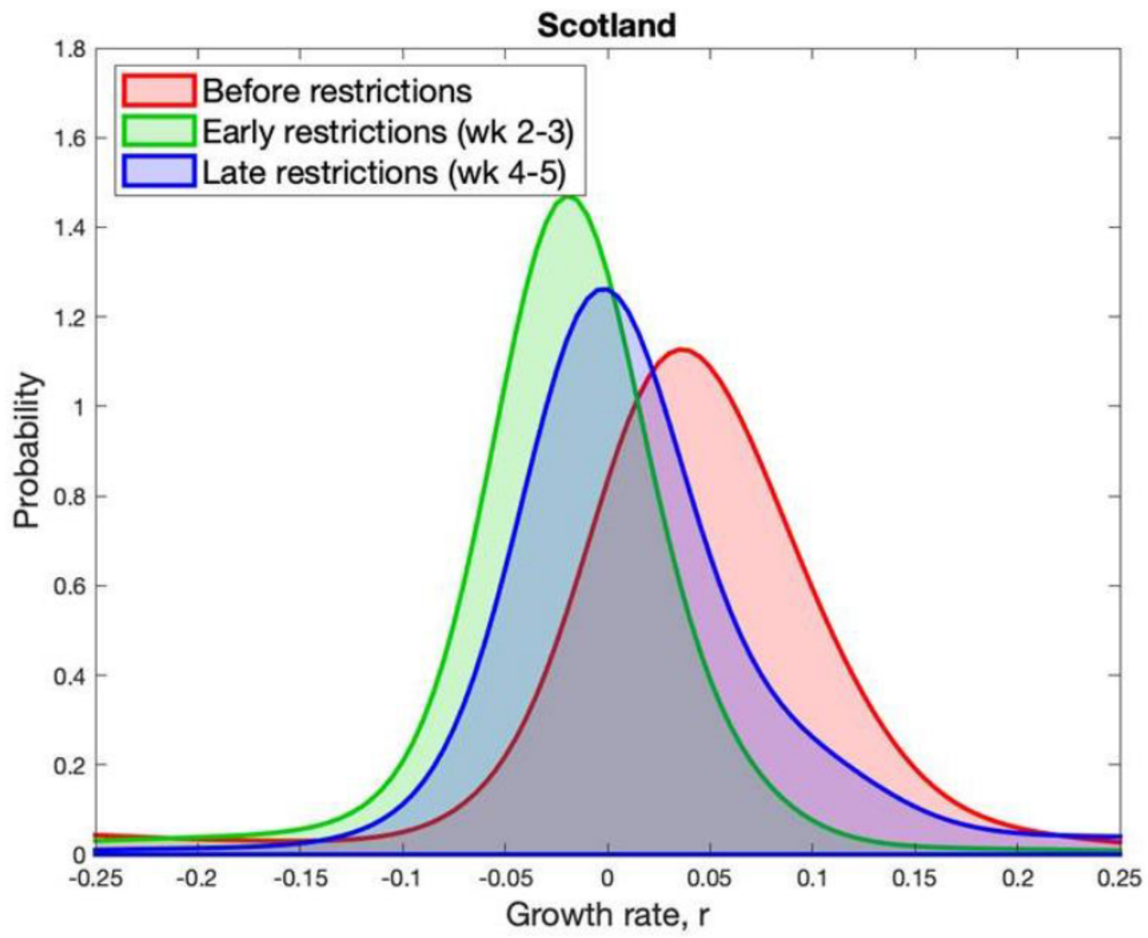


Figures 10a-c: Plots showing, for each nation, the sum of the growth rate probability densities across all LTLAs, before, immediately after, and some time after restrictions.

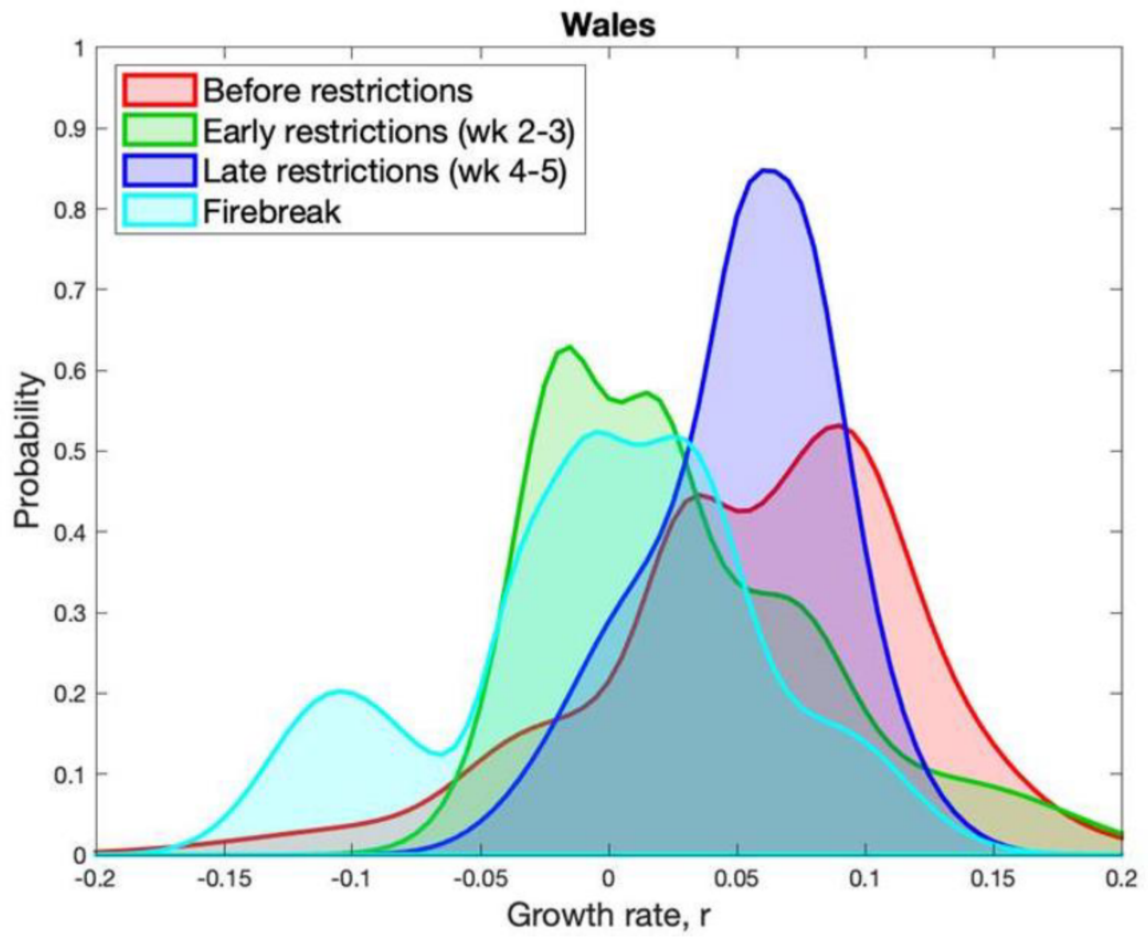
10a



10b



10c



3. What do we learn?

We must be careful not to infer process from these patterns for a variety of confounders could exist, including the fact that more severe interventions were introduced to places that were failing under lighter interventions.

Nevertheless, it is encouraging that two nations see almost all epidemics shrinking during some interventions. Those are, the vast majority of Tier 3 LTLAs in England and all 11 districts in Northern Ireland following their national restrictions. But the picture is more mixed in Wales during their firebreak and in Scotland during the central belt restrictions, although the general trend is for a reduced growth rate following restrictions.

After interventions have been in place for some weeks growth rates continue to shift. There is no overwhelming pattern of either improvement or deterioration visible in the data available to date. But it is clear that early benefits do not always endure, and we must therefore guard against over-optimism when we examine early outcomes. In Northern Ireland epidemics shrank in all districts in the early weeks of national restrictions. That pattern endured in all but one district for the late weeks of national restrictions. It would be very useful to know how to replicate this consistent and beneficial pattern.

Through the autumn England waited until after prevalence had increased to impose measures just about able to slow or stop epidemic growth. The inexorable outcome was high prevalence in many places and the need for four weeks of national restrictions. For the future a more logical procedure might be to introduce measures (such as Tier 2) that can be hoped to retard the growth everywhere and maintain low prevalence. As soon as rising prevalence is detected, measures should escalate to interventions that are associated with negative growth rates (such as Tier 3).

All four nations had periods of school closure during the interventions examined here. Further work is needed (and is underway) to understand what role that played in local epidemic dynamics. We have treated local areas as though they were separated from each other, ignoring boundary effects. Analyses of the patterns described here that take spatial distribution into account will help us understand the role of boundary effects.

Two of our four nations have recently introduced new schemes of intervention and it will be soon be possible to repeat these exercises in data exploration for the national restriction in England and the system of levels in Scotland. There is strength in the diversity of approaches adopted by our four nations. When we plot information in ways that make it is easy to compare one nation's experience with another's, each can learn from what others have tried. Keeping prevalence low enough during the coming winter will be a great challenge. It is a challenge we should face armed with all the understanding we can muster.

Annex A – Methodology

The approach involves estimating the growth rate, *r*, from a two-week sample of testing data by fitting an exponential to the proportion of swab tests that are positive. This is achieved by assuming that the number of positive swabs is distributed as a beta binomial function and calculating the likelihood across the 2-D parameter space of initial prevalence (x_o, the proportion of swabs that are positive at the start of the two-week period) and growth rate. Mathematically, we use the following form:

$$\text{Proportion Positive } = \frac{p_{COVID}\ \#COVID}{p_{CLI}\ \#CLI\ +\ \ p_{COVID}\ \#COVID} = \frac{p_{COVID}X_0\ \exp(rt)}{p_{CLI}\#CLI + p_{COVID}X_0 \exp\ (rt)}$$
$$= \frac{x_o\ \exp(rt)}{1 + x_o \exp\ (rt)}$$

where #COVID-19 and #CLI are the numbers of symptomatic COVID-19 infections and COVID-Like Infections respectively, and *p* is the propensity to get tested given either infection. In estimating the growth rate, *r*, we are implicitly assuming that the number of non-COVID infections and the ratio p_{CLI}:p_{COVID} change slowly compared to changes in the level of COVID infection. We integrate across parameter x_o to generate the likelihood of any particular growth rate, *r*. The results for England have now been independently verified by fitting alternative statistical models to the same data sources, and reaches the same qualitative conclusions.

The data used varies between nations.

For England, we use Pillar 2 swab testing data in each of the 317 LTLAs (Lower Tier Local Authorities), broken into 5-year age cohorts (0-4, 5-9, … 80+); each of the age groups generates its own likelihood for *r*, which are combined to achieve an aggregate value.

For Northern Ireland, we use Pillar 2 testing data in each of the 12 Local Government Districts, broken into 20-year age cohorts.

For Scotland, we use Pillar 2 swab testing data for each of the 32 LTLAs; age structured break-down of these data is not available, so we calculate the growth rate from the aggregate information.

For Wales, we use Pillar 2 testing data for the 22 LTLAs, and again use 5-year age cohorts.