The Data Open

Investigating the effectiveness of government lockdown measures during the COVID-19 pandemic

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1 Topic Question

The end of 2019 saw the emergence of the COVID-19 virus, which proceeded to sweep across the world in 2020, leaving chaos and mass misinformation in its wake. As governments across the world continue to battle with the spread of the disease, it becomes clear that a robust method of evaluating the effectiveness of government measures and their potential consequences on countries is necessary. The overall focus of our investigation can be illustrated through the following question:

Topic Question: Which government measures have been effective during the COVID-19 pandemic, and how can we assess this?

In evaluating this question, we found two main themes of analysis to be insightful:

1. How effective have mobility-restricting measures been in terms of hindering the spread of coronavirus, and how does general public compliance factor in this?
2. What effects have the pandemic and lockdown measures had on the performance of the stock market?

By answering these questions, we aim to provide an insight into the effectiveness of government measures and to suggest a variety of methods to quantitatively evaluate this effectiveness.

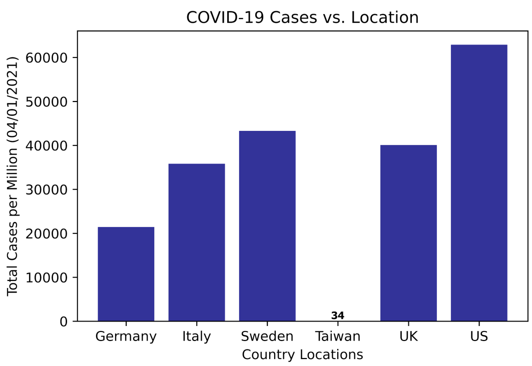
2 Executive Summary

The aim of this investigation is to assess the relationship between the measures taken by governments against COVID-19, and the rate of spread of the virus. We use this correlation to show where restrictions such as lockdowns may have been more effective, and to potentially indicate where populations adhere more strictly to regulations (i.e. the compliance of the population). The compliance can then be used in conjunction with economic impact to identify the most “efficient” strategies in the fight against coronavirus i.e. the measures which reduce case numbers while minimising the damage to the economy - an important balance to strike for any national government.

3 Technical Exposition

Initial Exploration

In order to evaluate and compare different measures in different countries, some initial exploration into the data was conducted.



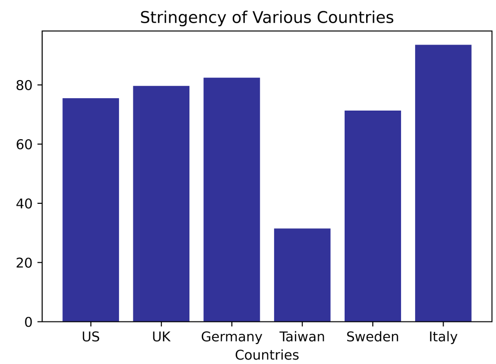


Figure 1(left): The total number of cases in various countries
Figure 2(right): The maximum stringency of various countries

Figures 1 and 2 show a selection of six countries which produced the most interesting disparity in the number of cases and stringency of government measures. These were used for comparisons as we explored public compliance and economic impacts of lockdown measures.

3.1 Investigating the Effect of Mobility on the Spread of Coronavirus

A predominant theme of government measures put in place to hinder the spread of COVID is the restriction of public mobility, with the aim of reducing disease transmission between members of the public and between different regions. Such measures include the closing of public venues, the introduction of regional and national lockdowns, and the prohibition of intra- and international travel.

3.1.1 Visualisation of the causal relationship between Mobility and the Reproduction Rate in the six selected countries

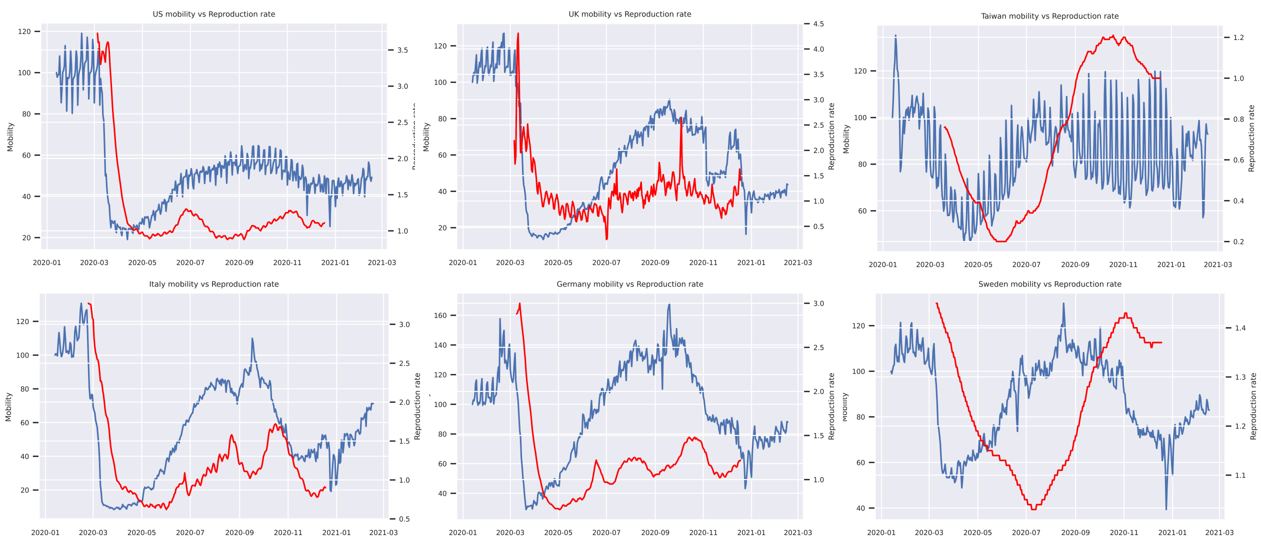


Figure 3: Mobility of specific countries versus the virus reproduction rate.

The reproduction rate (R) is the average number of people that an infected individual passes the disease to, and is calculated from mathematical models which take into account the amount of susceptible individuals in a community. It is a better indicator to map the virus spread in the community than the absolute number of cases, as it measures the rate of spread and takes into account the number of COVID tests being carried out. By visualising the time evolution of mobility and comparing it with that of the reproduction rate, we observed that countries who impose restrictions as soon as community spreading is detected would experience a quicker rebound in mobility (Taiwan initial R number = 0.8). Keeping these restrictions would be less likely to cause a sharp drop in mobility, as compared to removing and reimposing them in most European countries.

3.1.2 Correlation Analysis of the Causal Relationship between Mobility and the Reproduction Rate in the UK

To gain an insight into the effects of mobility-restricting measures on the spread of COVID data, we conducted correlation analysis to investigate the relationship between the time evolution of public mobility and reproduction rate in the UK (see Figure 1). The data, provided by Google, is split into location categories (retail and recreation; grocery and pharmacy; parks; transit stations; workplaces; and residential) and given as the percentage difference from typical “baseline” mobility levels in Jan-Feb 2020. The residential category refers to the amount of time spent at home; the remaining categories refer to the number of visits made to the corresponding locations. Note that this data is collated from smartphone users, and thus may show some differences from the entire population.

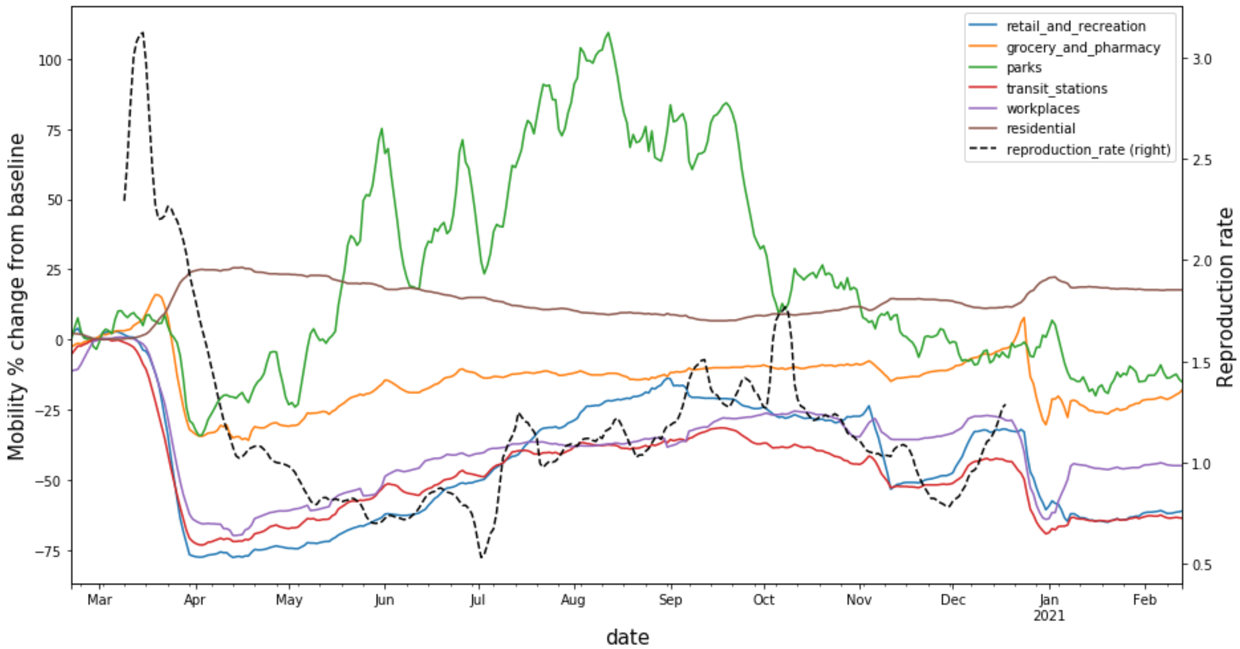


Figure 4: UK mobility (Google) and reproduction rate trends over time, MA(7)

To quantify the relationship between public mobility and reproduction rate, we made use of Spearman's rank correlation coefficient. We chose to use this coefficient as it assesses how well the relationship between the variables can be described by a monotonic function, without assuming linearity – we expect that the relationship between mobility and reproduction rate is more complicated than a linear relationship. The coefficients for each mobility category are given in Figure 5.

Mobility category	**Correlation with Reproduction Rate**	
	Spearman coefficient	**Lag / days**
Retail and recreation	0.527	5
Grocery and pharmacy	0.445	3
Transit stations	0.548	3
Workplaces	0.503	3
Residential	-0.573	4

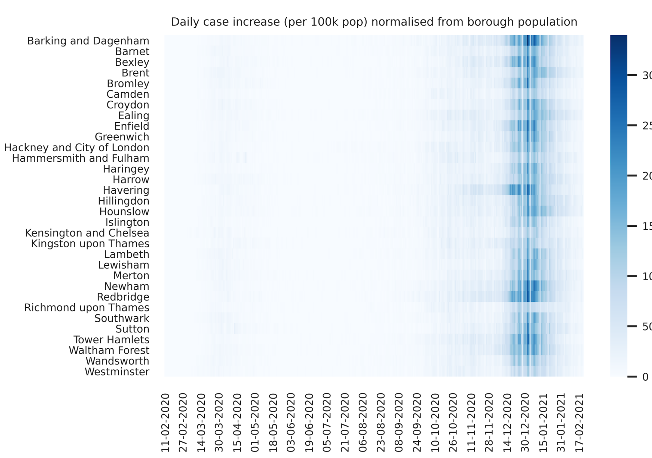
Parks	-0.002	N/A

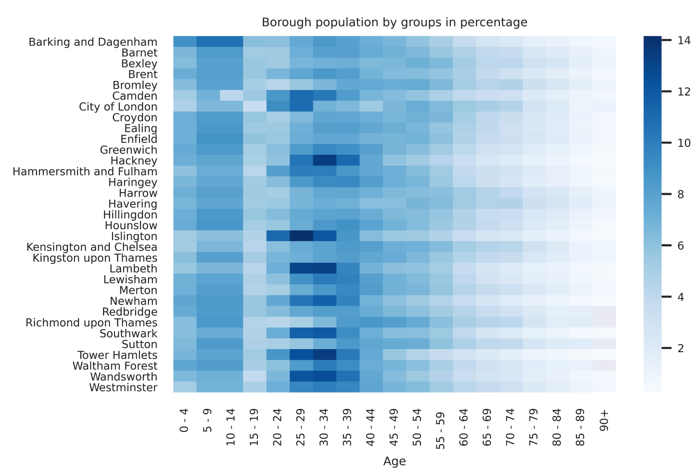
Figure 5: Correlation data between mobility and reproduction rate in the UK

The Spearman coefficients demonstrate that the majority of the mobility categories are positively correlated with reproduction rate (with values of ~0.5 implying moderate correlation), and thus provides evidence that restriction of public mobility helps to reduce the rate of spread of coronavirus. This is as expected – the majority of the mobility categories in Figure 4 show similar trends to the reproduction rate. The 'residential' mobility category is negatively correlated with the reproduction rate, again in line with expectations – if the public spends more time at home, this corresponds to less time spent in public areas and less contact with members of other households. The "parks" mobility category shows little-to-no correlation with reproduction rate, probably due to reduced contact between people in large outdoor areas.

Another observation made from Figure 4 was the temporal delay of the reproduction rate behind the time evolution of the mobility data (for all categories except "parks", which showed minimal correlation with reproduction rate). The cross correlation of the reproduction rate with each mobility series was calculated; the lag with maximum correlation provides an estimate of the delay, which was found to vary between three to five days depending on the mobility category (see Figure 5). This lag implies that the national mobility level has a causal effect on the spread of coronavirus, as expected, and that this effect becomes apparent within the timescale of several days.

3.1.3 Comparison of Mobility-Reproduction Rate Trends between Age Groups in London





(a)

(b)

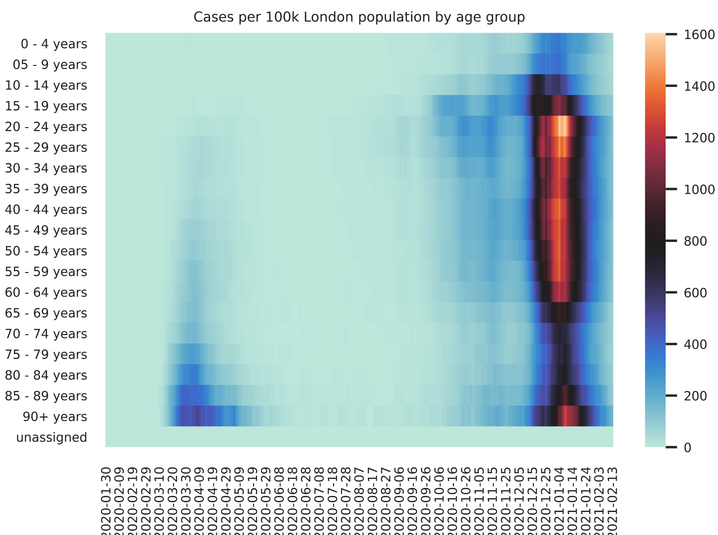


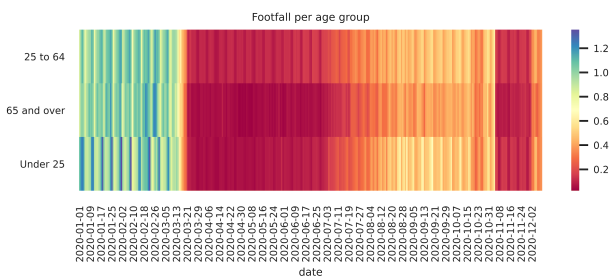
Figure 6: (a) shows the evolution of cases in each London borough against time. Plot (b) displays the borough's population split into distinct age groups. (c) shows cases of each age group over time.

(c)

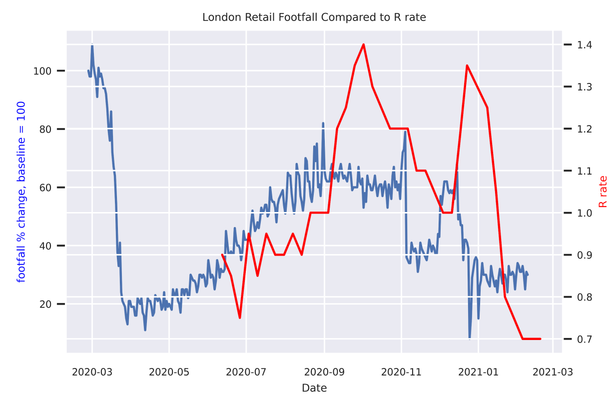
London has a total of 33 different boroughs, these are split into 2 groups. There are 12 inner London boroughs, who typically have a younger population - observed by the dark blue spots in Figure 6(b). The outer boroughs have generally smoother age distribution, with a higher resident population of over 60's. Bromley, Richmond, and Sutton have a reasonably lower 15 - 30 year old population with a median of around 40 - 44, they had a smaller daily increase during the second wave. This suggests that the former age group was responsible for carrying the spread around, which can be correlated with the start of the new academic year (Sep/Oct) with students moving to university.

Boroughs with a median population of 20 - 35 (Hackney, Islington, Lambeth) are made up of students and young working adults. They record a smaller daily increase as compared to outer london boroughs and might be caused by people moving closer to their families since working from home is encouraged. This is clearly amplified in Westminster where retail, recreation, and transit services dropped by 70% from the baseline.

There exists a noticeable lag of 10 days between infections of the age group 15 - 65 and 95 and above. The cases within the group 20 - 49 increased earlier (bright red spots) on 15th Dec, and then ages 50 - 70 on the 25th Dec. Indicating that the virus is passed on to the older generations from the younger ones who are out and about. Those between 70 to 85 years of age seem to be isolating more strictly during the second wave as cases in that age range are lower than their neighbours.



(a)



(b)

Figure 7: (a) Time series of footfall categorised into age groups. (b) Comparison of retail footfall and R number.

The first lockdown (23/3/20 - 10/5/20) worked effectively in suppressing the transmission, this is quantified by a drop of 80% in pedestrian traffic. The government's programme of “Eat out to help out” (1/8/20 - 31/8/20) acted as a catalyst to spur economic growth, as seen on Figure 7(b), unfortunately, this also led to an increase in the R number. The apparent non increase in cases might suggest the virus was not virulent in the community yet, or the amount of COVID tests being done was not adequate. The UK was put back into a second lockdown (5/11/20) which would last a month, this successfully decreased the R number from a peak of 1.4 down to 1. The R number has a lag of around 3 weeks.

This measure was short lived as cases and the R number would spike once lockdown was over and the tier system introduced. People were getting restless of the restrictions and enforcement was not adequate, we can infer that the tier system was not sufficiently effective in suppressing the spread.

3.2 Investigating the Relationship between Stringency of Measures and Reproduction Rate

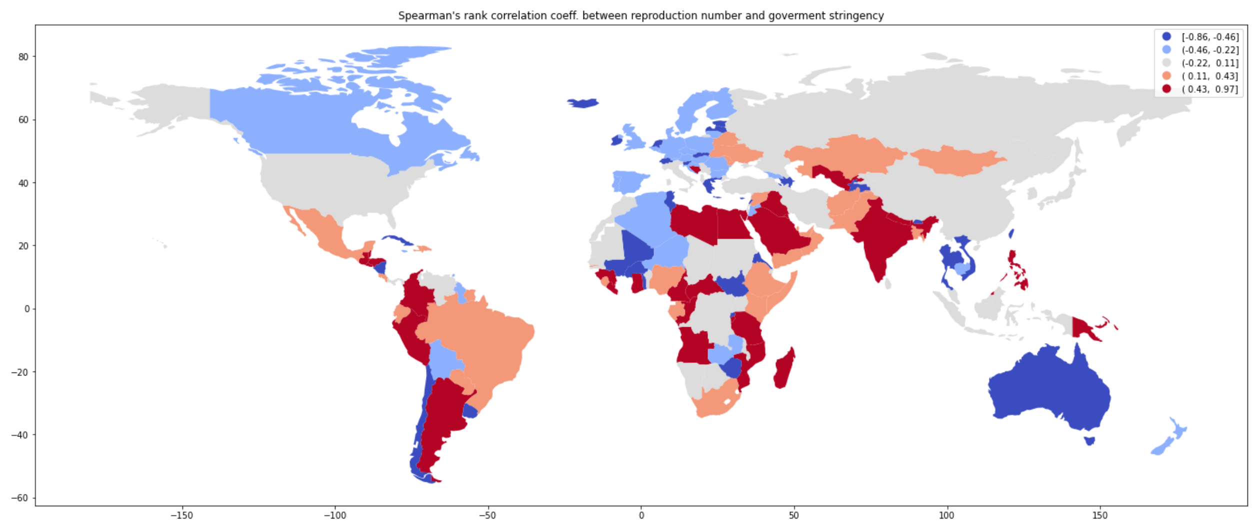


Figure 8: Correlation coefficients between reproduction rate and government stringency index.

Our World in Data, using data collected by the University of Oxford, provides a "Government Stringency Index", which aims to quantify the overall strength of restrictions and other measures introduced by national governments to try and stop the spread of COVID. This statistic takes a wide variety of measures into account, from stay-at-home orders and closures of schools and workplaces, to vaccination and testing policies.

Coefficients for both Pearson's and Spearman's ranks were calculated for stringency against three separate measures of the virus' spread: daily new positive cases, reproduction rate (R), and percentage of positive tests. Spearman's rank was deemed to be more representative of the relationship between the statistics, as it can characterise a general monotonic correlation, rather than the linear relationship measured by Pearson's rank. We also decided that reproduction rate would be the best statistic to compare against, given that its calculation already takes certain factors into account, such as the delay in onset of symptoms.

The correlation coefficients shown in Fig. 5 indicate a relatively weak correlation between the stringency of government measures, and the reproduction rate (R) of the virus, for the majority of countries.

An interesting result to note is that countries with a strong positive correlation between R and stringency tended to have a strong negative correlation between cases and stringency. This is likely indicative of a lag between R and cases, such as some cyclical pattern in the data causing 'peaks' in R to line up with 'troughs' in cases and vice versa.

However, it must be noted that the coefficients in Fig. 5 were calculated directly on the time-series data, without adjusting for any time lag between the two statistics. Performing a time-lagged cross-correlation analysis for the UK showed that maximum correlation was found when R lagged behind stringency by ~100 days (suggesting an extremely long time for restrictions to take effect), or when stringency lagged behind R by ~30 days. This could imply that the British Government's response was delayed with respect to increases in the virus' spread.

Taking these results and caveats into account, it seems unlikely that the Spearman's rank correlation coefficient provides a useful measure of the relationship between overall government stringency and the reproduction rate of the virus. Additionally, analysis of the data quickly showed that any correlation between *individual* measures and reproduction number would be extremely difficult to identify from the available data. At the level of individual government measures, most restrictions are either 'on' or 'off', and for many countries, even at this stage of the pandemic, the majority of measures have been continuously 'on' since March 2020.

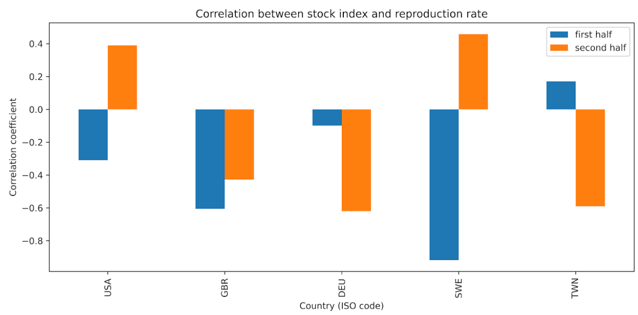
3.3 Investigating the Relationship between Economic Performance and Reproduction Rate

The uncertainty during the COVID-19 pandemic caused great fluctuations in the movement of the stock markets of various countries. Comparing the movement with reproduction rates and the stringency of lockdown measures presented some interesting correlations. Spearman's rank correlation coefficients were calculated between each country's primary stock index, and the aforementioned government stringency index. On the whole, Figures 9 and 10 indicate that there was no general trend for all countries, although taking averages and looking at the world as a whole showed some notable patterns.

With respect to the reproduction rate of the COVID-19 virus, the United Kingdom, United States and Sweden all saw a negative correlation with the market movement in the first half of 2020, as expected. This potentially reflects the uncertainty of investors, the nature of the virus was initially unknown and as it became more widespread . However, as more was understood about the virus and corporations made adjustments to effectively function remotely, it can be observed that investors' confidence was regained and became more independent of the number of cases. This is particularly clear in Fig. 10, where we can see negative correlations between the stock index and government stringency level in the first half of the pandemic for all but one of the sampled countries. This shows that as restrictions were brought in to curb the spread of the virus, economic markets suffered. In the second half, all countries experience a positive correlation between these statistics, indicating that even though restrictions may have been increased (as many countries experienced a second wave towards the end of 2020), stocks rebounded and indices increased.

However, care must be taken when interpreting these data.

In the case of Sweden, an explanation for the positive correlation between economic performance and stringency could be explained by the country's hesitancy to enact a national lockdown.



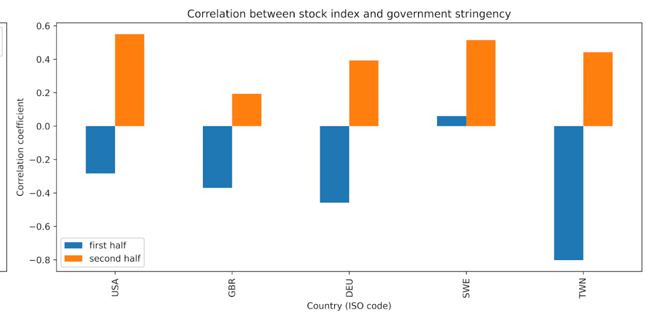


Figure 9(left): The total number of cases in various countries
Figure 10(right): The maximum stringency of various countries

3.4 Quantifying the 'Compliance' of Countries Worldwide

An important factor in the efficiency of a government measure is the extent to which public behaviour changes in response to the introduction of a measure - in other words, the overall 'compliance' and willingness of members of the public to follow government guidelines. We attempted to assess the extent of compliance by analysing the relationship between national mobility and the degree of stringency of government measures, for countries worldwide. For this, we used the 'stringency index' data provided by 'Our World In Data', which rates the stringency of individual government measures of a country and sums their ratings as an aggregated index.

As an initial insight into the relationship between the average amount of time spent at home and government stringency, we plotted the time evolution of both variables for each country, and noted that the variables appear to correlate closely. To verify this, we calculated the corresponding Spearman coefficients to assess the extent of the correlation (see Figure 11 for coefficients calculated for a selection of countries).

Next, we attempted to quantify the extent to which public mobility behaviour changes when measures are introduced, by modelling the relationship between the amount of time spent at home depending on the level of government stringency. We had previously observed that the plots of amount of time at home versus stringency appeared to approximately follow an exponential relationship for most countries. Therefore, to transform the data to a near-linear relationship, we calculated the logarithm of the dependent variable (amount of time spent at home), as follows:

$$y = Ae^{Bx} \text{ (Eq. 1)}$$

$$log(y) = log(A) + Bx \text{ (Eq. 2),}$$

where *y* is the time spent at home each day as a percentage of baseline levels, *x* is the overall stringency index, and *A* and *B* are parameters to be fitted. We then applied linear regression to the transformed data, assuming zero intercept as you would expect the time spent at home to tend towards the baseline value when no government measures are in place. An example of a model fitted on data for the UK and Italy can be seen in Figure 11.

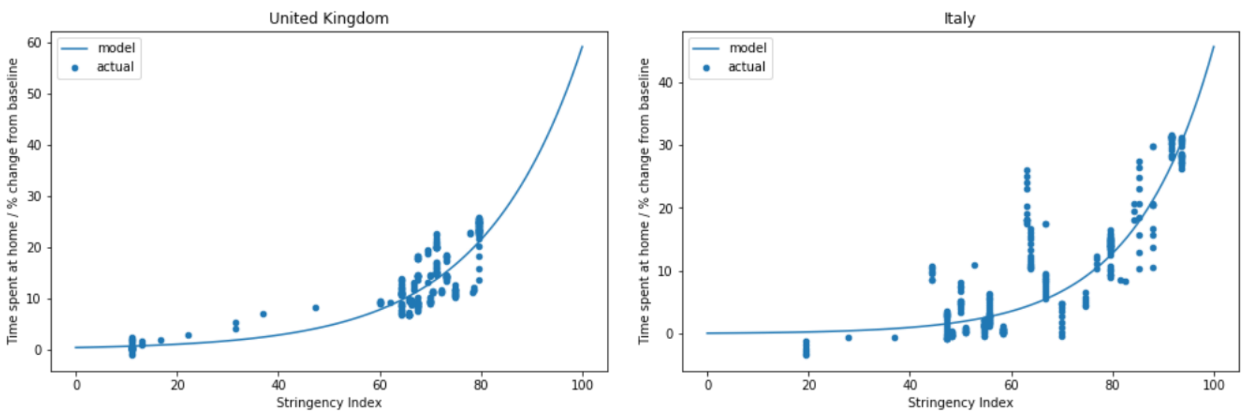


Figure 11: Examples of exponential curves fitted to mobility versus stringency index data for the UK and Italy

Fitting the data with curves provides parameters that can be used to quantitatively evaluate the compliance of a country. First, the R-squared value (i.e. the spread of the data about the model) gives an estimate of the degree of correlation between public behaviour and measure stringency, assuming that the chosen model (exponential in this case) is a good choice. Second, the slope of the straight line, when plotting the logarithmically transformed data (*A* in Equations 1-2) can be used to gauge the extent to which public behaviour changes with measure stringency.

	Time Spent at Home vs. Government Measure Stringency		
Country	Spearman correlation	Parameters from linear regression of log(time spent at home) vs. stringency	
		R-squared (exponential model)	Slope (*A* in Eq 1-2)
Germany	0.860	0.530	0.039
Italy	0.810	0.524	0.064
Sweden	0.647	0.474	0.027
Taiwan	0.631	0.334	0.128
UK	0.810	0.841	0.051
US	0.910	0.522	0.030

Figure 12: Table of parameters relating the time spent at home to the overall stringency of government measures, for a selection of countries

Parameters calculated for a selection of countries are given in Figure 12. Note the significantly high value of slope for Taiwan, which would imply increased ‘compliance’ of the country. This could be due to the general trend of relatively strict enforcing of government rules in Asia, as well as the fact that Taiwan had previously been through the 2003 SARS pandemic, so members of the public are better prepared for COVID measures. On the other hand, the slope is relatively low for Sweden and the US, which could be attributed (in part) to less strict enforcement of government measures in these countries. Collectively, these parameters (or parameters calculated by applying another model) could be used to define some form of ‘compliance index’ for each country.

4 Conclusion

Through conducting a detailed quantitative analysis on various intuitive hypotheses, several interesting relations have been uncovered. We identified that public mobility has a causal effect on viral reproduction rate via correlation analysis. By analysing data between different age groups, we found that the Tier system in the UK was unsuccessful as younger generations (15-35 year old) continue to transmit the disease despite more stringent measures. We observed that national stock markets tend to struggle more in the first half of the COVID pandemic, compared with the second half. Finally, we suggested a method of quantifying the compliance of members of the public in a country, which is an important factor in determining the effectiveness of lockdown measures and could be used in cases of COVID-19 resurgence.

5 References / data sources

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- Our open data - Transport for London
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