What effect do government policies have on the transmission of COVID-19?

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Introduction

COVID-19 has impacted life globally, and a question that is widely discussed is how to slow its spread. Throughout the pandemic the scientific community has found effective methods to minimise infection rates. However, the implementation has been widely dependent on political leadership and public response. The key objectives of this investigation are:

- Determine the effect of government policies on the transmission of COVID-19, using the measure R_t.
- Use both qualitative data in the form of policy legislation and journals, and quantitative data in the form of official government pandemic figures.
- Compare the UK's approach with other countries to see specific examples of different approaches.

Materials and Methods

The Data

Pandemic and testing data for the UK[1], pandemic data for New Zealand and Brazil[2], and policy information for the UK, New Zealand, and Brazil are used.

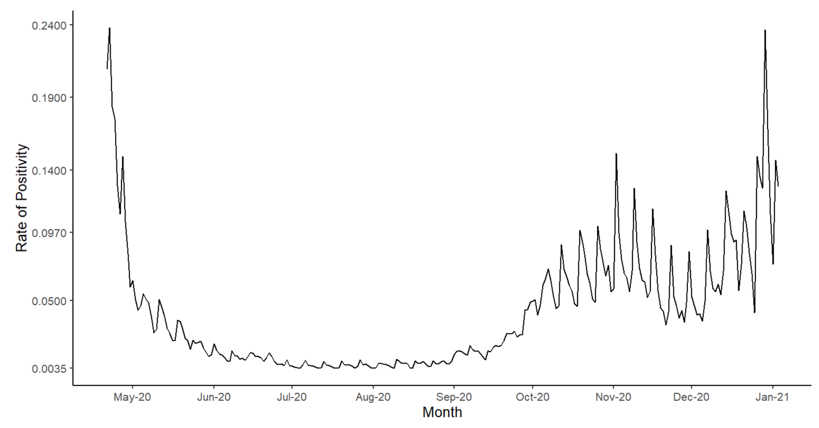

Figure 1: Plot of the rate of positivity over time, calculated by taking the ratio of the number of people testing positive out of the number of people tested.

Figure 1 shows the rate of positivity is variable throughout the pandemic, but follows an upward trend from December 2020 to January 2021 - indicating a rising proportion of infections.

Estimating Transmission

Two methods were used to estimate the rate of transmission:

1. Deterministic SIR model: a system of ODEs which can be used to estimate β and γ:

$$\frac{dS(t)}{dt} = -\frac{\beta I(t)S(t)}{N},$$
$$\frac{dI(t)}{dt} = \frac{\beta I(t)S(t)}{N} - \gamma I(t),$$
$$\frac{dR(t)}{dt} = \gamma I(t).$$

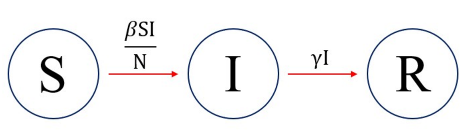

Figure 2: The SIR model system, $S = S(t)$, $I = I(t)$, $R = R(t)$.

Figure 2 shows us that a higher value of β would increase the speed at which people become infected, and a higher value of γ would increase the speed at which people become removed. If β and γ are estimated over time intervals (7 days), we can estimate transmission over time as $R_t = \frac{\beta_t}{\gamma t}$.

2. Stochastic epidemic model: model using a Poisson process to model incidence and a Gamma distributed prior of $R_{t,\tau}$, for an interval of τ days, to find the posterior distribution of $R_{t,\tau}$. Which can be used as an estimate of transmission rates over sliding windows of $\tau = 7$ days:

$$R_{t,\tau} \sim Gamma\left(a + \sum_{s=t-\tau+1}^{t} I_s\,,\ \left(\frac{1}{b} + \sum_{s=t-\tau+1}^{t} \Lambda_s\right)^{-1}\right).$$

Time Series Models

Two types of time series modelling are then used to make predictions about key pieces of data for the UK - the daily confirmed cases, positivity rate, and transmission rate, with weekly frequency:

1. Univariate modelling - seasonal Auto Regressive Integrated Moving Average (seasonal ARIMA) models: $ARIMA(p,d,q)(P,D,Q)_m$., where (p,d,q) is for non-seasonal data, and $(P,D,Q)_m$ is for seasonal data. We have m observations per period, p, P AR terms, d, D I terms and q, Q MA terms.
2. Multivariate modelling - a Vector Auto Regressive (VAR) model, written as: $\mathbf{X}_t = \boldsymbol{\phi}\mathbf{D}_t + \Theta_1\mathbf{X}_{t-1} + ... + \Theta_p\mathbf{X}_{t-p} + \boldsymbol{\epsilon}_t$, where p is the number of lags included, $\mathbf{X}_t$ is the vector of time series, Θ_i is the matrix of parameters, and $\boldsymbol{\epsilon}_t$ is the vector of error terms.

Results

Estimating Transmission

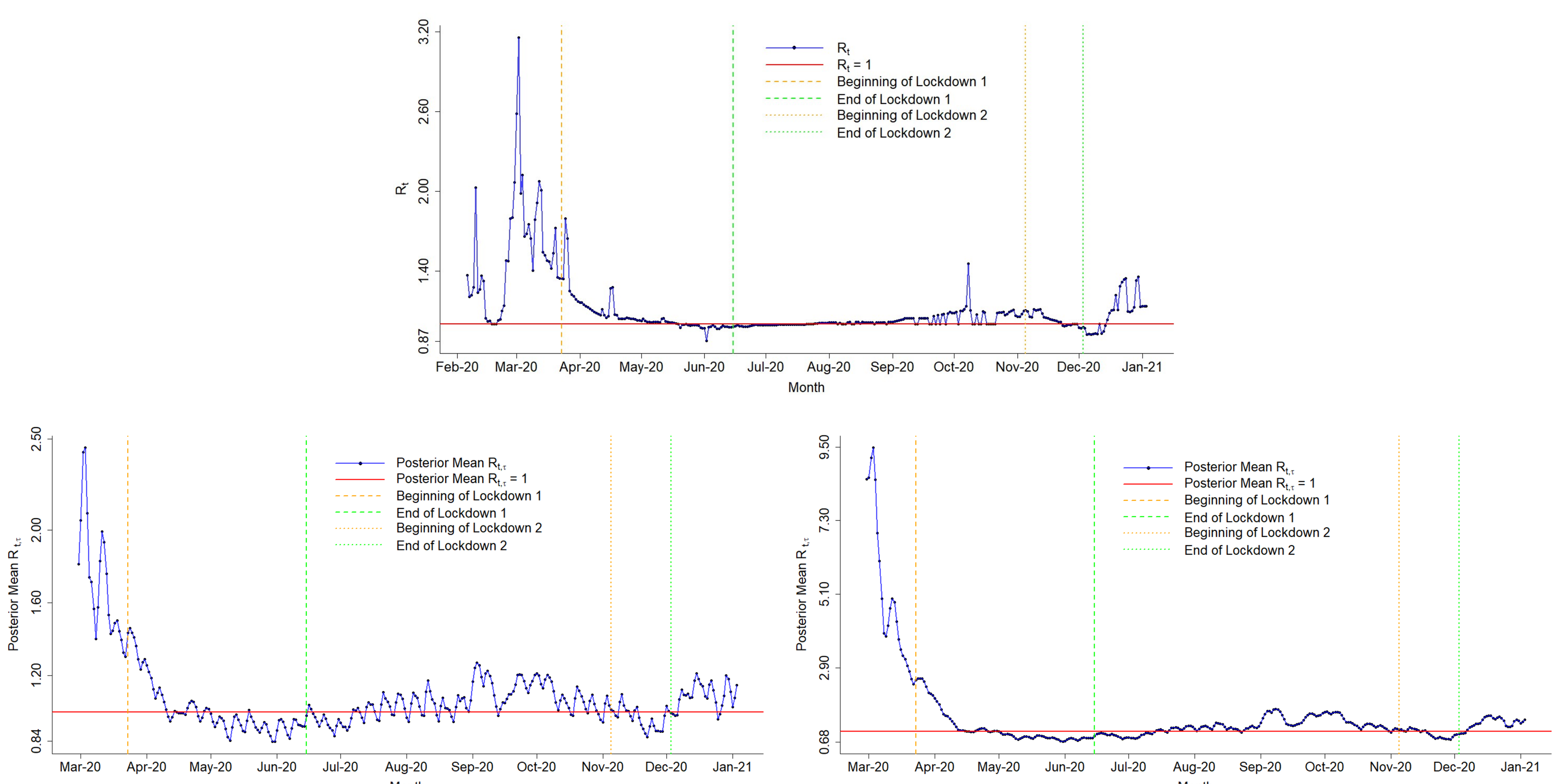

Figure 3: Plots of transmission over time in the UK, top plot uses the deterministic SIR model, bottom two plots use the stochastic epidemic model with parametric (left) and uncertain (left) serial intervals respectively.

Figure 3 shows that estimations of the transmission rate were lower during, and just after, a national lockdown. Additionally, we see that this is true regardless of the method used to estimate the rate. This is the key result found by this investigation.

Time Series Models

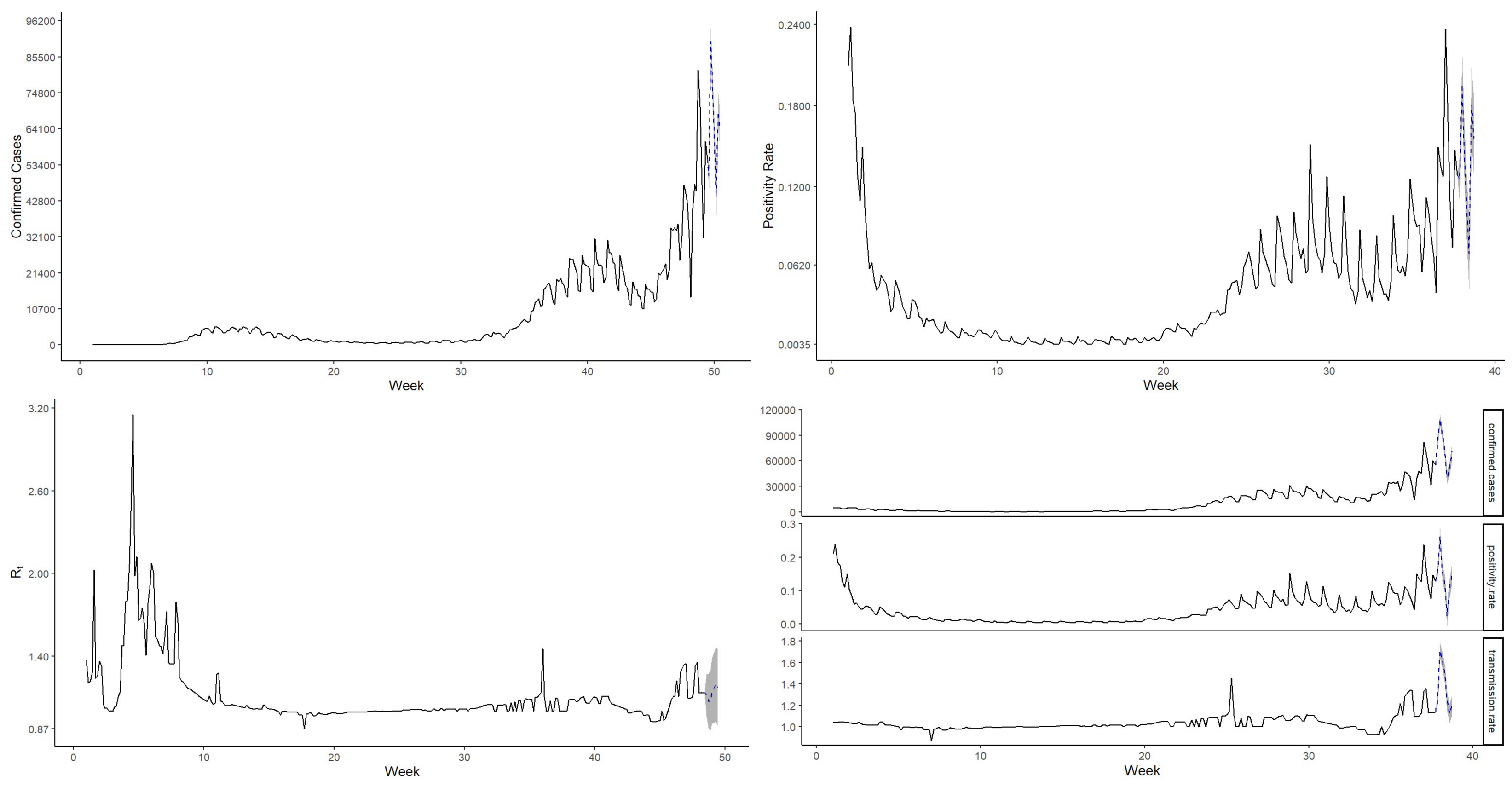

Figure 4: Top left plot shows univariate model of daily confirmed cases and predictions for the next 7 days. Top right plot shows univariate model of positivity rate and predictions for the next 7 days. Bottom left plot shows univariate model of transmission rate and predictions for the next 7 days. Bottom right plot shows multivariate model of daily confirmed cases, positivity rate, and transmission rate and predictions for the next 7 days.

Figure 4 shows predictions from three seasonal ARIMA models, and one VAR model. We see predicted rises in new confirmed cases and transmission rates. We also see predicted variability in positivity, which is consistent with the variability seen throughout. Note that the multivariate predictions do not match the predictions from the univariate models, but follow similar trends.

Comparisons

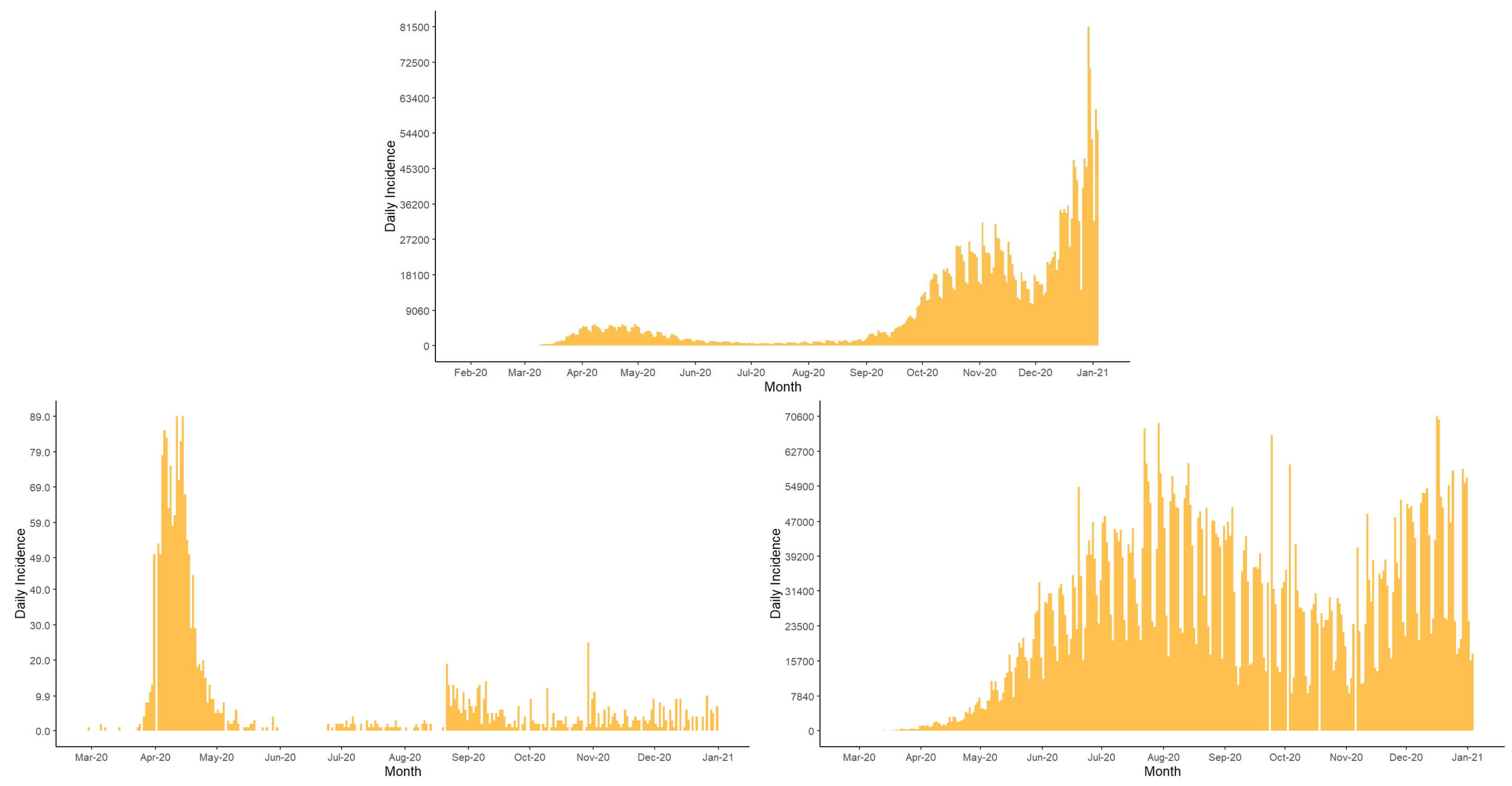

Figure 5: Top plot shows the incidence for the UK, bottom left plot shows the incidence for New Zealand, bottom right plot shows the incidence for Brazil.

Figure 5 shows comparisons between the UK, New Zealand, and Brazil which can be used to determine the possible impacts different approaches have had. We see that there are very different patterns in infections between the three countries.

Remarks

- Border control in the UK was minimal until the introduction of travel corridors[3] but controlled by national lockdowns. However, these lockdowns were lifted quite quickly.
- However, in New Zealand border control has been very tight since March 2020, with large scale testing conducted at controlled facilities[4]. In addition, lockdowns in New Zealand were only lifted after a long period of no community transmission, with them being reinstated immediately upon the discovery of new cases in the community.
- Whereas in Brazil border control was loosened in July 2020 when restrictions no longer applied to air travel[5] - which is the main mode of entry. Furthermore, Brazil had no national lockdown, with local areas introducing measures but being forced to lift them early.
- By changing the following, the UK may be able to reduce transmission rates more effectively:
  1. Policies should be clearly outlined to the public, and with their motivations being communicated.
  2. Testing should be expanded to include close contacts of individuals who test positive for COVID-19.

References

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