Covid_Mixed_effect_analysis

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11/24/2021

Data source

https://github.com/CSSEGISandData/COVID-19

Introduction

In this analysis, we want to examine and quantify how the COVID19 pandemic impacted different parts of the globe in different ways.

```
library(tidyverse)
```

```
## -- Attaching packages --------------------------------------- tidyverse 1.3.0 --

## v ggplot2 3.3.3     v purrr   0.3.4
## v tibble  3.0.6     v dplyr   1.0.4
## v tidyr   1.1.2     v stringr 1.4.0
## v readr   1.4.0     v forcats 0.5.1

## -- Conflicts ------------------------------------------ tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
```

Exploratory data analysis with Visualization

```
data = read.csv('WHO-COVID-19-global-data.csv')
summary(data)
```

```
##  ï..Date_reported   Country_code         Country           WHO_region
##  Length:163767      Length:163767      Length:163767      Length:163767
##  Class :character   Class :character   Class :character   Class :character
##  Mode  :character   Mode  :character   Mode  :character   Mode  :character
##
##
##
##    New_cases      Cumulative_cases     New_deaths     Cumulative_deaths
##  Min.   :-32952   Min.   :       0   Min.   : -92.0   Min.   :     0
##  1st Qu.:     0   1st Qu.:      64   1st Qu.:   0.0   1st Qu.:     0
```

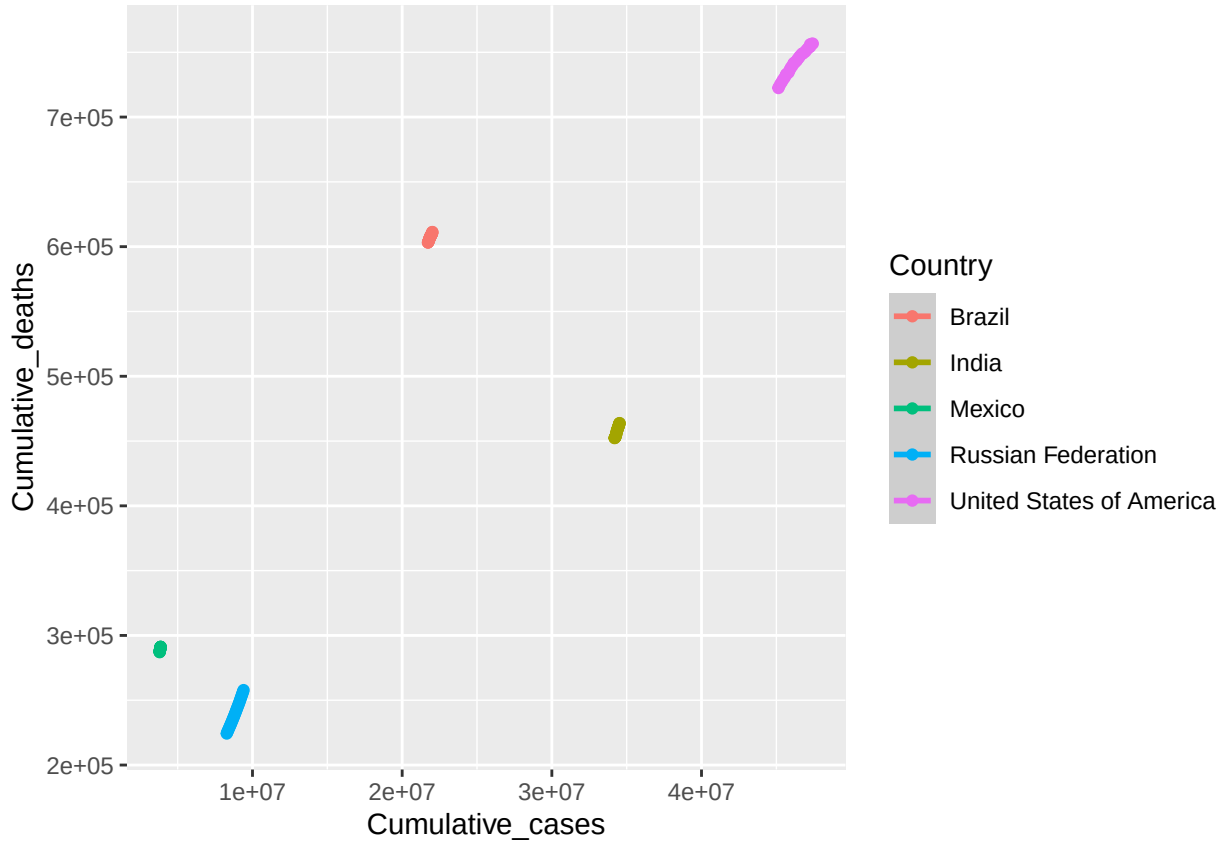
```
##  Median :    15   Median :    5676   Median :   0.0   Median :    87
##  Mean   :  1572   Mean   :  391213   Mean   :  31.5   Mean   :  8822
##  3rd Qu.:   397   3rd Qu.:   99346   3rd Qu.:   6.0   3rd Qu.:  1698
##  Max.   :414188   Max.   :47434791   Max.   :8786.0   Max.   :767278
```

```
#There is often a lag between COVID-19 cases and deaths, so we manually introduce a 7 day lag for bette
data = data %>% group_by(Country) %>% mutate(Cumulative_deaths = lag(Cumulative_deaths,n=7, default = NA
#We want to learn about the COVID pandemic at its peak, so we only take the 30 days with the highest ne
data = data  %>% group_by(Country) %>% slice_max(order_by = Cumulative_deaths, n=30)


#Initial visualization - for clarity, I only plot the five countries with the highest COVID deaths
top5 = data %>% group_by(Country) %>% summarise(count = max(Cumulative_deaths)) %>% slice_max(order_by =

data %>% filter(Country %in% top5$Country) %>% ggplot(aes(x = Cumulative_cases,y = Cumulative_deaths,gr
  geom_smooth(aes(color=Country),method = "lm")+
  geom_point(aes(color=Country))
```

```
## `geom_smooth()` using formula 'y ~ x'
```



From the above visualization, we can see the relationship between case count & the death count is very different from country to country, so we must control for the country-specific effect for new cases.

Mixed model with lme4

Linear Mixed-Effects Models from lme4 can take country-specific effects into account, this will allow us to better understand the variability in the number of death across different countries

```
#standardization before fitting
data$Cumulative_cases=scale(data$Cumulative_cases)
data$Cumulative_deaths=scale(data$Cumulative_deaths)
library(lme4)
```

```
## Loading required package: Matrix
```

```
##
## Attaching package: 'Matrix'
```

```
## The following objects are masked from 'package:tidyr':
##
##     expand, pack, unpack
```

```
library(sjstats)#needed for icc
```

```
## Warning: package 'sjstats' was built under R version 4.0.5
```

```
covid_mixed = lmer(Cumulative_deaths ~ Cumulative_cases + (Cumulative_cases| Country),data)
summary(covid_mixed)
```

```
## Linear mixed model fit by REML ['lmerMod']
## Formula: Cumulative_deaths ~ Cumulative_cases + (Cumulative_cases | Country)
##    Data: data
##
## REML criterion at convergence: -260664.1
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -39.328  -0.001   0.000   0.002  29.055
##
## Random effects:
##  Groups   Name             Variance  Std.Dev. Corr
##  Country  (Intercept)      1.951e+00 1.396953
##           Cumulative_cases 9.831e-01 0.991537 -0.12
##  Residual                  1.992e-06 0.001411
## Number of obs: 25808, groups:  Country, 237
##
## Fixed effects:
##                  Estimate Std. Error t value
## (Intercept)      -0.04401    0.09101  -0.484
## Cumulative_cases  1.07645    0.08753  12.298
##
## Correlation of Fixed Effects:
##             (Intr)
## Cumultv_css -0.041
```

```
icc(covid_mixed)
```

```
## Warning: 'icc' is deprecated.
## Use 'performance::icc()' instead.
## See help("Deprecated")

## # Intraclass Correlation Coefficient
##
##      Adjusted ICC: 1.000
##   Conditional ICC: 0.717
```

Conclusion

You might notice the previous provides no p-value, that is because the degree of freedom can be hard to calculate for mixed designs. The ICC(Intraclass-Correlation Coefficient) shows the majority of the variability in the number of death is due to the between-subject variations. This analysis suggests that the COVID impacted counties in different ways. In future modeling, we need to consider the country-specific effect.

Model Diagnostics

To check whether the assumptions for lme model holds.

```
coef(covid_mixed)$Country
```

```
##                                                 (Intercept)
## Afghanistan                                    1.220177e-01
## Albania                                       -4.278398e-02
## Algeria                                        6.739083e-02
## American Samoa                                -2.067604e-03
## Andorra                                       -6.214126e-02
## Angola                                         5.097540e-02
## Anguilla                                      -3.871047e-02
## Antigua and Barbuda                            7.398863e-04
## Argentina                                      7.033571e-01
## Armenia                                       -7.917608e-03
## Aruba                                         -1.090231e-02
## Australia                                     -7.459026e-02
## Austria                                        1.044696e-01
## Azerbaijan                                    -4.535902e-02
## Bahamas                                        2.684952e-02
## Bahrain                                       -1.019650e-01
## Bangladesh                                    -1.734791e-01
## Barbados                                      -7.183575e-02
## Belarus                                       -9.448141e-02
## Belgium                                        4.307774e-01
## Belize                                        -1.714756e-02
## Benin                                         -1.264599e-02
## Bermuda                                        8.490823e-04
## Bhutan                                        -3.433424e-03
## Bolivia (Plurinational State of)               2.755205e-01
```

```
## Bonaire                                                -1.489133e-02
## Bosnia and Herzegovina                                  1.716629e-01
## Botswana                                               -7.705438e-02
## Brazil                                                  5.103660e-01
## British Virgin Islands                                 -7.928715e-03
## Brunei Darussalam                                      -7.280019e-02
## Bulgaria                                                1.255116e-01
## Burkina Faso                                            1.143484e-02
## Burundi                                                -9.646361e-02
## CÃ´te dâ\200\231Ivoire                                       -8.933991e-03
## Cabo Verde                                             -1.282378e-02
## Cambodia                                                1.831757e-01
## Cameroon                                                4.672955e-02
## Canada                                                  1.244488e-01
## Cayman Islands                                         -1.355664e-01
## Central African Republic                               -1.801762e-02
## Chad                                                   -5.360071e-03
## Chile                                                   5.693804e-01
## China                                                   2.332154e-02
## Colombia                                                1.064374e+00
## Comoros                                                -1.865282e-02
## Congo                                                   1.032057e-01
## Cook Islands                                           -2.057765e-03
## Costa Rica                                             -2.452902e-01
## Croatia                                                 4.495818e-02
## Cuba                                                   -1.748047e-01
## CuraÃ§ao                                                -6.240628e-03
## Cyprus                                                 -1.140431e-01
## Czechia                                                 4.706604e-01
## Democratic People's Republic of Korea                  -2.057765e-03
## Democratic Republic of the Congo                       -3.171711e-03
## Denmark                                                -7.849257e-02
## Djibouti                                               -3.314022e-03
## Dominica                                               -3.312471e-02
## Dominican Republic                                     -4.860894e-02
## Ecuador                                                 5.990136e-01
## Egypt                                                   2.456732e-01
## El Salvador                                             8.095763e-02
## Equatorial Guinea                                      -1.056151e-03
## Eritrea                                                -6.921415e-03
## Estonia                                                -8.744461e-02
## Eswatini                                                7.612621e-03
## Ethiopia                                               -7.382187e-02
## Falkland Islands (Malvinas)                            -7.658428e-03
## Faroe Islands                                          -1.092097e-01
## Fiji                                                    1.669645e-03
## Finland                                                -1.007555e-01
## France                                                  2.189251e+00
## French Guiana                                          -2.289991e-02
## French Polynesia                                       -8.267008e-03
## Gabon                                                  -3.708532e-03
## Gambia                                                  1.557681e-03
## Georgia                                                -3.439588e-02
## Germany                                                 1.813242e+00
```

```
## Ghana                                          -1.918000e-02
## Gibraltar                                      -3.867166e-02
## Greece                                          1.486942e-01
## Greenland                                      -1.097459e-01
## Grenada                                         7.046562e-04
## Guadeloupe                                     -9.838630e-03
## Guam                                            2.787289e-02
## Guatemala                                      -3.448327e-01
## Guernsey                                       -7.183412e-02
## Guinea                                         -7.437956e-03
## Guinea-Bissau                                  -5.841384e-03
## Guyana                                          7.548852e-02
## Haiti                                           6.736324e-02
## Holy See                                       -2.844430e-03
## Honduras                                       -2.178832e-02
## Hungary                                         4.557421e-01
## Iceland                                        -1.333547e-01
## India                                          -1.969812e+01
## Indonesia                                      -1.433309e+00
## Iran (Islamic Republic of)                      3.635240e-01
## Iraq                                           -7.517917e-01
## Ireland                                        -2.103530e-02
## Isle of Man                                    -4.705985e-02
## Israel                                         -1.925536e-01
## Italy                                           2.355961e+00
## Jamaica                                         2.202998e-01
## Japan                                          -4.440998e-01
## Jersey                                         -9.726484e-02
## Jordan                                          4.662199e-02
## Kazakhstan                                     -9.945584e-02
## Kenya                                           1.850477e-02
## Kiribati                                       -2.057765e-03
## Kosovo[1]                                      -7.479556e-03
## Kuwait                                         -1.364701e-01
## Kyrgyzstan                                     -5.893150e-03
## Lao People's Democratic Republic               -1.262262e-01
## Latvia                                         -3.166788e-02
## Lebanon                                        -1.948919e-03
## Lesotho                                         4.354091e-03
## Liberia                                         2.105570e-03
## Libya                                          -6.460405e-02
## Liechtenstein                                  -7.726071e-02
## Lithuania                                      -4.262369e-02
## Luxembourg                                     -9.633949e-02
## Madagascar                                     -3.268324e-04
## Malawi                                          2.598420e-02
## Malaysia                                       -5.015358e-02
## Maldives                                       -1.084127e-01
## Mali                                            1.741660e-02
## Malta                                          -5.025751e-02
## Marshall Islands                               -2.093609e-03
## Martinique                                      9.218182e-04
## Mauritania                                     -2.445833e-02
## Mauritius                                       1.141378e-01
```

```
## Mayotte                                                  -1.057052e-02
## Mexico                                                    1.313502e+00
## Micronesia (Federated States of)                         -2.057765e-03
## Monaco                                                   -1.323681e-02
## Mongolia                                                 -1.241115e-01
## Montenegro                                               -4.821145e-02
## Montserrat                                               -2.614586e-03
## Morocco                                                  -4.200791e-01
## Mozambique                                               -2.623893e-02
## Myanmar                                                   1.931387e-01
## Namibia                                                   2.920353e-02
## Nauru                                                    -2.057765e-03
## Nepal                                                    -1.152881e-01
## Netherlands                                               2.410244e-01
## New Caledonia                                             5.681342e-03
## New Zealand                                              -1.223389e-01
## Nicaragua                                                -1.902422e-02
## Niger                                                     2.498139e-02
## Nigeria                                                  -5.675177e-03
## Niue                                                     -2.057765e-03
## North Macedonia                                           9.109866e-02
## Northern Mariana Islands (Commonwealth of the)           -3.814380e-03
## Norway                                                   -1.157172e-01
## occupied Palestinian territory, including east Jerusalem -1.279926e-01
## Oman                                                     -4.786622e-02
## Other                                                    -3.381380e-03
## Pakistan                                                 -4.080860e-02
## Palau                                                    -2.099935e-03
## Panama                                                   -2.109489e-02
## Papua New Guinea                                         -8.558481e-03
## Paraguay                                                  1.141876e-01
## Peru                                                      3.409608e+00
## Philippines                                              -3.558448e+00
## Pitcairn Islands                                         -2.057765e-03
## Poland                                                    1.216232e+00
## Portugal                                                  2.176075e-01
## Puerto Rico                                              -2.228275e-02
## Qatar                                                    -1.210141e-01
## RÃ©union                                                 -9.895398e-02
## Republic of Korea                                        -8.676265e-02
## Republic of Moldova                                      -4.725213e-03
## Romania                                                  -9.419861e-01
## Russian Federation                                       -4.723077e-01
## Rwanda                                                   -7.684077e-03
## Saba                                                     -2.150861e-03
## Saint BarthÃ©lemy                                       -2.742092e-03
## Saint Helena                                             -2.057765e-03
## Saint Kitts and Nevis                                    -1.505423e-03
## Saint Lucia                                               2.072871e-02
## Saint Martin                                             -3.524174e-03
## Saint Pierre and Miquelon                                -3.325501e-03
## Saint Vincent and the Grenadines                          6.127303e-03
## Samoa                                                    -2.060249e-03
## San Marino                                               -7.804903e-03
```

```
## Sao Tome and Principe                              -2.647946e-03
## Saudi Arabia                                       -9.117866e-02
## Senegal                                             9.161471e-03
## Serbia                                             -1.771089e-01
## Seychelles                                         -3.623430e-02
## Sierra Leone                                       -2.511795e-03
## Singapore                                          -1.233937e-01
## Sint Eustatius                                     -2.619813e-03
## Sint Maarten                                       -1.968704e-03
## Slovakia                                            1.497799e-01
## Slovenia                                           -2.286218e-02
## Solomon Islands                                    -2.834161e-03
## Somalia                                             1.900645e-01
## South Africa                                       -3.381698e+00
## South Sudan                                        -1.518400e-02
## Spain                                               1.464514e+00
## Sri Lanka                                           4.494087e-02
## Sudan                                               1.473166e-01
## Suriname                                            1.058599e-01
## Sweden                                              1.168208e-01
## Switzerland                                         9.649648e-02
## Syrian Arab Republic                                1.644435e-01
## Tajikistan                                         -2.576093e-02
## Thailand                                           -1.497275e-02
## The United Kingdom                                  2.351328e+00
## Timor-Leste                                        -8.068951e-03
## Togo                                               -8.613760e-03
## Tokelau                                            -2.057765e-03
## Tonga                                              -2.058096e-03
## Trinidad and Tobago                                 4.067960e-02
## Tunisia                                             8.702017e-02
## Turkey                                              1.278296e-03
## Turkmenistan                                       -2.057765e-03
## Turks and Caicos Islands                           -5.349204e-03
## Tuvalu                                             -2.057765e-03
## Uganda                                              4.253983e-02
## Ukraine                                            -4.587033e-01
## United Arab Emirates                               -2.481101e-01
## United Republic of Tanzania                         1.668743e-03
## United States of America                            1.356187e+00
## United States Virgin Islands                       -3.316013e-03
## Uruguay                                            -1.168530e-02
## Uzbekistan                                         -8.486757e-02
## Vanuatu                                            -2.079151e-03
## Venezuela (Bolivarian Republic of)                 -5.944683e-02
## Viet Nam                                            2.523594e-01
## Wallis and Futuna                                  -2.103508e-03
## Yemen                                               9.789017e-02
## Zambia                                             -1.384062e-02
## Zimbabwe                                            6.446183e-02
##                                                    Cumulative_cases
## Afghanistan                                              1.43881712
## Albania                                                  0.61022047
## Algeria                                                  1.72743406
```

```
## American Samoa                                    1.07013917
## Andorra                                           0.61762192
## Angola                                            1.48899047
## Anguilla                                          0.79102374
## Antigua and Barbuda                               1.08802010
## Argentina                                         0.88092799
## Armenia                                           1.78572627
## Aruba                                             1.02667076
## Australia                                         0.50187879
## Austria                                           0.09053524
## Azerbaijan                                        0.66787929
## Bahamas                                           1.26927862
## Bahrain                                           0.87794061
## Bangladesh                                        1.23895515
## Barbados                                          0.54305614
## Belarus                                           0.45379715
## Belgium                                           0.11583811
## Belize                                            0.95332400
## Benin                                             1.04797817
## Bermuda                                           1.09504058
## Bhutan                                            1.06865738
## Bolivia (Plurinational State of)                  0.41892060
## Bonaire                                           0.97613514
## Bosnia and Herzegovina                            2.21663558
## Botswana                                          0.13706606
## Brazil                                            1.46139545
## British Virgin Islands                            1.02769299
## Brunei Darussalam                                 0.54297044
## Bulgaria                                          2.12315291
## Burkina Faso                                      1.19515750
## Burundi                                           0.36828024
## CÃ´te dâ\200\231Ivoire                                 1.12496120
## Cabo Verde                                        1.06188460
## Cambodia                                          3.33309860
## Cameroon                                          1.76077734
## Canada                                            0.67903770
## Cayman Islands                                    0.04571537
## Central African Republic                          0.96716365
## Chad                                              1.03015767
## Chile                                             0.32483727
## China                                             0.36022288
## Colombia                                          0.89252540
## Comoros                                           0.92871975
## Congo                                             1.94634450
## Cook Islands                                      1.07021352
## Costa Rica                                        2.27481392
## Croatia                                           0.41341593
## Cuba                                              0.78490775
## CuraÃ§ao                                           1.06860733
## Cyprus                                            0.18113381
## Czechia                                           0.20130256
## Democratic People's Republic of Korea             1.07021352
## Democratic Republic of the Congo                  1.06901618
## Denmark                                           0.05689453
```

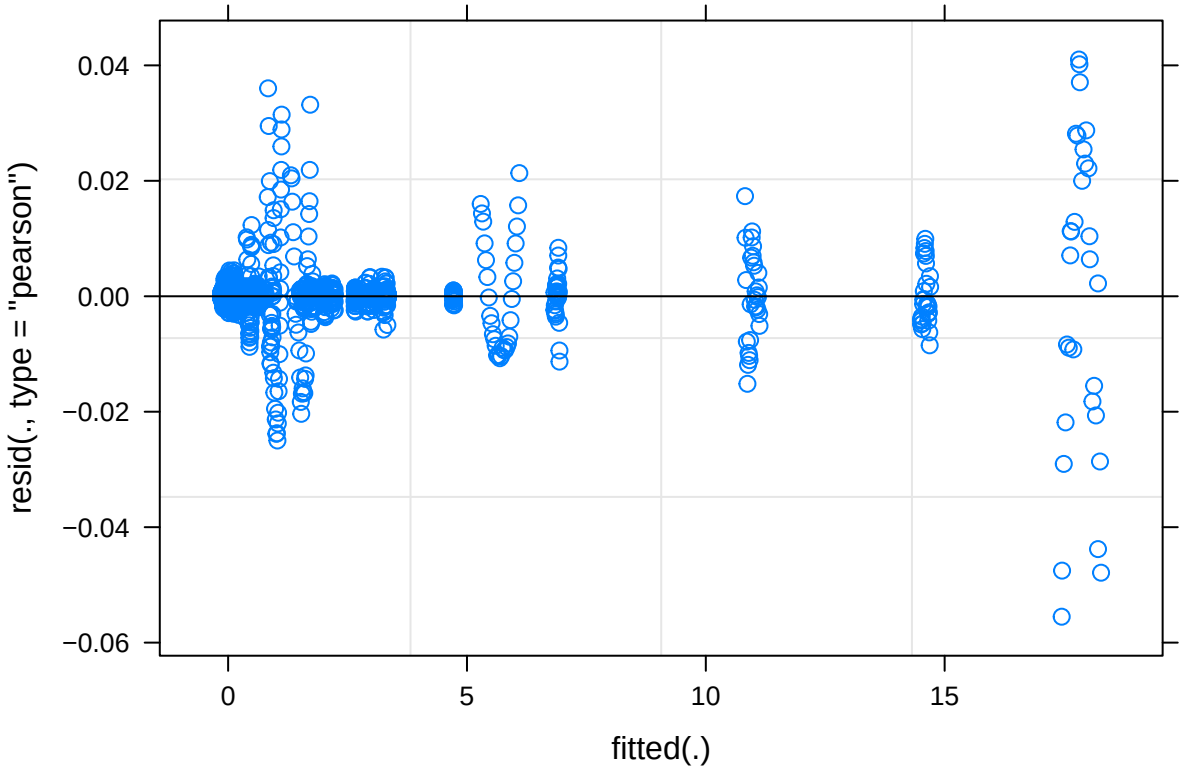
```
## Djibouti                                  1.07634520
## Dominica                                  0.84032654
## Dominican Republic                        0.16840319
## Ecuador                                   0.58872479
## Egypt                                     3.24632922
## El Salvador                               1.70961955
## Equatorial Guinea                         1.09761054
## Eritrea                                   1.04937585
## Estonia                                   0.42212038
## Eswatini                                  1.08617092
## Ethiopia                                  2.64375330
## Falkland Islands (Malvinas)               1.02736352
## Faroe Islands                             0.24899912
## Fiji                                      1.18590109
## Finland                                   0.19786419
## France                                    0.15605375
## French Guiana                             1.00848055
## French Polynesia                          1.07162569
## Gabon                                     1.15571924
## Gambia                                    1.07124498
## Georgia                                   0.67373963
## Germany                                   0.18440459
## Ghana                                     1.29945732
## Gibraltar                                 0.78796800
## Greece                                    0.43913838
## Greenland                                 0.24415081
## Grenada                                   1.07632010
## Guadeloupe                                1.05611572
## Guam                                      1.32243925
## Guatemala                                 4.06381136
## Guernsey                                  0.53471307
## Guinea                                    1.06963452
## Guinea-Bissau                             1.03690997
## Guyana                                    1.70588401
## Haiti                                     1.60996904
## Holy See                                  1.06424682
## Honduras                                  3.41804086
## Hungary                                   0.55686431
## Iceland                                   0.05941436
## India                                     2.01503045
## Indonesia                                 2.70006875
## Iran (Islamic Republic of)                1.00695251
## Iraq                                      1.48201404
## Ireland                                   0.14160268
## Isle of Man                               0.73915848
## Israel                                    0.53186480
## Italy                                     0.35108437
## Jamaica                                   3.40798884
## Japan                                     1.16564393
## Jersey                                    0.33820123
## Jordan                                    0.30449645
## Kazakhstan                                1.13578459
## Kenya                                     1.88252842
## Kiribati                                  1.07021352
```

```
## Kosovo[1]                                                    1.06088070
## Kuwait                                                       1.00995155
## Kyrgyzstan                                                   1.44209817
## Lao People's Democratic Republic                             0.12549035
## Latvia                                                       1.07427231
## Lebanon                                                      0.42026377
## Lesotho                                                      1.07690938
## Liberia                                                      1.07010324
## Libya                                                        1.51430638
## Liechtenstein                                                0.48823796
## Lithuania                                                    0.73802428
## Luxembourg                                                   0.26482538
## Madagascar                                                   1.06349791
## Malawi                                                       1.08779171
## Malaysia                                                     0.61529917
## Maldives                                                     0.30069018
## Mali                                                         1.18010213
## Malta                                                        0.70624703
## Marshall Islands                                             1.06994660
## Martinique                                                   1.13587067
## Mauritania                                                   0.86135375
## Mauritius                                                    2.05651364
## Mayotte                                                      1.04472796
## Mexico                                                       3.52426656
## Micronesia (Federated States of)                             1.07021352
## Monaco                                                       0.98920024
## Mongolia                                                     0.69007843
## Montenegro                                                   0.65890457
## Montserrat                                                   1.06582512
## Morocco                                                      2.16680613
## Mozambique                                                   1.09135334
## Myanmar                                                      1.23580436
## Namibia                                                      1.16210960
## Nauru                                                        1.07021352
## Nepal                                                        1.07167878
## Netherlands                                                  0.07553936
## New Caledonia                                                1.12435441
## New Zealand                                                  0.14539346
## Nicaragua                                                    0.94325148
## Niger                                                        1.26596458
## Nigeria                                                      1.85484991
## Niue                                                         1.07021352
## North Macedonia                                              1.53788833
## Northern Mariana Islands (Commonwealth of the)               1.05742364
## Norway                                                       0.10890699
## occupied Palestinian territory, including east Jerusalem     1.36668126
## Oman                                                         1.08141857
## Other                                                        1.06035899
## Pakistan                                                     1.34108167
## Palau                                                        1.06989285
## Panama                                                       0.70380678
## Papua New Guinea                                             1.06574885
## Paraguay                                                     1.83100066
## Peru                                                         1.52975111
```

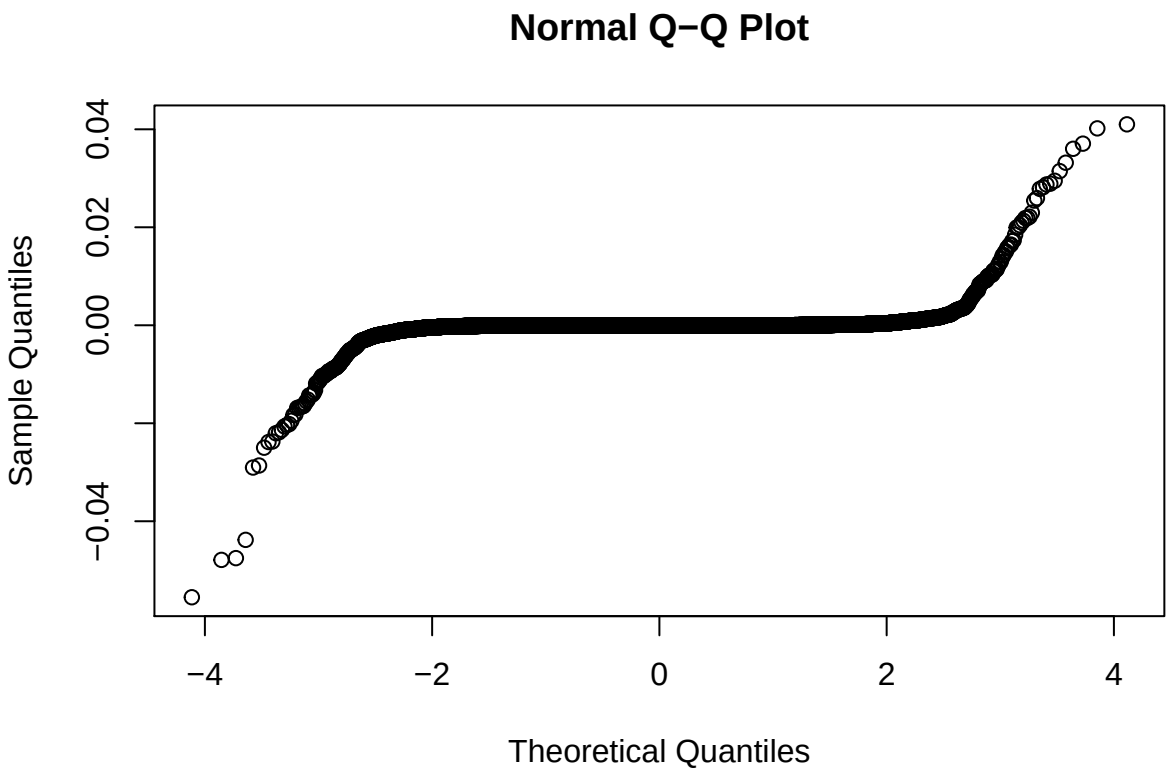
```
## Philippines                                    3.98310534
## Pitcairn Islands                               1.07021352
## Poland                                         0.40791816
## Portugal                                       0.22681011
## Puerto Rico                                    0.86076499
## Qatar                                          0.24913656
## RÃ©union                                       0.31761222
## Republic of Korea                              0.36991608
## Republic of Moldova                            2.21374779
## Romania                                        3.13410374
## Russian Federation                             1.61391940
## Rwanda                                         1.18603792
## Saba                                           1.06951852
## Saint BarthÃ©lemy                             1.07030908
## Saint Helena                                   1.07021352
## Saint Kitts and Nevis                          1.08011705
## Saint Lucia                                    1.25232435
## Saint Martin                                   1.06646169
## Saint Pierre and Miquelon                      1.06054371
## Saint Vincent and the Grenadines               1.14112186
## Samoa                                          1.07019638
## San Marino                                     1.02872589
## Sao Tome and Principe                          1.06885786
## Saudi Arabia                                   1.41887304
## Senegal                                        1.08040621
## Serbia                                         0.70184744
## Seychelles                                     0.85246800
## Sierra Leone                                   1.06756389
## Singapore                                      0.24779071
## Sint Eustatius                                 1.06594339
## Sint Maarten                                   1.07369213
## Slovakia                                       0.25773960
## Slovenia                                       0.22138317
## Solomon Islands                                1.06429658
## Somalia                                        2.50702165
## South Africa                                   4.59444729
## South Sudan                                    0.98689790
## Spain                                          0.24456657
## Sri Lanka                                      1.29489265
## Sudan                                          1.92022710
## Suriname                                       2.04250176
## Sweden                                         0.26863909
## Switzerland                                    0.09167226
## Syrian Arab Republic                           2.21027544
## Tajikistan                                     0.92005931
## Thailand                                       0.45424732
## The United Kingdom                             0.22902102
## Timor-Leste                                    1.07446142
## Togo                                           1.07069506
## Tokelau                                        1.07021352
## Tonga                                          1.07021111
## Trinidad and Tobago                            1.35871537
## Tunisia                                        2.03355269
## Turkey                                         0.44340103
```

```
## Turkmenistan                                  1.07021352
## Turks and Caicos Islands                      1.05138594
## Tuvalu                                        1.07021352
## Uganda                                        1.43725403
## Ukraine                                       1.59164196
## United Arab Emirates                          0.78998137
## United Republic of Tanzania                   1.05880224
## United States of America                      0.80321878
## United States Virgin Islands                  1.07225792
## Uruguay                                       0.38394878
## Uzbekistan                                    0.52961319
## Vanuatu                                       1.07005458
## Venezuela (Bolivarian Republic of)            0.67261546
## Viet Nam                                      0.46670714
## Wallis and Futuna                             1.07022441
## Yemen                                         1.53920472
## Zambia                                        1.06175375
## Zimbabwe                                      1.30510587
```

```
plot(covid_mixed)
```




```
qqnorm(residuals(covid_mixed))
```



From the residual plot and the QQ plot, we can see that the residual is not normally distributed and has a nonconstant variance. The shape of our QQ plot also suggests our data is over-dispersed. Thus making the output of our lme model unreliable.

Known biases

Due to over-dispersion, the estimated coefficients are likely to be heavily biased, but the conclusion should still hold since the source of the problem originated from the fact that the data from different countries are vastly different from one to another.

```
sessionInfo()
```

```
## R version 4.0.4 (2021-02-15)
## Platform: x86_64-w64-mingw32/x64 (64-bit)
## Running under: Windows 10 x64 (build 22000)
##
## Matrix products: default
##
## locale:
## [1] LC_COLLATE=English_United States.1252
## [2] LC_CTYPE=English_United States.1252
## [3] LC_MONETARY=English_United States.1252
## [4] LC_NUMERIC=C
## [5] LC_TIME=English_United States.1252
## system code page: 932
##
```

```
## attached base packages:
## [1] stats     graphics  grDevices utils     datasets  methods   base
##
## other attached packages:
##  [1] sjstats_0.18.1  lme4_1.1-26     Matrix_1.3-2    forcats_0.5.1
##  [5] stringr_1.4.0   dplyr_1.0.4     purrr_0.3.4     readr_1.4.0
##  [9] tidyr_1.1.2     tibble_3.0.6    ggplot2_3.3.3   tidyverse_1.3.0
##
## loaded via a namespace (and not attached):
##  [1] httr_1.4.2        jsonlite_1.7.2    splines_4.0.4     modelr_0.1.8
##  [5] datawizard_0.2.1  assertthat_0.2.1  statmod_1.4.35    highr_0.8
##  [9] cellranger_1.1.0  yaml_2.2.1        bayestestR_0.11.5 pillar_1.4.7
## [13] backports_1.2.1   lattice_0.20-41   glue_1.4.2        digest_0.6.27
## [17] rvest_0.3.6       minqa_1.2.4       colorspace_2.0-0  htmltools_0.5.1.1
## [21] pkgconfig_2.0.3   broom_0.7.4       haven_2.3.1       xtable_1.8-4
## [25] mvtnorm_1.1-3     scales_1.1.1      emmeans_1.7.0     mgcv_1.8-34
## [29] generics_0.1.0    farver_2.0.3      sjlabelled_1.1.8  ellipsis_0.3.1
## [33] withr_2.4.1       cli_2.3.0         magrittr_2.0.1    crayon_1.4.1
## [37] effectsize_0.5    readxl_1.3.1      estimability_1.3  evaluate_0.14
## [41] fs_1.5.0          nlme_3.1-152      MASS_7.3-53       xml2_1.3.2
## [45] tools_4.0.4       hms_1.0.0         lifecycle_1.0.0   munsell_0.5.0
## [49] reprex_1.0.0      compiler_4.0.4    rlang_0.4.10      grid_4.0.4
## [53] nloptr_1.2.2.2    parameters_0.15.0 rstudioapi_0.13   labeling_0.4.2
## [57] rmarkdown_2.6     boot_1.3-26       gtable_0.3.0      DBI_1.1.1
## [61] sjmisc_2.8.7      R6_2.5.0          lubridate_1.7.9.2 performance_0.8.0
## [65] knitr_1.31        insight_0.14.5    stringi_1.5.3     Rcpp_1.0.6
## [69] vctrs_0.3.6       dbplyr_2.1.0      tidyselect_1.1.0  xfun_0.28
```