Public Health Policies and Economic Recovery: A Global Analysis of COVID-19

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Abstract:

This study examines the effects of public health interventions during the COVID-19 pandemic on economic activities worldwide between 2019 and 2024. By working with longitudinal data from the World Health Organization, the World Bank, and Our World in Data, we examine the relationships between vaccination and testing rates, workplace-closure policies, and changes in economic indicators such as GDP growth and CPI. After performing data cleaning, standardization, and variable construction, multiple regression models and log-transformed sensitivity analyses were implemented.

Results indicate that the high vaccination levels correlate with a quicker recovery in GDP, implying that the large-scale usage of vaccines reopened and stabilized the economic market early. On the other hand, countries with fewer workplace closures experienced lower CPI growth. Here, policies that limit the movement and operation of businesses served to reduce inflationary pressure. Comparisons within individual regions indicate that the economy's responses varied significantly. For example, predictors had stronger impacts in African nations, but Asian economies appeared to be more stable. The strength of these findings is verified by using log-transformed models.

Ultimately, the research supports the conclusion that policy-making in the public health field affects economic resilience through the pandemic and offers conceptual insight that can promote better policy-making in future global emergencies.

Background:

The COVID-19 pandemic began in late 2019 and turned into one of the largest health crises in world history. The World Health Organization (WHO) confirmed a total of more than 700 million cases and more than 7 million deaths throughout the world[1]. To battle the new disease caused by the SARS-CoV-2 virus, governments implemented measures such as lockdowns in public places and vaccination mandates to slow down its spread.

Although these implementations played a role in protecting people's health, they also came with economic consequences. For example, lockdowns paused business operations, disrupted traveling plans, and disrupted supply chains that manage the distribution of goods. Due to these consequences, essential resources such as food and medical equipment experienced shortages and shipping delays, so many hospitals struggled with receiving supplies.

As economic activity decreased, many countries experienced declines in Gross Domestic Product (GDP), which calculates the value of all goods and services in a country. Inflationary pressures

emerged since supply chains were halted and production costs rose. This is calculated by the Consumer Price Index (CPI), which is the average change over time in prices of goods and services paid by consumers. These calculations are important because although governments participated in monetary invention, economic recovery varies from country to country due to resource availability and different policies.

These conditions raised many questions about the relationship between public health interventions and economic outcomes. In this study, we analyze global data from the World Health Organization (WHO), World Bank, and Our World in Data. This study focuses on data from 2019 to 2024 and, by examining patterns in vaccination, testing, and workplace closures, this study aims to investigate how responses to the COVID-19 pandemic influenced economic outcomes on a global scale.

Significance:

When the pandemic began, many countries struggled to protect citizens' health and economic stability simultaneously. Occurrences of lockdowns, workplace closures, and travel restrictions grew exponentially, and as countries attempted to reopen, factors such as vaccination and testing rates were crucial in determining the rate of economic recovery. Studying these relationships is important because it illustrates how government interventions participate in economic resilience, whether by supporting or hindering it.

A notable outcome from the pandemic is the differences in the economic impact across the world. Although wealthy countries could distribute vaccines rapidly to repair their societies, many low-income countries experienced slower growth due to the lack of access to medical resources, which caused more severe economic consequences. This suggests that policies can have different impacts on the world, depending on a country's development level. By investigating the economic impact from a global perspective, this study will highlight how some economies recovered quickly, while others were more vulnerable.

This study will not only illustrate the economic effects of the pandemic, but also promote economic resilience for the future. In future global crises, governments will still have to make the most effective decisions about resources and healthcare infrastructure, so this study can provide guidance that can help them prepare. With this study, governments and other institutions can minimize health and economic damage, illustrating how understanding the economic consequences of the pandemic is important to both interpreting the past and preparing for future global crises.

Data:

This study draws on nine datasets from three major international sources, which are the World Health Organization (WHO), the World Bank, and Our World in Data. We narrowed the datasets to provide a view of the public health response to COVID-19 and its economic conditions in countries from 2019 to 2024. This dataset includes national vaccination rates, COVID-19 testing rates, and workplace closures that can be used to analyze government interventions. Additionally, we included the Human Development Index (HDI), which ranks countries based on overall human development, as another predictor to control for disease severity and differences in development levels that can influence the results[2].

In this study, economic indicators primarily consist of annual measurements of Gross Domestic Product (GDP) and Consumer Price Index (CPI), which serve as response variables for assessing economic recovery and inflation trends. Before the analysis process, the datasets required extensive cleaning due to differences in structure and time scales. Data originally provided in wide formats were converted to long form, and missing columns and rows were removed to focus on consistent and reliable observations. Furthermore, variables such as yearly percent changes in GDP and CPI were calculated to have more data that illustrate economic trends over time.

After yearly averages were calculated, the datasets were combined. The final dataset contains longitudinal data that illustrates how vaccination rates, testing, restrictions, and other factors relate to economic indicators such as GDP and CPI. By assembling the data in this way, this study has a master dataset that provides a reliable foundation for evaluating how public health responses correlate with economic trends.

Goals:

The main purpose of this study is to assess the impact of various public health responses to COVID-19 on economic recovery in the world. This study will investigate how vaccination rates, testing, and policies concerning the closures of workplaces affect GDP growth and inflation. Another objective of this study is to investigate whether these relationships vary among countries with diverse levels of development, public health capacity, and economic vulnerability.

By consolidating several datasets and narrowing the outputs to ones between 2019 and 2024, these datasets can provide a useful guide to future crises in the world. This may explain the ways in which intervention in healthcare may either promote or pose a threat to the economy.

Analysis:

In our analysis, we focus on the role of public health interventions in GDP growth and CPI changes during the pandemic. Following the merging of multiple datasets that incorporated vaccinations, testing, workplace closures, mortality, Human Development Index (HDI), and economic indicators, we used regression models to analyze economic effects.

Vaccination and GDP Recovery

There is a positive, significant relationship between vaccination and GDP growth. Countries that had more people vaccinated did so at a higher rate economically. This trend is an indication that vaccination allows for replenishing the available workforce, the decrease of health-related interference, and early business reopening. Log-transformed models support this relationship and denote that the effect will not change when skewed distributions are taken into consideration.

Closure and Dynamics of CPI in the Workplace

The intensity of workplace closure highlights a negative relationship with CPI growth. Inflation increased at a slower rate in environments where there were more constraints. This could have been due to low consumption and demand. An important result is that vaccination and testing rates directly affect the CPI less when they are considered on a global scale, which means that the increase in inflation was more related to the disruption of supply chains, not national health policies.

Regional Differences

Responses in CPI were significantly different among regions. For example, in most African countries, there are strong relationships between CPI and vaccination, testing, mortality, and workplace-closure indicators, which represent more economically sensitive and unstable inflation trends. On the other hand, there are weak relationships in Asian economies, and the only significant impact on CPI is the testing rates. This implies that the economic resilience and capacity to cope with pandemic shocks are higher.

Log Transformation

We used log-transformed models to correct sexual distortion among variables such as testing rates and COVID-19 mortality. The results of these models are similar to the previous results. The contribution of vaccination to GDP recovery is the most similar, and restrictions in the workplace are the most stable predictor of inflation. This section highlights how public health interventions affected global economies through different mechanisms. Vaccinations stimulated

recovery in GDP because of the ability to reopen the economy, and workplace restrictions mediated inflation because of limiting economic activity. Furthermore, regional differences illustrate how economic resilience is not determined by the nature of health policies alone, but also by pre-existing conditions.

Results and Interpretation:

Our initial models investigated testing rates, vaccination rates, and workplace closures as our variables of interest, along with COVID-19 death rates to control for COVID-19 severity. We built two models with these predictors – one for GDP and one for CPI.

GDP Model

```
> model_gdp <- lm(GDP_growth ~ annual_vaccinations_per_million +
+                   annual_tests_per_thousand +
+                 .... [TRUNCATED]

> coeftest(model_gdp, vcov = vcovHC(model_gdp, type = "HC1"))

t test of coefficients:

                                Estimate  Std. Error t value  Pr(>|t|)
(Intercept)                   3.4002e+00  1.3079e+00  2.5997  0.009919 **
annual_vaccinations_per_million  7.2794e-06  1.2181e-06  5.9760 8.374e-09 ***
annual_tests_per_thousand      -1.7370e-04  2.1360e-04 -0.8132  0.416930
avg_workplace_closure           6.5074e-01  1.1886e+00  0.5475  0.584554
covid_deaths_per_million       -4.6758e-04  9.9689e-04 -0.4690  0.639475
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

CPI Model

```
> model_cpi <- lm(CPI_growth ~ annual_vaccinations_per_million +
+                   annual_tests_per_thousand +
+                 .... [TRUNCATED]

> coeftest(model_cpi, vcov = vcovHC(model_cpi, type = "HC1"))

t test of coefficients:

                                Estimate  Std. Error t value Pr(>|t|)
(Intercept)                   2.8854e+02  1.2453e+02  2.3171  0.02139 *
annual_vaccinations_per_million -1.9665e-04  1.4164e-04 -1.3884  0.16637
annual_tests_per_thousand      2.0422e-02  2.3035e-02  0.8866  0.37625
avg_workplace_closure         -1.3176e+02  6.4047e+01 -2.0572  0.04081 *
covid_deaths_per_million       1.7115e-02  6.5582e-02  0.2610  0.79435
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Our GDP model indicated that vaccination rates were the only statistically significant predictor, with a positive association of 7.28% increase in GDP growth for every additional vaccine per person. All other predictors were non-significant, including our control variable. Also, our CPI

model only had a single significant relationship: workplace closure was weakly negatively associated with CPI growth. Once again, all other predictors showed no significance.

Selected countries in Africa (2020-2022)

```
t test of coefficients:

                                Estimate  Std. Error  t value  Pr(>|t|)
(Intercept)                   8.1855e+01  1.2165e+01   6.7285 0.0067022 **
annual_vaccinations_per_million -1.2438e-04  1.5953e-05  -7.7967 0.0043913 **
annual_tests_per_thousand      1.6792e+00  5.2708e-02  31.8578 6.797e-05 ***
avg_workplace_closure         -3.9470e+01  5.1554e+00  -7.6560 0.0046282 **
covid_deaths_per_million      -6.6643e-01  3.1700e-02 -21.0227 0.0002354 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Selected countries in Asia (2020-2022)

```
t test of coefficients:

                                Estimate  Std. Error t value Pr(>|t|)
(Intercept)                   4.3146e+01  1.1798e+02  0.3657  0.72954
annual_vaccinations_per_million -2.6326e-04  1.7307e-04 -1.5211  0.18871
annual_tests_per_thousand      3.2505e-02  1.1827e-02  2.7484  0.04039 *
avg_workplace_closure         -1.0808e+01  4.3358e+01 -0.2493  0.81306
covid_deaths_per_million       6.6790e-01  4.5481e-01  1.4685  0.20189
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Since geographic regions can be a potential confounder, we also isolated individual continents to see whether there might be geographic differences. In Africa, we found that increased testing was positively associated with CPI growth, while all other predictors had a negative association. In Asia, increased testing had a positive association with CPI, but other variables were not significant, indicating that Asia has a more resilient economy.

Overall, our global analysis results were unexpected, with most variables being statistically insignificant. We decided to adjust our models to see if we could find a better fit for this data. The first thing we added was an additional control, which is the Human Development Index (HDI), for each country. This helps control economic and structural differences between countries. We also log-transformed all three predictors of interest to account for the significant right skew of the data.

Log Transformation with HDI (GDP)

```
Coefficients:
                                    Estimate Std. Error t value Pr(>|t|)
(Intercept)                          -9.3667     6.3155  -1.483   0.1394
avg_workplace_closure                 2.1217     1.0367   2.047   0.0418 *
log(annual_vaccinations_per_million + 1)   1.8058     0.2820   6.404 8.23e-10 ***
log(annual_tests_per_thousand + 1)    1.7610     0.7141   2.466   0.0144 *
log(covid_deaths_per_million + 1)    -0.3225     0.4975  -0.648   0.5175
human_development_index             -18.5174     8.9491  -2.069   0.0396 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 10.33 on 234 degrees of freedom
  (14301 observations deleted due to missingness)
Multiple R-squared:  0.2456,    Adjusted R-squared:  0.2294
F-statistic: 15.23 on 5 and 234 DF,  p-value: 5.88e-13

> vif(model_1D_log)
                  avg_workplace_closure log(annual_vaccinations_per_million + 1)
                               1.174715                                1.142995
      log(annual_tests_per_thousand + 1)       log(covid_deaths_per_million + 1)
                               2.988104                                1.635674
                 human_development_index
                               3.195857
```

Log Transformation with HDI (CPI)

```
(Intercept)                          41.354    559.637   0.074   0.9412
avg_workplace_closure              -158.443     90.958  -1.742   0.0829 .
log(annual_vaccinations_per_million + 1)    1.716     25.288   0.068   0.9460
log(annual_tests_per_thousand + 1)   -51.301     63.450  -0.809   0.4196
log(covid_deaths_per_million + 1)     -4.059     43.724  -0.093   0.9261
human_development_index              583.603    793.535   0.735   0.4628
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 899.4 on 227 degrees of freedom
  (14308 observations deleted due to missingness)
Multiple R-squared:  0.0234,    Adjusted R-squared:  0.001886
F-statistic: 1.088 on 5 and 227 DF,  p-value: 0.368

> vif(model_1D_CPI_log)
                  avg_workplace_closure log(annual_vaccinations_per_million + 1)
                               1.160946                                1.143667
      log(annual_tests_per_thousand + 1)       log(covid_deaths_per_million + 1)
                               3.037804                                1.619952
                 human_development_index
                               3.203018
```

Our log-transformed GDP model revealed statistically significant results for all three predictors, with all of them being positively associated with GDP growth. The model had a correlation of 0.24. This low R^2 is unsurprising, as GDP is an incredibly complex and multi-faceted measurement with a multitude of other non-COVID-19-related inputs. Additionally, the variables had low to moderate VIF, indicating that multicollinearity was likely not a major issue.

The log-transformed CPI model indicated no statistical significance for any of the predictors, and a near-zero R^2.

Random Effects Model (GDP)

```
Formula: GDP_growth ~ annual_vaccinations_per_million + annual_tests_per_thousand +
    avg_workplace_closure + covid_deaths_per_million + (1 | Country)
   Data: df

REML criterion at convergence: 1879.2

Scaled residuals:
    Min      1Q  Median      3Q     Max
-2.6848 -0.4649 -0.0986  0.3971  6.1454

Random effects:
 Groups   Name        Variance Std.Dev.
 Country  (Intercept) 26.54    5.152
 Residual             96.49    9.823
Number of obs: 241, groups:  Country, 110

Fixed effects:
                               Estimate Std. Error t value
(Intercept)                   3.105e+00  1.438e+00   2.159
annual_vaccinations_per_million  8.325e-06  1.267e-06   6.571
annual_tests_per_thousand       -2.041e-04  3.890e-04  -0.525
avg_workplace_closure            5.337e-01  1.089e+00   0.490
covid_deaths_per_million        -4.381e-04  1.202e-03  -0.364
```

Random Effects Model (CPI)

```
Formula: CPI_growth ~ annual_vaccinations_per_million + annual_tests_per_thousand +
    avg_workplace_closure + covid_deaths_per_million + (1 | Country)
   Data: df

REML criterion at convergence: 3826.1

Scaled residuals:
     Min       1Q   Median       3Q      Max
-11.1704  -0.1224   0.0171   0.1950   3.0388

Random effects:
 Groups   Name        Variance Std.Dev.
 Country  (Intercept)      0     0.0
 Residual             796224   892.3
Number of obs: 233, groups:  Country, 106

Fixed effects:
                               Estimate Std. Error t value
(Intercept)                   2.885e+02  1.204e+02   2.397
annual_vaccinations_per_million -1.966e-04  1.075e-04  -1.829
annual_tests_per_thousand        2.042e-02  2.926e-02   0.698
avg_workplace_closure           -1.318e+02  9.187e+01  -1.434
covid_deaths_per_million         1.711e-02  9.429e-02   0.182
```

One final model we investigated incorporates random effects in our linear model. In our GDP model, accounting for random effects is important because the country-level random intercept variance is 26.54, while the residual variance is 96.49, so there is a large variation in their baseline and GDP growth. In this model, vaccination has a positive effect (8.3% growth in GDP, for each additional vaccine per person), which matches our original model's results. Other variables are insignificant.

In our CPI model, after accounting for random effects, we also found no statistically significant variables, matching our prior models and prior research on the topic.

Conclusion:

The most consistent finding in our analysis was that vaccination rates have a strong, positive correlation with GDP growth and economic recovery from COVID-19. All models showed this relationship with extremely low p-values. Other variables were either not significant or weakly positively correlated with GDP growth.

CPI had no statistically significant predictors in most models. Although this is unexpected and different from our pre-analysis predictions, after further research on the topic, past studies have similar conclusions. CPI is seemingly unrelated to country-specific COVID-19 protocols. The general consensus among researchers is that CPI changes are mostly due to global supply chain shortages and changing consumer demand[3]. Therefore, country-specific COVID-19 policies may have a negligible impact in most cases.

Ultimately, we found that some public health policies, particularly vaccination rates, affected GDP, but they had little to no effect on inflation.

Discussion and Future Directions:

We encountered some limitations and difficulties when analyzing this data. As is common in global data sets, we had some missing data, which may have led to bias toward countries with more complete data. Regional patterns and differences that exist may also be hidden when looking at the global model. For instance, the differences between Africa and Asia mentioned previously would not be visible in our global model. Using more region-specific models or incorporating more control variables to help compare similar countries could help with this.

To further investigate the cause of the post-COVID-19 inflationary period, we could study global indicators like shipping costs and oil prices that might better explain inflationary dynamics[4]. Many other potentially relevant variables, including fiscal stimuli, supply-chain exposure, and health system capacity, could give us more explanatory power. Further study of these factors will be crucial to better understand how governments can balance public health interventions with economic stability during potential future crises.

Contributions:

Alex’s task for this report was to formally write the results and interpretation, conclusion, discussion, and future directions. He also performed the log transformations mentioned in the results and supplementary material section with the following results.

Thoai's task for this report was to formally write the background, significance, and data information. He also performed the test of coefficients and random effect models mentioned in the results section and calculated the correlation matrix presented in the supplementary material section.

Wencheng's task for this report was to formally write the abstract, goals, and analysis of our statistical models. He also read the regression models to ensure that the goals of this study are met.

References:

1.
https://www.who.int/news-room/fact-sheets/detail/coronavirus-disease-(covid-19)

2.
https://hdr.undp.org/data-center/human-development-index#/indicies/HDI

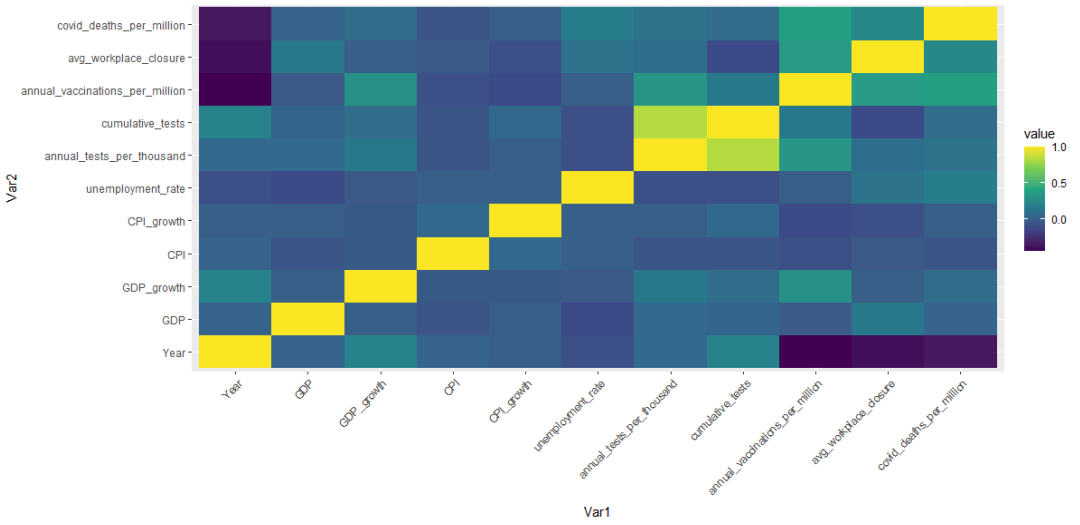
3.
https://www.imf.org/en/publications/wp/issues/2023/01/20/understanding-post-covid-inflation-dynamics-528404

4.
https://www.bls.gov/opub/mlr/2023/beyond-bls/shipping-prices-import-price-inflation-and-the-covid-19-pandemic.htm

Supplementary Material (Results):

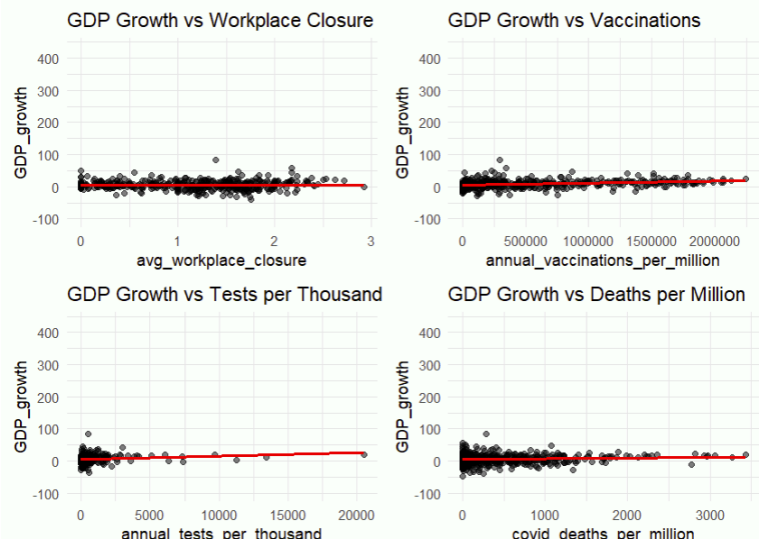
	Year	GDP	GDP_growth	CPI	CPI_growth	unemployment_rate	annual_tests_per_thousand
Year	1.000000000	0.03631880	0.21342013	0.041311101	-0.0015456943	-0.0670821183	0.075975087
GDP	0.036318797	1.00000000	-0.00186046	-0.045969556	0.0116749147	-0.0992633709	0.069969464
GDP_growth	0.213420132	-0.00186046	1.00000000	-0.012837005	-0.0119403142	-0.0192679352	0.150331301
CPI	0.041311101	-0.04596956	-0.01283700	1.000000000	0.0738179742	0.0011975191	-0.057521894
CPI_growth	-0.001545694	0.01167491	-0.01194031	0.073817974	1.0000000000	-0.0041797620	0.002751869
unemployment_rate	-0.067082118	-0.09926337	-0.01926794	0.001197519	-0.0041797620	1.0000000000	-0.064165251
annual_tests_per_thousand	0.075975087	0.06996946	0.15033130	-0.057521894	0.0027518690	-0.0641652509	1.000000000
cumulative_tests	0.204510684	0.05092810	0.08169730	-0.044744083	0.0693004673	-0.0789544826	0.839055723
annual_vaccinations_per_million	-0.435855226	-0.01567177	0.30454183	-0.086378711	-0.0940626105	0.0002790615	0.318046042
avg_workplace_closure	-0.394608223	0.15844744	0.01316163	-0.030036783	-0.0760584053	0.1209284685	0.103618862
covid_deaths_per_million	-0.348319514	0.03725083	0.08772411	-0.037226205	0.0003679303	0.1678668559	0.119170983

	cumulative_tests	annual_vaccinations_per_million	avg_workplace_closure	covid_deaths_per_million
Year	0.20451068	-0.4358552255	-0.39460822	-0.3483195140
GDP	0.05092810	-0.0156717732	0.15844744	0.0372508274
GDP_growth	0.08169730	0.3045418324	0.01316163	0.0877241053
CPI	-0.04474408	-0.0863787112	-0.03003678	-0.0372262051
CPI_growth	0.06930047	-0.0940626105	-0.07605841	0.0003679303
unemployment_rate	-0.07895448	0.0002790615	0.12092847	0.1678668559
annual_tests_per_thousand	0.83905572	0.3180460422	0.10361886	0.1191709831
cumulative_tests	1.00000000	0.1613136230	-0.09226935	0.0807064350
annual_vaccinations_per_million	0.16131362	1.0000000000	0.35254357	0.3847595520
avg_workplace_closure	-0.09226935	0.3525435652	1.00000000	0.2460221683
covid_deaths_per_million	0.08070644	0.3847595520	0.24602217	1.0000000000

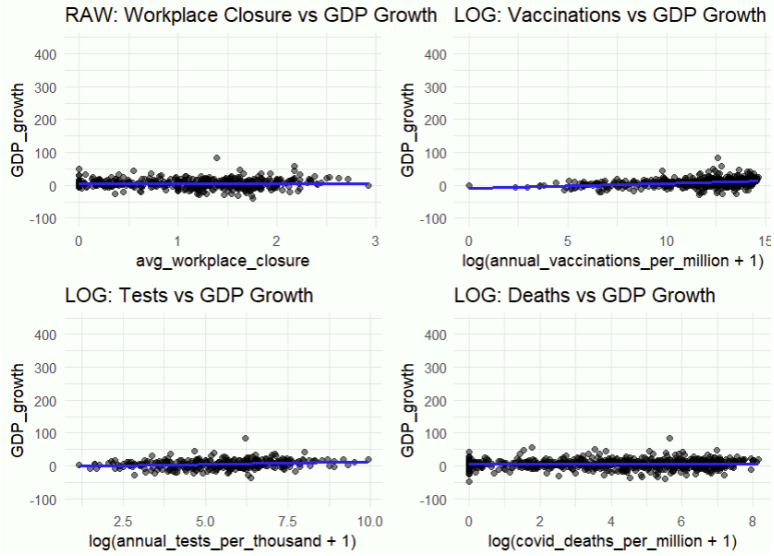


This is a correlation matrix with its corresponding heatmap, which illustrates how economic indicators (GDP and CPI) and COVID-19 variables relate to one another. The correlation between GDP growth and vaccinations is 0.305, which is most likely because vaccinations enabled economic opening; therefore, they have a positive relationship. Additionally, the correlation between vaccinations and workplace closures is 0.353, suggesting that, given the nature of the pandemic, countries with strict closures tend to vaccinate more.

Graphs of GDP growth before log transformation:



Graphs of GDP growth after log transformation:



Supplementary Material (Code):

```
# Correlation Matrix
cor_matrix <- df %>%
  select_if(is.numeric) %>%
  cor(use = "pairwise.complete.obs")
print(cor_matrix)


# Regression Model: GDP
model_gdp <- lm(GDP_growth ~ annual_vaccinations_per_million +
                annual_tests_per_thousand +
                avg_workplace_closure +
                covid_deaths_per_million,
              data = df)
coeftest(model_gdp, vcov = vcovHC(model_gdp, type = "HC1"))

# Regression Model: CPI
model_cpi <- lm(CPI_growth ~ annual_vaccinations_per_million +
                annual_tests_per_thousand +
                avg_workplace_closure +
                covid_deaths_per_million,
              data = df)
coeftest(model_cpi, vcov = vcovHC(model_cpi, type = "HC1"))

# Regression Model: CPI (Africa)
selected_countries <- c("Zimbabwe", "Angola", "Botswana", "Ethiopia", "Guinea", "Kenya")
df_selected <- df %>%
  filter(
    Country %in% selected_countries,
    Year >= 2020 & Year <= 2022
  )
model_cpi_countries <- lm(
  CPI_growth ~ annual_vaccinations_per_million +
    annual_tests_per_thousand +
    avg_workplace_closure +
    covid_deaths_per_million,
  data = df_selected
)
coeftest(model_cpi_countries, vcov = vcovHC(model_cpi_countries, type = "HC1"))
```

```
# Regression Model: CPI (Asia)
selected_countries <- c("China", "India", "Mongolia", "Philippines", "Thailand", "Viet Nam")
df_selected <- df %>%
  filter(
    Country %in% selected_countries,
    Year >= 2020 & Year <= 2022
  )
model_cpi_countries <- lm(
  CPI_growth ~ annual_vaccinations_per_million +
    annual_tests_per_thousand +
    avg_workplace_closure +
    covid_deaths_per_million,
  data = df_selected
)
coeftest(model_cpi_countries, vcov = vcovHC(model_cpi_countries, type = "HC1"))


# Random Effects Model By Country: GDP
gdp_re <- lmer(GDP_growth ~ annual_vaccinations_per_million +
                    annual_tests_per_thousand +
                    avg_workplace_closure +
                    covid_deaths_per_million +
                    (1 | Country),
                  data = df)
summary(gdp_re)

# Random Effects Model By Country: CPI
cpi_re <- lmer(CPI_growth ~ annual_vaccinations_per_million +
                    annual_tests_per_thousand +
                    avg_workplace_closure +
                    covid_deaths_per_million +
                    (1 | Country),
                  data = df)
summary(cpi_re)


# Non-transformed data
p1 <- ggplot(master, aes(x = avg_workplace_closure, y = GDP_growth)) +
  geom_point(alpha = 0.5) +
  geom_smooth(method = "lm", se = FALSE, color = "red") +
```

```
  labs(title = "GDP Growth vs Workplace Closure") +
  theme_minimal()

p2 <- ggplot(master, aes(x = annual_vaccinations_per_million, y = GDP_growth)) +
  geom_point(alpha = 0.5) +
  geom_smooth(method = "lm", se = FALSE, color = "red") +
  labs(title = "GDP Growth vs Vaccinations") +
  theme_minimal()

p3 <- ggplot(master, aes(x = annual_tests_per_thousand, y = GDP_growth)) +
  geom_point(alpha = 0.5) +
  geom_smooth(method = "lm", se = FALSE, color = "red") +
  labs(title = "GDP Growth vs Tests per Thousand") +
  theme_minimal()

p4 <- ggplot(master, aes(x = covid_deaths_per_million, y = GDP_growth)) +
  geom_point(alpha = 0.5) +
  geom_smooth(method = "lm", se = FALSE, color = "red") +
  labs(title = "GDP Growth vs Deaths per Million") +
  theme_minimal()

(p1 | p2) / (p3 | p4)

# Log-transformed data
lp1 <- ggplot(master, aes(x = avg_workplace_closure, y = GDP_growth)) +
  geom_point(alpha = 0.5) +
  geom_smooth(method = "lm", se = FALSE, color = "blue") +
  labs(title = "RAW: Workplace Closure vs GDP Growth") +
  theme_minimal()

lp2 <- ggplot(master, aes(x = log(annual_vaccinations_per_million + 1), y = GDP_growth)) +
  geom_point(alpha = 0.5) +
  geom_smooth(method = "lm", se = FALSE, color = "blue") +
  labs(title = "LOG: Vaccinations vs GDP Growth") +
  theme_minimal()

lp3 <- ggplot(master, aes(x = log(annual_tests_per_thousand + 1), y = GDP_growth)) +
  geom_point(alpha = 0.5) +
  geom_smooth(method = "lm", se = FALSE, color = "blue") +
  labs(title = "LOG: Tests vs GDP Growth") +
```

```
  theme_minimal()

lp4 <- ggplot(master, aes(x = log(covid_deaths_per_million + 1), y = GDP_growth)) +
  geom_point(alpha = 0.5) +
  geom_smooth(method = "lm", se = FALSE, color = "blue") +
  labs(title = "LOG: Deaths vs GDP Growth") +
  theme_minimal()

# Show all 4 models together with log transforms
(lp1 | lp2) / (lp3 | lp4)


# Regression model (GDP) log transformation
model_1D_log <- lm(
  GDP_growth ~
    avg_workplace_closure +
    log(annual_vaccinations_per_million + 1) +
    log(annual_tests_per_thousand + 1) +
    log(covid_deaths_per_million + 1) +
    human_development_index,
  data = master
)
summary(model_1D_log)
vif(model_1D_log)

# Regression model (CPI) log transformation
model_1D_CPI_log <- lm(
  CPI_growth ~
    avg_workplace_closure +
    log(annual_vaccinations_per_million + 1) +
    log(annual_tests_per_thousand + 1) +
    log(covid_deaths_per_million + 1) +
    human_development_index,
  data = master
)

summary(model_1D_CPI_log)
vif(model_1D_CPI_log)
```