Your Paper Title Here

Your Name(s)

Date

Abstract

Write your abstract here.

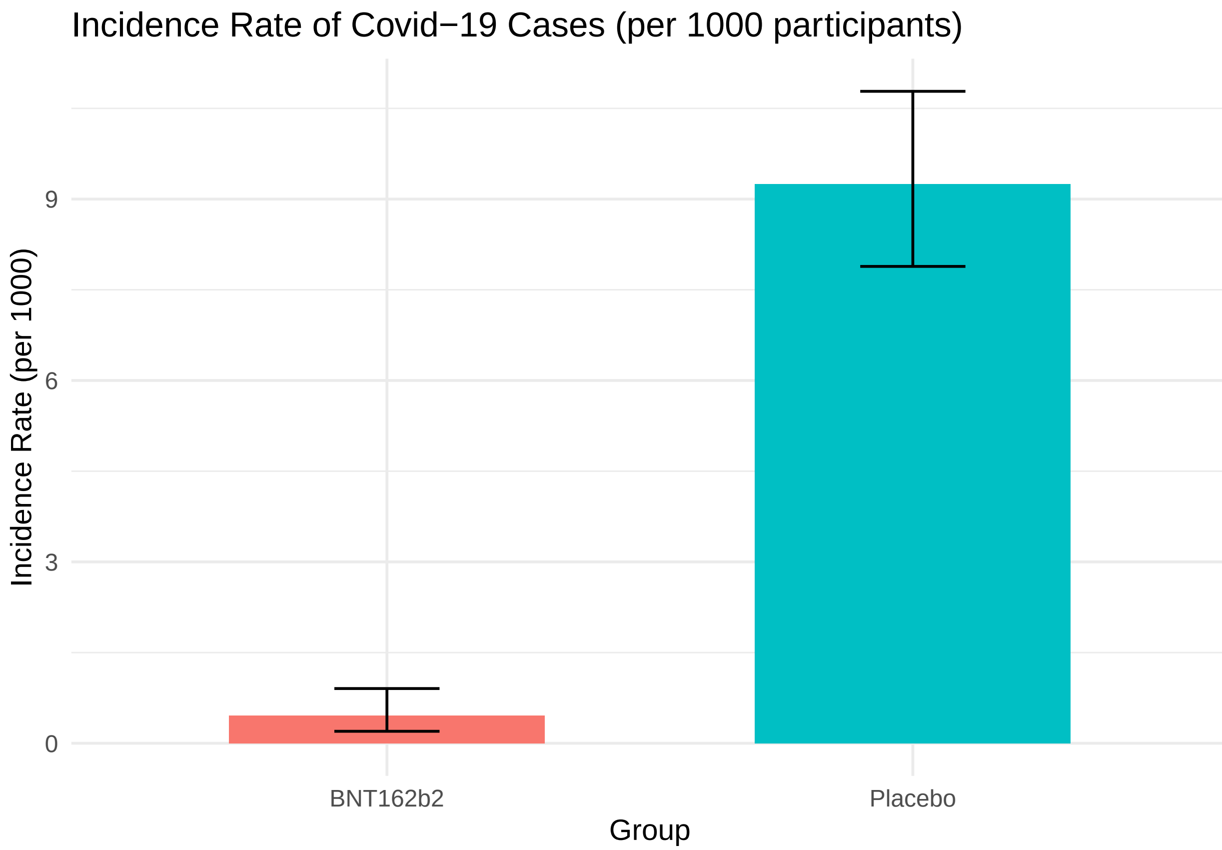
TESTTTING*

Keywords

Keyword 1, *Keyword 2*, *Keyword 3*, *Keyword 4*

Introduction / Background

Provide an introduction with background information.




```
## Estimated Vaccine Efficacy (VE): 95.03 %
```

Statistical Methods

Model

Describe the statistical model used.

Likelihood Inference

Detail the likelihood approach.

#likihood function:

#MLE

#Confidence Interval for Psi

#Large sample confidence interval

#Bootstrap

We will also use a computational approach to find our $\hat{\psi}_{MLE}$ interval by bootstrapping our $\hat{\pi}$. We will randomly draw with replacement many times from a $Binomial(n, \pi_{observed})$ distribution. We will then calculate a value of $\hat{\psi}_i$ for each $\hat{\pi}_i$ from our bootstrap. We will then a construct a 95% confidence interval by calculating the 2.5th and 97.5th percentile of our $\hat{\psi}$s

Bayesian Inference

Detail the Bayesian approach.

Results

Present your findings.

Our bootstrap 95% confidence interval is:

```
##      2.5%     97.5%
## 0.9115646 0.9808917
```

We will use a beta binomial model:

$T_\pi \sim Binom(170, \pi)$ $g(\pi) = Beta(a, b)$

$P(\psi \geq 0.3) = P(\frac{1-2\pi}{1-\pi} \geq 0.3) = P(\pi \leq \frac{7}{17}) = \frac{7}{17}$

for our model we will use the following priors

experimental prior $P(\psi \geq 0.3) \approx 0.57$ $P(\psi \geq 0) = 1$

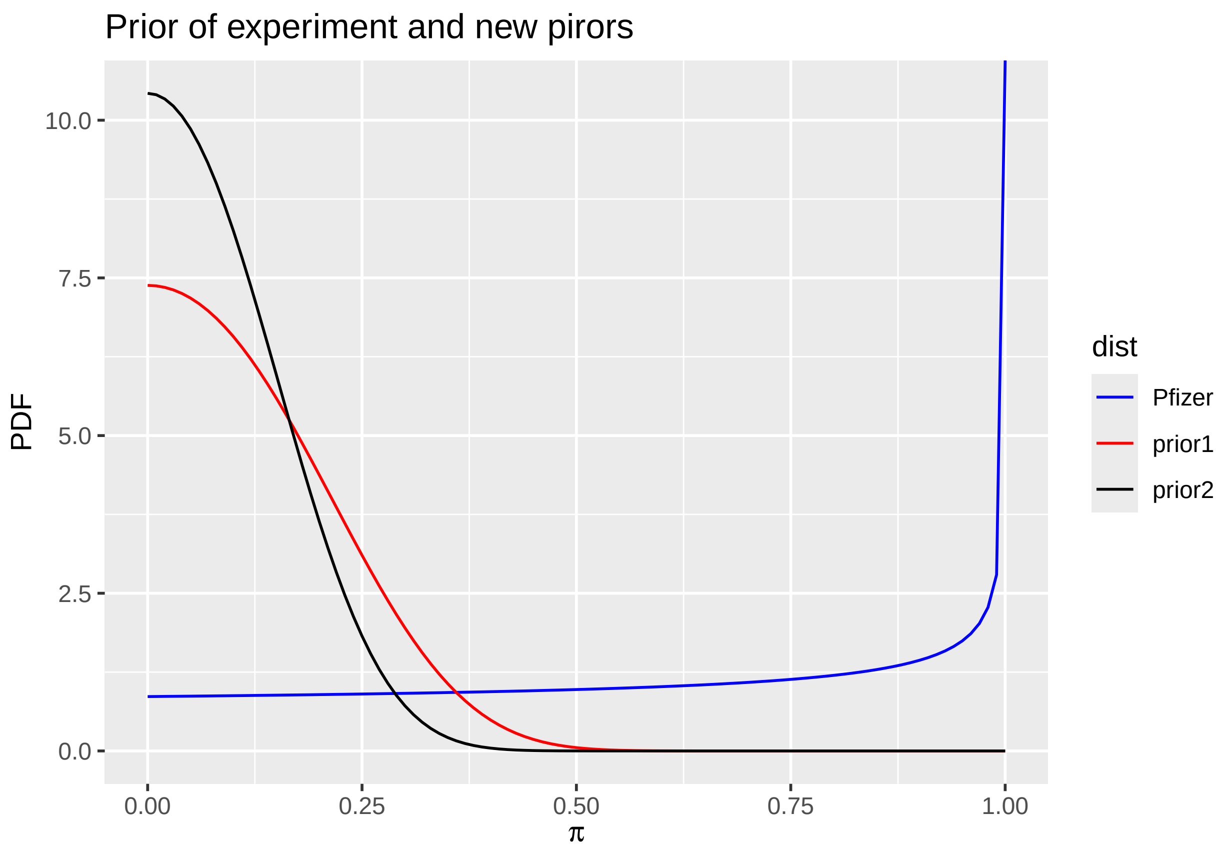
0.05 prior $P(\psi \geq 0.3) = 0.05$ $P(\psi \geq 0) = 0.5$

0.01 prior $P(\psi \geq 0.3) = 0.01$ $P(\psi \geq 0) = 0.5$

The experimental prior is the prior that Pfizer used in their study, which gives the vaccine the best chance of passing the tests. The following two priors have a decreasing chance of passing the tests.

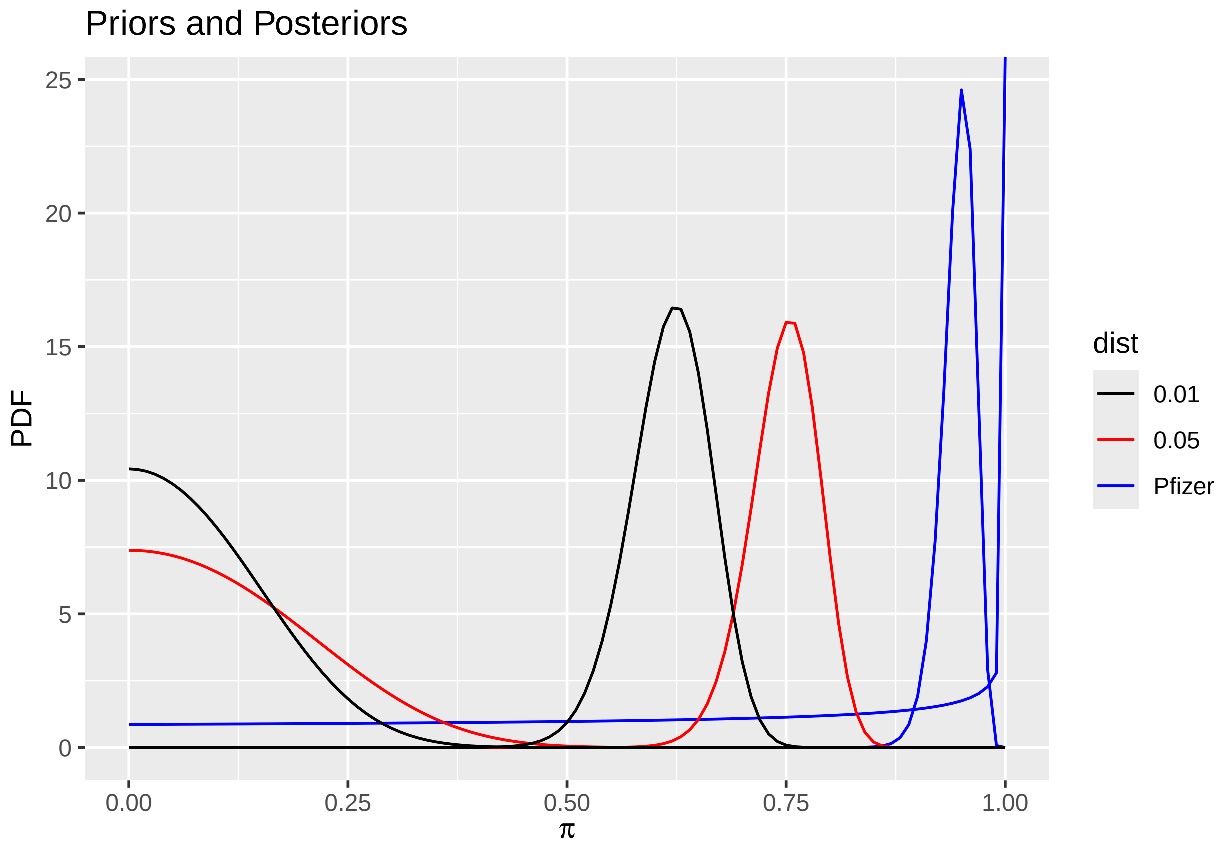
The Pfizer study used $Beta(0.700102, 1)$ as their prior Betas. We will be trying \$Beta(43.03, 43.03)\$ and \$Beta(85.63, 85.63)\$ as our prior Beta values.

We can visualize how much more likely their prior is than ours



So, the posterior distributions are as follows: Pfizer: $h(\pi|t) = Beta($ 8.700102, 163) 0.05 posterior: $h(\pi|t) = Beta($ 51.03, 205.03) 0.01 posterior: $h(\pi|t) = Beta($ 93.63, 247.63)

We can visualize the comparison between all of the priors and posteriors:



summarizing the posterior distribution of π

```
## Pfizer posterior median: 0.0489
```

```
## 95% CI for Pfizer: [ 0.0232 , 0.088 ]
```

```
## 0.05 prior posterior median: 0.1985 0.1985
```

```
## 95% CI for 0.05 prior: [ 0.1528 , 0.2503 ]
```

```
## 0.01 prior posterior median: 0.2739 0.2739
```

```
## 95% CI for 0.01 prior: [ 0.2284 , 0.3228 ]
```

Significance Tests and Posterior Distributions

The Pfizer study used a $\text{Beta}(0.700102, 1)$ prior. In our analysis, we compare this with two alternative prior distributions:

$$\text{Beta}\Big(\text{Prior 1: Beta}\Big(43.03,\ 43.03\Big)\Big) \quad \text{and} \quad \text{Beta}\Big(\text{Prior 2: Beta}\Big(85.63,\ 85.63\Big)\Big).$$

Given the data (with 8 successes and 162 failures), the posterior distributions are as follows:

- **Pfizer Posterior:**

$$h(\pi \mid t) = \text{Beta}\Big(0.700102 + 8,\ 162 + 1\Big)$$

- **0.05 Prior Posterior:**

$$h(\pi \mid t) = \text{Beta}\Big(43.03 + 8,\ 162 + 43.03\Big)$$

- **0.01 Prior Posterior:**

$$h(\pi \mid t) = \text{Beta}\Big(85.63 + 8,\ 162 + 85.63\Big)$$

Below we compute the posterior medians and approximate 95% credible intervals (using the 2.5th and 97.5th percentiles):

- **Pfizer Posterior:**

  Posterior median: ≈ 0.0489

  95% CI: $\Big[0.0232,\ 0.088\Big]$

- **0.05 Prior Posterior:**

  Posterior median: ≈ 0.1985

  95% CI: $\Big[0.1528,\ 0.2503\Big]$

- **0.01 Prior Posterior:**

Posterior median: ≈ 0.2739

95% CI: $\left[0.2284,\ 0.3228\right]$

Hypothesis Tests

We test the hypothesis for vaccine effectiveness:

$$H_0 : \pi \geq 0.5 \quad \text{vs} \quad H_1 : \pi < 0.5.$$

For each posterior distribution, the p-value is computed as the probability of observing $\pi \geq 0.5$ under the posterior, i.e.,

$$p\text{-value} = 1 - F(0.5),$$

where $F(\beta)$ is the cumulative distribution function of the corresponding Beta posterior.

Pfizer Posterior:

$$p\text{-value} \approx 0.$$

0.05 Prior Posterior:

$$p\text{-value} \approx 0.$$

0.01 Prior Posterior:

$$p\text{-value} \approx 0.$$

Discussion / Conclusion

Discuss / conclude here.

Bibliography

Brown, B. (2024). *Lecture Title.* Lecture slides, Course Name, University Name.

Doe, J. (2020). Title of the Paper. *Journal Name*, 12(3), 45-67.

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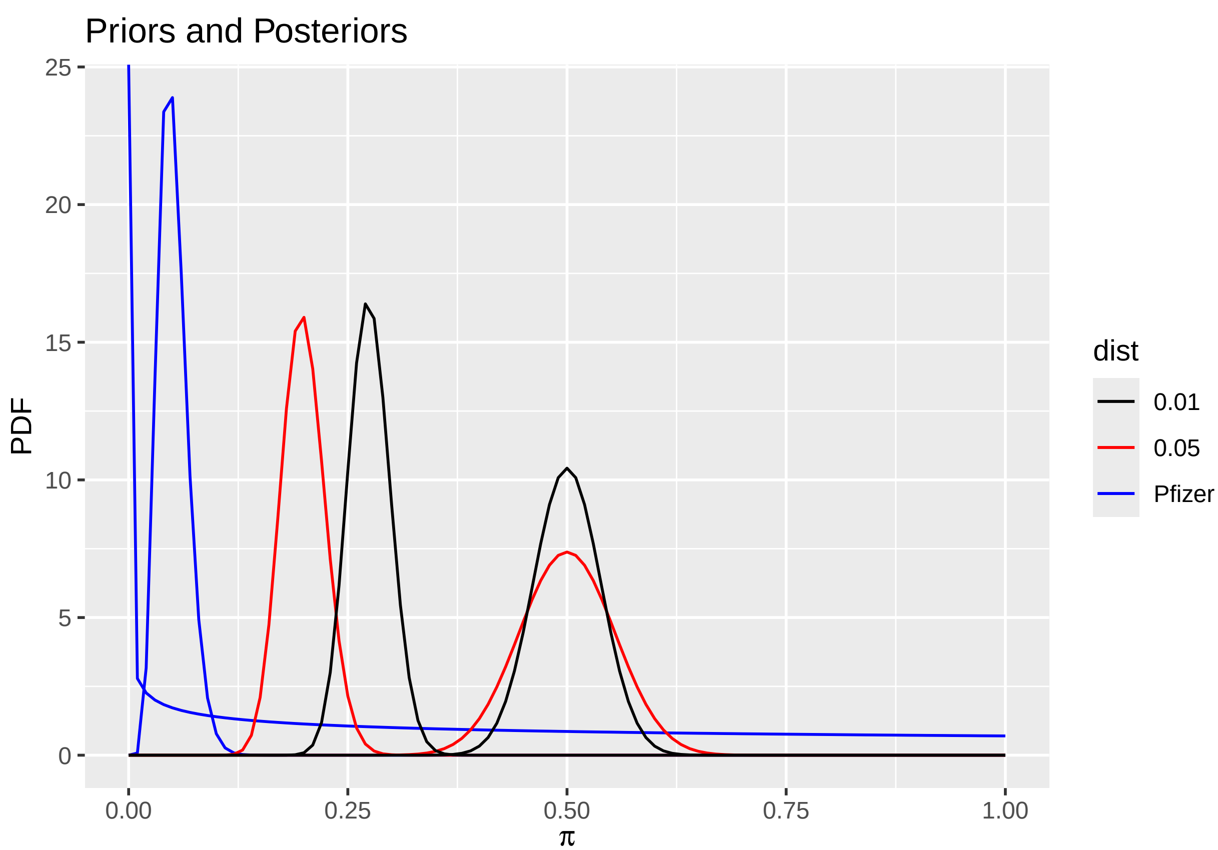
Appendix

Code

Plots



Proofs

If applicable, include detailed mathematical derivations or additional theoretical explanations.

Proof of the Maximum Likelihood Estimator for $\widehat{\psi}_0^{mle}$:

We can begin with the Likelihood function. Recall that the design of our experiment is binomial; we observe 170 infections and try to make inference on π, the proportion of infections from those who have the vaccine. Assuming each observation is independent (which is necessary for a binomial model), we can write our likelihood function in terms of π:

$$L(\pi) = \binom{170}{x}(\pi)^x(1-\pi)^{170-x}$$

Where x is the observed number of infections where the patient had the vaccine. We observe $x = 8$, so we can rewrite our likelihood function:

$$L(\pi; x = 8) = \binom{170}{8}(\pi)^8(1-\pi)^{162}$$

Notably, however, we are not hoping to draw inference on π, but rather on ψ, the efficacy of the vaccine. We can write this parameter in terms of π.

$$\psi = \frac{1-2\pi}{1-\pi}$$

In order to write our Likelihood function in terms of ψ, we can rewrite ψ in terms of π:

$$\pi = \frac{\psi-1}{\psi-2}$$

Now we rewrite our likelihood function.

$$L^*(\psi) = \binom{170}{8}\left(\frac{\psi-1}{\psi-2}\right)^8\left(\frac{-1}{\psi-2}\right)^{162}$$

Now that we have written our full likelihood function in terms of ψ, we can write the log likelihood function.

$$\ell^*(\psi) = \log \binom{170}{8} + 8\log(\psi - 1) - 8\log(\psi - 2) - 162\log(\psi - 2) + 162\log(-1)$$

We have $162\log(-1) = \log((-1)^{162}) = \log(1) = 0$:

$$\ell^*(\psi) = \log \binom{170}{8} + 8\log(\psi - 1) - 170\log(\psi - 2)$$

To maximize this equation, we take its derivative with respect to ψ:

$$\frac{d}{d\psi}\ell^*(\psi) = \frac{8}{\psi - 1} - \frac{170}{\psi - 2}$$

Setting this derivative finds the maximum:

$$0 = \frac{8}{\hat{\psi}_0^{mle} - 1} - \frac{170}{\hat{\psi}_0^{mle} - 2}$$

$$\frac{170}{\hat{\psi}_0^{mle} - 2} = \frac{8}{\hat{\psi}_0^{mle} - 1}$$

$$170\hat{\psi}_0^{mle} - 170 = 8\hat{\psi}_0^{mle} - 16$$

$$\hat{\psi}_0^{mle} = \frac{154}{162}$$