What proportion of people with COVID-19 do not get symptoms?

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Abstract

Over the period Dec 2020 - Feb 2021, the UK government, and its scientific advisers, made the persistent and widely publicised claim that "1 in 3 people with the SARS-Cov-2 virus have no symptoms”. In this paper we use a contemporaneous study of asymptomatics at Cambridge University to show that the claim is contradicted by the government’s own case numbers over that same period. A Bayesian analysis shows that, firstly, if the “1 in 3” claim is correct then, over this period, the actual infection rate must be at least 11 times higher than the infection rate reported by the Office for National Statistics (ONS), 0.71% ; and, secondly, if the reported infection rate of 0.71% is correct then the actual number of people with the virus, who have no symptoms, is at most 2.9% (1 in 34) and not 1 in 3. We argue that this contradiction can only be explained by the false positives being generated by RT-PCR testing. Hence, the published infection rate is estimating the number of people who test positive rather than the number of people with SARS-Cov-2 virus. When the false positive rate is correctly accounted for, the most likely explanation for the observed data, over the period in question, is an infection rate of approximately 0.375% rather than the ONS publicised claim of 0.71%. Likewise, we conclude that the actual number of people with the SARS-Cov-2 virus who have no symptoms is approximately 1 in 19 and not 1 in 3. We show that these results are robust under a sensitivity analysis that allows for a wide range of assumptions about testing accuracy and proportion of people with symptoms. Hence, the UK government and ONS claims cannot both be simultaneously true and the actual infection rates are significantly less than publicised.

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1. Introduction

Since January 2020, when the World Health Organisation (WHO) upgraded an outbreak of pneumonia cases caused by Sars-CoV-2 in China to global pandemic status (WHO (World Health organization) 2020), the United Kingdom's scientific advisors have played a prominent role in influencing both the UK government and international responses. The work of mathematicians and behavioural psychologists has been especially influential. Models from a UK theoretical physicist were used by many countries to justify what the UK public was told would be a three-week lockdown (St Onge 2020; Dayaratna 2020; Corvalan 2020). But it was the recommendations of the behavioural psychologists which ensured that the public would eventually accept lockdowns and other restrictions lasting much longer. In its recommendations, coined "persuasion through fear", the Independent Scientific Pandemic Influenza Group on Behaviours (SPI-B) asserted (SPI-B 2020):

- 'A substantial number of people still do not feel sufficiently personally threatened'.
- 'The perceived level of personal threat needs to be increased among those who are complacent using hard-hitting emotional messaging'.
- 'Use media to increase sense of personal threat'.

There have since been many examples where the Government has indeed saturated the media with 'hard-hitting' messages that 'increase sense of personal threat'. Especially prominent has been the message that "One in three people with Covid-19 have no symptoms and so you could be spreading it without knowing it". Figure 1 is a screenshot of the landing page of the UK Government Covid-19 website[2] on the day this article was first drafted.

Figure 1 Screenshot of Gov.UK landing page 11 Feb 2021

The same message has also been widely promoted in radio and TV adverts (such as those in Figure 2) as well as billboards across the country. It is accompanied by emotionally manipulative images and the assertion that "By leaving home you may be spreading the virus without knowing it".

[2] www.gov.uk/coronavirus

Figure 2 Typical Government advertising message

For the various reasons explained in previous articles (Fenton et al. 2020; Neil et al. 2020; Fenton 2020), it is difficult to estimate the proportion of people infected because of issues with test accuracy, whether confirmatory testing is done, the period of active infection, and the fact that the UK government's data[3] does not distinguish between those, with and without symptoms, getting tested and (for those testing positive) who did and did not eventually develop and show symptoms of disease caused by the virus.

A person is generally classified[4] as having SARS-Cov-2 if they receive a positive RT-PCR test result. It has long been conjectured by researchers that many RT-PCR test results may be false positives (Craig et al. 2020; Cohen, Kessel, and Milgroom 2020; Surkova, Nikolayevskyy, and Drobniewski 2020). This would be especially true for people who have no symptoms, and for any where there was no testing done to confirm the presence of the virus. The possible biological reasons for false positives include genetic fragments of dead virus left over from active infection, test cross reactivity with other viruses and reagents used in the RT-PCR test, as well as quality control problems that may cause direct bacterial or viral contamination during the testing process.

We believe the government's "1 in 3" claim may, in part, be based on work reviewed in (Pollock and Lancaster 2020). However, the authors of this study highlight severe limitations in those studies which have claimed high proportions of people with the virus, but no symptoms (who we will subsequently refer to as asymptomatics), and they note that:

> "Earlier estimates that 80% of infections are asymptomatic were too high and have since been revised down to between 17% and 20% of people with infections."

It is also possible that research published very early in the pandemic, in the period from March to June 2020 and reporting around 1 in 3 as asymptomatic, may have led to belief in this assumption (Long et al. 2020; Hu et al. 2020; Nishiura et al. 2020; Zhou et al. 2020). However, each of these studies reported a very small number of asymptomatics in otherwise trivial populations of RT-PCR hospital-confirmed cases, which were not representative of the general community.

[3] https://coronavirus.data.gov.uk/

[4] Note that SARS-Cov-2 is the virus, and the disease caused by the virus is Covid-19. Government and other agencies often confuse the two but here we are careful to draw the causal distinction. Thus, our shorthand use of 'virus' here means 'SARS-Cov-2 virus' and not the disease or symptoms associated with the disease.

While this evidence already suggests the government claim is exaggerated, in this article we will show that, if we accept the government data on number of 'active cases' then the true proportion of people with the virus who are asymptomatic is much lower still.

It should be noted that a major possible 'blurring' of the government "1 in 3" message lies in the semantic interpretation of the label 'asymptomatic'. There is, of course, an incubation period before any person who gets infected experiences symptoms (although, as noted in (Pollock and Lancaster 2020) there is still great uncertainty about how long this period is), so in a sense every person must at some point be asymptomatic while infected with the virus. There is even greater uncertainty about whether a person can transmit the virus during this period or at all if they remain asymptomatic (again noted in (Pollock and Lancaster 2020)). Clearly, there is already considerable dispute about any claims of the dangers of asymptomatic people spreading the virus, irrespective of what their overall proportion is in the general population.

In the interests of clarity, we interpret the government claim as the hypothesis that:

> "At this moment (assuming testing is accurate) 1 in 3 of all people who have the virus have no symptoms".

Hence, we will not distinguish between 'those who are currently asymptomatic because they have only just been infected' and 'those who remain asymptomatic throughout the whole period of infection', or variants on this theme.

For all the reasons outlined above there is an urgent need to focus on the most complete public data available to test the UK government's claims. Hence, we focus here on one extended period, Dec 2020 – Feb 2021, and one location, Cambridge, where significant relevant data is available[5].

2. The fallacy of the transposed conditional in the UK government claim

Before analysing the data, it is important to note that the claim:

> "1 in 3 people who have the virus have no symptoms."

is neither logically nor probabilistically equivalent to:

> "1 in 3 people who have no symptoms have the virus."

To understand the distinction let:

> V be the assertion: "Person has the virus"; and
>
> $\neg S$ be the assertion: "Person has no symptoms (of the virus)."

Then the claim "1 in 3 people who have the virus have no symptoms" is an assertion about the probability of $\neg S$ given V, which we write as $P(\neg S \mid V)$, while the second is an assertion about $P(V \mid \neg S)$.

[5] As the claim in the UK government hypothesis was being made continually during that period, whatever happened before or after is not relevant when testing these claims.

Unfortunately, many people wrongly assume these assertions are equivalent and to do so is to commit a classic fallacy (Evett 1995) called *the fallacy of the transposed conditional* (or prosecutor's fallacy). To see why the two probabilities are not generally equal, consider this trite example:

> An unknown animal is hidden behind a screen. We are interested in the hypothesis that the animal is a cow or some other animal. We know that cows have four legs. So, if I tell you that the animal has four legs, can you deduce that the unknown animal is certainly a cow? Of course not, since it might be another animal that possess four legs, such as a sheep or goat.
>
> If this is the case logically it is also the case probabilistically. The conditional probability statement $P(four\ legs \mid cow) = 1$. However, we cannot conclude that $P(cow \mid four\ legs) = 1$ since other four-legged animals are not cows. Instead, we must conclude $P(cow \mid four\ legs) < 1$.

It is of course quite possible that the UK government's "1 in 3" message was phrased to deliberately exploit this known fallacy.

3. The Cambridge and ONS data

To test the UK government's claims we use the data from the Cambridge University asymptomatic screening study[6] in Table 1.

Table 1 The Cambridge University data

Week	No. students screened	No. confirmed positive cases	Weekly incidence	Cambridge** 'infection rate'	number of pools tested	false positives	false postive rate
30 Nov - 6 Dec	9376	0	0.00%	**0.44%**	1937	10	0.52%
18-24 Jan	3570	4	0.11%	**0.85%**	1552	3	0.19%
25-31 Jan	3945	2	0.05%	**0.96%**	1674	0	0.00%
1-7 Feb	4058	0	0.00%	**0.84%**	1740	13	0.75%
8-14 Feb	4156	1	0.02%	**0.63%**	1743	9	0.52%
15-21 Feb	4099	0	0.00%	**0.52%**	1748	1	0.06%
Average	**4867**	**1**	**0.02%**	**0.71%**	**1732**	**6**	**0.35%**

At time of writing the data in Table 1 covered the last 6 weeks for which a full data set are available (end and beginning of weeks 7-11 Dec and 11-17 Jan do not contain the false positive data). The column marked ** is taken from the ONS estimates of SARS-CoV-2 infection rates analysed by sub-regions[7]. For each column entry this is the mean estimate for Cambridge during that week.

All those tested are assumed to be asymptomatic using pooled PCR-RT testing[8], where for any pooled sample that tests positive each individual contributor's sample is subject to a second confirmatory test. Over the entire period 43 of the 10,394 pooled tests were positive, of which 36 were found to be false positives after confirmatory testing. Hence, while the overall

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[6] https://www.cam.ac.uk/coronavirus/stay-safe-cambridge-uni/asymptomatic-covid-19-screening-programme

[7] https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/conditionsanddiseases/bulletins/coronaviruscovid19infectionsurveypilot/latest

[8] https://www.england.nhs.uk/coronavirus/publication/pooling-of-asymptomatic-sars-cov-2-covid-19-samples-for-pcr-or-other-testing/

false positive rate for the pooled PCR testing was low, 0.35%, a high proportion, 84%, of those who did test positive were false positives.

So, over the entire period, just 7 out of the 29,204 asymptomatics tested were confirmed positive. We do not know how many of these remained asymptomatic since we do not know if the positive test occurred during the incubation period or not. This means that, on average, at any time during this period just 1 out of every 4867 asymptomatic people tested in Cambridge was a confirmed positive 'case'.

Over the same period the ONS estimated an average infection rate of 0.71% for Cambridge. This would mean on average 1 out of every 141 people in Cambridge had the virus. The ONS estimate is based on the 'official case' data where a 'case' is a person testing positive. However, unlike the Cambridge study it is unknown whether any of these 'cases' are subject to confirmatory testing.

4. Testing the UK government and ONS's claims

Using the data in Table 1 we can determine the validity of the Government and ONS claims (in relation to Cambridge for the period of the study). We show it is impossible for both the UK government's "1 in 3" claim and the ONS 0.71% infection rate claim to be simultaneously correct because we can conclude the following from the data:

Conclusion 1: If the ONS reported infection rate, 0.71%, is correct, then at most 2.9% (1 in 34) of people with the virus have no symptoms, and not 1 in 3 as claimed by the government.

Informal explanation:

a) The population of Cambridge is 129,000.
b) So, since only 1 in 4867 asymptomatics have the virus, the maximum possible number of asymptomatics with the virus is about 27.
c) If the ONS claimed infection rate is correct, then 0.71% of people in Cambridge would have the virus. This is about 916 people.
d) Hence, at most 27 out of 916 with the virus had no symptoms. That is a maximum of 2.9% (27/916), i.e. 1 in 34.

But, on the other hand, it tells us:

Conclusion 2: If the government claim that "1 in 3 people with the virus has no symptoms" is correct, then the ONS reported infection rate must be at most 0.062%. This would mean the reported rate of 0.71% is at least 11 times greater than the true infection rate.

Informal explanation:

a) We already noted that in Cambridge the maximum number of asymptomatics with the virus is about 27.
b) But if 1 in 3 people with the virus have no symptoms, then the maximum total number of people with the virus is three times that number, i.e. 81.
c) That means a maximum 81 out of 129,000 have the virus.
d) Thus, the maximum infection rate consistent with the government's claim is 0.06% (81/129,000).

Hence, the UK government claim "1 in 3" claim and the ONS infection rate claim **cannot both be simultaneously true.**

The formal proof of these conclusions, which require a straightforward application of Bayes Theorem, are provided in Appendix 1.

5. Possible limitations in the data

It could be argued that the Cambridge study is not representative of asymptomatics generally, since these are all students living, mostly, away from home. However, the data set covers the Christmas/New year period during which almost all the students would have returned home and returned to University. And during this period the population infection rate reached the peak of the 'second wave'.

Moreover, we believe it is reasonable to assume that it is young people who are the ones most likely to have the virus while being asymptomatic. Hence, if anything, the Cambridge University 'sample' should produce a higher number of asymptomatics with the virus than the general population. In other words, it could reasonably be argued that the 1 in 4867 rate of asymptomatics who have the virus is higher than what one would expect to find in the general population.

It is difficult to obtain other comparable high-quality data on asymptomatics because published test results typically make no distinction between symptomatic and asymptomatic people. Moreover, unlike the Cambridge study, we could find no public information about the proportion of reported PCR-RT positives that were subject to confirmatory testing.

Possibly the most relevant data that could be used for comparison is the weekly testing data provided by the football Premier League[9]. For February 2021 the results were:

- 1 -7 Feb 2,970 tested; 2 positives
- 8 - 14 Feb 2,915 tested; 2 positives
- 15 - 21 Feb 2,633 tested; 2 positives
- 22 - 28 Feb 2,733 tested; 2 positives

We do not know the proportion of symptomatic people among those tested, but we can assume it must be quite low, because, given the high public profile of football, it is very likely that had players tested positive with symptoms this would have been widely reported in the media. Whether or not those testing positive were symptomatic and whether they were subject to a confirmatory test is unknown. Only 1 in 7 of those testing positive in Cambridge was confirmed positive, so if a similar false positive rate applied here, the number of asymptomatics with the virus would be higher than that observed. It is also important to note that professional footballers are among the very few people who do not have to socially distance, and – as with the students – these are young men who should produce a higher proportion of asymptomatics with the virus compared to the general population.

Moreover, professional footballers are based all over the country and the national ONS estimated infection rate during this period was 1.25%, which is much higher than reported for Cambridge. So, even if none of the footballers testing positive had symptoms and even if there were no false positives, our conclusions would remain valid. Hence, again this demonstrates that the government's "1 in 3" claim is incompatible with the ONS's claimed infection rate.

[9] https://www.premierleague.com/news/1814863

6. What *is* the virus infection rate and proportion of people with the virus who are asymptomatic?

If the government and ONS claims are mutually incompatible, what then is the likely virus infection rate and proportion of people with the virus who are asymptomatic? In this section we use a Bayesian analysis to provide an answer to both questions, by accounting for false positive rates.

Unlike in the Cambridge study, the government assumes that a person who tests positive in a single PCR test has SARS-Cov-2 (there is no routine confirmatory testing). So, with an 0.71% infection rate, we would expect that 710 out of every 100,000 people sampled would test positive.

But, from the Cambridge study, we might also assume that during this same period there was an overall false positive rate of 0.35% for the PCR-RT testing of asymptomatics. Note that this assumption may be generous given that the PCR-RT testing was done in a highly competent University laboratory rather than in a UK lighthouse laboratory, where quality control problems have been widely reported and suspicions have been raised as to whether WHO rules and and manufacturer guidelines are adhered to [Neil 2021].

Taking account of the Cambridge University false positive rate, their observed infection rate for asymptomatics (0.0205% based on 1 in 4867) and the ONS's estimate of 0.71% of people who would test positive, the most likely virus infection rate is 0.379% (with 95% confidence interval is 0.372% to 0.387%). This is approximately half of the ONS's estimate.

Our analysis is based on the following reasonable assumptions (we also relax these assumptions in the subsequent sensitivity analysis):

- The false positive rate for symptomatics is 0.4%. PCR-RT testing is more likely to produce false positives for symptomatics than asymptomatics since the former includes people with COVID-like symptoms, who were not infected with SARS-Cov-2 but instead may have been infected by another coronavirus (Neil 2021)
- The true positive rate for people with the virus, with symptoms, is 95% and the true positive rate for people, with the virus, without symptoms is 90%; the analysis is not particular sensitive to these rates.
- The proportion of people with symptoms, either from SARS-Cov-2 or another related virus with similar symptoms[10], is 4%.

The full Bayesian analysis is presented in Appendix 2. The estimates that result from this analysis can be informally illustrated by considering 100,000 people being tested at random, as shown in Table 2.

Table 2 Testing 100,000 people.

	No symptoms (96,000)		Symptoms (4,000)		Total
	SARS-Cov-2	No SARS-Cov-2	SARS-Cov-2	No SARS-Cov-2	
Negative test	20	95,980	359	3,641	100,000
Positive test	18	336	341	15	710

[10] https://en.wikipedia.org/wiki/Common_cold

By working backwards from our model estimate for the infection rate, the results in Table 2 can be explained as follows:

- Our model estimates an infection rate of 0.379% so from 100,000 people there are 379 who have the virus.
- Based on the Cambridge University infection rate of 0.0205%, for asymptomatics, and a true positive rate for asymptomatics of 90%, we estimate that only 20 of the 96,000 asymptomatics has SARS-Cov-2 and, of these, 18 will test positive.
- Assuming the true positive rate for symptomatics is 95%, of the 4,000 symptomatics 359 have the virus, but will test negative and 341 have the virus and will test positive.
- With a false positive rate of 0.35% for asymptomatics, from the 96,000 asymptomatics, we expect 336 false positives
- With a false positive rate of 0.4% we expect 15 false positives from the 4,000 with symptoms, and 3,641 of those with symptoms do not have SARS-Cov-2.

So, a total of 341 are true positives and when combined with a total of 351 false positives this gives an expected value of 710 total positives in a population of 100,000 and an estimated infection rate of 0.71%. This positivity rate, which includes false positives, is consistent with the ONS estimate for the virus infection rate.

So, given our data and assumptions:

- The infection rate was 0.379% and not 0.71% (so the estimate was exaggerated by 89%)
- As there are 20 out of 379 people with SARS-Cov-2 who have no symptoms that means about 1 in 19 (5.3%) with the virus have no symptoms, rather than the 1 in 3 claimed (so the estimate was exaggerated by over 500%).

We use the same Bayesian network model to perform a full sensitivity analysis. Specifically, instead of using the above assumed point estimates for: true positive rates, false positive rate for people with symptoms, and proportion of people with symptoms we use the prior distributions stated in Appendix 3. In this case the 95% confidence interval for the true infection rate is 0.355% to 0.440% (with mean 0.395%). So the ONS infection rate is exaggerated at least 61%. Moreover, the percentage of people with SARS-Cov-2, but no symptoms is between 4.4 and 5.4%. There is thus no reasonable scenario in which more than 1 in 18 people with Covid-19 had no symptoms.

The extent to which the government claims are exaggerated clearly depends on the estimated infection rate. While we have focused on a period when this rate was 0.71% for Cambridge, the Cambridge data over a longer period also provides good estimates of the asymptomatic infection rate and false positive rates when the ONS infection rates were different to 0.71%. Table 3 show the full sensitivity analysis results for ONS infection estimated rates of 1%, 0.5% and 0.35% using the following observations:

- At 1%: asymptomatic infection rate 0.04%; false positive asymptomatic infection rate 0.0035%
- At 0.5% asymptomatic infection rate 0.015%; false positive asymptomatic infection rate 0.003%
- At 0.35% asymptomatic infection rate 0.01%; false positive asymptomatic infection rate 0.0025%

As the infection rate drops, the extent to which the estimated infection is exaggerated increases, because the proportion of false positives inevitably increases. At the time of writing the estimated infection rate is 0.35%, and so it is likely that the true infection rate is only around 0.1%.

One other interesting observation is that, when the ONS estimated infection rate is 1% the proportion of people testing positive who have no symptoms is approximately 1 in 3. So, the claim that "1 in 3 people with the virus have no symptoms" claim is approximately true if we replace "with the virus" with "test positive".

Table 3 Estimated mean infection rate incorporating sensitivity analysis and different ONS estimated infection rates (95% confidence intervals in brackets)

	ONS estimated infection rate			
	1%	0.71%	0.5%	0.35%
Mean infection rate with 95% confidence interval	0.7 (0.657, 0.790)	0.394 (0.355, 0.440)	0.216 (0.183, 0.246)	0.10 (0.067, 0.123)
ONS overestimate	27% to 52%	61% to 100%	103% to 173%	185% to 422%
Mean % with virus but no symptoms with 95% confidence interval	5.39 (4.81, 5.88)	5.0 (4.44, 5.54)	6.73 (5.81, 7.74)	9.62 (7.68, 13.9)
Mean % positives but no symptoms	33%	49%	64%	73%

7. Conclusions

The claim that "1 in 3 people with Covid-19 have no symptoms" has been the UK government's mostly widely promoted statistic across all modes of media (billboards, radio, internet and TV) It has been a very effective message in ensuring that people stick rigorously to lockdown regulations, but it has also instilled unjustified fear. Many people wrongly assume that the statement means that 1 in 3 people without symptoms have SARS-Cov-2 virus, and it is possible that the messaging played on this known probabilistic fallacy to exaggerate the level of fear felt by the general population. By analysing the Cambridge study of asymptomatics we have shown that the "1 in 3 people with Covid-19 have no symptoms" claim is incompatible with the ONS published infection rate.

The only explanation for this is that the government is clearly equating a 'case' with a 'positive test'. They are failing to properly take account of the impact of false test results from RT-PCR testing and the fact that most reported 'cases' are not subjected to confirmatory testing. For the duration of the period analysed in the Cambridge study, 43 of the 10,394 'pools' tested positive, of which 36 were found to be false positives after confirmatory testing. Hence, while the overall false positive rate for the pooled PCR testing was low, 0.35%, a high the proportion, 84%, of those who did test positive were false positives. In total there were just 7 'cases' (meaning where a confirmatory test was done following a positive test result) out of the 29,204 asymptomatics tested.

Our analysis shows that the ONS reported infection rate of 0.71% is really an estimate of the proportion of people who would test positive. We have shown that, under reasonable assumptions, the true infection rate, for the period in question, was most likely to be 0.379% (95% confidence interval is 0.372% to 0.387%). So, the estimated infection rate exaggerates the actual rate by 87%. We also performed a sensitivity analysis that showed that the results are robust against a range of prior assumptions; specifically, there is no reasonable scenario under which the maximum value for the infection rate exceeded 0.44%, thus making the ONS estimate of the infection rate highly improbable.

Moreover, we can also conclude that only 5.3% of people with the virus have no symptoms. That is 1 in 19, not 1 in 3 as claimed. Again, we showed this result was robust under a sensitivity analysis.

We also considered the extent to which the government and ONS claims are exaggerated for different possible infection rates. As the infection rate drops, the extent to which the estimated infection rate is exaggerated increases, because the proportion of false positives inevitably increases. At the current estimated infection rate of 0.35%, it is likely that the actual infection rate is only around 0.1% meaning that the current estimated infection rate exaggerates the true rate by 250%.

One other interesting observation we found was that, when the ONS estimated infection rate is 1% the proportion of people testing positive who have no symptoms is consistently around 1 in 3. Hence, the claim that "1 in 3 people with the virus have no symptoms" claim is approximately true in this case if we replace "with the virus" with "test positive".

While the focus was on just one UK city there is reason to believe that the results apply generally throughout the UK, and it is therefore also reasonable to conclude that SARS-Cov-2 case numbers have been systematically exaggerated across the country. It is also reasonable to conclude that mass testing of asymptomatic people (who have not been in recent contact with a person confirmed as having the virus) may be causing unnecessary anguish for minimal benefit at a very high societal and economic cost.

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APPENDIX 1: Formal Proofs of Conclusions 1 and 2

Formal Proof of Conclusion 1:

Conclusion 1: If the government claim that "1 in 3 people with the virus has no symptoms" is correct, then the ONS reported infection rate must be at most 0.062%. This would mean the reported rate of 0.71% is at least 11 times greater than the true infection rate.

We assume $P(\neg S|V) = 1/3$.

From the Cambridge study: $P(V \mid \neg S) = 1/4867$

By Bayes Theorem:

$$P(V) = \frac{P(V|\neg S) \times P(\neg S)}{P(\neg S|V)} = \frac{1/4867 \times P(\neg S)}{1/3}$$

$$= 0.000616 \times P(\neg S) \ < 0.000616$$

since $P(\neg S) < 1$

Formal Proof of Conclusion 2:

Conclusion 2: If the ONS reported infection rate, 0.71%, is correct, then at most 2.9% (1 in 34) of people with the virus have no symptoms, and not 1 in 3 as claimed by the government.

We assume $P(V) = 0.0071$

From the Cambridge study: $P(V \mid \neg S) = 1/4867$

By Bayes Theorem:

$$P(\neg S|V) = \frac{P(V|\neg S) \times P(\neg S)}{P(V)} = \frac{1/4867 \times P(\neg S)}{0.0071}$$

$$= 0.029 \times P(\neg S) \ < 0.029$$

since $P(\neg S) < 1$

APPENDIX 2: BAYESIAN MODEL AND COMPUTED RESULTS

An estimate of the unknown infection rate given the various known parameters and assumptions can be obtained using a Bayesian network model, computed using AgenaRisk (Agena Ltd 2021).

The model variables are:

$V, \neg V$ – infected and not infected

$S, \neg S$ – symptomatic and asymptomatic

$T, \neg T$ – positive test result and negative test result

The Bayesian network model required to express the relationships between the variables is:

$$P(V) \sim Uniform(0, 1)$$

$$P(\neg V) = 1 - P(V)$$

$$P(S \mid \neg V) \sim Uniform(0, 0.07)$$

$$P(\neg S \mid \neg V) = 1 - P(S \mid \neg V)$$

$$P(S \mid V) \sim Uniform(0, 1)$$

$$P(\neg S \mid V) = 1 - P(S \mid V)$$

$$P(S) = P(S \mid V)P(V) + P(S \mid \neg V)P(\neg V) = 0.04$$

$$P(\neg S) = 1 - P(S)$$

$$P(V \mid \neg S) = P(\neg S \mid V)P(V)/P(\neg S) = 0.000205$$

$$P(T \mid S, V) = 0.95$$

$$P(T \mid \neg S, V) = 0.90$$

$$P(T \mid S, \neg V) = 0.004$$

$$P(T \mid \neg S, \neg V) = 0.0035$$

$$P(T \mid S, V) = P(T \mid S, V)P(S \mid V)P(V)$$

$$P(T \mid \neg S, V) = P(T \mid \neg S, V)P(\neg S \mid V)P(V)$$

$$P(T \mid S, \neg V) = P(T \mid S, \neg V)P(S \mid \neg V)P(\neg V)$$

$$P(T \mid \neg S, \neg V) = P(T \mid \neg S, \neg V)P(\neg S \mid \neg V)P(\neg V)$$

$$P(T) = P(T \mid S, V) + P(T \mid \neg S, V) + P(T \mid S, \neg V) + P(T \mid \neg S, \neg V) = 0.0071$$

Given all variables are probabilities they are expressed as continuous in the unit domain. We calculate the model, using a simulation convergence stopping rule of 10^{-3} to infer the marginal distribution of $P(V)$, resulting in a value of 0.379%, with 95% confidence interval (0.372%, 0.387%).

For $P(T) = 0.0071$ the sensitivity analysis results are shown in Figure 3.

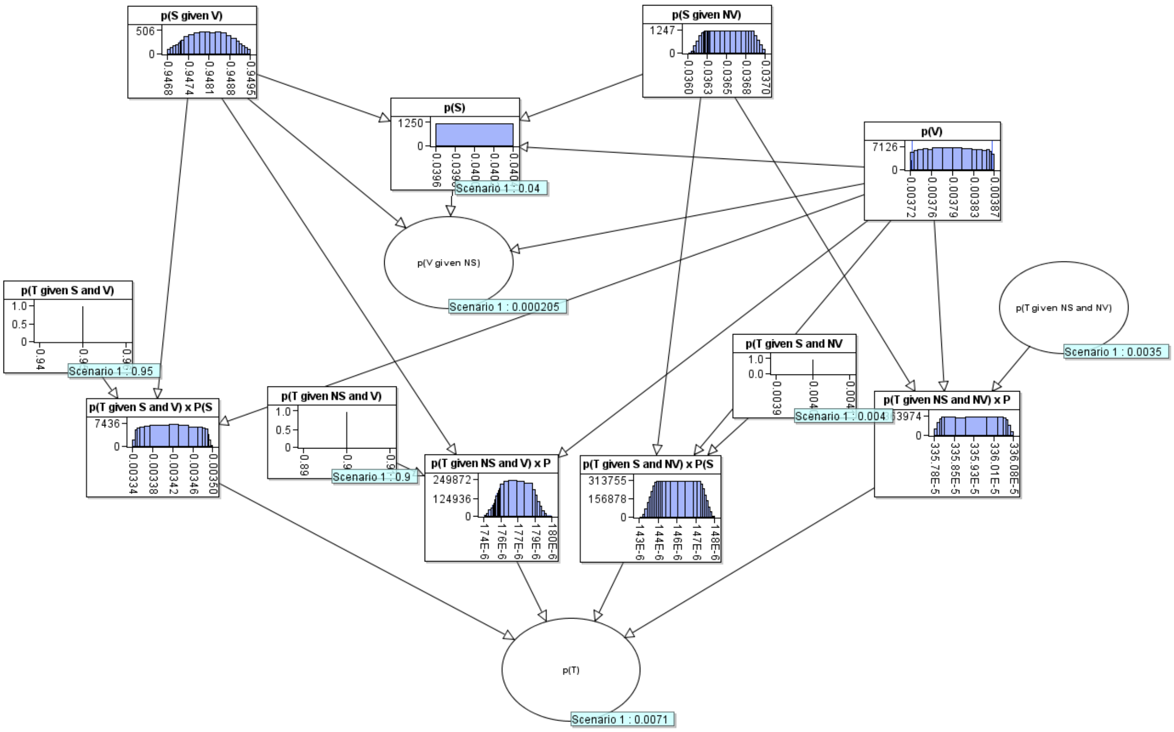

Figure 3 Bayesian network showing posterior marginal distributions for sensitivity analysis

APPENDIX 3: ASSUMPTIONS IN BAYESIAN MODEL FOR SENSITIVITY ANALYSIS

Triangular distributions were used to express greater uncertainty about these variables for the purpose of sensitivity analysis.

$$P(T \mid S, V) = Triangular(0.8, 0.95, 1)$$

$$P(T \mid \neg S, V) = Triangular(0.7, 0.9, 1)$$

$$P(T \mid S, \neg V) = Triangular(0.001, 0.002, 0.1)$$

For $P(T) = 0.0071$ the sensitivity analysis results are shown in Figure 4.

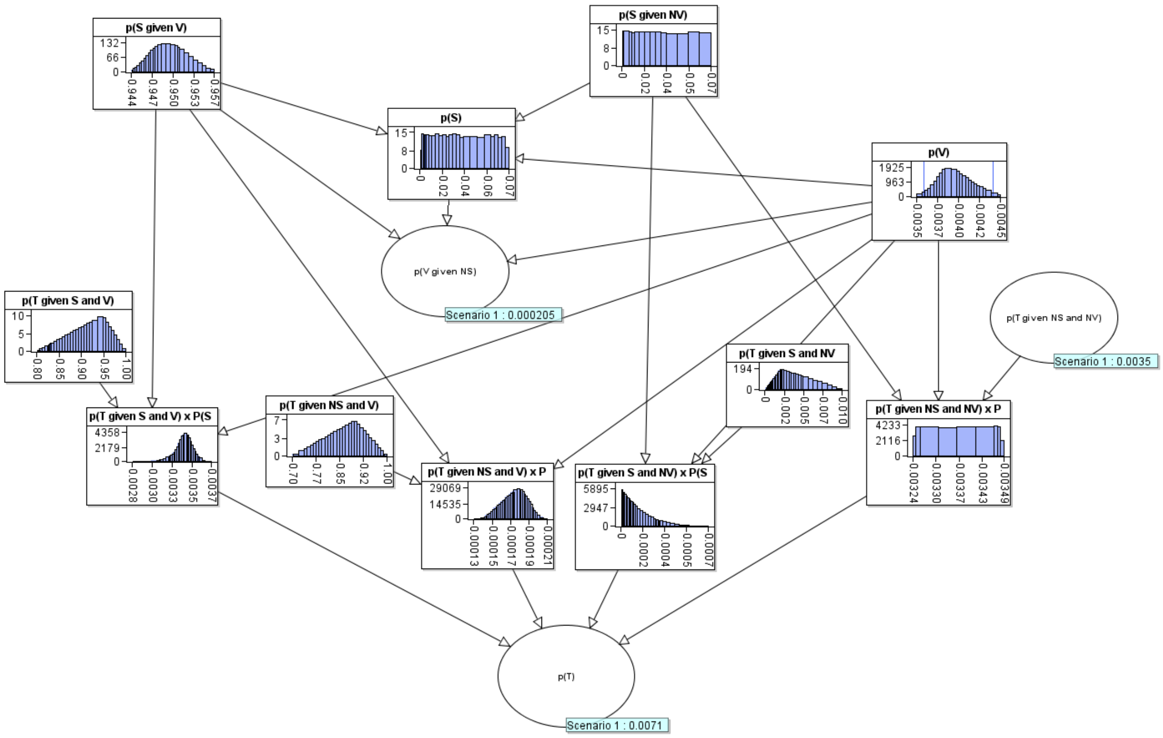

Figure 4 Bayesian network showing posterior marginal distributions for sensitivity analysis

The resulting posterior expectations on each of the variables was:

$$E(T \mid S, V) = 0.92$$

$$E(T \mid \neg S, V) = 0.87$$

$$E(T \mid S, \neg V) = 0.004$$