

# 1 Introduction

Most of the important questions answered by forecasters are still done manually. This 1) is time-consuming and inefficient 2) may lead to subjective decisions since personal judgements are made frequently on when and how to adjust the probability. There are certain constraints due to the scalability and accessibility to useful datasets. In general, automated forecasting can be positive. However, due to the limited spending on forecasters and a "forecasting market", automation is not realistic at this stage. This project serves as an early-stage discovery to the possibility of following a quantitative/statistical approach while at the same time adopt the conventional reference class method(or in another word, interactive machine model taking input from human forecasters). A further question of interest but may not be solvable currently is whether these models can outperform human forecasters(as stated in Superforecasting, superforecasters already beat experts in Math, Stat and other fields).

## 2 Testing Simple Models

This section is dedicated to testing this statistical model method in forecasting. Two resolved questions are selected here, **Election Fraud** and **Cultured Meat**.

### 2.1 Simple Model for Election Fraud

Here is the Metaculus [link](#) for this question. I now try to use a very simple and inaccurate model, and do a forecast with data accessible on [Google Search](#), keyword set as "election fraud".

#### 2.1.1 Model Setting

Our problem of interest is "Probability of greater than 20% people believe election rigged". Let's define  $b$  as a random variable corresponding to the individual's belief in a rigged election.  $b = 1$  if one believes this firmly, and  $b = 0$  otherwise. Then  $p = \mathbf{E}(b)$  is the proportion of people firmly believe in the fraud election. So  $\mathbf{P}(p > 0.2)$  is what we cares about. This  $p$  also follows a normal distribution(I adopt the Bayesian approach).

As for Google Search, denoted as  $I$ , has a relationship with  $b$  and  $p$ . Intuitively, all those with  $b = 1$  with search this topic definitely while the others will pay attention to this with some probability(random variable  $s$ ). I assume  $s$  to follow a normal distribution in the month when everyone is talking about this and it becomes a constant 0.

To summarize, Statistical Model is

$$\begin{aligned} b &\stackrel{iid}{\sim} \mathbf{Bino}(1, p) \\ \text{Prior} : p &\stackrel{iid}{\sim} \mathbf{N}(1/2, 1/9) \\ I &\sim \mathbf{N}(p + s(1 - p), 1/9) \\ s &\sim \mathbf{N}(1/2, 1/9) \mathbf{1}\{T \leq 1\} \end{aligned}$$

#### 2.1.2 Result

In the month when election was really trendy(Nov 2021), the posterior distribution of  $p$  is  $p \stackrel{iid}{\sim} \mathbf{N}(\frac{2}{5}\hat{I} + \frac{9}{20}, 4/45)$ ,  $\hat{I} = 0.28$ . To estimate the believers of a rigged election in the following year(except Nov 2021),  $\hat{I} = 0.05$ ,  $p \stackrel{iid}{\sim} \mathbf{N}(\frac{1}{2}\hat{I} + \frac{1}{4}, 1/18)$ .

The final estimation of  $\mathbf{P}(p > 0.2)$  is then 0.76 and 0.59 respectively. According to [Reuters](#), in Nov 2020, 68% of Republicans said they were concerned that the election was "rigged," while only 16% of Democrats and one-third of independents were similarly worried. However, in 2021 Nov, [report](#) shows that only 31% of the interviewees are still suspicious.

For reference,the Metaculus Community gave a almost consistent 80% confidence for this question and the question was resolved positively.

$n_{break}$	2016	2017	2018	2019	2020
9	0.03	0.08	0.21	1.00	1.00
10	0.01	0.02	0.05	0.49	1.00
11	0.00	0.00	0.01	0.15	1.00
12	0.00	0.00	0.00	0.03	0.33

Table 1: Predictions based on Poisson Model

### 2.1.3 Comments

The model is extremely simplified. Better work can be done to have some hyper-parameters for  $p$  and more data should be used in prediction since the final outcome in this model is largely relied on our prior believe.

## 2.2 Simple Model for Cultured Meat

Here is the Metaculus [link](#) for this question. I now try to use a very simple and inaccurate model, and do a forecast based on the information provided by [Wikipedia](#), keyword set as "cultured meat".

### 2.2.1 Methodology

In this question, we are asked to predict the probability that cultured meat will be served in a restaurant before . We think of this question abstractly as "what is the possibility that a scientific invention can be brought to the public within certain time period", so as to find our reference class, "scientific inventions", biological scientific interventions or inventions regarded as a novel consumption good.

Further unveiling the requirements of a successful invention, we may break it down into small stages of breakthroughs and assume that, on average an invention will be successful after  $n_{break}$  times of small breakthroughs have occurred. For example, in the case of cultured meat, the first patent in 1991 and the first public trial on TV in 2013 should be counted. To get a rough list of all breakthroughs, most events included in History section on Wikipedia are counted(This of course, is just a rough list, since we does not even have a rigorous definition of breakthroughs. However, there are some potential ways to do this, i.e. list their search times on google, ask an expert).

### 2.2.2 Model Setting

For this breakthrough model, we can readily adopt a regular poisson process model, where the probability of a breakthrough happening in any time unit is a constant  $\lambda$ . A bayesian's approach is again used here to estimate and update our estimation of  $\lambda$  over time.  $N(t)$  is defined as the total number of breakthroughs at time.

To summarize, Statistical Model is

$$\begin{aligned}
 \text{Prior : } \lambda &\sim \mathbf{Gamma}(\alpha, \beta) \\
 N(t) &\sim \mathbf{Poi}(\lambda t) \\
 \lambda | N(t) &\sim \mathbf{Gamma}(\alpha + N(t), \beta + t)
 \end{aligned}$$

Hyperparameter  $\alpha$  and  $\beta$  are chosen such that the prior belief imitate a uniform distribution.

### 2.2.3 Result

If we acknowledge the time of breakthroughs are recognized to be 1991,2001,2003,2008,2013,2017,2018, 2019,2019,2020,2020(Without the one when cultured meat had its debut at [Singapore](#)), the model predictions the following probability at different combinations of  $n_{break}$  and  $t_p$ (the end of each year) which means the time of forecasting.

We can see that when  $n_{break}$  is set to be 10, the prediction agrees best with the community. But it is still far from satisfactory.

<i>Type</i>	2016	2017	2018	2019	2020
Community	0.38	0.80	0.72	?	?
Metaculus	0.22	0.48	0.50	?	?

Table 2: Metaculus Predictions

Leader	Country	Start	End	Inpower	Born	Death
Putin	Russia	2000	2022	22	1952	$\geq 2022$
Mao Zedong	China	1949	1976	27	1893	1976
Deng Xiaoping	China	1980	1991	11	1904	1997
Jiang Zeming	China	1991	2004	13	1926	$\geq 2022$

Table 3: Basic Information of Leaders

### 2.2.4 Comments

Better work can be done to estimate hyperparameters(the ones we set manually, such as  $n_{break}$ ). It would be possible if  $n_{break}$  itself is random(follow a normal distribution maybe ). Mostly important, a stricter definition or model for breakthroughs should be discussed. The full timeline is not accessible on Metaculus, so how well the model truly performs is hard to say at this point. The main reason why this model is not satisfactory may due to the fact that there was a "breakthrough boom" where their occurrence accelerated dramatically. This points out a undeniable drawback of the model.

## 3 Important Questions

In the previous section, some preliminary results are shown and the simplest statistical models may lead to overall satisfactory predictions.

In this section, I will continue stretching the limit of this approach, starting by generalizing our model so that it is equipped with great flexibility to cover most of the forecasting questions. To achieve this, case studies on typical and important questions need to be done, in order that a few common traits will be revealed. I start with those shortlisted by this [Lesswrong post](#). Notice that the problems are classified according to its **cause area** and **question type**.

### 3.1 Leader of China in 2030 (Great Power; Binary)

Here is the Metaculus [link](#) for this question. My table of data(Table 3) includes key information such as length of reign and lifetime.

#### 3.1.1 Methodology

To tackle this problem, I have chosen a rather simple and straight forward idea of reference class. First retrieve data about political party. We can roughly think of each leaders' ruling time and their lifetime as **i.i.d** normal random variables. Then our task is to estimate the mean and variance. Plugging in year 2030(or other time points as well) will give us the probability. Secondly, one adjustment was made to attach a forecaster's insider's view: I add **5** to the simple average, considering Xi's almost sure winning in the upcoming term. But I understand the exact number to add can be a controversial point so some experiments are done without this modification.

#### 3.1.2 Model Setting

To estimate  $\mathbf{P}(\text{Xi still in 2030})$ , I propose breaking it down into  $\mathbf{P}(\text{Inpower}_{Xi} \geq 2030 - 2012) * \mathbf{P}(\text{Life}_{Xi} \geq 2030 - 1953)$ . These two can be further revised into a conditional probability, given he has already been the president since 2013 and is still alive.

To summarize, Statistical Model is

$$\begin{aligned} \text{Prior} : \text{Inpower} &\sim \mathbf{N}(\mu_{C\_Inpower}, \sigma_{C\_Inpower}^2) \quad \text{Prior} : \text{Life} \sim \mathbf{N}(\mu_{C\_Life}, \sigma_{C\_Life}^2) \\ \text{Posterior} : \text{Inpower} &\sim \mathbf{N}(\mu_{Xi\_Inpower}, \sigma_{Xi\_Inpower}^2) \quad \text{Posterior} : \text{Life} \sim \mathbf{N}(\mu_{Xi\_Life}, \sigma_{Xi\_Life}^2) \end{aligned}$$

Scenario	Prob	Scenario	Prob
C1	0.56	C3	0.41
C2	0.72	C4	0.56

Table 4: Predictions based on Different Assumptions

and in specific,  $\hat{\mu}_{Xi\_Inpower} = \hat{\mu}_{C\_Inpower} + C$ , where C can be a constant(say 5), subject to our belief,  $\sigma_{Xi\_Inpower}^2 = \hat{\sigma}_{C\_Inpower}^2$ .

### 3.1.3 Result

Agreeing on the ruling period of leaders, the model predicts the following probability 5.  $C = 5$  in C1 and C2 versus  $C = 0$  in C3 and C4. While in C1 and C2, the set of all Chinese leaders are considered as the reference class, only Mao, Deng and Jiang are included in C3 and C4's. Personally, I want to choose somewhere between C1 and C2.

1. C1 and C2 reflects the distinct present situation
2. C2 has too small a dataset

In conclusion, a simple average of C1 and C2 generates a probability of 0.64, which is very close to the community prediction on Metaculus of 0.60.

### 3.1.4 Comments

Firstly, a small dataset is used. Secondly, the manual adjustment of 5 in Xi's expectation is debatable. It is possible to use an alternative model, say adding a more concrete event-based update. For example, adjust his mean by modeling the event of constitution revision. This way of thinking is promising, but it is hard to use in this particular question because this event only happened once(we may need to find other reference class to model this). Thirdly, variance of the distribution has not been adjusted at all. Lastly, lifespan and length of reign may not be independent and we could as well get rid of the r.v. *Life*.

## 3.2 AI Wins IMO Gold Medal (AI Safety; Continuous)

Here is the Metaculus [link](#) for this question. A breakthrough model is used(Very similar to cultured meat model). Some milestones of AI is listed [here](#). I drew inspiration from one of the earliest paper adopting the Bayesian approach [here](#).

### 3.2.1 Methodology

The details are very similar to that of cultured meat. However, some refinements are made.

1. Gamma distribution is replaced by a simple exponential distribution, after reviewing the paper I mentioned.
2. The estimation of hyperparameter  $\beta$  is more reasonable. This can be done by adjusting  $\beta$ , so that the expected  $\lambda$  which means how long the next breakthrough will take, fits our intuition. Though this may seem random and not convincing, the choice of beta is not very influential and our model is robust enough(due to the comparatively large dataset).

### 3.2.2 Model Setting

$$\begin{aligned}
\text{Prior : } \lambda &\sim \mathbf{Gamma}(\alpha, \beta) \\
N(t) &\sim \mathbf{Poi}(\lambda t), \alpha = 1 \\
\lambda | N(t) &\sim \mathbf{Gamma}(\alpha + N(t), \beta + t)
\end{aligned}$$

### 3.2.3 Result

### 3.2.4 Comments

I intended to make it a rule that the threshold of breakthrough is 10 (meaning that we are selecting historical events that we think counts as one out of ten milestones from the pool of events), so this could well be biased. Therefore, maybe an outsider could use this model to do a test? However, noticed from both cultured meat and IMO problem, the model is not able to capture the usual assumption that innovations are "accelerating".

## 3.3 GPT3 Revenue < 1\$Bn by 2025 (AI Safety; Binary)

Here is the Metaculus [link](#) for this question. This model is chosen because it can be solved using regression model. However, the process of calculation final prediction is disputable due to the fact that this question is not very well-defined. My understanding is that the question will resolved positively if the annual revenue generated by GPT3 in year 2014 is  $\geq$  1Bn. The dataset I have used is collected from [here](#).

### 3.3.1 Methodology

It is natural to assume that GPT3 grows exponentially. Hence a generalized linear model with log link function is used. There is a standard function help us to do this in R. The model can be summarized as:

$$Revenue \sim \text{Gamma}(\alpha, \beta)$$

$$\log(E[Revenue]) = a_0 + a_1 year + \epsilon$$

Note that this is the total revenue of the whole industry. Suppose the revenue generated by NLP is around 10-15% and within this field, GPT3 contributes 5 to 10%.

### 3.3.2 Comments

In summary, this model is an attempt to capture the exponential growth, which we fail to consider in previous ones. Test on four scenarios are done and a combined result of 50% is given. This result can be inaccurate due to many possibilities, including the fact that the question itself is unclear and the nature of this problem requires high accuracy data of which we have none. Hence more similar test should be done on questions of the same type.

## 4 Conclusion

In this writeup, we mainly focuses on the usage of both simple and sophisticated statistical models with conventional assumptions in forecasting some social and political events.

1. These models can be unbiased from individual subjective opinions. For example, when setting up the model after obtaining the data, it is hard to bring in one's irrational personal believes. However, on the other hand, if one has in-depth understanding of a problem, it may be difficult to embed it in the model as well. Some possible solutions involves: Personalized input, Bayesian model and Simple average of one's belief and the model's output.

Percentile	10	11	12	Community
25	2030	2035	2042	2026
50	2035	2043	2051	2031
75	2044	2053	2062	2041

Table 5: Predictions based on Poisson Model

2. The model based on the gradual evolution of human society and technological advance(or the breakthrough model) has certain practical usage and may be used in the forecasting of geopolitical events. However, further work needs to be done so that the "exponential growth" of technology can be better captured. Nevertheless, I personally believe a exponential model might overstate our progress in the long run, meaning that a conventional model is good enough if we are on a centennial or even millennial scale. For other rare events(such as invention of nuclear bomb) that appears to pop out from nowhere, it is extremely hard to predict using any models and a common solution is to use Bayesian thinking and add one's personal belief.
3. One useful property of this statistical approach is that we actually can personalize easily. For example, different input parameter stands for unique believes(as shown in previous analysis). It is much more convenient if we want to take an average from a wide range of "believes". One possible extension of this is that we can gather believes from a crowd of people and plug them into the model. This can give also us a distribution of predictions, helping us understand how uncertain this question is and what is a typical belief.

## References

All the code used are available [here](https://github.com/wjshku/Forecasting)(<https://github.com/wjshku/Forecasting>).