

STATISTICALLY SPEAKING

How long can Pope Francis expect to live?

He joked in 2014 that he had “two or three years left”, but that might be overly pessimistic, say **Julian Stander**, **Luciana Dalla Valle** and **Mario Cortina Borja**

When elected pope of the Roman Catholic Church on 13 March 2013, the Argentinian priest Jorge Mario Bergoglio, Archbishop of Buenos Aires, took the papal name of Francis

and instantly became one of the most famous people in the world.

In August 2014, Pope Francis jokingly announced that he expected to live another two or three years, and that he might even retire within this

Julian Stander is associate professor (reader) in mathematics and statistics in the School of Computing, Electronics and Mathematics, Plymouth University

Luciana Dalla Valle is a lecturer in statistics in the School of Computing, Electronics and Mathematics, Plymouth University

Mario Cortina Borja is chairman of the *Significance* editorial board, and professor of biostatistics in the Centre for Paediatric Epidemiology and Biostatistics, UCL Institute of Child Health

period (bit.ly/1J1JV6H). Like other populations, popes have experienced a generally increased life expectancy – but statistically, how many years can the present pope expect to live after his election? To answer this question we analysed data on the post-election survival times of popes, starting with Pope Innocent VII, whose pontificate began in 1404.

We arbitrarily started at the beginning of the fifteenth century as dates of birth, election and death (or resignation) are well documented from that century onwards. The resulting data set (bit.ly/1ZSrpjt) is based on the 62 popes before Pope Francis. Note that apart from Gregory XII and Benedict XVI – who choose to resign the papacy in 1415 and 2013, respectively – all the popes analysed died in office.

After an initial analysis of the data, we modelled t_i , the post-election survival time of the i th pope in our data set, using a Weibull survival model – a common model for positive times to events. Our data included one observation that is censored – that is, the pope in question (Pope Francis’s predecessor, Pope Emeritus Benedict XVI) is still alive. Effectively, we have a lower bound on his survival. Our model also had two centred covariates: age at election (x_1) and year of election (x_2), both of which were centred by the subtraction of the sample mean. Our model took the form:

$$t_i \sim \text{Weibull}(r, \mu_i)$$

$$\log \mu_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i}$$

For most popes in our data set the post-election survival time is the same as pontificate length. The exceptions are Pope Gregory XII and Pope Emeritus Benedict XVI. We performed inference in the Bayesian framework, and so we



LEFT Pope Francis, pictured in November 2013, sends a kiss to the faithful gathered in St. Peter’s Square, Vatican City

neneos/iStock Editorial/Thinkstock

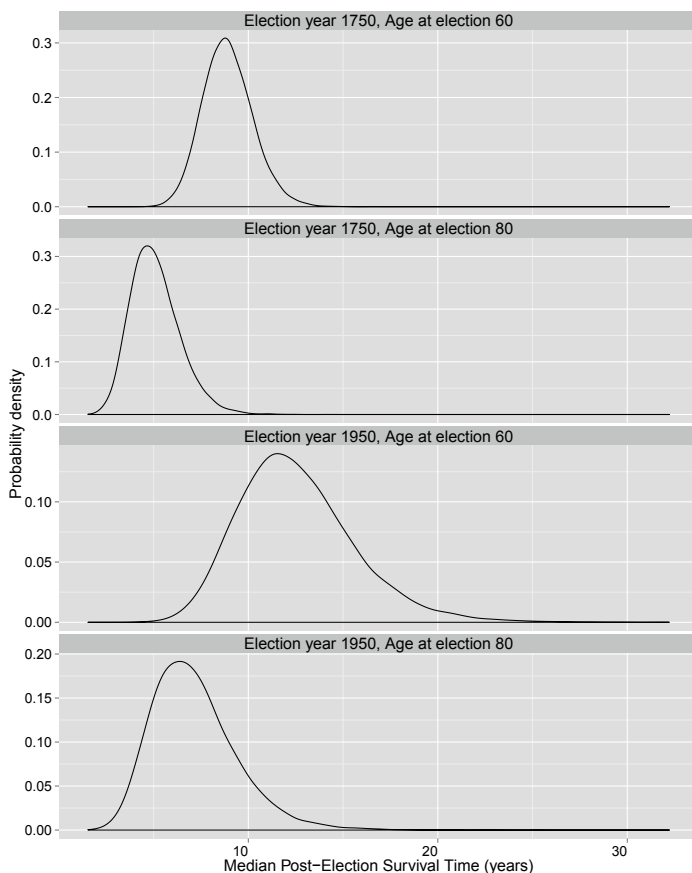


FIGURE 1

needed to specify prior distributions for the unknown parameters in our model, r , β_0 , β_1 and β_2 :

$$r \sim \text{Exp rate } 0.001$$

$$\beta_0, \beta_1, \beta_2 \sim \mathcal{N}(\text{mean} = 0, \text{variance} = 10000)$$

There was no posterior support for an interaction term between age at election and year of election. Our inference is thus based on the posterior distribution of the unknown parameters given the data: $\pi(r, \beta_0, \beta_1, \beta_2 \mid \text{data})$. We simulated 500 000 values of r , β_0 , β_1 and β_2 from this posterior distribution using a Markov chain Monte Carlo algorithm implemented in JAGS¹ using R2jags.²

Figure 1 shows posterior distributions of the median post-election survival time for hypothetical popes elected in 1750 and 1950, aged 60 and 80 at the time of election. The graphs suggest that, as the years have passed, the median survival time has increased somewhat. Naturally, popes who are

FIGURE 1 Posterior distributions of the median post-election survival time for popes elected in 1750 and 1950, aged 60 and 80 when elected

FIGURE 2 The predictive probability density function of the post-election survival time for a pope elected in 2013, aged 76, who, like Pope Francis, has already served 2.89 years

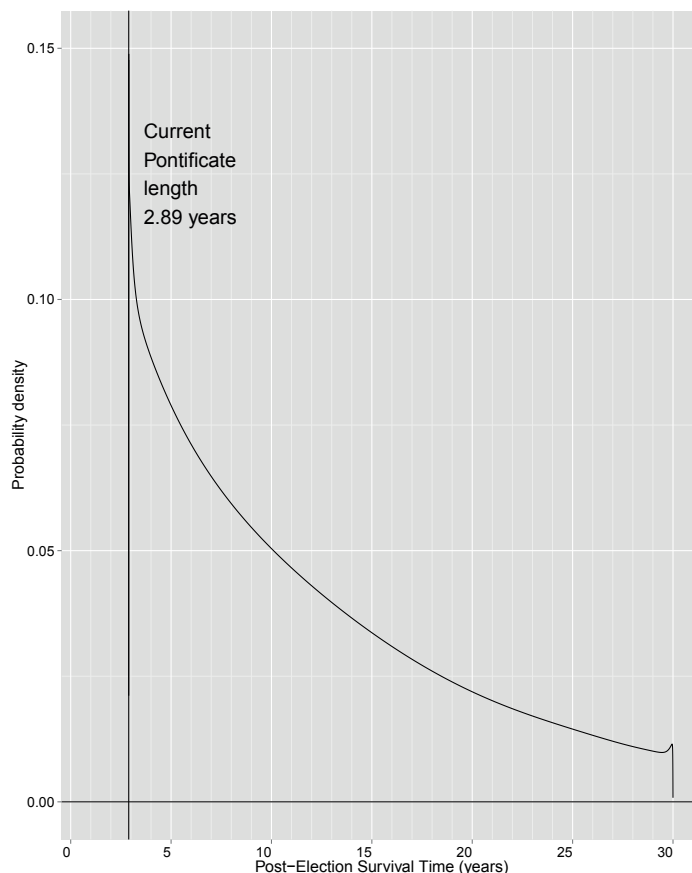


FIGURE 2

older at the time of their election tend to have shorter pontificates.

Pope Francis was 76 years old when elected in 2013. His pontificate has so far lasted 2.89 years at the time of writing (February 2016). We can understand the future survival time t^{new} of a pope such as Pope Francis by considering the predictive probability density function:

$$\pi(t^{\text{new}} \mid \text{all available data}, t^{\text{new}} > 2.89)$$

We can use the sample from the posterior density, $\pi(r, \beta_0, \beta_1, \beta_2 \mid \text{data})$, together with simulations from an appropriate Weibull distribution, to generate values from this predictive distribution. Figure 2 shows the predictive probability density function of the post-election survival time for a pope such as Pope Francis. The median survival time is 10 years, with the 0.95 quantile being approximately 25 years.

We therefore conclude that the forecast made by Pope Francis in 2014

about his own survival seems rather pessimistic: based on the survival of past popes, he can expect to live at least 10 years with probability 50%, and 25 years with probability 5%.

Of course, there is scope for more sophisticated analysis of papal post-election survival times. In addition, similar analyses could be conducted for individuals comprising different special populations, such as monarchs and other heads of state. Note, however, that unless we are dealing with leaders that have all been male, such as presidents of the United States, a covariate indicating gender must be included. ■

References

1. Plummer, M. (2003) JAGS: A program for analysis of Bayesian graphical models using Gibbs sampling. <http://citeseer.ist.psu.edu/plummer03jags.html>
2. Su, Y.-S. and Yajima, M. (2015) R2jags: Using R to Run "JAGS". R package version 0.5-6. <http://cran.r-project.org/package=R2jags>