eAppendix for: "Sun smoke in Sweden: Perinatal implications of the Laki volcanic eruptions, 1783–1784"

Statistical methods

We used Box-Jenkins methods[1] to identify and specify autocorrelation in the annual perinatal outcome measures in Sweden for the 50 years from 1751–1800. Box-Jenkins methods essentially answers the questions: "Does knowing that the Laki event exposed Swedes to air pollution and other environmental changes in 1783–1785 allow us to predict the observed values of our dependent variables more accurately than knowing only the historic patterns (i.e., autocorrelation) in the variables?" The models essentially predict an observation at time t from observations at t-n and use the mathematical equivalent of long (i.e., autoregressive) and short (i.e., moving average) memory to efficiently describe autocorrelation. The residuals of a Box-Jenkins model exhibit no autocorrelation and have an expected value of "0" implying efficient estimation of the model coefficients and their confidence intervals.

We estimated a test equation formed by expanding the Box-Jenkins equation identified in our first step. The most general form of our test equation appears as follows:

$$(1-\phi B^q)Y_t=c+\omega X_{t-n}+(1-\theta B^p)a_t$$

Y_t is the dependent variable at time t. ϕ is the autoregressive parameter. B^q is the backshift operator or value of Y at time t-q. C is a constant. X_{t-n} is a binary variable scored 1 for time periods in which the population is exposed to the presumed insult and 0 otherwise. X occurs in the same time period as Y when n=0. ω measures the difference between the observed and expected (i.e., from autoregressive and moving average parameters) values of Y when X_{t-n} is scored 1. θ is the moving average parameter. B^p is the backshift operator or value of a at time t. a_t is the residual of the model at time t. We selected the autoregressive coefficients (i.e., moving average and autoregressive parameters) based on AIC and the Ljung-Box Q statistic. If the dependent variable exhibited no autocorrelation, we indicated that it had "none," (see **Table 1**) meaning that no autocorrelation modeled by either a moving average or autoregressive parameters appeared. The sex ratio, female infant mortality, and female births, for example, exhibited no autocorrelation (no autoregressive or moving average parameters) implying that Granger Causation reduces to a simple regression that asks whether knowing when the Laki event occurred allows prediction of the observed values of y better than the mean of y for all values before and after the eruption.

The above steps use Box-Jenkins methods to apply Wiener-Granger logic in that they remove from the dependent variable any cycles or trends induced, for example, by seasonal weather changes, population growth or decline, or the status of the economy. Any association discovered between the Laki event and perinatal outcomes cannot arise from shared trends, seasonality, or regression to the mean after high or low values because the Box-Jenkins routines remove such autocorrelation. We performed analyses using Scientific Computing Associates Statistical System (Scientific Computing Associates, 2017).

References

1. Box G, Jenkins G, Reinsel G. *Time Series Analysis: Forecasting and Control*. 4th ed. Hoboken, NJ: Wiley, 2008.