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A diagnostic tool for Weibull tail-distributions

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Abstract

In this paper, we propose a diagnostic tool to visually assess if a dataset is Weibull tail-distributed. It also leads to new estimators of the Weibull tail-coefficient based on linear regression methods.

Weibull tail-distributions are defined through their distribution function by:

$$F(x) = 1 - \exp \left\{ -x^{1/\theta} \ell(x) \right\} \quad (1)$$

where ℓ is a slowly-varying function, see Table 1 for examples and [20] for a review. A sufficient condition for subexponentiality has been established in [19], Theorem 1. Mixtures of Weibull tail-distributions are studied in [21].

There exist numerous estimators of $\theta > 0$. Berred [5] uses record values while most of estimators are based on the largest observations of the sample: Asimit *et al.* [1], Beirlant *et al.* [2, 3, 4], Broniatowski [6], Diebolt *et al.* [7, 8], Dierckx *et al.* [9], Gardes *et al.* [10, 11, 12, 13, 18], Girard [14], Goegebeur *et al.* [15, 16] and Mercadier *et al.* [17].

Equivalently, one can show that the $(1 - \alpha)$ th quantile of a Weibull tail-distribution is given by

$$q(\alpha) = (\log(1/\alpha))^\theta L(\log(1/\alpha)) \quad (2)$$

where L is a slowly-varying function and $\alpha \in (0, 1)$.

Theorem. *Let F be defined following (1). Then,*

$$\log q(\alpha) \sim \theta \log \log(1/\alpha)$$

as $\alpha \rightarrow 0$.

Proof. Clearly, as $\alpha \rightarrow 0$, properties of slowly-varying functions entail:

$$\log q(\alpha) = \theta \log(\log(1/\alpha)) + \log L(\log(1/\alpha)) \sim \theta \log \log(1/\alpha). \quad (3)$$

Let X_1, \dots, X_n be a sample from F and denote by $X_{1,n} \leq \dots \leq X_{n,n}$ the corresponding upper order statistics. As a consequence, for a fixed number k of upper order statistics, the points $(\log \log(n/i), \log X_{n-i+1,n})$, $i = 1, \dots, k$ are approximately located on a line with slope θ . We believe that this property has great practical consequences. It permits to visually assess if the dataset is Weibull tail-distributed and to estimate θ with linear regression methods. It can be interpreted as a particular QQ-plot.

Recall that a QQ plot is a plot of the quantiles of two distributions against each other, or more generally a plot based on estimates of the quantiles. The pattern of points in the plot is used to compare the two distributions. The main step in constructing a QQ plot is calculating or estimating the quantiles to be plotted. If one or both of the axes in a QQ plot is based on a theoretical distribution with a continuous cumulative distribution function, all quantiles are uniquely defined and can be obtained by inversion. If the QQ plot is based on data, there are multiple quantile estimators in use. Rules for forming QQ plots when quantiles must be estimated or interpolated are called plotting positions.

A simple case is where one has two data sets of the same size. In that case, to make the QQ plot, one orders each set in increasing order, then pairs off and plots the corresponding values. A more complicated construction is the case where two data sets of different sizes are being compared. To construct the QQ plot in this case, it is necessary to use an interpolated quantile estimate so that quantiles corresponding to the same underlying probability can be constructed. In the general case, given two cumulative probability distribution functions F and G , the QQ plot draws the α th quantile of F against the α th quantile of G for a range of values of α . Thus, the QQ plot is a curve indexed over $[0, 1]$ with values in the real plane.

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Distribution	θ
Gaussian $\mathcal{N}(\mu, \sigma^2)$	$1/2$
Gamma $\Gamma(\alpha, \lambda)$	1
Weibull $\mathcal{W}(\alpha, \lambda)$	$1/\alpha$

Table 1: Weibull tail-distributions