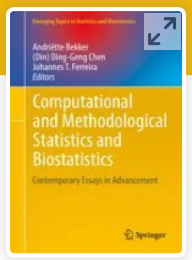

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Modelling Earthquakes: Characterizing Magnitudes and Inter-Arrival Times

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Abstract

Statistical modelling of earthquakes is a challenging and delicate topic: research activity is vivid in this respect, and tailored to an improved understanding of the seismic phenomena and of their dynamics over time and space in all its shades. By surfing on some of the available literature, a critical investigation of the probability distributions best fitting earthquake sizes and inter-arrival times is performed, by using data on the Pacific Ring of Fire as illustrative example. As a by-product of our analysis, new ideas about adequate modelling of earthquake sizes and inter-event times together with the location of the earthquakes are advanced, which in turn

could pave the way to further developments in a directional perspective.

Keywords

Earthquake size
Statistical modelling
Probability distribution
Power-law models
Earthquake interarrival times
Composite models
Lognormal distribution
Tapered Pareto distribution
Corner moment
Pareto distribution
Gutenberg-Richter law
Generalized Gamma distribution
Pacific Ring of Fire
Goodness of fit
Earthquake seismic moments
Earthquake magnitude
Shallow earthquakes
Data analysis
Maximum likelihood
Seismic hazard
Probability of a major shock
Earthquake catalog
Exponential distribution
Gamma distribution
Weibull distribution
Bayesian Information Criterion
QQ-plot
Circular-linear data
Abe-Ley model
Spherical-linear data

Notes

1. Some other methods are proposed in del Castillo and Puig (1999) to speed up the convergence of the LRT distribution to its asymptotic distribution.

2. Here, D_i denotes the ith decile of the seismic moments distribution.

References

Abe, T., & Ley, C. (2017). A tractable, parsimonious and flexible model for cylindrical data, with applications. *Econometrics and Statistics, 4*, 91–104.

Abu Bakar, S. A. (2015). gendist: Generated probability distribution models. R package version 1.0.

https://CRAN.R-project.org/package=gendist

Betbeder-Matibet, J. (2008). Seismic engineering. *Wiley Online Library*. https://doi.org/10.1002/9780470611135. Online ISBN:9780470611135.

Chen, C.-H., Wang, J.-P., Wu, Y.-M., Chan, C.-H., & Chang, C.-H. (2013). A study of earthquake inter-occurrence times distribution models in Taiwan. *Natural Hazards, 69*, 1335–1350.

Cooray K., & Ananda M. M. A. (2005). Modeling actuarial data with a composite lognormal-Pareto model. *Scandinavian Actuarial Journal, 5*, 321–334.

Corral, A. (2004). Long-term clustering, scaling, and universality in the temporal occurrence of earthquakes. *Physical Review Letters, 92*, 108501.

Cremers, J., Pennings, H. J. M., & Ley, C. (2019). *Regression models for cylindrical data in psychology*. Multivariate Behavioral Research, in press.

del Castillo, J. (1994). The singly truncated normal distribution, a non-steep exponential family. *Journal of the Royal Statistical Society Series A, 46*, 57–66.

del Castillo, J., & Puig, P. (1999). The best test of exponentiality against singly truncated normal alternatives. *Journal of the American Statistical Association, 94*, 529–532.

Dominicy, Y., & Sinner, C. (2017). Distributions and composite models for size-type data. In T. Hokimoto (Ed.), *Advances in statistical methodologies and their applications to real problems*. London: IntechOpen. https://doi.org/10.5772/66443.

Dutang, C., Goulet, V., & Pigeon, M. (2008). actuar: An R package for actuarial science. *Journal of Statistical Software, 25*(7), 1–37. http://www.jstatsoft.org/v25/i07

Ficcadenti, V., & Cerqueti, R. (2017). Earthquakes economic costs through rank-size laws. *Journal of Statistical Mechanics: Theory and Experiments, 2017*, 083401.

Gutenberg, B., & Richter, C. F. (1941). Seismicity of the Earth. *Geological Society of America Special Papers, 34*, 1–131.

Hollander, M., & Proschan, F. (1972). Testing whether new is better than used. *Annals of Mathematical Statistics, 43*, 1136–1146.

Kagan, Y. Y. (1969). A study of the energy of the seismoacoustic pulses arising during bursts in a coal

bed. *Izvestiya Physics of the Solid Earth*, 85–91 (English translation).

Kagan, Y. Y. (1993). Statistics of characteristic earthquakes. *Bulletin of the Seismological Society of America, 83*, 7–24.

Kagan, Y. Y. (1997). Seismic moment-frequency relation for shallow earthquakes: Regional comparison. *Journal of Geophysical Research, 102*, 2835–2852.

Kagan, Y. Y., & Knopoff, L. (1984). A stochastic model of earthquake occurrence. In *Proceedings of the 8th International Conference on Earthquake Engineering* (Vol. 1, pp. 295–302).

Kagan, Y. Y., & Schoenberg, F. (2001). Estimation of the upper cutoff parameter for the tapered Pareto distribution. *Journal of Applied Probability, 38A*, 168–185.

Lagona, F., Picone, M., & Maruotti, A. (2015). A hidden Markov model for the analysis of cylindrical time series. *Environmetrics, 26*, 534–544.

Lomnitz, C. (1964). Estimation problems in earthquake series. *Tectonophysics, 1*, 130–144.

Lomnitz-Adler, J., & Lomnitz, C. (1979). A modified form of the Gutenberg-Richter magnitude-frequency relation.

Bulletin of the Seismological Society of America, 69, 1209–1214.

Malevergne, Y., Pisarenko, V., & Sornette, D. (2011). Testing the Pareto against the lognormal distribution with the uniformly most powerful unbiased test applied to the distribution of cities. *Physical Review E, 83*, 036111.

Mitzenmacher, M. (2003). A brief history of generative models for power law and lognormal distributions. *Internet Mathematics, 1*, 226–251.

Musson, R. M. W., Tsapanos, T., & Nakas, C. T. (2002). A power-law function for earthquake interarrival time and magnitude. *Bulletin of the Seismological Society of America, 92*, 1783–1794.

NCEDC (2014). Northern California Earthquake Data Center. UC Berkeley Seismological Laboratory. https://doi.org/10.7932/NCEDC.

Nishenko, S. P. (1991). Circum Pacific seismic potential. *Pageoph, 135*, 169–259.

Panagiotopoulos, D. C. (1995). Long-term earthquake prediction in Central America and Caribbean Sea based on the time- and magnitude-predictable model. *Bulletin of the Seismological Society of America, 85*, 1190–1201.

Pareto, V. (1897). Cours d'Économie Politique, Tome Second, Lausanne, F. Rouge, quoted by Pareto, V. (1964), Oeuvres Complètes, published by de Giovanni Busino, Genève, Droz, vol II.

Rydelk, P. A., & Sacks, I. S. (1989). Testing the completeness of earthquake catalogues and the hypothesis of self-similarity. *Nature, 337*, 251–253.

Sadeghianpourhamami, N., Benoit, D. F., Deschrijver, D., & Develder, C. (2019). Bayesian cylindrical data modeling using Abe-Ley mixtures. *Applied Mathematical Modelling, 68*, 629–642.

Schoenberg, F. P., Barr, C., & Seo, J. (2009). The distribution of Voronoi cells generated by Southern California earthquake epicenters. *Environmetrics, 20*, 159–171.

Schorlemmer, D., Mele, F., & Marzocchi, W. (2010). A completeness analysis of the National Seismic Network of Italy. *Journal of Geophysical Research 115*, B04308.

Slifka, M. K., Whitton, J. L., Sierra, I., & Corral, A. (2000). Deviation from power law of the global seismic moment distribution. *Scientific Reports, 7*, 40045. https://doi.org/10.1038/srep40045.

Sornette, D., & Sornette, A. (1999). General theory of the modified Gutenberg-Richter law for large seismic

moment. *Bulletin of the Seismological Society of America, 89*, 1121–1130.

Stacy, E. W. (1962). A generalization of the Gamma distribution. *Annals of Mathematical Statistics, 33*, 1187–1192.

Utsu, T. (1999). Representation and analysis of the earthquake size distribution: A historical review and some new approaches. *Pure and Applied Geophysics, 155*, 509–535.

Vere-Jones, D., Robinson, R., & Yang W. Z. (2001). Remarks on the accelerated moment release model: Problems of model formulation, simulation and estimation. *Geophysical Journal International, 144*, 517–531.

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