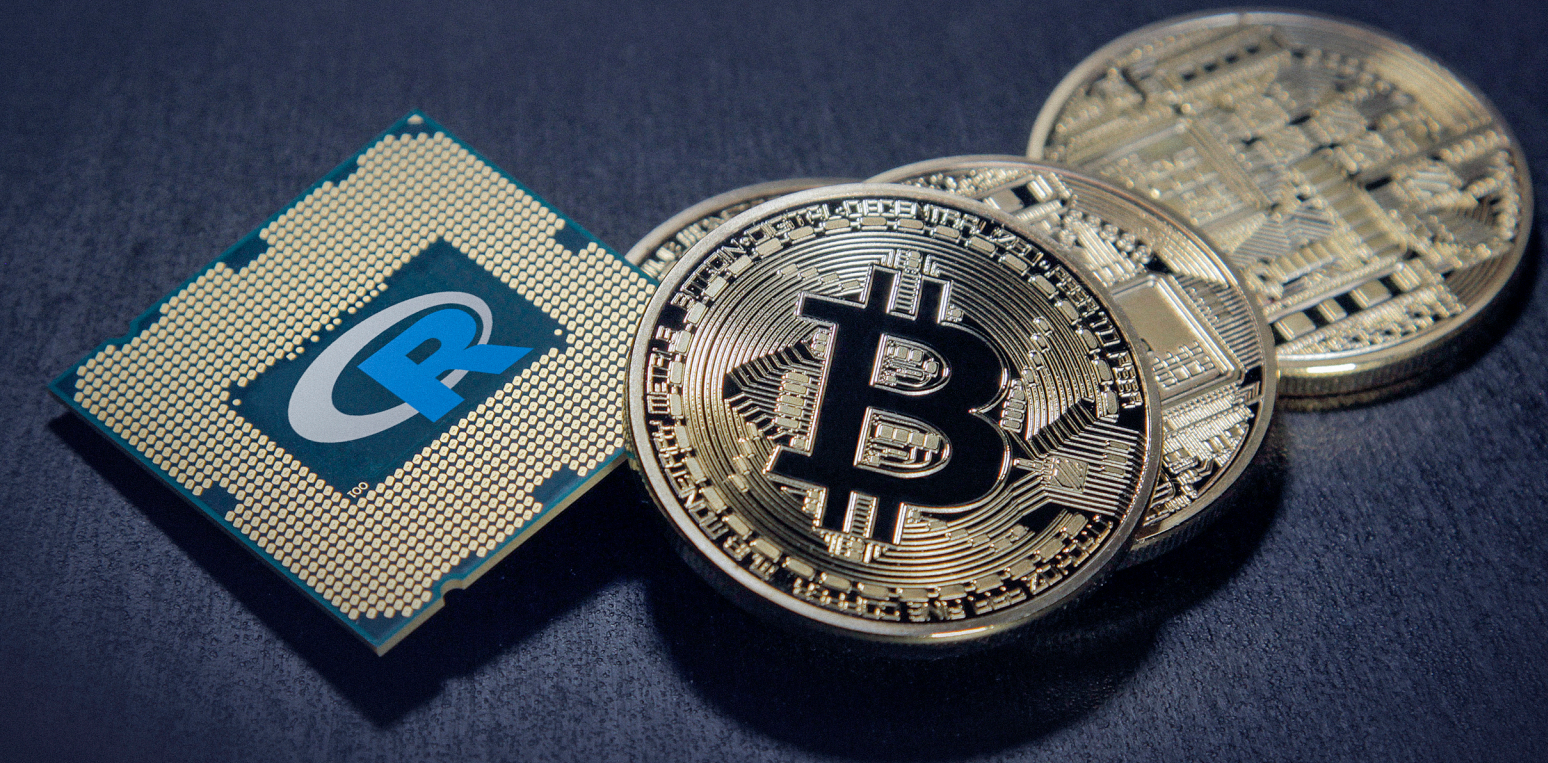
QUANTITATIVE FINANCE WITH R AND CRYPTOCURRENCIES



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Quantitative finance with R and cryptocurrencies

Dean Fantazzini

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Preface

I wrote this book with the idea to organise the materials that I developed over time for the Perm Summer/Winter School on Blockchain & CryptoEconomics, as well as for my course in Numerical methods for finance using R. This book also introduces the R packages **bitcoinFinance** and **bubble**, which are mainly (but not only) devoted to the financial analysis of bitcoin in particular, and cryptocurrencies in general.

Let's make things clear immediately: the meteoric rise of cryptocurrencies in the last years bears all the symptoms of the famous dot-com bubble, and it is very likely we will witness in the future a bubble burst similar to what happened in 2000/2001. However, similarly to the aftermath of the dot-com bubble, this price collapse will select the most reliable companies and the most resilient technologies. In this regard, Sornette (2008), Gisler and Sornette (2009), Gisler and Sornette (2010), Gisler et al. (2011), and Gisler et al. (2013) introduced the so-called 'social bubble hypothesis' which claims that *strong social interactions between enthusiastic supporters weave a network of reinforcing feedbacks that lead to widespread endorsement and extraordinary commitment by those involved, beyond what would be rationalized by a standard cost-benefit analysis.* Notably, they emphasise that *... collective over-enthusiasm similar to those developing during financial bubbles seems a necessary and unavoidable process to foster a collective attitude towards risk-taking, breaking the stalemate of society that is restrained in a tendency towards risk avoidance* [1]. It is for these reasons that bubbles may not be necessarily evil, given they can foster new ideas/concepts/ projects.

This book aims to provide the necessary background to analyze cryptocurrency prices, focusing on price modelling, bubble testing, market risk management and credit risk management. This knowledge will be particularly useful when the inevitable technology selection will take place, either after a market price collapse like the bursting of the dot-com bubble in 2000-2001, or simply by the discovery of limitations/bugs/problems that make the large scale adoption of a specific cryptocurrency impossible.

To whom the book is addressed

This book is intended for both undergraduate and graduate students in economics, finance, and statistics, financial professionals, researchers and anyone interested in cryptocurrencies financial modelling. I assume that the reader has a background in mathematics, statistics, and financial econometrics, as well as a working knowledge of R software.

[1] http://www.er.ethz.ch/media/publications/social-systems-finance/social_bubbles.html

If you need a quick introduction or a fast refresh of R programming, I recommend this thread at stackexchange.com[2]. If you prefer a more systematic approach at the textbook level, I suggest the following list (with an increasing level of difficulty):

- Knell, R. (2014). *Introductory R: A Beginner's Guide to Data Visualisation, Statistical Analysis, and Programming in R.* Amazon Digital Services LLC.
- Wickham, H., & Grolemund, G. (2016). *R for Data Science: Import, Tidy, Transform, Visualize, and Model Data.* O'Reilly Media, Inc.
- Matloff, N. (2011). *The art of R programming: A tour of statistical software design.* No Starch Press.
- Wickham, H. (2014). *Advanced R.* CRC Press.
- Burns, P. (2012). *The R inferno.* Lulu.com.

If you need an introduction to financial modelling and econometrics using R, I strongly recommend these textbooks:

- Bennett, M.J., Hugen, D.L. (2016). *Financial Analytics with R: Building a Laptop Laboratory for Data Science.* Cambridge University Press.
- Ang, C. (2015). *Analyzing financial data and implementing financial models using R.* Springer.
- Tsay, R. S. (2010). *Analysis of financial time series.* Wiley, 3rd edition.
- McNeil, A.J., Frey, R., Embrechts, P. (2015). *Quantitative risk management: Concepts, techniques and tools.* Princeton university press.

Structure of the book

This book consists of three parts: the first part is devoted to cryptocurrency markets and explains how to retrieve cryptocurrency data, how to compute liquidity measures with this data, how to calculate bounds for bitcoin (and other cryptocurrencies') fundamental value and how competing exchanges contribute to the price discovery process in the Bitcoin market. The second part is devoted to time series analysis with cryptocurrencies and presents a large set of univariate and multivariate time series models, tests for financial bubbles and explosive price behaviour, as well as univariate and multivariate volatility models. The third part focuses on risk and portfolio management with cryptocurrencies and shows how to measure and backtest market risk, how to build an optimal portfolio according to several approaches, how to compute the probability of closure/bankruptcy of a crypto-exchange, and how to compute the probability of death for crypto-assets. More specifically:

[2] https://stats.stackexchange.com/questions/138/free-resources-for-learning-r

Chapter 1 briefly reviews how Bitcoin works and provides an introduction to a selected group of competing cryptocurrencies.

Chapter 2 presents several methods to download (free) cryptocurrency market data from the web, including both trade data and order-book data.

Chapter 3 provides a brief review of liquidity measures and shows how to compute these measures with R and free cryptocurrency data.

Chapter 4 implements the main models proposed to compute the upper and lower bounds for bitcoin fundamental value, ranging from market sizing to the bitcoin marginal cost of production based on electricity consumption.

Chapter 5 shows how to compute the information share of various bitcoin exchanges concerning the information generated by the whole market.

Chapter 6 presents univariate time series models for modelling short-term price dynamics, while Chapter 7 discusses multivariate time series models.

Chapter 8 reviews and implements the main approaches proposed to detect financial bubbles and explosive behaviour in cryptocurrency prices.

Chapter 9 discusses univariate volatility models, while multivariate volatility models are introduced in Chapter 10.

Chapter 11 provides a treatment of the theoretical concepts and modelling techniques for market risk management and presents several empirical examples and applications with crypto-currencies.

Chapter 12 implements some of the leading portfolio management models with cryptocurrencies data, and compare them to a simple approach for portfolio diversification recently proposed by Kristoufek (2013) using Google Trends data.

Chapter 13 is devoted to credit risk management models, focusing on the probability of bankruptcy/closure of an exchange trading crypto-assets, as well as the probability of death for a crypto-asset.

Chapter 14 briefly concludes and highlights several challenges ahead for cryptocurrencies.

This book can be used for different courses:

- chapters 6-13 can be useful for courses in portfolio and risk management or financial econometrics;
- chapters 1-2, 6-10 can be used for a course in time series analysis;
- chapters 1-5, 13 can be discussed within a course strictly focused on crypto-assets and crypto-exchanges;
- chapters 3-5, 8, 11-13 can be considered in a course devoted to advanced quantitative finance.

In general, I have noticed that students tend to pay much more attention if cryptocurrencies are used as applied examples within traditional courses, like econometrics/time series analysis/risk management, etc.

The R scripts, the datasets used in the text, and any potential updates can be found on the book's companion website: https://sites.google.com/view/quafirc .

Finally, I want to inform the reader that I did not discuss derivatives because, in the case of cryptocurrencies, they are still in their infancy: the CME and the CBOT introduced the first futures on bitcoin only in December 2017. Moreover, options on crypto-currencies are currently traded only on small and illiquid exchanges, which are poorly regulated and therefore rather risky.

Acknowledgments

First, this book would not exist without the R software developed by the R Development Core Team, and thus I want to thank the R Development Core Team for their great work, as well as all the R package authors whose packages I cited and employed in this book.

Second, I'd like to thank my students, whose enthusiasm, dedication and work contributed immensely in starting this project.

I want to give special thanks to Sergey Ivliev and Lena Mechenkova for bringing me closer to bitcoin and the exciting world of cryptocurrencies: I really enjoyed talking about bitcoin while doing rafting in the Ural mountains!

Several colleagues helped me along the way. Boris Demeshev kindly and generously read my R packages and this textbook at various stages of development and provided me with valuable feedback. Olga Demidova, Grigory Kantorovich and Mario Maggi reviewed the manuscript and provided useful comments and suggestions. Special thanks to Alexander Nekipelov, Sergey Shakin and Maxim Nikitin for being supportive of this project throughout its entire development. A particular thought goes definitely to the long-lasting memory of my friend and colleague Sergey A. Aivazian, who supported me since the beginning of this work, but unfortunately passed away a few months before the publication of this book.

The R logo on the front cover is from https://www.r-project.org/logo/Rlogo.svg and is ©2016 *The R Foundation*. It is used under the terms of the Creative Commons Attribution-ShareAlike 4.0 International license, see https://creativecommons.org/licenses/by-sa/4.0/ for more information. No changes were made to the logo itself, except for a small change in its orientation and its background color. The logo was overlaid onto a microchip image on the book cover. I am grateful to Yihui Xie, software engineer working at RStudio, Inc, for solving some issues related to the R packages bookdown and tinytex, which I used to write this book.

Lastly, I want to thank my wife and sons for their support and patience: without their unconditional love and trust, I would not have been able to finish this book.

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