Introduction to Quantitative Finance for Cryptocurrency using R

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White Paper

Analytics and Insights

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**Table of Content**

[Abstract 3](#_Toc511331170)

[1. Cross Hedging of Cryptocurrency 4](#_Toc511331171)

[1.1 Cryptocurrency 4](#_Toc511331172)

[1.2 Data Summary 6](#_Toc511331173)

[1.3 Cross Hedging Bitcoin 7](#_Toc511331174)

[2. Cryptocurrency Portfolio Optimization 8](#_Toc511331175)

[2.1 Cryptocurrency 8](#_Toc511331176)

[2.2 Minimum Variance Portfolio 10](#_Toc511331177)

[3. Asset Pricing Models for Cryptocurrency 12](#_Toc511331178)

[3.1 Cryptocurrency 12](#_Toc511331179)

[3.2 Market Portfolio and Risk Free Asset 13](#_Toc511331180)

[3.3 Capital Asset Pricing Model 14](#_Toc511331181)

# Abstract

**Introduction to Quantitative Finance for Cryptocurrency using R**

Cryptocurrency is a type of digital currency that uses cryptography for security and anti-counterfeiting measures. Public and private keys are often used to transfer cryptocurrency between individuals. Cryptocurrency must be cryptographically signed each time they are transferred, each user has both public and individual private keys.

In this paper we have addressed rea -world quantitative finance for cryptocurrency problems using the statistical computing language R. We have covered cross hedging of cryptocurrency, cryptocurrency portfolio optimization and asset pricing models for cryptocurrency.

For demonstration purposes, we have fetched the following cryptocurrencies from Kaggle dataset (https://www.kaggle.com/sudalairajkumar/cryptocurrencypricehistory/data):

* Bitcoin (BTC)
* Ethereum (ETH)
* Ripple (XRP)
* Litecoin (LTC)
* Monero (XMR)
* DASH (DASH)
* NEM (XEM)

# Cross Hedging of Cryptocurrency[[1]](#footnote-1)

## Cryptocurrency

A cryptocurrency a digital asset designed to work as a medium of exchange that uses cryptography to secure its transactions. Cryptocurrencies are classified as a subset of digital currencies and are also classified as a subset of alternative currencies and virtual currencies.

**Figure 1: How Cryptocurrency works**

**The economics behind cryptocurrency:** Cryptocurrency is essentially a fiat currency. This means users must reach a consensus about cryptocurrency's value and use it as an exchange medium. However, because it is not tied to a particular country, its value is not controlled by a central bank. With bitcoin, the leading functioning example of cryptocurrency, value is determined by market supply and demand, meaning that it behaves much like precious metals, like silver and gold. Cryptocurrency is designed to bring back a "decentralized currency of the people", taking centralized banks out of the equation. Because bitcoins must be cryptographically signed each time they are transferred, each bitcoin user has both public and individual private keys.

**Possible abuse of crypto currencies:** Cryptocurrency transactions are anonymous, untraceable and have created a niche for illegal transactions, like drug trafficking. Because the currency has no central repository, law enforcement and payment processors have no jurisdiction over bitcoin accounts. For cryptocurrency supporters, this anonymity is a primary strength of this technology, despite the potential for illegal abuse, as it enables a shift in power from institutions to individuals.

**Types of Cryptocurrencies:** Although there are technically over 1000 cryptocurrencies, only few are discussed below:

**Figure 2: Types of Cryptocurrencies**

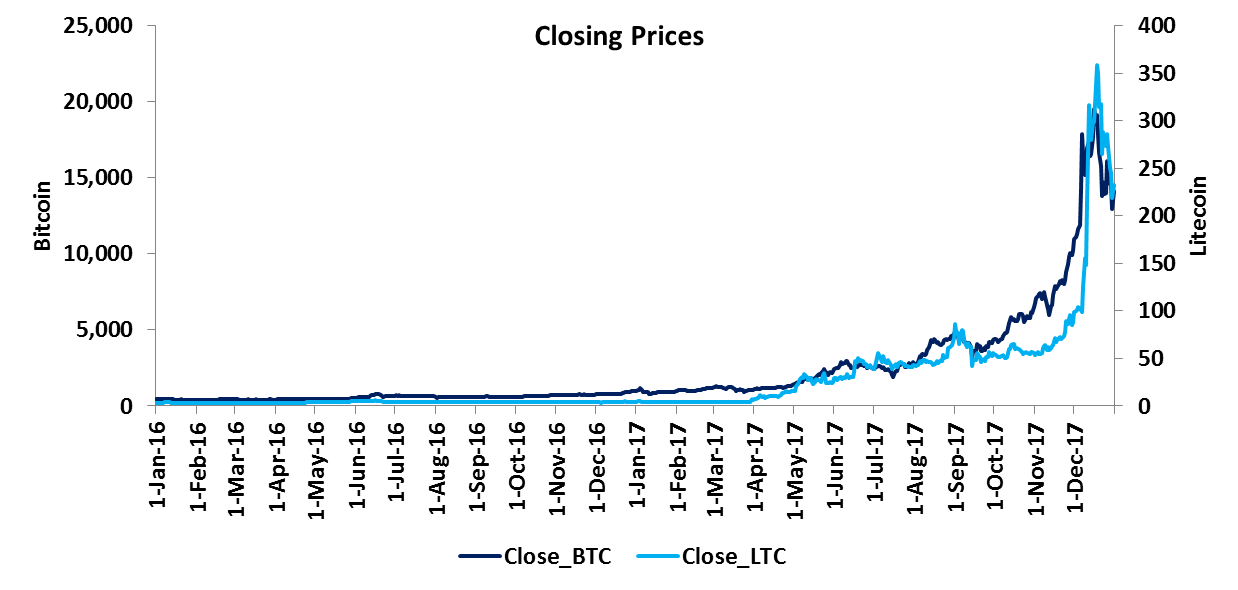
|  |  |
| --- | --- |
| Prevailing bitcoin logo | **Bitcoin (BTC):** Bitcoin is the first decentralized digital currency, as the system works without a central bank or single administrator. It has the highest market cap, its coins generally trade at the highest cost of all cryptocurrencies. Bitcoins are created as a reward for a process known as mining. |
| C:\Users\rg83892\Desktop\download.png | **Ethereum (ETH):** Ether is a cryptocurrency whose blockchain is generated by the Ethereum platform. Ether can be transferred between accounts and used to compensate participant mining nodes for computations performed. It doesn’t have the longevity at the top like Litecoin, but it is built on a system that other coins are built on. Most ICOs (Initial Coin Offerings) use ethereum. |
| Ripple logo.svg | **Ripple (XRP):** Ripple was released in 2012, Ripple purports to enable secure, instantly and nearly free global financial transactions of any size with no chargebacks. Ripple tends to have a steady price due to its large supply. It has had staying power over time. |
| 6 Full Logo S-2.png | **Litecoin (LTC):** Litecoin is a peer-to-peer cryptocurrency and open source software project released under the MIT/X11 license. The Litecoin Network aims to process a block every 2.5 minutes, rather than Bitcoin's 10 minutes. The developers claim that this allows Litecoin to have faster transaction confirmation. |
| Monero-Logo.svg | **Monero (XMR):** Monero is an open-source cryptocurrency created in April 2014 that focuses on privacy and decentralization that runs on Windows, macOS, Linux, Android, and FreeBSD. Monero uses a public ledger to record transactions while new units are created through a process called mining. |
| https://upload.wikimedia.org/wikipedia/en/thumb/a/a6/Dash_%28cryptocurrency%29_logo.svg/220px-Dash_%28cryptocurrency%29_logo.svg.png | **DASH (DASH):** Dash is an open source peer-to-peer cryptocurrency. On top of Bitcoin's feature set, it currently offers instant transactions, private transactions and operates a self-governing and self-funding model that enables the Dash network to pay individuals and businesses to perform work that adds value to the network. |
| NEM (cryptocurrency) logo.svg | **NEM (XEM):** NEM was launched on March 31, 2015. NEM has a stated goal of a wide distribution model and has introduced new features to blockchain technology such as its proof-of-importance (POI) algorithm, multisignature accounts, encrypted messaging, and an Eigentrust++ reputation system. |

## Data Summary (Bitcoin and Litecoin)

Time series analysis is concerned with the analysis of data collected over time. Adjacent observations are typically dependent. Time series analysis hence deals with techniques for the analysis of this dependence.

We create a time series objects from the daily closing prices of Bitcoin and Litecoin. To get a first impression of the data, we plot the price chart:

**Figure 3: Closing prices of Bitcoin (BTC) and Litecoin (LTC)**



**Table 1: Date Range and Data Range**



When dealing with time series, one is normally more interested in returns instead of prices. This is because returns are usually stationary. So we will calculate continuously compounded returns:

|  |  |
| --- | --- |
| **R Code to calculate the continuous returns** | **assets = data[, -1]**  **return = log(tail(assets, -1) / head(assets, -1))** |

## Cross Hedging Bitcoin

Since the price of Bitcoin can be volatile, most investors should hedge at least part of their exposure to Bitcoin price changes. In the absence of Bitcoin OTC instruments, investors can use related cryptocurrencies for hedging purposes. In this example, Litecoin has been used to hedge.

**Cointegration: The idea behind cointegration is to find a linear combination between non-stationary time series that result in a stationary time series. It is hence possible to detect stable long-run relationships between non-stationary time series.**

Testing Bitcoin for stationarity: The null hypothesis of non-stationarity (Bitcoin time series contains a unit root) cannot be rejected at the 1% significance level

**Table 2: Testing Bitcoin for stationarity**



Testing Litecoin for stationarity: The null hypothesis of non-stationarity (Litecoin time series contains a unit root) cannot be rejected at the 1% significance level

**Table 3: Testing Litecoin for stationarity**



Now we try to estimate the hedge ratio by using an existing long-run relationship between the levels of Bitcoin and Litecoin prices. **We obtain a hedge ratio of 61.23.**

**Table 4: Estimating hedge ratio**



Testing error for stationarity: The null hypothesis of non-stationarity is rejected at the 1% significance level

**Table 5: Testing error for stationarity**



# Cryptocurrency Portfolio Optimization[[2]](#footnote-2)

## Cryptocurrency

For demonstration purposes, we have fetched the following cryptocurrencies from Kaggle dataset. The observation window is from 20-Aug-2016 to 20-Feb-2018.

* Bitcoin (BTC)
* Ethereum (ETH)
* Ripple (XRP)
* Litecoin (LTC)
* Monero (XMR)
* DASH (DASH)
* NEM (XEM)

|  |  |
| --- | --- |
| **R Code to calculate the continuous returns** | * **assets = data[, -1]** * **return = log(tail(assets, -1) / head(assets, -1))** |

**Table 6: Data Summary of Close Price**



**Table 7: Data Summary of Returns**



**Table 8: Comparison of Volatility with NASDAQ Composite**



**Figure 4: Close Price and Daily Return**

|  |  |  |
| --- | --- | --- |
| **Prevailing bitcoin logo** |  |  |
| **C:\Users\rg83892\Desktop\download.png** |  |  |
| **Ripple logo.svg** |  |  |
| **6 Full Logo S-2.png** |  |  |
| **Monero-Logo.svg** |  |  |
| **https://upload.wikimedia.org/wikipedia/en/thumb/a/a6/Dash_%28cryptocurrency%29_logo.svg/220px-Dash_%28cryptocurrency%29_logo.svg.png** |  |  |
| **NEM (cryptocurrency) logo.svg** |  |  |

## Minimum Variance Portfolio

For the mathematical formulation of Mean-Variance model by Markowitz, we need some definitions. They are explained as follows:

* By asset Xi, we mean a random variable with finite variance.
* By portfolio, we mean the combination of assets: P =­ ΣwiXi , where Σ­wi = 1
* By optimization, we mean a process of choosing the best wi coefficients (weights) so that our portfolio meets our needs (that is, it has a minimal risk on the given expected return or has the highest expected return on a given level of risk).

|  |  |
| --- | --- |
| **R Code to check the head and tail of return** | * **head(return)** * **tail(return)** |

**Table 9: Head of Return Dataframe**



**Table 10: Tail of Return Dataframe**



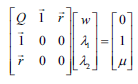
Minimum variance on a desired level of return: It is clear that wTQw is the variance of the portfolio and wr is the expected return. For the sum of the weights we have w1 =1, which means that we would like to invest 1 unit of cash.

**Equation 1: Minimum Variance**



It can be shown that this problem is equivalent to the following system of linear equations. Two rows and two columns are added to the covariance matrix, so we have conditions to determine the two Lagrange multipliers as well. We can expect a unique solution for this system.

**Equation 2: Linear Equation**



We start building the left side of the linear equality system specified at the Lagrange theorem, where we combine the covariance matrix (cov), ones repeated (rep) by the number of columns (ncol) in the dataset and the means (colMeans) of the returns as rows (rbind). Now, we also combine the last two rows of the matrix (tail) as new columns (rbind) on the left to make it complete for the linear system with the extra zeros specified in the Lagrange theorem (matrix of 2x2):

|  |  |
| --- | --- |
|  | * **Q = rbind(cov(return), rep(1, ncol(assets)), colMeans(return))** * **Q = cbind(Q, rbind(t(tail(Q, 2)), matrix(0, 2, 2)))** * **round(Q, 5)** |

**Table 11: Left Part of the Equation**



Next, we build the right side of the linear equality system. Expected return (mu) is 0.005 and ones repeated (rep) by the number of columns (ncol):

|  |  |
| --- | --- |
|  | * **mu = 0.005** * **b = c(rep(0, ncol(assets)), 1, mu)** * **round(b, 5)** |

**Table 12: Right Part of the Equation**



After successfully building the parts of the linear equality system, we are only left with the task of solving it. **The result is the vector of optimal weights and the Lagrange multipliers to get the desired expected return with a minimal variance:**

|  |  |
| --- | --- |
|  | * **w = solve(Q, b)** * **round(w,5)** |

**Table 13: Weights**



# Asset Pricing Models for Cryptocurrency

## Cryptocurrency

For demonstration purposes, we have fetched the following cryptocurrencies from Kaggle dataset. The observation window is from 20-Feb-2017 to 20-Feb-2018.

* Bitcoin (BTC)
* Ethereum (ETH)
* Ripple (XRP)

**Figure 5: Bitcoin Close Price and Daily Return**

|  |  |
| --- | --- |
|  |  |

**Figure 6: Ethereum Close Price and Daily Return**

|  |  |
| --- | --- |
|  |  |

**Figure 7: Ripple Close Price and Daily Return**

|  |  |
| --- | --- |
|  |  |

## Market Portfolio and Risk Free Asset

A market portfolio is a theoretical bundle of investments that includes every type of asset available in the world financial market, with each asset weighted in proportion to its total presence in the market. The expected return of a market portfolio is identical to the expected return of the market as a whole.

**NASDAQ Composite (IXIC):** The NASDAQ Composite is a stock market index of the common stocks and similar securities listed on the NASDAQ stock market. Along with the Dow Jones Average and S&P 500 it is one of the three most-followed indices in US stock markets. The composition of the NASDAQ Composite is heavily weighted towards information technology companies.

**Figure 8: NASDAQ Close Price and Daily Return**

|  |  |
| --- | --- |
|  |  |

A risk-free asset has a certain future return. Treasuries are considered to be risk-free because they are backed by the U.S. government. Because they are so safe, the return on risk-free assets is very close to the current interest rate.

**LIBOR:** The London Inter-bank Offered Rate is the average of interest rates estimated by each of the leading banks in London that it would be charged were it to borrow from other banks. It was formerly known as BBA Libor (for British Bankers' Association Libor) before the responsibility for the administration was transferred to Intercontinental Exchange. It is the primary benchmark, along with the Euribor, for short-term interest rates around the world.

**Figure 9: LIBOR Close Price and Daily Return**

|  |  |
| --- | --- |
|  |  |

## Capital Asset Pricing Model

The Capital Asset Pricing Model (CAPM) gives an answer to the question asking what can be said of the market by aggregating the rational investors' decisions. The market portfolio contains all securities and the proportion of each security is its market value as a percentage of the total market value. The risk premium on the market depends on the average risk aversion of all market participants. The best-known consequence of the resulting equilibrium is a linear relationship between market risk premium and the individual security's risk.

**Equation 3: CAPM Linear Relationship**

E(ri) − rf = βi [E(rm) – rf]

* E(ri) is the expected return of a certain security
* rf is the risk-free return
* E(rm) is the expected return of the market portfolio.

The risk in CAPM is measured by the beta βi, which is a function of the individual security's covariance with the market and the variance of the market return. Beta has numerous interpretations. On the one hand, beta shows the sensitivity of a stock's return to the return of the market portfolio and, on the other, a certain security's beta shows how much risk that security adds to the market portfolio. The CAPM states that the market gives a higher return only in cases of higher systematic risk since unsystematic risk can be diversified, so no risk premium can be paid after that:

**Equation 4: Beta Equation (Approach 1)**

βi = Covi,m / Varm

* Covi,m is the covariance between the given security's return and the market return
* Varm is the variance of the market return.

|  |  |
| --- | --- |
| **R Code to calculate Beta (Approach 1)** | * **cov(return$BTC - return$LIBOR, return$IXIC - return$LIBOR) / var(return$IXIC - return$LIBOR)** * **cov(return$ETH - return$LIBOR, return$IXIC - return$LIBOR) / var(return$IXIC - return$LIBOR)** * **cov(return$XRP - return$LIBOR, return$IXIC - return$LIBOR) / var(return$IXIC - return$LIBOR)** |

**Table 14: Beta Estimates (Approach 1)**



We can use linear regression in order to estimate beta, where the explanatory variable is the Market Risk Premium (MRP), while the dependent variable will be the risk premium of the security. So, the regression equation has the following form, which is the formula for the Security Characteristic Line (SCL). The intercept of the characteristic line is α, the part of the stock return unexplained by the market factor. The slope of the function shows the sensitivity toward the market factor, measured by beta.

**Equation 5: Beta Equation (Approach 2)**

Ri = α + βi Rm + ei

|  |  |
| --- | --- |
| **R Code to calculate Beta (Approach 2)** | * **(fit <- lm((return$BTC - return$LIBOR) ~ (return$IXIC - return$LIBOR)))** * **(fit <- lm((return$ETH - return$LIBOR) ~ (return$IXIC - return$LIBOR)))** * **(fit <- lm((return$BTC - return$LIBOR) ~ (return$IXIC - return$LIBOR)))** |

**Table 15: Beta Estimates (Approach 2)**



**Figure 10: Scattered Plots**

|  |  |
| --- | --- |
| **Bitcoin (Beta = 1.511):**  Start Date – 22-Feb-2017  End Date – 16-Feb-2017  Y Axis – Bitcoin Returns - Rf  X Axis – NASDAQ Returns - Rf  y = 1.511x + 0.0079  R² = 0.036 |  |
| **Ethereum (Beta = 2.1209):**  Start Date – 22-Feb-2017  End Date – 16-Feb-2017  Y Axis – Ethereum Returns - Rf  X Axis – NASDAQ Returns - Rf  y = 2.1209x + 0.0146  R² = 0.0328 |  |
| **Ripple (Beta = 2.0193):**  Start Date – 22-Feb-2017  End Date – 16-Feb-2017  Y Axis – Ripple Returns - Rf  X Axis – NASDAQ Returns - Rf  y = 2.0193x + 0.0175  R² = 0.0152 |  |

**Thank You**

**Contact**

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1. A cross hedge is used to manage risk by investing in two positively correlated securities that have similar price movements. The investor takes opposing positions in each investment in an attempt to reduce the risk of holding just one of the securities. In this paper, we have hedged the exposure in Bitcoin is using Litecoin. [↑](#footnote-ref-1)
2. Portfolio optimization is a part of modern portfolio theory on how risk-averse investors can construct portfolios to optimize or maximize expected return based on a given level of market risk, emphasizing that risk is an inherent part of higher reward. According to the theory, it's possible to construct an "efficient frontier" of optimal portfolios offering the maximum possible expected return for a given level of risk.

   In this paper, we have discussed minimum-variance portfolio. A type of well diversified portfolio that contains assets that are considered risky on an individual basis but attain a much lower level of risk, given the anticipated return, when pooled together. [↑](#footnote-ref-2)