

Deep Learning Powered HAR Models

Forecasting the Realized Volatility of Bitcoin

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This project was created using Google Colab.

The notebook can be found at Google Colab.

<https://colab.research.google.com/drive/1sJzRECcHC5H5JR5X7B5iEZdrGE-onn3X?usp=sharing>

The computations done in Colab was done on a GPU, with a Colab Pro License.

Contents

1	Introduction	4
1.1	The Electronic Currency Bitcoin	4
1.2	Volatility in the Financial Markets	5
1.3	Machine Learning	5
1.4	Research Question	5
1.5	Thesis Structure	5
2	Theory	6
2.1	Financial Assets and Efficient Markets	6
2.2	The Volatility of Financial Assets	6
2.2.1	Volatility Jumps	6
2.3	Market Microstructure	6
2.4	Cryptocurrencies as a Financial Asset	6
3	Econometric Models	7
3.1	Linear Time Series Models	7
3.2	HAR Models	7
3.2.1	Variants of the HAR Model	7
3.3	Assumptions	7
4	Deep Learning	8
4.1	Machine Learning	9
4.1.1	Origins of Deep Learning	9
4.2	Multilayer Perceptron	9
4.2.1	Neural Network Architecture	9
4.2.2	Activation Functions	9
4.2.3	Stochastic Gradient Descent	9
4.3	Deep Learning in Time Series Forecasting	9
4.4	Recurrent Neural Networks	9
4.4.1	Long Short-Term Memory	9
4.4.2	9
4.5	Convolutional Neural Networks for Time Series Forecasting	9
4.5.1	Dilated Causal Convolutional Neural Networks	9
4.6	HAR-Inspired Neural Networks	9

4.6.1	Training Data	9
4.6.2	Network Architecture	9
5	Results	10
5.1	Stationarity	10
5.2	In-Sample Evaluation	10
5.2.1	HAR Models	10
5.2.2	Neural Networks	10
5.2.3	HAR Inspired Neural Networks	10
5.3	Forecasting Performance	10
5.3.1	HAR Models	10
5.3.2	Neural Networks	10
5.3.3	HAR Inspired Neural Networks	10
6	Discussion	11
6.1	Machine Learning in Finance	11
6.2	Inference or Accuracy	11
7	Conclusion	12

Chapter 1 Introduction

1.1 The Electronic Currency Bitcoin

Since the mythical author Satoshi Nakamoto published the whitepaper on Bitcoin "*Bitcoin: A Peer-to-Peer Electronic Cash System*" in 2008, blockchain technologies and cryptocurrencies have become everyday names and subject of much research. The original intend for Bitcoin was to be "*A purely peer-to-peer version of electronic cash*" (Nakamoto, 2008, p. 1). The goal of this electronic cash is to allow "*...online payments to be sent directly from one party to another without going to a financial institution*" (Nakamoto, 2008, p. 1). Bitcoin, was thus invented as an alternative to cash and other currencies, as a digital and secure medium to make transactions with.

To be viewed as a currency, Bitcoin must satisfy the following characteristics. Bitcoin must be a medium of exchange, which by the fact that it enables peer-to-peer transactions, may be deemed satisfied. It must function as a unit of account, thus, one must be able to use bitcoin as a measure of relative worth of economic transactions (Mankiw, 2009, p. 80-81). Lastly, it must function as a store of value, and therefore, must be able to transfer the purchasing power from the present to the future (Mankiw, 2009, p. 80-81). The first of the characteristics, being a medium of exchange, seems to be satisfied, particularly because more businesses have begun accepting Bitcoin as a payment (Yermack, 2015, p. 36-38). To function as a store of value, a currency must be able to be securely stored and maintain a relatively stable value in the periods between use. Ordinarily, the ability of a currency of being securely stored is maintained by a bank. Storing Bitcoins is done through digital wallets, and the ability of being securely stored is facilitated by insuring the digital wallet, often done by the digital wallet companies. The major concern for Bitcoin in terms of being considered a viable currency is its fluctuations in value. The characteristics of being a store of value and a unit of value, is reliant on a somewhat stable value of the currency. Bitcoin shows extreme volatilities compared with other currencies, and its market value can vary greatly within a short period of time (Yermack, 2015, p. 38-43). This challenges Bitcoin as a currency, but enables Bitcoin to be seen and used as a speculative investment. It is this extreme volatility that makes Bitcoin an interesting asset to consider in this thesis.

1.2 Volatility in the Financial Markets

Volatility can, in layman terms, be described as the size of the fluctuations or dispersion of an asset over a given period of time. It is one of the central measures of interest in finance. Volatility is used extensively in risk management, asset allocation, derivatives pricing, hedging and many more financial subjects (Engle & Patton, n.d., p. 237). One of the primary goals of volatility modeling is to predict the future volatility. Being able to accurately predict future volatility, one may better price various financial assets, select portfolios, and manage risks. Volatility is therefore a subject of great interest for financial applications.

Being a subject of much research and application, volatility is well researched. It is, however, not possible to directly observe volatility (Tsay, 2005, p. 98). Thus, volatility must be estimated by the practitioner or researcher, before being modeled or used in research. The most common ways to estimate volatility is by using the standard deviation of historic returns or estimating the implied volatility as given by options pricing theory (Tsay, 2005, p. 98) (Hull, 2015, p. 325). A third approach, that has been increasing in its use, for estimating volatility is by using the realized volatility Andersen & Bollerslev (1998) Using

1.3 Machine Learning

1.4 Research Question

How can neural networks enhance the forecasting capability of HAR-style models in realized volatility

1.5 Thesis Structure

The thesis will be structured as follows. Chapter 2 will contain an examination of the financial theory underlying volatility forecasting and cryptocurrency trading. The linear econometric time series models and their assumptions will be introduced in chapter 3. Chapter 4 is devoted to the field of deep learning, with an overview of the types of neural networks and their methods used in the analysis. The evaluation setup of the analysis will be presented in chapter 5. Chapter 6 will present the results of the analysis, with a comparison between the econometric models as baselines and the neural network. The discussion, chapter 7, will be revolving around the applicability of neural networks for volatility forecasting and especially the ability of making inference on neural networks. Chapter 8 will conclude the project

Chapter 2 Theory

The research statement specifies that this thesis revolves around the prediction of the volatility of Bitcoin returns. This section aims to lay the foundation for the subjects from a financial perspective. Hence, an introduction to the nature of financial markets, volatility and its stylistic facts will be presented. Furthermore, as we are working with high-frequency intraday data, the subject of market microstructure is necessary to understand. Lastly, a general overview of cryptocurrencies as financial assets is given.

2.1 Financial Assets and Efficient Markets

2.2 The Volatility of Financial Assets

2.2.1 Volatility Jumps

2.3 Market Microstructure

2.4 Cryptocurrencies as a Financial Asset

Chapter 3 Econometric Models

3.1 Linear Time Series Models

The predominant types of models in the econometric literature is linear models. Linear models have the benefit of being easy to implement and make inference from. This section will introduce implementation and assumptions of linear time series models.

A classical linear model can be written of the form:

$$y = \alpha + \beta\mathbf{X} + \varepsilon \quad (3.1)$$

where, y is the dependent variable of the system, \mathbf{X} is the vector of independent variables of the system, β is the coefficients, α the slope and ε the error term.

3.2 HAR Models

3.2.1 Variants of the HAR Model

3.3 Assumptions

Chapter 4 Deep Learning

4.1 Machine Learning

4.1.1 Origins of Deep Learning

4.2 Multilayer Perceptron

4.2.1 Neural Network Architecture

4.2.2 Activation Functions

4.2.3 Stochastic Gradient Descent

4.3 Deep Learning in Time Series Forecasting

4.4 Recurrent Neural Networks

4.4.1 Long Short-Term Memory

4.4.2

4.5 Convolutional Neural Networks for Time Series Forecasting

4.5.1 Dilated Causal Convolutional Neural Networks

4.6 HAR-Inspired Neural Networks

4.6.1 Training Data

4.6.2 Network Architecture

Network Architecture

Criterion and Optimizer

Training Setup

Chapter 5 Results

5.1 Stationarity

5.2 In-Sample Evaluation

5.2.1 HAR Models

5.2.2 Neural Networks

5.2.3 HAR Inspired Neural Networks

5.3 Forecasting Performance

5.3.1 HAR Models

5.3.2 Neural Networks

5.3.3 HAR Inspired Neural Networks

Chapter 6 Discussion

6.1 Machine Learning in Finance

6.2 Inference or Accuracy

Chapter 7 Conclusion

References

- Andersen, T. G., & Bollerslev, T. (1998, November). Answering the Skeptics: Yes, Standard Volatility Models do Provide Accurate Forecasts. *International Economic Review*, 39(4), 885. doi: 10.2307/2527343
- Engle, R. F., & Patton, A. J. (n.d.). What good is a volatility model? *QUANTITATIVE FINANCE*, 9.
- Hull, J. (2015). *Options, Futures, and Other Derivatives* (Ninth edition ed.). Boston: Pearson.
- Mankiw, N. G. (2009). *Macroeconomics* (7th ed ed.). New York, NY: Worth Publishers.
- Nakamoto, S. (2008). Bitcoin: A Peer-to-Peer Electronic Cash System. , 9.
- Tsay, R. S. (2005). *Analysis of Financial Time Series* (Second ed.). Wiley.
- Yermack, D. (2015). Chapter 2 - is bitcoin a real currency? An economic appraisal. In D. Lee Kuo Chuen (Ed.), *Handbook of digital currency* (pp. 31–43). San Diego: Academic Press. doi: 10.1016/B978-0-12-802117-0.00002-3