CHARLES UNIVERSITY
FACULTY OF SOCIAL SCIENCES
Institute of Economic Studies

Noise reduction and feature extraction with principal component analysis for cryptocurrency price modeling

Bachelor's thesis

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Year of defense: 2024

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Prague, March 7, 2024

Tomas Barhon

Abstract

The abstract should concisely summarize the contents of a thesis. Since potential readers should be able to make their decision on the personal relevance based on the abstract, the abstract should clearly tell the reader what information he can expect to find in the thesis. The most essential issue is the problem statement and the actual contribution of described work. The authors should always keep in mind that the abstract is the most frequently read part of a thesis. It should contain at least 70 and at most 120 words (200 when you are writing a thesis). Do not cite anyone in the abstract.

JEL Classification	C01, G00, F23, H25, H71, H87
Keywords	Cryptocurrency, Bitcoin, Ethereum, Litecoin, Machine Learning, PCA, Noise Reduction

Title	Noise reduction and feature extraction with principal component analysis for cryptocurrency price modeling

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Supervisor's e-mail	`ladislav.kristoufek@fsv.cuni.cz`

Abstrakt

Nutnou součástí práce je anotace, která shrnuje význam práce a výsledky v ní dosažené. Anotace práce by neměla být delší než 200 slov a píše se v jazyce práce (tj. česky, slovensky či anglicky) a v překladu (tj. u anglicky psané práce česky či slovensky, u česky či slovensky psané práce anglicky). Anotace práce by neměla být delší než 200 slov a píše se v jazyce práce (tj. česky, slovensky či anglicky) a v překladu (tj. u anglicky psané práce česky či slovensky, u česky či slovensky psané práce anglicky). V abstraktu by se nemělo citovat.

Klasifikace JEL C01, G00, F23, H25, H71, H87

Klíčová slova KryptomÄ›ny, Bitcoin, Ethereum, Litecoin, StrojovĂ© uÄŤenĂ, PCA, Redukce Ĺˇumu

Název práce Redukce šumu a extrakce rysů pomocí analýzy hlavních komponent pro modelování cen kryptoměn

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Acronyms

BTC	Bitcoin
ETH	Ethereum
LTC	Litecoin
ML	Machine Learing
DL	Deep Learing
ANN	Artificial Neural Network
SGD	Stochastic Gradient Descent
LR	Linear Regression
SVM	Support Vector Machines
SVR	Support Vector Regression
RNN	Recurrent Neural Network
LSTM	Long Short-Term Memory
PCA	Principal Component Analysis
SVD	Support Vector Decomposition
ARIMA	Autoregressive Integrated Moving Average
PoW	Proof of Work

Bachelor's Thesis Proposal

Author	Tomáš Barhoň
Supervisor	prof. PhDr. Ladislav Krištoufek Ph.D.
Proposed topic	Noise reduction and feature extraction with principal component analysis for cryptocurrency price modeling

Motivation Crypto assets have always been exceptionally volatile compared to traditional assets such as stocks or gold. The historical window is relatively short, thus modeling their price or volatility proposes quite a difficult challenge. It is generally believed that noise in any data decreases the precision of predictions. This effect might be reduced, which will improve the performance of traditional models that are used for cryptocurrency price modeling.

The main motivation for researching this topic is that there is still an ongoing discussion about the role of different features in crypto pricing dynamics. (Kukacka; Kristoufek 2023) have shown that a lot of the pricing dynamic emerges from complex interactions between fundamental and speculative components. They also show the different correlations between all of the explanatory variables which have a direct connection to principal component analysis. It is crucial to study the real impact of those variables in different models as many of them might turn out to be obsolete.

There is currently little use of this dimensionality reduction technique in the academic literature about cryptocurrencies. However, for more traditional financial series this technique is already quite established as a preprocessing technique to reduce noise and dimensionality from which financial data inherently suffer (Chowdhury, U. ; Chakravarty, S. and Hossain, M. 2018). Moreover (Bouri, E.; Kristoufek, L.; Ahmad, T. et al. 2022) studied the effect of microstructural noise on idiosyncratic volatility in cryptocurrencies which further supports the need for a technique that will mitigate this effect on the predictions.

The research will address the problem of variable selection for different types of predictive models with respect to the analysis of the principle components aiming to reduce the dimensionality and simultaneously increase precision. The second question is whether it is more appropriate to transform the high dimensionality with

PCA into lower dimensionality or simply omit the variables with high multicollinearity from the models. These approaches are fundamentally different and the answer is not clear.

Methodology The data will come from various sources because the aim is to look at all the possible variables even if they might not seem useful at first glance. As already mentioned the dynamic is driven by a lot of completely different effects. Most of it will be collected from: coinmetrics.io, studio.glassnode.com, and for macroeconomic indicators https://fred.stlouisfed.org/. Some of the data might need to be interpolated to daily observations. Lastly, the observations will need to be sliced to different window sizes and shifted by one so that the predictions can be made for the next day with the data available on that day.

Afterward, the multicollinearity in the data will be examined and different approaches to solve it will be used. The two main ones are using only a smaller set of uncorrelated variables (simple dimensionality reduction) and the second being employing PCA transformation to preserve a predefined threshold of variance or directly targeting the number of principal components.

All the different setups will be compared across three models: linear regression, SVM, and LSTM neural network. The hypothesis is that PCA transformation will substantially lower the measured errors for linear regression and SVM although for LSTM it will result in lower performance as it will only decrease the capacity of the model as the model is powerful enough to create such uncorrelated features without the PCA transformation.

Expected Contribution Existing research agrees that financial data and especially cryptocurrency data are significantly affected by noise. The main goal is to extend the research on the topic of variable selection for algorithmic trading models as there are still a lot of unanswered questions. It will most likely become clearer which approach to dimensionality reduction is the most efficient concerning cryptocurrencies.

Also, not only the underlying pricing dynamics will be detected but the results can be used for investors that are trying to lower their risk of loss which is relatively high in crypto markets. The effect of having a more stable and precise model might significantly cut the transaction costs that are associated with more frequent exchanges as the predictions will become less volatile. That is a desirable property needed to maximize profit and increase credibility towards its customers.

Core bibliography

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Author Supervisor

Chapter 1

Introduction

Since the introduction of the first cryptocurrency **BTC!** (**BTC!**) associated with the unknown author Satoshi **?** cryptocurrencies have become part of our everyday life. Their high volatility, futuristic name and alternative nature are of interest to the media and the general public. According to **coinmarketcap.com** the overall cryptocurrency market capitalization peaked at around 2.8 trillion $USD in the year 2022 which makes them a substantial part of the financial sphere. The initial idea of **BTC!** was to establish an alternative to traditional fiat currencies. The **BTC!** whitepaper pointed out the weakness of the current trust-based model that relies on a third-party instance responsible for verifying transactions. A different approach was suggested to validate transactions known as the proof-of-work which utilizes the computational power of miners in the network. The fact that the power is distributed across the network ensures that it becomes exponentially harder with an increasing number of blocks to generate blocks faster than the rest of the miners (**?**, pg. 6). However, the mining process is interconnected with the creation of new **BTC!**s which is a crucial parameter in all monetary systems. This fact gives researchers such as **?** the possibility to use various attributes of the network to study the pricing dynamics of cryptocurrencies. On the other hand, there are a couple of substantial drawbacks that make price modeling relatively challenging. Those are non-stationarity of the target prices, relatively short historical window, the limited power of proxies for speculative components and as pointed out by many researchers such as **?**, **?**, **?** an idiosyncratic noise in volatility. Addressing these issues might potentially lead to better-performing models, especially with longer forecasting periods. Likewise in other fields, the recent rise of machine learning has also affected the cryptocurrency area where various **ML!** (**ML!**)

and **DL!** (**DL!**) models are often being used to model the price **?** or volatility ?.

The main objective of this thesis is to try to tackle the problem of idiosyncratic noise in the high dimensional data used for price and returns modeling across three ML models: Ridge **LR!** (**LR!**), **SVM!** (**SVM!**) and **LSTM!** (**LSTM!**) **RNN!** (**RNN!**). We will examine the effect of a method known as **PCA!** (**PCA!**) which was according to **?** developed in 1933 by Harold Hotelling. However, others often refer to the fact that the idea was already introduced before by Karl Pearson in the article *On lines and planes of closest fit to systems of points in space* ?. This technique aims to compress data from a higher dimensionality space into a lower space while retaining a maximum amount of variance. It utilizes linear transformation of the covariance matrix to do that. Nevertheless, despite the initial focus on dimensionality reduction different types of **PCA!** are often being used as noise reduction techniques in signal or image processing. Interestingly many studies in recent years have incorporated **PCA!** for time series data as a part of their preprocessing pipeline ?, ?. The idea stems from the fact that removing the most idiosyncratic components might help with capturing clear dynamics that enter the price-making process. We perceive that there is currently a lack of literature that would examine the effects of noise reduction techniques on the performance of other **ML!** based regression techniques for cryptocurrencies. We want to mitigate most of the identified challenges using the currently available academic knowledge and focus exclusively on the effect of noise in the data. Admittedly it is always intricate to establish a ceteris paribus relationship in such a scenario where many variables change, the randomness of the training process using **SGD!** (**SGD!**) plays a crucial role and the size of the dataset is relatively limited. We want to contribute with an alternative approach, especially in the preprocessing pipeline that can be used in future studies to decrease the volatility of predictions. We do not aim to provide a generally applicable approach, as different techniques can produce varying outcomes on different datasets. This phenomenon partially corresponds to the *No Free Lunch Theorem* **?** which has turned into a buzzword in the **ML!** community over the years.

The remainder of the thesis is organized as follows: The following chapter introduces the fundamentals of cryptocurrencies and their unique characteristics. It also covers the usage of **ML!** methods in this field and especially focuses on the literature about the usage of **PCA!** in various areas. The data chapter explains in detail which data were used and elaborates on the basic resampling methods that we used. In methodology, we focus on each specific **ML!** method and explain the core concepts that are crucial for understanding the training process. Similarly, we propose our complete forecasting framework. Chapter results and discussion evaluates the findings for each currency-model pair across different settings. We also include a limitations section which is especially crucial for our study where we acknowledge those problematic parts of the study that might be improved in the future. The Conclusion focuses on the overall impact and proposes paths that should be explored in the years to come. All the tables, source codes and visualizations can be found in the appendices.

Chapter 2

Literature Review

2.1 Cryptocurrencies

2.1.1 Bitcoin

In the year 2008, an unknown author with the pseudonym Satoshi Nakamoto introduced the idea of a purely peer-to-peer electronic cash system. Interestingly the author mentions small casual transactions as something that the current model relying on third-party financial institutions fails to deliver because of unavoidable transaction costs **?**. In contrast, from today's perspective, Bitcoin is a relatively slow medium for micro-transactions because technically the receiver has to always wait for a certain amount of blocks to be mined such that it becomes statistically unlikely that double-spending has been committed by the payer **?**. This phenomenon can be demonstrated on the data from **coinmetrics.io** which show that the mean size of a **BTC!** transaction ranges in thousands of USD$. Another important aspect is that the miners prioritize transactions with higher fees in the block which introduces considerable costs to each payment. **?** have shown the relationship between the transaction fee and the transaction latency meaning the time it takes for the transaction to be almost surely valid. Even though there has been some divergence from the original idea of small transactions all of the security measures regarding the double spending problem in the original whitepaper have turned out to be relatively well-defined in a medium time horizon.

Despite the fact, that Bitcoin is generally regarded as the first cryptocurrency it relies on many older ideas and technologies that are mostly mentioned in the original whitepaper. First and foremost stands the conference paper *How to Time-Stamp a Digital Document* **?** which focuses on the problem of third parties responsible for verification of digital documents. It makes use of an already established family of functions known as hashes that surpass privacy concerns and generally surpass the need for a third party to be involved in the verification process when combined with the correct consensus algorithm. They define a hash function as follows:

Definition 2.1 (Hash). This is a family of functions $h : \{0,1\} \rightarrow \{0,1\}^l$ compressing bit-strings of arbitrary length to bit-strings of a fixed length l, with the following properties:

1. The functions h are easy to compute, and it is easy to pick a member of the family at random.
2. It is computationally infeasible, given one of these functions h, to find a pair of distinct strings x, x' satisfying $h(x) = h(x')$. (Such a pair is called a collision for h)(**?**, see Chapter 4.1)

Hashes are the most crucial building blocks of cryptocurrencies. However, the time-stamping might fail if the users can tweak the time of their machines. Interestingly, the authors have already mentioned that and introduced the idea of chaining the data together with their metadata sequentially in a long chain so that the user can trust that something was not overwritten (**?**, see Chapter 5). This is possible due to the properties of the hash functions. Meaning that we can concatenate arbitrarily long inputs and always produce a fixed-size output. Another significant influence came from the idea of b-money which was an idea for an anonymous digital cash system presented in **?**. B-money proposed the concept of proof-of-work which is a validation protocol that many cryptocurrencies still use. The idea was to solve computationally challenging puzzles where it can be determined how much effort was used (see **?**, pg. 1). However, certain worries were being raised about how to regulate a system if the computational power of computers is increasing every year (see **?**, pg. 3). This has been addressed by Bitcoin with the regulation of difficulty based on the average time it takes to solve rather than the difficulty itself (see **?**, pg. 3).

Since many characteristics of the network are often being used by researchers such as: (**?**, **?**, **?** or **?**) in their cryptocurrency research, it is critical to understand the underlying mechanics that form them. Bitcoin takes a completely adverse approach than the general financial system. Whereas in the traditional sphere banks and other institutions try to keep every transaction encrypted Bitcoin makes all the transaction publicly visible and available but hashing the addresses of the sender and receiver. The process of sending Bitcoins to someone else essentially means adding a digital signature to the previous transaction from which you received that money. However, as (see Chapter 2 **?**, pg. 2) suggests this only mitigates the privacy concerns but the double spending risk needs to be dealt with a smarter design. This is solved by the introduction of the **PoW!** (**PoW!**) algorithm. The idea is that transactions are collected into blocks by the miners who try to solve a computationally difficult task that can only be solved by a brute-force search. It is simply a race to find a hash with a certain amount of leading zeros which is adjusted based on the mining power of the network. The miners are incentivized by **BTC!** price for winning the race and also by the transaction fees that can be added to each transaction as a reward for being prioritized. The main concept is that the blocks are connected sequentially in a chain through the hash. If we assume that most of the nodes/miners are honest their profit-maximizing behavior should always be working on the longest chain and thus transactions that have already been spent do not get included in the chain. After the puzzle is solved by a node it can be validated by all other nodes in a linear time and they move on to the next block. Despite that, there remains the risk of an attacker forking a malicious block and sending his money back or elsewhere.

Algo

Security

Research

2.1.2 Ethereum

2.1.3 Litecoin

2.2 Machine Learning Methods for Cryptocurrencies

2.3 Principal Component Analysis

2.3.1 PCA in Other Areas

2.3.2 PCA in Time Series

2.4 Web Search Data in Financial Applications

Chapter 3

Data

3.1 Cryptocurrency Specific Technical Data

3.2 Macroeconomical Data

3.3 Web Search Data

3.4 Preprocessing

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To achieve compatibility with PDF/A 2u, your file must not include links to external fonts, audio, video, or scripts. On the other hand, your file must declare each color environment you use, it must include all the pictures/figures either in jpeg or PDF/A 2u format, used fonts compliant under Unicode (your file cannot use any external fonts), and it must include meta-data in XMP format.

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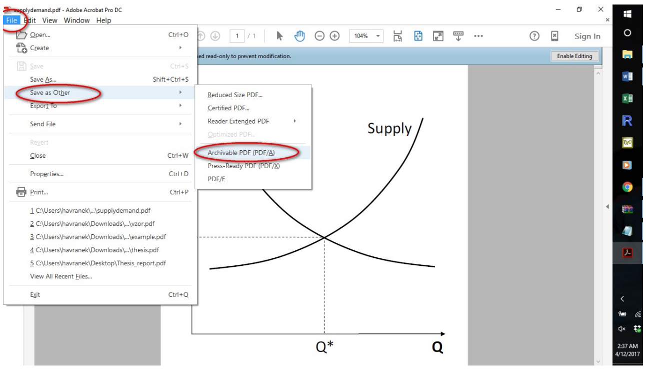

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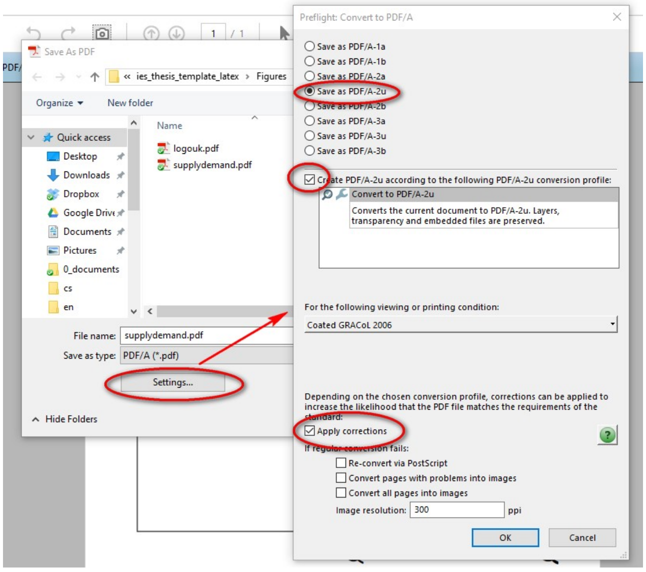

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https://kam.mff.cuni.cz/pdfix/

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Figure 3.1: Market equilibrium

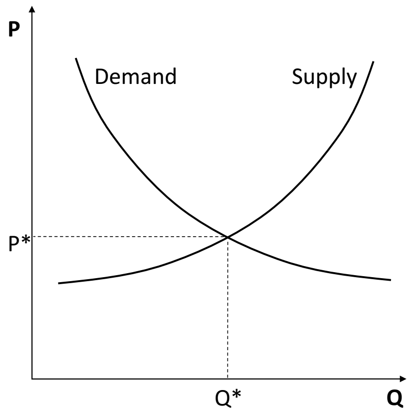

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Table 3.1: Model's predictions

Case	Y_1	Y_2	τ_1	τ_2	a	n
CR—Slovakia	10.9	10	0.24	0.19	1,000	2.16
CR—Poland	13.3	12	0.24	0.19	1,000	0.38
CR—Hungary	10.4	8	0.24	0.16	1,000	1.10

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Figure 3.2: Boxy's example

- Welcome to Boxy paragraph. We sincerely hope you will all enjoy the show.
- Welcome to Boxy paragraph. We sincerely hope you will all enjoy the show.
- Welcome to Boxy paragraph. We sincerely hope you will all enjoy the show.

Source: **?**

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Definition 3.1 (My original definition). This is a definition.

Assumption 3.1 (My realistic assumption). This is an assumption.

Proposition 3.1 (My clever proposition). *This is a proposition.*

Lemma 3.1 (My useful lemma). *This is a lemma.*

Example 3.1. This is an example.

Proof. This is a proof. □

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$$U = \int_0^\infty \overbrace{\frac{1}{1-\sigma}\left(C^{1-\sigma}-1\right)}^{\text{instantaneous utility}}e^{-\rho t}\,\mathrm{d}t \tag{3.1}$$

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$$\boldsymbol{A} = \boldsymbol{B} + \boldsymbol{C} \tag{3.2}$$

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- see **??**,
- to **??**,
- to Definition **??**, to Proposition **??**, Example **??**,
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omega = 1;
syms zeta;
jmn = [1 2*zeta*omega omega^2];
figure(1);
    for zeta = 1E-5 : 0.2 : 1+1E-12
        G = tf(omega^2,subs([1 2*zeta*omega omega^2]));
        bode(G); hold on;
    end
legend('\zeta = 0','\zeta = 0,2','\zeta = 0,4','\zeta = 0,6',');
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Chapter 4

Methodology

4.1 ML!

4.2 Ridge Linear Regression

4.3 Support Vector Machines

4.4 LSTM! RNN!s

4.5 PCA!

4.6 Time-Series Specifics

4.7 Proposed Forecasting Framework

Many people use simple n-dash in many occasions – like this –, where however typographic convention—it looks a bit strange at first sight—requires m-dash. Text text text text text text text text text text text text text text text. Text text text text text text text text text text. Text text text text text text ?.

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> It ought to be the happiness and glory of a representative to live in the strictest union, the closest correspondence, and the most unreserved communication with his constituents. Their wishes ought to have great weight with him; their opinion, high respect; their business, unremitted attention. It is his duty to sacrifice his repose, his pleasures, his satisfactions, to theirs; and above all, ever, and in all cases, to prefer their interest to his own. But his unbiased opinion, his mature judgment, his enlightened conscience, he ought not to sacrifice to you, to any man, or to any set of men living. These he does not derive from your pleasure; no, nor from the law and the constitution. They are a trust from Providence, for the abuse of which he is deeply answerable. Your representative owes you, not his industry only, but his judgment; and he betrays, instead of serving you, if he sacrifices it to your opinion.

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Chapter 5

Results and Discussion

5.1 Results Intepretation

5.1.1 Basline ARIMA!

5.1.2 LR!

5.1.3 SVM!

5.1.4 LSTM!

The following checklist should help in avoiding some frequently made mistakes, if any of the following propositions apply for your thesis, there is a problem:

- You have citations in your abstract.
- The introduction does not cover the three parts as described in **??**.
- The introduction contains subheadings.
- You described different aspects than promised in the title.
- You copied some parts of the text from other work without proper referencing and citing.
- You used automatic translation tools to produce text by translating it from another language.
- Your thesis contains many typos and grammatical errors. (Use an electronic spell checker. Please!)

- You used color in your figures and refer to the “blue” line (assume that your readers use a monochrome printer).
- You mainly used websites and other unrefereed material as your sources or you used Wikipedia as your source.
- You refer to something in your conclusion which you have not mentioned before.
- Some forenames in the references are abbreviated, some not.
- Some references miss a publishing date.

5.2 Limitations

Chapter 6

Conclusion

If you write in English, you might find the following hint useful: The indefinite article a is used as an before a vowel sound—for example an apple, an hour, an unusual thing, an (because the acronym is pronounced Em-En-See). Before a consonant sound represented by a vowel letter a is usual—for example a one, a unique thing, a historic chance. Few more tips to follow:

- Don't give orders—don't write in the imperative mood—unless you are training to be a teacher.
- Avoid the use of questions. You may know the answer: does your reader? It's much safer to tell her, or him.
- Do not become entangled in the problems of 'sexist' language. It is much easier to write in the plural. "Students should check their work" is good English. "A student should check—" is also good English, but now the problems begin: "—her work?" "—his work?" Which? You can write "his or her," but that seems clumsy. Stick to the plural.
- If you must refer to yourself, use the third person such as "The present writer would recommend that . . . " may be useful.
- Use the full forms of words and phrases, not contractions like "he's," "don't," etc. Keep the apostrophe to indicate possession—and use it correctly. Academics really sneer at students who use the "Greengrocer's apostrophe."
- Do not despise short, workmanlike, and effective plain English words. If they mean what you want to say. Accurately.

- Avoid the use of humor in academic writing—unless you are very sure of yourself.

- Even when you are not being funny, avoid the use of irony or sarcasm.

- Paragraphs in academic English should contain more than one sentence. (Short paragraphs look as if you are writing for a tabloid newspaper—or a simple Template!) I guess that the average academic book runs to two or three paragraphs per page. Look at the books in your subject, and get a feel for how long your own paragraphs should be when you are imitating the academic style.

- Use the word that more in formal writing than most of us do in speech—particularly after such verbs of utterance as to say, to report, to think etc. It can help to make your writing much clearer.

- Develop an academic vocabulary. The 'long words' you learn in the course of your studies are long usually because they have more precise meanings than their less formal equivalents. They are therefore better when you want to be accurate. (Also they allow you to sound like someone who deserves a degree.)

- Use as few words as you can; but use enough words to express your meaning as fully as you can. Your judgment of what is appropriate here is part of what you should learn throughout your course.

- Avoid lazy words such as "nice". It is usually better to say "acquire" or "obtain" than "get;" and it may be better, if you mean "through the use of money," to say "purchase" or—better still—"buy."

- A short word like "buy" is better than a long one like "purchase"—unless the long one is more accurate. A "statutory instrument" is better than a "rule"—to a lawyer, at any rate.

- Proof-read with care. Ask someone else to help—you may be too close to your work to be able to see your mistakes.

- If in doubt, choose the more formal, or possibly just the more old-fashioned, of two words. For example, say quotation rather than quote whenever you mean the use of somebody else's words.

- You will often sound more academic if you include doubts in your work—and qualifications. Within the scope of this thesis, the current writer cannot hope to cover all the possible implications of the question.ÔŤ
- In this context, the use of litotes sounds very academic. This is the construction where a writer uses a negative with a negative adjective, e.g. it is not unlikely that . . . This does not mean the same as it is probable that . . . It has a shade of meaning and qualification that can be useful to academic writers.

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Appendix A

Detailed Results Tables

Appendix B

Aditional Contents

All of the source codes and data to reproduce the results are available at https://github.com/Tomas-Barhon/Noise-reduction-and-feature-extraction. Including all the instructions on how to install the necessary dependencies.