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Strategic Diversification for Asynchronous Asset Trading: Insights from Generalized Coherence Analysis of Cryptocurrency Price Movements: Open Review

Nirvik Sinha,[*†] Yuan Yang [‡]

Reviewers: Reviewer A, Reviewer B

Abstract. The final version of the paper "Strategic Diversification for Asynchronous Asset Trading: Insights from Generalized Coherence Analysis of Cryptocurrency Price Movements" can be found in Ledger Vol. 6 (2021) 102-125, DOI 10.5195/LEDGER.2021.227. There were two reviewers involved in the review process, neither of whom has requested to waive their anonymity at present, and are thus listed as Reviewers A and B. After initial review by Reviewers A and B, the submission was returned to the authors with feedback for revision (1A). The authors responded (1B) and resubmitted their work. After subsequent evaluation, the decision was made that the revisions made to this point were sufficient to address any concerns, thus ending the peer review process. Author responses have been bulleted for reader clarity.

1A. Review

Reviewer A

Does this paper represent a novel contribution to cryptocurrency or blockchain scholarship?

Yes

[*]0x481d4E56Ba29deD0aCEDA11a293d5D6E0cB58801

[†]Nirvik Sinha (nirviksinha2024@u.northwestern.edu) is a PhD candidate in Interdepartmental Neuroscience at Feinberg School of Medicine, Northwestern University, IL, USA.

[‡]Yuan Yang (yan.yang-2@ou.edu) is an assistant professor at Stephenson School of Biomedical Engineering, University of Oklahoma, Tulsa, OK, USA.

If you answered "yes" to the previous question, in one sentence, describe in your own words the novel contribution made by this paper.

A comprehensive generalised coherence analysis of 55 cryptocurrencies.

Is the research framed within its scholarly context and does the paper cite appropriate prior works?

Yes

Please assess the article's level of academic rigor.

Good (not excellent but a long way from poor)

Please assess the article's quality of presentation.

Good (not excellent but a long way from poor)

How does the quality of this paper compare to other papers in this field?

Top 10%

Please provide your free-form review for the author in this section.

This paper examines pairwise relations between the price time series for 55 of the top cryptocurrencies. In the words of the author, it is a generalized coherence analysis for the price movements of crytocurrencies. The words "generalized" and "coherence" have specific meanings here. Most readers of Ledger will be familiar with correlation. If Crypto A is highly correlated with Crypto B, then if tomorrow Crypto A increases in price, we would expect Crypto B to also increase in price. If an hour later, Cryto A decreases in price, we would expect Crypto B to likewse decrease in price. Coherence, roughly speaking, breaks correlation into frequency bands. While correlation is a number, coherence is a function (of frequency). If Crypto A has high coherence with Crypto B on the dailys, then if tomorrow Crypto A increase in price, we would expect Crypto B to also increase in price. But, these two cryptocurrencies might ALSO have LOW coherence hourly, which means that if Crypto A increased in price an hour from now, we couldn't infer anything about Crypto B's price movement. The author calls this effect "iso-frequency coupling (IFC)"

The word "generalized" adds further complexity. Rather than using the traditional equation to calculate "coherence" (mathematically, it's proportional to the cross-power-spectrum for the pair), the fourier transforms for the time series are raised to integer powers before being fed into the coherence equation. Through some mathematical magic that I don't understand (and I'm not sure is ever explain in the paper) this allows us to detect coupling for frequency harmonics too. For example, we could find that Crypto C on the hourlies has a high coupling with Crypto D on the daily. The author calls this effect "cross-frequency coupling (CFC)."

Beyond the nice graphics visualizing the results, the results support the interesting claims

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made by the author. For example:

(1) IFCs are weaker for small cryptos than for large cryptos (which means that portfolio diversification here can improve risk-adjusted returns)

(2) Risk adjusted returns can almost always be improved if the larger market cap crypto is traded at a higher frequency than the lower market cap crypto

Overall, I think this is a well written paper with excellent grammar and good flow. The author has put considerable time into this analysis. The methodology appears sound and the results are sensible. I think the paper is basically publishable as is.

My biggest critique, however, is the sophistication of the mathematics used. It feels like overkill, or like a method (the generalized coherence framework) in search of a problem. This paper might have lower impact due to the inaccessibility of the mathematical framework. If there were a way to hold the readers hand a bit more through the math (maybe by starting with regular coherence) that might be helpful...I'm not sure.

Below are additional notes I made:

ABSTRACT --

Well written (good grammer and flow).

Highly technical (but in an OK way).

1. INTRODUCTION --

Well written, good flow, lots of citations to related literature. I like how the references are weaved fluidly into the prose.

2. METHODS --

Thanks for telling me exactly how you fetched the data (with Python over the Binance public Rest API).

Maybe rethink the word "most" in this sentence: "Binance...is the most trusted and popular cryptocurrency exchange with the highest 24 hour trading volume worldwide..." How about "Binance...is a trusted and popular cryptocurrency exchange with the highest 24 hour trading volume worldwide..."".

I'm already over my head with these equations. Eq 1 makes sense, but I don't understand why the computed returns must be normalized against volatility to facilitate comparison. Do you mean "facilitate comparison on a risk-adjusted basis"? If so, can't you just call the normalization "risk adjused returns"?

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"Generalized coherence measure" was new to me. I googled it expecting a wikipedia article, but found only references in academic papers, suggesting that it will be new to most the readers of Ledger as well.

Eq. (3) confused me at first because S_XY looks like the regular cross power spectrum. If you put the "nm" in a superscript like you did for the terms in the denominator, it would have been more obvious to me that the fourier transforms in the numerator are raised to powers too (which is needed for the Cauchy-Schwarz inequality to hold)

I am really confused how the NMC works. Are there four degrees of freedom (n, m, fx, fy) or only two (fx, fy)? Further, I don't understand why the terms are raised to the powers of n and m. Is this NEEDED in order to detect the cross couplings (some math magic where squaring the fourier transform scales the frequency) or is this done for another reason? This relates to my question above the number of degrees of freedom. Overall, I'm very confused about the NMC framework and uncertain whether it is even sensible. I can see, however, that it reduces to regular coherence for n=m=1 and fx=fy=f.

Eq. (8). What are script R and script F/I? Are you taking the real and imaginary parts?

Eq. (9) Again I think a superscript "nm" in the numerator would be better notation

Eq. (10 - 12) hurt my brain

3. RESULTS --

Fig. 2a. This chart shows the same data twice, correct? It's mirrored about the red line. Why not omit the upper triangle (everything above the red line?)

Fig. 2b. I was confused that this chart was NOT mirrored, but it's just that the upper triangle is negative the lower triangle. Again, why not omit the upper triangle for clarity? Or at least make a note that (A) has to be symmetric, and (B) has to be anti-symmetric.

Fig. 6 (IFC based dendrogram) is interesting. Seems you are indeed detecting that coins one might reasonably expect to trade similarly (e.g, privacy coins) actually are.

In general, I think this section is well written and clear.

4. DISCUSSION AND CONCLUSION --

Again, well written and clear. I like the practical discussion on risk reduction.

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Reviewer B

Does this paper represent a novel contribution to cryptocurrency or blockchain scholarship?

No

Is the research framed within its scholarly context and does the paper cite appropriate prior works?

Important references are missing

Please assess the article's level of academic rigor.

Good (not excellent but a long way from poor)

Please assess the article's quality of presentation.

Good (not excellent but a long way from poor)

How does the quality of this paper compare to other papers in this field?

Top 20%

Please provide your free-form review for the author in this section.

I thought the paper had some merit but a couple of elements were missing:
- the ecosystem view of market participants was missing. More specifically, the paper discusses the cross-frequency relationship between different cryptocurrency but fails to explain this with common crypto products or strategies that would explain the physical connection. I would point to a very simple strategy that involves maintaining a portfolio of cryptocurrencies based on their market cap. My question to the authors would be: how does this strategy explain or support some of the claims you are making?
- I would also put forward the sectorisation argument. Some of these cryptocurrencies are more or less close to each other in terms of fundamentals. Does that in any way shape and form change the pure data driven approach of the methodology. More specifically figure 6 of the paper represents a dendogram based on IFC. The dendogram suggest that BTC and ETH are close. More specifically BTC is closer to ETH than Bitcoin Cash or ETH is closer to BTC than Etherium Classic. Any person who have worked on cryptocurrencies know that this cannot be the case based on fundamentals. The reason why these things are close with the data chosen is because of strategies associated to market cap and not fundamentals.

You can reflect on both of these points by taking a look at this article:
https://www.researchgate.net/publication/350220749_Cryptocurrency_sectorisation_through_clustering_and_webscraping_Application_to_Systematic_Trading

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1B. Author Responses

Reviewer A

This paper examines pairwise relations between the price time series for 55 of the top cryptocurrencies. In the words of the author, it is a generalized coherence analysis for the price movements of crytocurrencies. The words "generalized" and "coherence" have specific meanings here. Most readers of Ledger will be familiar with correlation. If Crypto A is highly correlated with Crypto B, then if tomorrow Crypto A increases in price, we would expect Crypto B to also increase in price. If an hour later, Cryto A decreases in price, we would expect Crypto B to likewse decrease in price. Coherence, roughly speaking, breaks correlation into frequency bands. While correlation is a number, coherence is a function (of frequency). If Crypto A has high coherence with Crypto B on the dailys, then if tomorrow Crypto A increase in price, we would expect Crypto B to also increase in price. But, these two cryptocurrencies might ALSO have LOW coherence hourly, which means that if Crypto A increased in price an hour from now, we couldn't infer anything about Crypto B's price movement. The author calls this effect "iso-frequency coupling (IFC)"

The word "generalized" adds further complexity. Rather than using the traditional equation to calculate "coherence" (mathematically, it's proportional to the cross-power-spectrum for the pair), the fourier transforms for the time series are raised to integer powers before being fed into the coherence equation. Through some mathematical magic that I don't understand (and I'm not sure is ever explain in the paper) this allows us to detect coupling for frequency harmonics too. For example, we could find that Crypto C on the hourlies has a high coupling with Crypto D on the daily. The author calls this effect "cross-frequency coupling (CFC)."

Beyond the nice graphics visualizing the results, the results support the interesting claims made by the author. For example:

(1) IFCs are weaker for small cryptos than for large cryptos (which means that portfolio diversification here can improve risk-adjusted returns)

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Overall, I think this is a well written paper with excellent grammar and good flow. The author has put considerable time into this analysis. The methodology appears sound and the results are sensible. I think the paper is basically publishable as is.

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there were a way to hold the readers hand a bit more through the math (maybe by starting with regular coherence) that might be helpful...I'm not sure.

- We would like to thank the reviewer for his/her lucid and insightful summary of our manuscript and the associated suggestion for improvement of the accessibility and readability of the n:m coherence description in the METHODS section. Following his/her suggestion we have revised the description of the n:m coherence in our METHODS section by explaining the simpler classical coherence first and then moving on to explain how the n:m coherence is a systematic generalization of the classical coherence approach. It is in this generalization that one gains the capability to assess and quantify not only iso-frequency coupling (as in classical coherence) but also cross-frequency coupling (see highlighted lines 119-175 in the revised manuscript). We hope that by adopting this narrative our analysis will be much more accessible to the readers since it incrementally builds on the widely used classical coherence measure and goes on to show how the added information obtained by extending this conventional technique can be used to perform a much more in-depth analysis of the cryptocurrency price co-movements. Specifically, the cross-frequency coupling information obtained by the n:m coherence measure can be used to assess the risk reduction obtained by portfolio diversification across cryptocurrency pairs when they are being traded asynchronously, which is indeed better representative of the real-world scenario as compared to their synchronous trading.

Below are additional notes I made:

ABSTRACT --

Well written (good grammer and flow).

Highly technical (but in an OK way).

- We thank the reviewer for his/her kind words of commendation.

1. INTRODUCTION --

Well written, good flow, lots of citations to related literature. I like how the references are weaved fluidly into the prose.

- We thank the reviewer for his/her kind words of commendation. We indeed spent a lot of time in organizing the information and the references in order to systematically build the motivation to our hypothesis.

2. METHODS --

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Thanks for telling me exactly how you fetched the data (with Python over the Binance public Rest API).

- You are welcome. The code is open source as provided in reference no. 27 of our revised manuscript. Throughout our METHODS section we have ensured that our work is amenable to future reproduction and further exploration by laying down in detail every step of our analysis.

Maybe rethink the word "most" in this sentence: "Binance...is the most trusted and popular cryptocurrency exchange with the highest 24 hour trading volume worldwide..." How about "Binance...is a trusted and popular cryptocurrency exchange with the highest 24 hour trading volume worldwide..."".

- We thank the reviewer for his/her careful observation. We have corrected it as per his/her suggestion in the revised manuscript (see highlighted lines 106-108).

I'm already over my head with these equations. Eq 1 makes sense, but I don't understand why the computed returns must be normalized against volatility to facilitate comparison. Do you mean "facilitate comparison on a risk-adjusted basis"? If so, can't you just call the normalization "risk adjused returns"?

- We thank the reviewer for voicing his/her concern regarding this matter. We adopted this technique of price variance correction following reference no. 15 where the authors performed a similar dendrogram analysis using classical coherence. We have updated the text to include the reference with the formula and addressed the reviewer's suggestion and renamed the correction as 'risk-adjusted returns' (see highlighted lines 113-117 in the revised manuscript).

"Generalized coherence measure" was new to me. I googled it expecting a wikipedia article, but found only references in academic papers, suggesting that it will be new to most the readers of Ledger as well.

- We thank the reviewer for raising this concern. As mentioned in our response to his/her free-form review, we have updated our METHODS section to enhance the clarity and accessibility of our coherence analysis.

Eq. (3) confused me at first because S_XY looks like the regular cross power spectrum. If you put the "nm" in a superscript like you did for the terms in the denominator, it would have been more obvious to me that the fourier transforms in the numerator are raised to powers too (which is needed for the Cauchy-Schwarz inequality to hold)

- We thank the reviewer for this immensely important typographical correction. We have updated the term everywhere as suggested in our revised manuscript (see highlights in pages 4-6).

I am really confused how the NMC works. Are there four degrees of freedom (n, m, fx, fy) or only two (fx, fy)? Further, I don't understand why the terms are raised to the powers of n and

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m. Is this NEEDED in order to detect the cross couplings (some math magic where squaring the fourier transform scales the frequency) or is this done for another reason? This relates to my question above the number of degrees of freedom. Overall, I'm very confused about the NMC framework and uncertain whether it is even sensible. I can see, however, that it reduces to regular coherence for n=m=1 and fx=fy=f.

- We thank the reviewer for raising this concern. The higher order cross- and auto-spectra are computed as given in Dr. Yang's publication detailing the n:m coherence method (reference no. 29 of our revised manuscript). To facilitate the readers' understanding of why the FFTs X(f) and Y(f) must be raised to the powers of n and m when computing the generalized cross- and auto-spectra, we provide a simple illustrative example of the case when n = 2 and m =1 (i.e., 1:2 harmonic coupling between X and Y). Using higher order spectral computation technique (as detailed in reference no. 30 of our revised manuscript) we show that the cross-spectrum between X and Y at $(fx,2fx)$ is given by $SXY1,2=X2(fx)(Y(2fx))*$. We hope that this demonstrative example motivates the readers' understanding of the more general formulae of n:m cross- and auto-spectra (see highlighted lines 138-159 in the revised manuscript).

Eq. (8). What are script R and script F/I? Are you taking the real and imaginary parts?

- We thank the reviewer for pointing out this ambiguity. We have updated the manuscript to mention that they are the real and imaginary parts as correctly identified by the reviewer (see highlighted line no. 190 in the revised manuscript).

Eq. (9) Again I think a superscript "nm" in the numerator would be better notation

- As mentioned in our response to the same issue raised by the reviewer for equation (3) in the original manuscript, we have updated the term everywhere as suggested in our revised manuscript (see highlights in pages 4-6).

Eq. (10 - 12) hurt my brain

- We apologize for the lack of clarity. We hope the following treatment of the equations (19, 20 and 22 in the revised manuscript) would make them easier to follow:

- **Equation 19:** As mentioned in reference 19 of our revised manuscript, optimal weightage of the portfolio Y in its mixed portfolio with X is given by:

$$w^Y = \frac{\sigma_X^2 - cov(X,Y)}{\sigma_X^2 + \sigma_Y^2 - 2cov(X,Y)}$$

- The above measure is obtained from the timeseries of X and Y. In our manuscript, we are interested on this measure specific for each trading frequency pair (fX,fY). Hence using the generalized cross- and auto-spectra (which are the frequency domain analogs of $\sigma 2$ and cov(X,Y) respectively, we define wfX,fYY as in equation 19.

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- **Equation 20:** Just like equation 19, this equation is a straightforward frequency domain extension of the mixed portfolio variance given by

$$\sigma^2_{portfolio} = w^Y\sigma^2_Y + w^X\sigma^2_X + w^X w^Y cov(X,Y)$$

- **Equation 22:** Following the same logic as in equations 19 and 20, this equation is the frequency domain counterpart of the risk-reduction computed in time domain (provided in reference no. 37 of our revised manuscript) as follows:

$$RR = 1 - \frac{\sigma^2_{portfolio}}{\sigma^2_X}$$

- Thus, the clarity of the equations is enhanced when considered in relation to their simpler time domain counterparts. We have updated the manuscript to include this information (see highlighted lines 208-226 in the revised manuscript).

3. RESULTS --

Fig. 2a. This chart shows the same data twice, correct? It's mirrored about the red line. Why not omit the upper triangle (everything above the red line?)

Fig. 2b. I was confused that this chart was NOT mirrored, but it's just that the upper triangle is negative the lower triangle. Again, why not omit the upper triangle for clarity? Or at least make a note that (A) has to be symmetric, and (B) has to be anti-symmetric.

- We thank the reviewer for this important observation. Our intention for keeping the mirrored data for iso-frequency and cross-frequency coherence in Fig 2a and 4a is to enable the readers to compare the two results. As per the suggestion of the reviewer, we have revised manuscript to include the information that the iso-frequency measure is symmetric while the cross-frequency measure is antisymmetric (see highlighted lines 287-288 in the revised manuscript).

Fig. 6 (IFC based dendrogram) is interesting. Seems you are indeed detecting that coins one might reasonably expect to trade similarly (e.g, privacy coins) actually are.

- We thank the reviewer for this important observation. Indeed, the price co-movement analysis at the daily level reveals functional clustering of cryptocurrencies.

In general, I think this section is well written and clear.

4. DISCUSSION AND CONCLUSION --

Again, well written and clear. I like the practical discussion on risk reduction.

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- We thank the reviewer for his/her kind words of commendation. We hope the novel approach to cryptocurrency price co-movements introduced in our paper stimulates its further research and exploration.

Reviewer B

Does this paper represent a novel contribution to cryptocurrency or blockchain scholarship?

No

- We would like to thank the reviewer for his/her kind review and analysis of our manuscript. However, we would like to clarify that our work does not contribute to cryptocurrency or blockchain technology per se. We believe our novelty lies in applying the generalized coherence framework to the analysis of dynamics of price co-movements of cryptocurrencies. Leveraging the additional information obtained by this analysis (over and above the usual coherence analysis employed by numerous previous studies), we attempt to better inform investors about realistic portfolio compositions that show reduction of financial risk.

Please provide your free-form review for the author in this section.

I thought the paper had some merit but a couple of elements were missing:
- the ecosystem view of market participants was missing. More specifically, the paper discusses the cross-frequency relationship between different cryptocurrency but fails to explain this with common crypto products or strategies that would explain the physical connection. I would point to a very simple strategy that involves maintaining a portfolio of cryptocurrencies based on their market cap. My question to the authors would be: how does this strategy explain or support some of the claims you are making?

- We would like to thank the reviewer for pointing out the vital ecosystem view of market dynamics and how our data and results provide light on this regard. We have included the recommended literature (and some of its references) in our discussion section to point out two aspects which we found notable:
    - We found that while conventional coherence analysis depicts a market capital dependent herding behavior, cross-frequency coupling reveals a more diversified market for cryptocurrencies. From an ecosystem point of view, this lends credibility to the fact that market capital driven investment strategy lends less importance to asset fundamentals. Thus, at least some of the panic driven flash crashes that currently plague the cryptocurrency markets maybe be indicative of an inefficient market rather than price bubble corrections (see highlighted lines 417-420 in the revised manuscript)
    - We also find that trading a larger market cap cryptocurrency at a higher frequency as compared to a smaller market capital cryptocurrency almost always produces a reduced risk. In other words, it entails a strategy of short-term trading of well-established assets while ‘HODL’ing newly emerging ones. This, we believe is a hallmark of an emergent market still in its ‘discovery’ phase wherein many new asset classes (each with its own new

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potential niche of use cases) are rising every day. (see highlighted lines 428-432 in the revised manuscript)

- I would also put forward the sectorisation argument. Some of these cryptocurrencies are more or less close to each other in terms of fundamentals. Does that in any way shape and form change the pure data driven approach of the methodology. More specifically figure 6 of the paper represents a dendogram based on IFC. The dendogram suggest that BTC and ETH are close. More specifically BTC is closer to ETH than Bitcoin Cash or ETH is closer to BTC than Etherium Classic. Any person who have worked on cryptocurrencies know that this cannot be the case based on fundamentals. The reason why these things are close with the data chosen is because of strategies associated to market cap and not fundamentals.

- We would like to thank the reviewer immensely for pointing out an important aspect of the interpretation of our results missing from our manuscript. The proximity of BTC and ETH in the dendrogram based on iso-frequency coupling is indeed a consequence of investment strategies associated with market capitalization rather than fundamentals. We have acknowledged this fact in our revised manuscript. In addition, as rightly pointed out in the article recommended by the reviewer, we have also reiterated the finding that with increasing number of cryptocurrencies, the natural sectorization between them becomes fuzzier because many of them have overlapping features (see highlighted lines 337-343 in the revised manuscript).

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