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Editorial: From Physics to Econophysics and Back: Methods and Insights

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Editorial on the Research Topic

From Physics to Econophysics and Back: Methods and Insights

The term "Econophysics" was coined by H. Eugene Stanley in 1995 during a statistical physics conference on the Dynamics of Complex Systems in Kolkata, India to refer to the then emerging interdisciplinary field of physicists working on problems in economics and finance [1]. An interdisciplinary area of research straddling computer science, economics, finance, mathematics, and physics, econophysics started out drawing heavily upon theories and methods developed in nuclear physics and statistical physics. From the use of Random Matrix Theory (RMT) to discriminate between signal and noise in financial time series data [2, 3], to the use of the Ising model and variants to explain stylized facts of stock markets in terms of the microscopic dynamics of traders [4–7], econophysicists have since gone on to develop methods and insights inspired by specific problems. These include the DebtRank measure of systemic risk in banking networks [8], and the discovery of unusual Brownian motion dynamics in order books [9–11], among many others.

Unfortunately, scientists and the public are generally unaware of these contributions. Even within the broader physics community, the fruits of econophysics remain relatively unknown. In fact, every now and then we will find physicists, mathematicians, electrical engineers, or computer scientists reinventing the wheel, and publish results that have been obtained by econophysicists 5–10 years ago. The main reason for this predicament, and also econophysics methods and insights not catching on in the broader physics community is that econophysicists tend to publish in a variety of journals with diverse audiences. As econophysics matures as a field—it is now more than 20 years old, we feel that it has progressed to a stage where we have derived new methods and results found nowhere else. We believe these have the potential to contribute towards deeper understanding in other areas of physics. This is our motivation for launching a Research Topic in Frontiers in Physics, read by serious physicists from different research fields, so that econophysics can give back to the broader physics community. Additionally, early econophysicists came from very different backgrounds, from those starting out in statistical physics, to those moving on from nuclear physics, to former string theorists and former condensed matter physicists. They have all benefitted greatly from cross fertilization amongst themselves, as well as with economists, mathematicians, and computer scientists. Having such a Research Topic appear in Frontiers in Physics will give the cross fertilization between physicists and scientists from other disciplines a renewed push.

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In this Research Topic, which we called *From Physics to Econophysics and Back: Methods and Insights*, we now have a Research Topic of 30 articles. We organized them into six groups:

1. Methods;
2. Models;
3. Financial times series;
4. Financial time series cross sections;
5. Banking and macroeconomics; and
6. Urban complexity.

While Methods and Models are clearly about new and existing econophysics methods, new methods are also introduced in the next four groups of papers focused on developing insights.

To begin, we find many claims in finance. Some are based on rigorous statistical analysis, while others are based on anecdotal evidence. For example, financial time series are expected to be more complex during crisis periods than in calm periods. In the first group of three papers on methods, we find first the paper by Yadav et al. who used the block decomposition method [12–14] to probe the algorithmic complexity in financial time series cross section data. Doing this for the daily returns of $N = 300$ stocks in NASDAQ between 1972 and 2018, over a sequence of 4-years overlapping sliding time windows, Samal et al. found that the 2007–2009 Global Financial Crisis did not register on the results of the first two measures, which were linear, but was clearly present on the results of the last two measures, which were nonlinear. Another claim tested in this Research Topic is a recent one suggesting that cryptocurrencies, such as Bitcoin, might also serve as safe havens. A safe haven is an instrument or investment sector that guarantees the value of one's capital during periods of financial turmoil. Of these, gold and other precious metals have been extensively tested [16–19], but the results for other safe havens have been largely inconclusive. Using the COVID-19 pandemic as the backdrop, Kristoufek used the method of quantile correlation to test the possibility of using Bitcoin as a safe haven for investors . In the method of quantile correlation, we can evaluate separately the correlations between small positive/negative deviations and those between large positive/negative deviations, and in so doing avoid diluting statistically significant signals coming from particular quantiles. Even with this care, Kristoufek found that gold continued to show promise as a safe haven during the COVID-19 pandemic, but neither Bitcoin nor the broader index of cryptocurrencies were able to do so. Finally, we find the paper by Wang et al., testing the impact of corporate culture (Confucianism) on firm performance. This is a claim that sounds plausible, but is very difficult to check. To perform this check, Wang et al. assume that Confucianist ideals and thinking become embedded into the fabric of local communities through the teachings of Confucianism schools after a long time, and the closer communities are to these schools, the stronger the influence. Therefore, as a proxy variable measuring the influence of Confucianism on firms, Wang et al. used the distance from the firms to schools known since the Qing Dynasty. They then measured the performance of a firm by its return on assets. For the 20,121 Chinese firms listed either on the Shanghai Stock Exchange or the Shenzhen Stock Exchange, they found that Confucianist influence does indeed improve firm performance, at the 1% level of statistical confidence.

In the second group on market models, we find four papers on models familiar to physicists, as well as those unfamiliar to the physics community. For the former, Maskawa and Kuroda wrote down a continuous random cascade model to investigate intermittency and multifractality in financial time series. Models on energy cascades are commonly used in the study of turbulent fluid flow. After estimating the parameters of the resulting Fokker-Planck equation for 111 component stocks of the FTSE 100 index on the London Stock Exchange between November 2007 and January 2009, Maskawa and Kuroda were able to reproduce from model simulations multifractal features seen in their earlier empirical study. The next paper by Sohn and Sornette extended rational expectation theory from economics, to explain why economic bubbles arise even when all agents have rational expectations . In economics, agents are treated as having independent beliefs. Sohn and Sornette showed that, when these beliefs are correlated, the time scale at which the market processes information can slow down dramatically, giving rise to a bubble. This is reminiscent of how the central limit theorem results in a normal distribution when a large number of statistically independent random variables with finite variance are combined [25, 26], but in distributions with fat tails when the random variables are correlated [27–31]. The remaining two papers in this group are on order book models. In the first, Yamada and Mizuno, reported an empirical study pointing to a linear correlation $r = \alpha\Delta V + \beta$, where r is the return, ΔV the executed order imbalance (number of bids–number of asks), α and β are stock-dependent constants. This empirical observation is important for building models of price impact of different trade volumes. In the second, Zhao et al. developed a multi-order book agent-based model, based on rules on asset design, investor design, price prediction by the agent, adaptive asset allocation, and order placing . Through simulations, Zhao et al. found that market liquidity decreases with increasing tick size.

Next, we find the group of seven papers on the analysis of single financial time series data. In the paper by Mahata and Nurujjaman, the authors first used empirical mode decomposition (EMD) to write the stock price time series as the sum of a set of intrinsic mode functions (IMF). The advantages of EMD over traditional spectral methods like Fourier transform or wavelet analysis are the far fewer basis functions (the IMFs) needed, these basis functions can be determined empirically from the data, and the basis functions represent the natural time scales found in the data. The Hilbert transform was then computed for each IMF, before R/S scaling was carried out to estimate its Hurst exponent H. Analyzing the stock indices of 12 different countries and the prices of six stocks from December 1995 to July 2018, Mahata and Nurujjaman found that indices and prices are mean-reverting at short time scales, but have long-range correlations at long time scales. In the paper by Liu and Chen, the authors applied the visibility graph method to discriminate between periods of concave price movements (accelerating price change) and periods of convex price movements (decelerating price change) in noisy time series data. Analyzing eight stock market indices from 28 June 1999, to 28 June 2019, they rediscovered the well-known asymmetry between accelerating price change and decelerating price change. In the next paper by Zhang et al., the authors explored machine learning methods to predict the movement of a stock index. Zhang et al. developed a feed-forward auto-encoder neural network with seven hidden layers using the daily closing prices between 1 January 2010 and 31 December 2018 (2,187 trading days) of the CSI 300 index and its constituent stocks. The model would first be trained on a four-month-window of the data, and then its index tracking performance tested on the 6 months following this time window. This performance was found to be better than conventional methods for stock selection and index tracking. Following this, we then find two papers on information flow in stock markets. Like most complex systems, the stock market is an open system. Economists argue that market crashes are exogenous events, i.e., they are triggered by information flowing in from outside of the stock market [37, 38], whereas econophysicists are open to endogenous explanations in terms of the interactions between stocks in the market [39–42]. In the first of these two, Zhang et al. analyzed the cross correlations between mass media news from 726 sources and new media news from 1,488 sources with the returns of 3,026 stocks, and found the existence of strong cross correlations both at equal times, as well as at various lags. In the second paper, Yao and Li used the transfer entropy method to investigate impacts on the stock market from economic policy uncertainties as well as investor sentiments. As far as the Chinese stock market is concerned, they found no information flow directly from economic policy to the stock market, nor indirectly from economic policy to investor sentiments to the stock market. Finally, the stock market is only one of many markets available to financial investors. Another popular market is the commodities market. In this Research Topic, we have two papers on the crude oil market. In the first paper Yang et al. investigated the lead-lag relationship between two important global crude oil indices between 20 May 1987 and 10 October 2017, and found the Western Texas Intermediate (WTI) leading the Brent slightly over the entire period. In the second paper Shao computed the Hurst exponent H. in 1-year, 2-years, and 4-years rolling windows of the WTI and Brent closing spot prices from 14 October 2011 to 6 March 2020. They found the WTI approaching $H = 0.5$, while Brent deviating from $H = 0.5$ after US lifted their export ban on 18 December 2015.

Another defining feature of complex systems is the large number of interacting variables. In a typical stock market like the New York Stock Exchange, investors can choose from more than 20,000 financial instruments, the majority of which are stocks. As we have just mentioned, interactions between stocks create endogenous forces affecting the prices of individual stocks. Therefore, instead of studying the time series of a single stock, or that of a stock index, econophysicists have also developed methods to investigate cross sections of time series. Because the stocks in these cross sections are interacting, they are often represented as networks. In this Research Topic, we have seven papers looking into various aspects of stocks as a network. In the first of these Kukreti et al. reviewed recent work on correlations-based networks of the stock market, and proposed the use of structural entropy and eigen-entropy for monitoring how these networks change over time. Then in the second of these Shi and Chen investigated the co-movement of asset returns over 120-days rolling windows advancing 1 day at a time, by first decomposing the daily log returns of 28 sector indices between 5 January 2000 and 29 March 2019 on the Chinese stock market using the French-Fama Five Factor Model into the value-weighted market portfolio return (MKT), the portfolio size (SMB), the portfolio value (HML), the portfolio probability (RMW), and the investment factor (CMA). Then, they constructed in each rolling window the minimum spanning tree (MST) based on the Spearman rank correlations between the 29 sector indices and the five factors. They found that the MST having a star-like structure over the entire period, with MKT as the hub, and this star-like structure changing over different parts of the market cycle. One common application of financial networks is to understand the market's response to crises. Related to this we have three papers. In the third of these Samal et al. instead of focusing on a single stock market, Samal et al. computed the cross correlations between the daily closing prices of 69 global financial market indices between 2000 and 2014. They then compared the networks obtained by simple thresholding (keeping cross correlations above some threshold level) and the minimal spanning trees within growth periods as well as crisis periods and found that the discrete edge-based Ricci curvature can be used as an indicator of fragility in global financial markets. In the fourth of these Yang et al. probed whether the network of stocks became stable after a market crash. To do so, they constructed the planar maximally filtered graphs (PMFG) [51] of the constituent stocks of the Shanghai Stock Exchange 180 index within stable and crash periods and computed the entropies of their degree distributions. They found that the stock market did indeed stabilize after market crashes. In the fifth of these Yen and Cheong used the increasingly popular topological data analysis (TDA) method to investigate the persistent homology of the cross correlations between stocks in the Singapore and Taiwan stock exchanges, as well as how these evolve over time. Based on how the Betti numbers change from one time window to the next, they found hints of multiple stages in market crashes. Lastly, in this group of papers we find two on the identification of communities and principal components in stock markets. In the sixth paper Purqon and Jamaludin tested two hybrid methods for detecting communities in the threshold network of cross correlations. While the community structures discovered by the two methods are not the same, these communities were nevertheless meaningful to human experts. Finally, in the seventh paper Souma computed the cross correlations between 445 component stocks of the S&P 500 index over the period 2010 to 2019 and used two methods to extract the meaningful part of the cross correlations. In the first method, he assumed that the eigenvalues of a fully noisy correlation matrix would follow the Pastur-Marcenko distribution, and be bounded between $\lambda_{\min}$ and $\lambda_{\max}$. In the second method, Souma generated a null model through random rotational shuffling of the cross correlations, using which he extracted the meaningful part of the correlation matrix. He then complexified the meaningful part of the correlation matrix using the Hilbert transform, before analyzing the leads and lags between stocks.

The next group of five papers in this Research Topic deals with the latest research problems in banking and macroeconomics. The paper by Wen et al. describes network structure properties for global remittance and found the key economics group using a community detection method. The impact that export has on domestic production is described by Saltarelli et al. using data from the World Input-Output Database. Recently, the interbank loan structure has been used to study the systemic risk in financial market. The paper by Xiao et al. focused on the connection between nighttime lights and GDP data, to probe regional economic convergence in China. Traditionally, properties of the banking system have been used to study a bank's profit and risk in global financial market. However, it can also be used to investigate the systemic risk of financial system using networks constructed from interbank loan information. Using random matrix theory, Namaki et al. describe the evolution of global bank network to examine the roles of individual countries. Constructing credit and interbank networks using real-world data, Fan and Sheng investigated the systemic risk that might result from credit risk and contagion effect in the banking system. Finally, the paper by Oh and Park provided a quantitative relationship between properties of the interbank network and bank performances, using syndicated loan data from the United States.

Finally, in this Research Topic, we also have two papers dealing with urban complexity, and one paper on a new measure of inequality. In the first paper on urban complexity, Ishikawa et al. analyzed municipal population data for the United States, Italy, and Spain over a period of 10 years, and found that small initial urban populations tend to decrease, but the probability for cities to expand does not depend on the initial population. Over 100 years, however, the populations of some cities increase exponentially while those of other cities decrease exponentially. In fact, large cities can also stop growing exponentially. Recognizing the heterogeneous spatial distribution of urban population in the second paper on urban complexity, Ito and Ohnishi used multifractal analysis to compare the spatial distributions of population, stores, and facilities, to find that stores and facilities are far more concentrated (within commercial districts) than human population. Finally, the paper Banerjee et al. surveyed the development of the Kolkata index for measuring social inequality, before comparing it against other measures of inequality like the Gini coefficient and the Pietra index.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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