

ECONOPHYSICS ON REAL ECONOMY – THE FIRST DECADE OF THE KYOTO ECONOPHYSICS GROUP

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Research activities of Kyoto Econophysics Group is reviewed. Strong emphasis has been placed on real economy. While the initial stage of research was a first high-definition data analysis on personal income, it soon progressed to firm dynamics, growth rate distribution and establishment of Pareto's law and Gibrat's law. It then led to analysis and simulation of firm dynamics on economic network. Currently it covers a wide range of dynamics of firms and financial institutions on complex network, using Japanese large-scale network data, some of which are not available in other countries. Activities of this group for publicising and promoting understanding of econophysics is also reviewed.

Introduction

Physics community in Japan has been blessed with open-mindedness about application of physics methods and attitudes to other areas of research. One of the earliest expression of such an ideal was by Torahiko Terada, a leading physicist and a well-respected writer of that time, who wrote the following defence¹ of bringing physics into biology in 1933 :

When making a statistical analysis of a large number of human individuals we may properly regard it as a mere conglomeration of inorganic material, and altogether neglect individual free will. Indeed, it is now clear that pure physical problems, such as the density of particles in a colloidal matter, may with propriety be compared to statistics of a purely

physical nature, such as the “density” or “average speed” of persons walking along street. . . . It is sheer folly to dismiss such insights as heresy simply because they are incompatible with the dogma that “living creatures cannot be understood by Physics”. Such absurdities remind us that no ignorant amateur poses so serious a threat to progress as a scientist unaware of the nature and goal of their discipline.

Hideki Yukawa, who won a Nobel Prize in Physics for his meson theory in 1949 for the first time in Japan, encouraged his disciples to spread the physics research to various areas, including biology and cosmology, which all blossomed in the following years. One of his favorite quote from Kyogen (Japanese traditional comedies, in the style of Noh) is the following² :

A patient mind looks everywhere for signs of thoughts and things of worth; The shallowest stream runs sparkling over secrets far beneath the earth.

Econophysics was introduced to Japanese physics community by Hideki Takayasu (Sony CSL), whose pioneering work may be, the very first mathematical modeling and simulation of stock market³ in 1992, and application of the Langevin equation to the stochastic process and the derivation of the power law⁴, among others.

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He also publicised the approach and fruits of econophysics widely in physics community through lectures and organization of conferences. The present authors, who studied various areas of physics; elementary particle physics (H.A. and W.S.), cosmology (Y.F.), condensed matter physics (H.I.) and high-energy and nuclear physics (Y.I.), met econophysics under his influence. Since then, Kyoto Econophysics Group has been conducting research with emphasis on real economy, and has published two books in Japanese^{5,6}, and a book in English⁷. In the following, we shall review our research activities of the last decade and will conclude it with the future prospect.

Pareto's Law and Gibrat's Law

The beginning of the econophysics research at Kyoto may be the empirical study of the personal income⁸ in 2000, which is the first high-definition study, covering some eighty thousand top income-earners in Japan. It came about as a result of a chance finding of a data CD that contained the list of the income, address, phone numbers, etc. of those people by one of the authors (H.A.) at a PC shop in Akihabara, Tokyo. (Such information were posted at the tax offices scattered all over in Japan and were collected by a database company at that time, but is no longer available for the protection of personal information.) This resulted in clear identification of the Pareto's (power) law, followed by several related works^{9,10}, earned its position as a logo of a conference^{11,78}

Y. Fujiwara joined this group in the midst of this line of work, after working on stock markets: some of which were on self-similarity and multifractality in stock price fluctuations¹³ and a spin model of stock market¹⁴.

The research thus started soon lead to study of the growth rate, the ratio of the income of a year and the income of the next year for each person, which was a collaborative work with economists, Masanao Aoki (UCLA) and Taisei Kaizoji (ICU)¹⁵, as we recognized importance of collaboration between physicists and economists. It may be noteworthy that H.A. knew that when physicists enter areas outside physics such a collaboration with experts is almost a must for fruitful results, from his earlier work with John Constable, a Cambridge-educated English critic/poet, on linguistics¹⁶⁻¹⁸.

Soon, it flourished to various research covering firms as well: establishment of the Gibrat's law in high definition data^{19,20}, study of European firms, with Italian economists, Corrado di Guilmi and Mauro Gallegati^{21,22}, further study of the firm-size distribution²³, study of small-to-medium firms using the Credit Risk Database (CRD) in Japan²⁴,

study of firm bankruptcy, the life-time distribution and a simulation model (Delli Gatti-Gallegati-Palestrini)²⁵, and twofactor stochastic model, with economist Nirei, to explain personal income distribution in Japan and U.S.²⁶⁻²⁸.

In the meantime, Y. Ikeda had been studying applying the real-option theories in financial engineering and game theoretical approach for risk assessment in multiple-business environment²⁹⁻³¹, which motivated him to join collaborative work with the other authors. He brought research funding from Hitachi to us, which was a key ingredient for the formation of the Kyoto group.

He also continued his own line of research, which was connected to his company's interest, including a study of project risk using Bloomberg data³², and a work on correlation between R&D investment and sales-growth³³.

Economic Networks

Interactions among heterogeneous agents are crucial for understanding of emergent phenomena at macroscopic levels of real economy. The econophysics community has recently witnessed considerable development of complex networks for quantifying structures, temporal changes of various economic networks, their relevance in macroeconomics, and so forth. See the Econophysics-Kolkata III³⁴ in 2007, a collection of monographs³⁵, and also a recent review³⁶ with references therein.

Our early papers^{37,38} studied the small-world effects of a Bouchaud-Mézard model for the stochastic dynamics of wealth distributed among agents on a network. We then examined real data of economic networks in Japan to investigate complex networks and economics³⁹, structure and change of shareholding relationships between firms⁴⁰⁻⁴³, growth of firms and networks⁴⁴, and a study on correlation between firm's financial states and its characteristics in a transaction (supplier-customer) network⁴⁵.

We also developed agent-based models to understand heterogeneous interactions among economic agents, particularly on a transaction network, including response of firm agent network to exogenous shock⁴⁶, simulation for chain of bankruptcy⁴⁷, firm dynamics with parameters estimated by financial and transaction data analysis⁴⁸, and a study on correlation between firms' performance and characteristic properties in the network⁴⁹. Dynamics of coupled balance-sheets of firms (*à la* Delli Gatti-Gallegati-Palestrini) was also studied^{50,51}, and the paper⁵² focused on the model of relation between transaction network and production activity of firms.

Recently, in addition to commercially available data, we had a quite unique opportunity to collaborate with a leading

credit research agency in Japan which regularly gathers credit information on most of active firms. Through collaboration, we examined a nation-wide transaction network comprising a million firms and millions of supplier-customer links. The studies on network structure, uncovering community (cohesive groups), visualization and graph drawing are included^{53,54} and more intensively later⁵⁵⁻⁵⁷. This direction would give an insight into industrial structure of the economic system of the nation as well as instability *via* chain of failures⁵⁸.

Financial networks are no less important than transaction networks. Focusing on banks and firms relationships, we also extended our study on financial networks^{59,60}.

In relation to productivity and production function discussed in the following section, we can mention the relation between networks of firms and the theory of “ridge” in the space of production function⁶¹.

Labour Productivity

Economists Hiroshi Yoshikawa (University of Tokyo) and Masanao Aoki proposed a model of labour productivity distribution based on statistical physics ideas^{62,63} in 2003. This spurred interests among us and we started analysing Japanese data in 2007 in collaboration with the two economists. It soon lead to finding of the power-law distribution and the superstatistics theory of labour distribution. The relevant paper appeared in 2008 as arXiv:0805.2792v1 [q-fin.GN] and RIETI Discussion Paper 08-E-035, but published only in 2010 after a long delay⁶⁴ in reviewing process and rejection by the traditional mainstream economists. In any case, this line of work soon lead to further mathematical disposition⁶⁵, study⁶⁶ of the Period 1996-2006, international comparisons⁶⁷, study of Japanese manufacturing and nonmanufacturing sectors⁶⁸, and use of large-scale data of firm’s financial statements⁶⁹.

As a by-product of the study of productivity, we proposed a new concept of *Production Copula*, which is a multi-variate statistical distribution that should replace the traditional ‘production function’⁷⁰.

Another line of work was created from the above: detailed study of productivity distribution, using the huge CRD data lead to a new finding about the medium range of the productivity, not explained by the superstatistics⁷¹. Furthermore, new scaling laws were discovered and new mathematical theory was developed, which opens up a whole new path to the formulation of statistical physics of economy⁷²,

Business Cycles

Business cycles are a long-standing basic issue for macroeconomics. Even whether a business cycle exists or not is controversial among economists.

Very recently we have analyzed⁷³ business cycles in Japan using the indices of industrial production (IIP), an economic indicator which measures the current conditions of production activities over the nation on a monthly basis. Careful elimination of statistical noises based on the random matrix theory (RMT) enabled us to extract two dominant factors each of which possesses its own economic characteristics, aggregate demand and inventory adjustment, respectively. The two factors collaborate in giving rise to business cycles with periods of 40 and 60 months which are hidden behind complicated stochastic behaviors of the indices. Compilation of all the results⁷³ suggests that the major cause of business cycles is real demand shocks. In passing we note that Japanese business cycles were studied also from the point of view of a chaotic theory through reconstruction of attractor for the GDP time series⁷⁴.

The genuine correlation matrix for the IIP thus obtained elucidates interindustry correlations in a statistically meaningful way⁷⁵ as well as the business cycles. The fluctuation-dissipation theory was invoked to elucidate input-output industrial correlations quantitatively. And we observed distinctive external stimuli on the Japanese economy exerted by the recent global economic crisis. Those stimuli were derived from residual of moving-averaged fluctuations of the IIP left over after subtracting the long-period components due to the business cycles.

The RMT is also useful for construction of stock portfolio⁷⁶. The idea of the RMT was then extended⁷⁷ to detect genuine dynamical correlations between price fluctuations of different stocks. A data set of one-day returns of 557 Japanese major stocks for the 11-year period from 1996 to 2006 was used for this study. Comparison of the eigenvalues of the empirical dynamical correlation matrix with the corresponding results for random data demonstrates existence of collective motions of the stock prices with periods well over days.

Extra-research Activities and Future Prospect

In addition to the research activities reviewed above, we have been working on outreaching to physicists and economists, publicizing the merits and viewpoints of econophysics, and at the same time encouraging discussions and collaborations between econophysicists in Japan as well as abroad.

We have run four domestic econophysics conferences at Yukawa Institute for Theoretical Physics at Kyoto University, in 2003, 2005, 2007 and 2009. Attendance was about 70 to 90, with undergraduate and graduate students at steady increase. The third conference report was published as a Supplement of *Progress of Theoretical Physics*, while the Proceedings of the other conferences were published in *Elementary Particle Physics Reports* and *Condensed Matter Physics Reports*, both of which are publications of the Yukawa Institute in Japanese, circulated widely to the Japanese theoretical physics community.

Further we are currently running a series of Japanese articles *Introduction to Econophysics in the Kinyu-Zaisei Business Journal* (Jiji Press, Ltd. Tokyo), where in addition to our own articles we have been inviting articles from every aspect of econophysics research in Japan. Since this weekly journal is widely read by high-ranking government officials and presidents of financial institutions, we expect that understanding of “econophysics” is deepened for them through this effort.

Graduate students studied under us for Master’s degree in physics are not many. But they have obtained positions at the cabinet office of the government of Japan, several financial institutions and other firms, which imply that econophysics background is welcomed. University positions held by the present authors are those of physics and natural-science departments and not of econophysics, which makes it difficult to accept graduate students who wish to study econophysics. But econophysics is attracting more and more interests of students, as demonstrated by their increasing attendance in our conferences. We thus trust that this situation could be remedied in future.

All in all, we conclude that the prospect for the econophysics is very high in Japan: Econophysics is expected to make huge impact on economics, with its new ideas and approaches suitable for economic phenomena, imported from various areas of physics.

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