Socio-economic inequality and prospects of institutional Econophysics

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Socio-economic inequality is measured using various indices. The Gini ($g$) index, giving the overall inequality is the most commonly used, while the recently introduced Kolkata ($k$) index gives a measure of $1 - k$ fraction of population who possess top $k$ fraction of wealth in the society. This article reviews the character of such inequalities, as seen from a variety of data sources, the apparent relationship between the two indices, and what toy models tell us. These socio-economic inequalities are also investigated in the context of man-made social conflicts or wars, as well as in natural disasters. Finally, we forward a proposal for an international institution with sufficient fund for visitors, where natural and social scientists from various institutions of the world can come to discuss, debate and formulate further developments.

I. INTRODUCTION: SOCIO-ECONOMIC INEQUALITY

The complex dynamics of human social interactions lead to interesting phenomena, and inequalities at various levels often show up in course. The recent availability of huge amount of data (empirical data from databases, electronic footprints, and sometimes large surveys) for various forms of human social interactions has made it easier to uncover certain patterns present, to analyze them and investigate the reasons behind various socio-economic inequalities manifested in them. The age of Big data has opened up new avenues and challenges, and scientists are in the quest to understand why certain things look like as they do and how do they happen. Researchers are pooling in knowledge and techniques from various disciplines, e.g., statistics, applied mathematics, information theory, computer science, while tools of statistical physics have proved to be quite successful in better understanding of the precise (spatio-temporal) nature and origin of socio-economic inequalities prevalent in our society. More the data that is acquired and analyzed, more we become confident in addressing the whys, and hows.

Statistical physics tells us that systems of a large number of interacting dynamical units collectively exhibit a behavior which is solely determined by only a few basic dynamical properties of the individual constituent units and of the embedding dimension, but is independent of all other details. This feature, which is specific to ‘critical phenomena’, as in continuous phase transitions, is known as universality. There is no shortage of empirical evidence that several social phenomena are characterized by simple emergent behavior out of the interactions of many individual constituent units. In recent times, a growing community of researchers have been analyzing large-scale social dynamics to uncover universal patterns and proposing simple microscopic models to describe them, very similar to the minimalistic models used in statistical physics to understand physical phenomena. These studies have revealed quite a few interesting patterns and behaviors in social systems, as in elections, population growth, income and wealth distributions, financial markets, languages, etc. (see Refs. [11, 12] for a review).

Socio-economic inequality usually concerns the existence of unequal ‘wealth’ and ‘fortunes’ accumulated due to complex dynamics and interactions within the society. Usually containing structured and recurrent patterns of unequal distributions of goods, wealth, opportunities, and even rewards and punishments, this is classically measured in terms of inequality of conditions, and inequality of opportunities. The former refers to the unequal distribution of income, wealth, assets and material goods, while the latter refers to the unequal distribution of ‘life chances’. This is reflected in levels of education, health status, treatment done by the criminal justice system etc. Socio-economic inequalities are mostly responsible for conflicts, wars, crises, oppressions, criminal activities, instability in political scenario and socio-political unrest, and that in turn affects economic growth. Historically as well as traditionally, economic inequalities have been extensively studied in the context of income and wealth, although it is also measured for many quantities like energy consumption. The studies of inequality in society has been always very important, and is also a topic of contemporary focus and immediate global interest, drawing attention of

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FIG. 1: Lorenz curve is shown in solid red line for a typical probability distribution function and the equality line in dotted black diagonal. The Lorenz curve shows the cumulative fraction of ‘wealth’ possessed by the corresponding fraction of poorer population. The $g$-index is given by area of the shaded region, while the $k$-index is computed from the coordinate of the point of intersection $C$ $(k, 1-k)$ of the Lorenz curve and the diagonal perpendicular to the equality line. Thus, while the $g$-index measures the overall inequality in the system, the $k$-index gives the fraction $k$ of wealth possessed by the $1-k$ fraction of richer population.

Quantifying socio-economic inequalities is a challenge, but is done in numerous ways. The probability distributions of various quantities, of course provide the most detailed measures. It is very common to find that most quantities display broad distributions – most common are log-normals, power-laws or their combinations. For example, the distribution of income is usually found to be exponential for the bulk followed by a power law [8, 26] for the top income range. However, such distributions can widely differ in their forms and details, and as such they are rather difficult to handle. This leads to the introduction of various indices like the Gini [27], Theil [28], Pietra [29] and other socio-geometric indices [30, 31], which try to characterize various geometric features of these distributions using a single number. Of course, each of these indices come with certain merits, and certain indices are more useful than others, depending on the context they are used in. In this article we will focus on the most common one, the Gini index and a recently proposed $k$ index ($k = Kolkata$) which has a nice, useful socio-geometric interpretation.

The empirical data on Gini index from World Bank data [37] for incomes over several years are given in Fig. 2. The values seem to be mostly between 0.2 and 0.6. In the later part of our article we will argue that the simple kinetic exchange models can even reproduce this feature.

We also discuss here the specific case of the citation distributions. It was shown earlier [38] that the distribution of citations $c$ to papers within a discipline has a broad distribution, which is universal across broad scientific disciplines,
by defining a relative indicator $c_f = c/\langle c \rangle$, where $\langle c \rangle$ is the average citation within a discipline. Our study confirmed this case for academic institutions as well as journals across disciplines.

Studies on the statistics of human deaths from wars, conflicts and natural disasters shows that the form of the probability distribution for number of people killed exhibit power law decay for the largest sizes, the exponent values being quite similar. We argue if a common mechanism is responsible for similarity that is manifested.

II. INTRODUCTION: INSTITUTIONAL ECONOPHYSICS AND SOCIOPHYSICS

In view of the truly interdisciplinary nature of econophysics and sociophysics, it can be argued that some interdisciplinary visiting facilities for social and natural scientists are absolutely necessary today. These will provide scientists from different disciplines to interact over some long period, discuss and debate and develop in their own discipline. In the concluding part of this article, we argue about the need to establish a research institute dedicated to socio-economic problems with an interdisciplinary character, with some specific model in mind.

III. INEQUALITY IN CITATIONS FOR ACADEMIC INSTITUTIONS AND JOURNALS

In a recent study, we were able to conclude that the citation distributions for articles published in different journals (Fig. B), as well as from different academic institutions (Fig. A) followed the same functional form, irrespective of time (the year they are published) and space (institution). One has to carefully scale the probability distributions by their average, and the rescaled curves show excellent scaling collapse. The most of the resulting scaling curve fits to a lognormal function

$$F(x) = \frac{1}{x\sigma\sqrt{2\pi}} \exp \left[ -\frac{1}{2\sigma^2} \left( \log x - \mu \right)^2 \right],$$

while the extreme right tail deviates from this and seem to fit more to a power law with a decay exponent around $2.6 - 2.8$. We additionally observed that for the academic institutions, Gini index was $g = 0.67 \pm 0.10$ and $k = 0.75 \pm 0.04$, which means around 75% citations come from the top 25% papers. For academic journals, $g = 0.58 \pm 0.15$, $k = 0.71 \pm 0.08$ which means about 71% citations come from the top 29% papers.

We further noted that Gini and $k$ indices fluctuate less around respective mean values $\bar{g}$ and $\bar{k}$ as the number of articles or the number of citations became large (Fig. D). For academic institutions, the values were $\bar{g} \approx 0.66$ for Gini and $\bar{k} \approx 0.75$. For journals, the values are $\bar{g} \approx 0.58$ and $\bar{k} \approx 0.71$.

IV. EMPIRICAL FINDINGS ON $g - k$ RELATIONSHIP

The huge variety of socio-economic data suggest that there might be a simple relation between the two seemingly different inequality measures. Analysis of the following were carried out: (i) citations of papers published from academic institutions and journals (data from ISI Web of Science and reported in Ref. 35), (ii) consumption expenditure data of India, Brazil, Italy, income data from USA, (iii) voting data from open list proportional elections of Italy, Netherlands and Sweden, first past the post election data for Indian Parliamentary...
FIG. 3: (A) Probability distribution $P(c)$ of citations $c$ rescaled by average number of citations $\langle c \rangle$ to publications from 1990 for several several academic institutions. The scaled distribution fits very well to a lognormal for most of its range, with $\mu = -0.73 \pm 0.02$, $\sigma = 1.29 \pm 0.02$. The largest citations do not follow the lognormal behavior, and seem to follow a power law: $c^{-\alpha}$, with $\alpha = 2.8 \pm 0.2$. (B) Probability distribution $P(c)$ of citations $c$ rescaled by average number of citations $\langle c \rangle$ to publications from 1990 for several academic journals. The scaled distribution function fits well to a lognormal function with $\mu = -0.75 \pm 0.02$, $\sigma = 1.18 \pm 0.02$, while $(c)P(c) \rightarrow \text{const. as } c/\langle c \rangle \rightarrow 0$ for the lower range of $c$. The largest citations fit well to a power law: $c^{-\alpha}$, with $\alpha = 2.9 \pm 0.3$. Data is taken from Ref. [32].

FIG. 4: Variation of Gini and $k$ indices with number of papers and citations for academic institutions and journals. For larger number of papers or citations, the values seem to fluctuate less or converge around the mean values $\bar{g}$ and $\bar{k}$ respectively. For academic institutions, the values are $\bar{g} \approx 0.67$ for Gini and $\bar{k} \approx 0.75$, while for the journals, the values are $\bar{g} \approx 0.58$ and $\bar{k} \approx 0.71$. Figure adapted from Ref. [35].

There has been an attempt to explain the slope of the $g-k$ curve for small values, by approximating the Lorenz curve as an arc of a circle [39]. This linear relationship (with the value of the slope $\gamma \approx 0.363$) can be argued to be more generally valid. If the Lorenz curve $L(x)$ in Fig. 1 is taken as a parabola ($L(x) = x^2$, as in case of normalized uniform distribution $P(m)$ of income/wealth $m$; $L(x) = \int_0^x 2mP(m)dm$), one gets $g = 2\int_0^1 (x - L(x))dx = \frac{1}{3} \approx 0.33$ and $1 - k = L(k) = k^2$, giving $k = \frac{1}{2}(\sqrt{5} - 1) \approx 0.62$, the values of $g$ and $k$ satisfy the above relationship very well.

$$k = \frac{1}{2} + \gamma \cdot g, \quad \text{for} \quad 0 \leq g \leq 0.70,$$

with $\gamma = 0.365 \pm 0.005$ [39].
wealth of the i-th agent at trading times \( t \) and \( t + 1 \) respectively. The steady state distribution of wealth is argued to be Gamma distribution \([54, 55]\) with the peak position shifting to higher income or wealth as \( k \) increases (\( k = 0 \) corresponds to Gibbs or exponential distribution and \( k \to 1 \) approaches \( \delta \)-function). The \( g - k \) relationship for such distributions is found to be linear (Fig. 6a), obeying \( k = 0.5 + 0.365g \) with \( \gamma \approx 0.365 \pm 0.005 \).

In the CCM model \([8, 54]\), each agent \( i \) has a saving fraction \( \lambda \) drawn from a (quenched) distribution \( \Pi(\lambda) = (1 + \delta)(1 - \lambda)^3 \). Following similar stochastic dynamics as in CC model,

\[
\begin{align*}
    m_i(t + 1) &= \lambda_i m_i(t) + r [(1 - \lambda_i)m_i(t) + (1 - \lambda_j)m_j(t)] \\
    m_j(t + 1) &= \lambda_j m_j(t) + (1 - r) [(1 - \lambda_i)m_i(t) + (1 - \lambda_j)m_j(t)],
\end{align*}
\]

one gets a steady state distribution of income or wealth with power law tails \( P(m) \sim m^{-(2+\delta)} \) for large \( m \) \([54]\). \( g \) and \( k \) computed for such distributions \([54]\) are given in inset of Fig. 6b for varying range of \( \delta \). The \( g - k \) relationship here is found to be nonlinear (see Fig. 6b) but very much around a similar linear relationship.

VI. UNIVERSALITY IN THE STATISTICS OF DEATHS IN CONFLICTS AND DISASTERS

The history of human civilization has been frequently shaped by events of wars, conflicts and disasters. In recent times, the scale of disaster events has increased remarkably. Growing population around the world has been seen as one of the reasons for the increase in counts of people affected by disaster events. A study on the statistics of human deaths from wars, conflicts as well as natural disasters shows that the probability distribution of number of people killed in natural disasters as well as man made situations exhibit similar universality in statistics with power law decay for the largest sizes, the exponent values being quite similar \([57]\), in the range of 1.5 – 1.8. Comparing with natural disasters, where event sizes are measured in terms of physical quantities, like the energy released in earthquake, the
FIG. 6: Monte Carlo simulation results for \( g \) vs. \( k \) in CC and CCM models (for 1000 agents). (a) For CC model, varying parameter \( \lambda \). The inset shows the plots of \( g \) and \( k \) in the range of \( 0 \leq \lambda \leq 1 \). The points fit to \( k = \frac{1}{2} + \gamma g \) with \( \gamma \approx 0.365 \pm 0.005 \). (b) For CCM model, varying parameter \( \delta \). The inset shows the variation of \( g \) and \( k \) in the range of \( -1 < \delta \leq 3 \). Figure adapted from Ref. [39].

volume of rainfall, the land area affected in forest fires, etc. also show striking similarities. These universal patterns in their statistics might suggest some subtle similarities in their mechanisms and dynamics.

FIG. 7: The probability distributions \( P(x) \) of event size \( x \), measured by the number of human deaths in the corresponding event. (a) Man-made events: human deaths from conflicts during 1946-2008, according to the PRIO database [57] (using lowest estimates), dead according to the Correlators of Wars (CoW) database [58] during 1816-2007, dead in terror attack [59] during 1910 till July 2016, and battle deaths according to UCDP database [60] during 1989-2014. Except the terrorist attack data, all these distributions seem to have a power law tail with similar exponents. The straight line is a guide to the exponent value 1.5 for comparison. (b) Natural disasters: human death from earthquakes, storms, wildfires, miscellaneous accidents, as well as all natural disasters listed in the EMDAT database [61] during 1900-2013. The values of the exponents are in 1.5 – 1.8 (details in Ref. [56]).

VII. DISCUSSIONS ON CITATIONS AND RELATIONSHIP BETWEEN INEQUALITY MEASURES IN GENERAL

The Gini index \( g \) is the most popular among economists and sociologists, since it gives an overall measure of the inequality in a society. As evident from Fig 1, it requires accurate data for the entire Lorenz curve to provide a measure of the shaded area enclosed by it and the equality line. The Kolkata index \( k \) being given by the intersection of the Lorenz curve and the cross diagonal to the equality line. The \( g - k \) linear relationship is extremely robust for not so high values of inequality and fits different forms of Lorenz curve and hence, distributions of income, wealth, citations, etc. and this robustness is also observed empirically (Fig. 5). We could even compare these findings with simple kinetic exchange models of wealth distributions, where the scaling relation between \( g \) and \( k \) was found to be also true. The \( g - k \) relationship would be extremely useful to translate from one inequality measure to the other;
VIII. CONCLUDING REMARKS: SOME RANDOM THOUGHTS ABOUT PROSPECTS OF INSTITUTIONAL ECONOPHYSICS

Twenty years have passed since the formal coining of the term and hence the launch of econophysics as a research topic (since 1995; see the entry by Barkley Rosser on Econophysics in The New Palgrave Dictionary of Economics [62]). Furthermore, econophysics has been assigned the Physics and Astronomy Classification Scheme (PACS) number 89.65Gh by the American Institute of Physics. However, regular interactions and collaborations between the communities of natural scientists and social scientists are rare. Though interdisciplinary research papers on econophysics and sociophysics are regularly being published at a steady and healthy rate (more than 1000 documents containing the explicit term “econophysics” and more than 240 documents containing the explicit term “sociophysics” in the years 2014 and 2015 according to Google Scholar) and published mostly in physics journals, and a number of universities (including Universities of Leiden, Bern, Paris and London) are offering the interdisciplinary courses on econophysics and sociophysics, not many clearly designated professor or other faculty positions for that matter are available yet (except for econophysics in Universities of Leiden and London). Neither there are any designated institutions on these interdisciplinary fields, nor separate departments or centres of studies for instance. We note however, happily in passing, a recently published highly acclaimed (“landmark” and “masterful”) economics book [63] by Martin Shubik (Seymour Knox Professor of Mathematical Institutional Economics, Emeritus, at Yale University) and Eric Smith (Santa Fe Institute) discusses extensively on econophysics approaches and in general on the potential of interdisciplinary researches inspired by the developments in natural sciences.

In view of these, it seems it is time to try for an international centre for interdisciplinary studies on complexity in social and natural sciences; specifically on econophysics and sociophysics [64]. The model of the Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste (funded by UNESCO and IAEA), could surely be helpful to guide us here. We are contemplating if an ICTP-type interdisciplinary research institute could be initiated for researches on econophysics and sociophysics.

We note that Helbing (ETH, Zurich) and colleagues have been trying for an European Union funded “Complex Techno-Socio-Economic Analysis Centre” or “Economic and Social Observatory” for the last five years (see Ref. [64] containing the White Papers arguing for the proposed centre). We are also aware that Indian Statistical Institute had taken a decision to initiate a similar centre in India (see the “Concluding Remarks” in [65]). Also there was an attempt for a similar Asian Centre in Singapore, initiated in Nyangyong Technological University. In view of some recent enthusiasms at the Japan-India Heads of States or Prime Minister level, and signing of various agreements (predominantly for business deals, infrastructure development, technical science and also cultural exchanges) by them, possibility of an Indo-Japan Center for studies on Complex Systems is also being explored. In such bilateral (Indo-Japan) initiatives, there are explicit Memorandum of Understandings already signed by the Prime Ministers. It did not have any economic or sociological study centres ever planned under such bilateral efforts.

These proposals are for regular research centres on such interdisciplinary fields, where regular researchers will investigate such systems. However, in view of the extreme interdisciplinary nature of econophysics and sociophysics, such efforts may be complemented by another visiting centre model. Unlike the above-mentioned kind of centres therefore this proposed centre may be just a visiting centre where natural and social scientists from different universities and institutions of the world can meet for extended periods to discuss and interact on various interdisciplinary issues and collaborate for such researches, following the original ICTP model.

Here, as in ICTP, apart from a few (say, about ten to start-with) promising young researchers on econophysics and sociophysics as permanent faculty who will continue active research and active visiting scientist programmes (in physics, economics and sociology) etc. can be pursued, The faculty members, in consultation with the advisers from different countries, can choose the invited visitors and workshops or courses, on economics and sociological complexity issues, can be organized on a regular basis (as for basic theoretical sciences in ICTP or in Newton Centre, Cambridge, etc.).
We think, it is an appropriate time for the healthy growth of these “New or Evolving Economic & Sociological Thinkings” including econophysics and sociophysics. We believe, Tokyo would be the ideal location for such an International Centre. In such new studies on social sciences, econophysics and sociophysics in particular, Japan has already significantly large, active and established groups and hence, Tokyo could be its natural location.

Acknowledgment

We are extremely thankful to Yuji Aruka and Taisei Kaizoji for sharing with us many enthusiastic ideas on several collaboration projects. We are also grateful to Sudip Mukherjee for his help in preparing the manuscript.

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[66] Although the presentation in the conference (by BKC) was mainly on the materials discussed in the earlier sections, extensive discussions with several participants, including the conference organizers, had been on this point.