Physica A 451 (2016) 123–134

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Statistical characteristics of dynamics for population migration driven by the economic interests

Jie Huo, Xu-Ming Wang *, Ning Zhao, Rui Hao

School of Physics and Electrical Information Engineering, Ningxia University, Yinchuan, 750021, PR China
Ningxia Key Laboratory of Intelligent Sensing for Desert Information, Yinchuan, 750021, PR China

HIGHLIGHTS

- Distribution of population migrations in China, 1990–2009, is performed.
- Migration: driven by higher financial gains, abated by fewer employment opportunities.
- Relative migration strength is used to describe the distribution.
- Shifted power law or truncated power law dominates the distributions.
- Randomness and determinacy jointly create the scaling law of the distributions.

ARTICLE INFO

Article history:
Received 11 June 2015
Received in revised form 16 January 2016
Available online 29 January 2016

Keywords:
Human migration
Statistical dynamics
Cumulative probability function
Shifted power-law
Truncated power-law

ABSTRACT

Population migration typically occurs under some constraints, which can deeply affect the structure of a society and some other related aspects. Therefore, it is critical to investigate the characteristics of population migration. Data from the China Statistical Yearbook indicate that the regional gross domestic product per capita relates to the population size via a linear or power-law relation. In addition, the distribution of population migration sizes or relative migration strength introduced here is dominated by a shifted power-law relation. To reveal the mechanism that creates the aforementioned distributions, a dynamic model is proposed based on the population migration rule that migration is facilitated by higher financial gains and abated by fewer employment opportunities at the destination, considering the migration cost as a function of the migration distance. The calculated results indicate that the distribution of the relative migration strength is governed by a shifted power-law relation, and that the distribution of migration distances is dominated by a truncated power-law relation. These results suggest the use of a power-law to fit a distribution may be not always suitable. Additionally, from the modeling framework, one can infer that it is the randomness and determinacy that jointly create the scaling characteristics of the distributions. The calculation also demonstrates that the network formed by active nodes, representing the immigration and emigration regions, usually evolves from an ordered state with a non-uniform structure to a disordered state with a uniform structure, which is evidenced by the increasing structural entropy.

1. Introduction

Human behaviors of both individuals and groups, are extremely complex, because the corresponding decisions are typically made according to personal knowledge, experience, judgment, and will. Such complexity arises from the

* Corresponding author at: School of Physics and Electrical Information Engineering, Ningxia University, Yinchuan, 750021, PR China.
E-mail address: wxmwang@nxu.edu.cn (X.-M. Wang).

http://dx.doi.org/10.1016/j.physa.2016.01.054

interactions among these ingredients as well as the influence imposed by the external environment. The environmental influence includes current economic situation, social consumption trend as well as behavior of people around. Determining the law governing these behaviors and revealing the mechanisms behind the behaviors is the topic of considerable research in social management. Such research is also important for the allocation of resources, such as hospitals, schools, and bus stations. The pioneering investigations of such topics were conducted by Barabási [1] and Brockmann [2]. The former suggested the theory of decision-based queuing to interpret the non-Poisson characteristics of the inter-event time distribution in the email communication process, and the latter studied the unique nature of human traveling, that is, the distribution of traveling distances dominated by a common power-law relation. This research indicated that traveling traces, obtained by tracking bank notes, can be described by a random walk and Lévy flight.

The two seminal studies were followed by many practical and theoretical investigations. Additionally, some characteristics and dynamic origins, different from those ground-breaking works, have been brought to light. The distribution of the inter-event time in traditional mail systems exhibits intermittency and memorability [3–6], and this process exhibits an identical scaling behavior as email correspondence. However, the mechanism lies in the priority selection of the responding letter or in a historical interest, which is different from queuing theory. The amount of page views and replies in a bulletin board system, similar to the cardiac rhythm for human beings, is found to have high burstiness and low memory [7,8]. Short-message communication interval is captured as a heavy-tailed power-law distortion, which may be caused by a highest-priority-first rule and activity seasonality [9,10]. The aforementioned investigations have illustrated the heterogeneity of individual activities, and such heterogeneity can be largely attributed to the differences among groups, which an individual was in Refs. [11,12]. Undoubtedly, further insight into the characteristics of human groups and the corresponding mechanisms underlying human behavior is necessary.

Extending the pioneering study that regarded human motion as a Lévy flight or continuous-time random walk [2], the spatial distribution features of human activities have also drawn great attentions. This interest is mainly due to the great progress in modern information technology, which makes it possible to precisely capture human motions. The movement of cellphone users, tracked by phone calls, have been proved to follow a so-called truncated Lévy flight (a distribution characterized by a product of a power-law-form function and an exponential function) [13,14]. The same distribution has also been observed in the data of short-message services [15–19]. These results imply that there are still some unknown dynamic mechanisms behind the distributions. González et al. attributed these distributions to the convolution between the statistics of individual trajectories approximately described by a Lévy flight and the population heterogeneity denoted by a radius of gyration [13]. Therefore, such a scaling distribution feature of human motion may be originated from the joint contribution of the two driving factors, randomness and determinacy. The same principle of dynamics proved the origin of distribution in some natural systems such as river networks [20] and some other structures [21]. Song et al. proposed an elaborate microscopic model to describe this mechanism [22]. They suggested two key factors in understanding the details of human motion including the number of distinct locations visited by a randomly moving individual, the visiting frequency to a given location and the ultra-slow diffusion of individuals returning home. The one factor is the individual explores a new location to move with a probability determined by a power-law function of the number of locations visited previously, the other is returns to one of the locations visited previously with the complementary probability. A deterministic driving force, preferentially returning home or going to workplace, is also hidden in this theoretical framework, although the description is based on probability analysis. However, a pertinent description of human motion generally requires a rich knowledge of the randomness and determinacy in the underlying dynamics.

It is highly possible that the distribution regularities in different motion processes are different. An exponential distribution combined with GPS data of taxis serves as a typical example of this phenomenon [23–29]. The differences in distribution can be naturally attributed to the difference in travel modes, traffic conditions and some other influencing factors. One may then ask the following question: what feature is exhibited by a distribution for population migration under certain resource constraints? Since domestic migration is quite common in different regions within some developing countries, the research on migration therefore should be of high scientific and practical significance especially when those regions are in possession of distinct resource endowments, e.g. population size, gross domestic product (GDP), socio-cultural resources, degree of civilization, and other aspects that are closely related to standards of living.

Interestingly, migration under resource constraints typically exhibits collectivity. This paper will primarily focus on exploring the population migration behavior, (i.e., group migration behavior), based on the data collected from China Statistical Yearbooks. And subsequently we will propose a dynamic model to simulate the population migration under the constrains of limited resources and low level of economic development. The empirical results reveal that regional GDP per capita (GDPpc) in China is linearly or non-linearly related to the population size; and the cumulative distribution function (CDF) of population migration sizes is found to be dominated by a shifted power-law (SPL) function. The model stresses the drawing effect of destinations with abundant resources and the repelling action of regions with fewer-resources. This suggestion was presented in Refs. [30,31]. However, these models only considered the single influencing factor, population size, which not reveal a clear mechanism of population migration. In our model, the attractive force is quantified as the differences in GDPpc between the destination and source (which may be the fundamental driving factor), and the repelling force is described by the difference in the population size between the source and destination. The difference in the definition of repelling force can simply be regarded as the difference in employment opportunities, since generally larger population size in a region will result in smaller employment opportunities. The simulation shows that the simple model can reproduce the main features of those obtained empirically and that a truncated power-law (TPL) relation dominates the cumulative