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Entropy and its relation with human population and rice production: A review

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Abstract
Entropy is understood to mean to consider all the processes that give rise to a change are absolutely irreversible, as evident in natural processes, such as the growing of a plant, as well as technical processes, such as the burning of fossil fuels in combustion engines. The concept of entropy was coined in thermodynamics-the science of energy, its origins dates back to the 19thcentury when scientists like Sadi Carnot, Rudolph Clausius and Lord Kelvin wanted to understand and enhance the efficiency at which steam engines performed useful mechanical work. But the original notion of entropy has been also applied to different contexts outside thermodynamics. It is relevant in Ecological Economics in a number of ways and on various levels of abstraction. As all processes of change are at bottom, energy processes and transformation of material, the entropy is applied to all of them and it creates a unifying perspective on ecology, environment and economy. On more applied levels, it provides an efficient tool for quantitative analysis of energetic and material transformations. In analyzing the economy-entropy interactions like resource extraction, energy use, waste generation as well as production, the concept of entropy is quite useful. India is the second largest populated country in the world after China and the Indian population too has been tremendously increasing after the 1950's. India's poverty rate, illiteracy, rapid decline in mortality rates, high fertility rate and immigration from other foreign nations are some of the main reasons attributed to this rapid growth of its population. Edelstein-Keshet (2009) has discussed about mathematical models like logistic model, Lotka-Volterra model for describing the dynamics of interaction among population in the same environment. Wang (1990) has proposed a logistic model for a single population and Wake, Watt (1996) have analyzed the noise fluctuation in carrying capacity of the population. Zhen *et al*. (2006) have proposed an improved population model in which the growth rate was taken to be based on power law exponent. Regional sustainability was extensively studied by Ding (2008) and Geng (2011) which emphasised the importance of sustainable growth particularly in agriculture. Yu (2005) has dealt with a time series model to determine the recurrent relationship in rice production and Vinodini *et al*. (2014) have developed a grey model for prediction of rice productivity and consumption in India. The present study focuses on the data for Indian population and rice production for a wide range of years from 1951 to 2013 to study the Shannon's Entropy in the Indian context.

Keywords: Energy, entropy, environment, population, production

Introduction
Entropy to understand in a simple way and grasp its fundamental meaning is to consider that all the processes that give rise to a change are absolutely irreversible. Few examples include natural processes, such as the growing of a plant, as well as technical processes, such as the burning of fossil fuels in combustion engines. Only to capture this fact the concept of entropy was coined in thermodynamics-the science of energy. The very name thermodynamics came from the study of how heat and movement convert into each other. Its origins are in the 19th century when scientists like Sadi Carnot, Rudolph Clausius and Lord Kelvin wanted to understand and enhance the efficiency at which steam engines performed useful mechanical work. But the original notion of entropy has been also applied to different contexts outside thermodynamics.
Entropy can also be applied in case of human beings as the amount of energy available to humans. As a piece of wood is burned, its available energy - also called 'exergy' - decreases as the piece of wood is transformed into high entropy matter - carbon dioxide and other substances useless from an energy point of view, its original energy dissipated as useless heat.

Available energy corresponds to the useful part of energy, which can be transformed into work. The Entropy Law (the Second Law of Thermodynamics) uses this definition to express the everyday experience that transformations of energy and matter are unidirectional.
In analyzing the economy-entropy interactions like resource extraction, energy use, waste generation as well as production, the concept of entropy is quite useful. Here it is important to note that the Entropy Law states that with every energy-based transformation, a system looses a part of its ability to perform some useful mechanical work. But after a while, potential of work of the system comes to zero. The economy as known is not an isolated system and takes energy and materials from outside thereby producing waste and dissipating heat. But for the purpose of analysis of energy use in the economy, we need not appeal to "heat death". Few applications of entropy in economics may be elaborated under the following:

- The entropy concept is relevant for economics in various ways and on different levels of abstraction.
- Second, the concept allows us to incorporate physical driving forces and constraints in models of economy-environment interactions, both microeconomic and macroeconomic.
- Third, the entropy concept provides a tool of quantitative analysis of energetic and material transformations for engineers and managers.

Baumgärtner (2003) [3] wrote that With its rigorous but multifarious character as an analytical tool, its rich set of fruitful applications, and it is obvious potential to establish relations between the natural world and purposeful human action, the entropy concept is one of the cornerstones of ecological economics.

Entropy and its relation with population and production

Human Population is defined as the total aggregate of humans living in a certain geographical location under consideration with reproductive capabilities. The human population of the world has been increasing slowly over the years and has crossed the seven billion mark too. India is the second largest populated country in the world after China and the Indian population too has been tremendously increasing after the 1950's. India's poverty rate, illiteracy, rapid decline in mortality rates, high fertility rate and immigration from other foreign nations are some of the main reasons attributed to this rapid growth of its population. The current Indian population stands at about 1.34 billion and is expected to increase at a steady rate of 1.2% annually. Although many efforts have been initiated by the government in spreading awareness and implementing policies to curb its rapid increase, human population is found to be steadily increasing year by year. This increase in population is of concern as it stagnates the economy and reduces the impact of developmental progress. So presently it is of prime importance to study its growth rate and predict its nature.
Mathematical Model is termed as the formulation of mathematical equations and concepts describing and characterising real world phenomena and systems under certain constraints. The process of developing such a description is called mathematical modelling. It establishes a relationship with the physical variable whose dynamics are represented mathematically through variables and equations. Such a model actually helps in better understanding of the real world process and aids in prediction, control, estimation, optimization, decision making and determination of its causes and effects. Recently, mathematical models have been used for describing complex systems. It finds its application in natural sciences for formulation of laws and theorems, business for maximising output, economics and finance for effective analysis of strategies and decision making, engineering discipline for design and study of numerous processes, social sciences, psychology and so on.
Entropy is a measure of randomness or microscopic disorderliness of a system. It represents the lack of predictability in the process. It is a state function and an extensive property which depends upon the mass of the substance in that system. The second law of thermodynamics states that the universe evolves in such a way that its total entropy always stays the same or increases which implies that entropy forms the basis of it. The spontaneity of a process is highly related to entropy. Always, spontaneous processes occur with increase in entropy. This indirectly means that the entropy of a system is dependent on the thermodynamic probability of the state of the system. The statistical information obtained from partial knowledge of process has entropy aspect incorporated in it. Maximisation Entropy Principle is used in statistical modelling of these processes while characterizing few unknown events. It is one of the least biased estimates possible when there is little information. This can be applied to many to Spatial Physics, Computer Vision and many other fields.
Edelstein-Keshet (2009) has discussed about mathematical models like logistic model, Lotka-Volterra model for describing the dynamics of interaction among population in the same environment. Wang (1990) [29] has proposed a logistic model for a single population and Wake, Watt (1996) [34] have analyzed the noise fluctuation in carrying capacity of the population. Zhen *et al*. (2006) [22] have proposed an improved population model in which the growth rate was taken to be based on power law exponent. Regional sustainability was extensively studied by Ding (2008) [8] and Geng (2011) [9] which emphasised the importance of sustainable growth particularly in agriculture. Yu (2005) [12] has dealt with a time series model to determine the recurrent relationship in rice production and Vinodini *et al*. (2014) [26] have developed a grey model for prediction of rice productivity and consumption in India. The concept of entropy for nonlinear dynamical systems was looked upon by Balestrino, Caiti, and Crisostomi (2009) [1] and Balestrino *et al*. (2008) [2] based on Ordinary Differential equations (ODE).

A. The Lotka-Volterra model

The Lotka-Volterra model as discussed by Edelstein-Keshet (2009) is a pair of nonlinear differential equations with deterministic and continuous solution, used to describe the dynamics of ecological prey-predator model. The first equation expresses the rate of change of the prey population which is the first state variable and the second equation expresses the rate of change of predator population which is the second state variable. In this work, rice production is taken as prey and Indian human population is considered as predator. Both the equations are represented as a function of rice production-human population and this model is supposedly built on certain assumptions. Some important assumptions made are that, during the process of evolution of both rice and humans, the environment that sustains them does not change significantly in favour of either of them. Further, the genetic adaptation and mutation of the species are considered inconsequential. It is also assumed that the food supply of Indian population depends predominantly on rice production and the rate of change of either of them depends on their respective sizes. Mathematically the Lotka-Volterra model is represented as,

$$\frac{dx}{dt} = ax - bxy \qquad (1)$$

$$\frac{dy}{dt} = cxy - dy$$

Where, x is the size of the rice production, y is the size of the Indian human population, dx/dt and dy/dt represent the growth rates of the two state variables respectively. Here a, b, c and d are fixed real parameters representing the growth rate of rice production, the rate at which the humans consume the rice, the rate at which Indian human population increases by consuming rice and the mortality rate of humans respectively. These parameters describe the interaction among the two state variables.

This means that the rice production increases at a rate proportional to its size denoted by ax and simultaneously decreases at a rate proportional to product of both the state variables indicated by — bxy. The human population decreases at a rate proportional to its size indicated by —dy and increases at a rate proportional to product of both the state variables which is represented by cxy.

B. Entropy

Maximum Entropy Principle (MEP) states that the best estimate of a missing data is the one which maximises the information entropy under specified constraints. There are several types of entropy measures that are used in information theory. Shannon entropy is one important measure used to measure the average missing information on a random source. The Shannon (1948) [32] defined Shannon's entropy mathematically as:

$$H(X) = -\sum_i p(x_i) \log_2 p(x_i) \qquad (2)$$

Where, X is the random variable and p is the probability distribution.

C. Estimation of parameters using GA

Genetic algorithm (GA) as discussed by Sivanandam, Deepa (2007) [30] and Li Min-qiang *et al*. (2002) [25] is an adaptive heuristic search algorithm used for solving complex optimisation problems under constrained and unconstrained conditions. Basically, it draws its inspiration from optimisation problems based on process of natural selection and processes that have their base in biological and ecological evolution. This method could be applied to solve a variety of optimization problems in which the objective function is non differentiable, stochastic, discontinuous or nonlinear in nature. In this algorithm, a base population with individuals is first considered and a fitness or objective function is defined. It then randomly selects the individuals from the current population and uses them to produce the offspring of the newly generated population. Each generation consists of a population of character strings and each individual represents a point in a search space with a possible solution. So this step is done repeatedly until an optimal solution is found that satisfies the criterion of minimization of the fitness function. It uses two terminologies namely crossover and mutation to execute the algorithm. Crossover refers to the production of offspring from the parents of the previous generation. Mutation refers to the alteration of a particular chromosome so as to maintain diversity in the population. The objective function J is given by

$$\min_{a\,b\,c\,d} J = e_R + e_H + \frac{1}{E} \qquad (3)$$

Where, J is the fitness function to be minimised,
e_H is the error in human population at time instant t
e_R is the error in rice production at time instant t
E is the Shannon's Entropy.
The errors are defined as:

$$e_R = P_R(t) - P_R(t-1) - ax + bxy \qquad (4)$$

$$e_H = P_H(t) - P_H(t-1) - cxy + dy$$

Where, $P_R(t)$ is the amount of rice production at time instant t and $P_H(t)$ is the human population size at time instant t

D. Data Acquisition

The data for Indian population and rice production is considered for a wide range of years from 1951 to 2013.

Conclusion

As discussed the concept of entropy is relevant in Ecological Economics in a number of ways and on various levels of abstraction. As all processes of change are at bottom, energy processes and transformation of material, the entropy is applied to all of them. Thus it creates a unifying perspective on ecology, environment and economy. It even allows to ask questions that could not be asked or answered from one scientific discipline perspective alone. It is essential for understanding the extent of resource and energy scarcity, the capacity of nature to assimilate the human waste and pollutants, as well as the irreversibility of the process of transformations, constrain economic action. Thereby, the entropy law allows economics to relate to its biophysical basis, yielding insights about the relationship which are not available otherwise. On more applied levels the concept provides an efficient tool for quantitative analysis of energetic and material; transformations. It may be even used for designing industrial production plants or individual components to maximize energy efficiency and minimize the negative environmental implications. With its rigorous but multifarious nature as an analytical too, its rich set of viable and fruitful applications and its great potential to establish relation between the natural world and human actions, Entropy is one of the cornerstones of Ecological Economics.

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