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Measuring System Entropy Generation in a Complex Economic Network (The Case of Iran)

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Abstract:
An economic system is comprised of different primary flows that can be captured in macroeconomic models with complex network relations. Theoretically and empirically in this system, weak substitution or complementarity of environmental materials, like energy and other production factors such as capital, is undeniable. This is an effective critique on neoclassical economics. In this paper, we view economy as a complex thermodynamic system in order to calculate entropy generation, specifically the trend of entropy production in Iran over time. Entropy can be measured as the amount of waste and pollution produced by a system based on Georgescu-Rogen's view. Using a conceptual model, we show the basic flows in a macroeconomic network (government, households, firms and financial sector), by focusing on the amount of waste and other entropy generators and show how to calculate the overall entropy for an economic system. Furthermore, we demonstrate this approach using a mathematical model and literature from ecology and macroeconomics of Iran economy as a case study. Finally, by using statistical data from the World Bank, we show the three important indices of a system- growth, development and entropy values- that increased in Iran during 1970–2014. As it is shown in results, the economic entropy of Iran is increasing.

JEL classification**:** Q21, Q43, Q53, P28, O21

Keywords: *Economic Entropy, Complex system, Iran, Thermodynamics, Macroeconomic, Network*

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1. Introduction

Social and economic patterns are a mixture of several basic features in macroeconomics with a strong relationship between them. In fact, studying one part without transparency, as some firms do, without paying attention to the role of government[1]or financial markets can reduce the accuracy of predictions. Applying complex systems theory is a useful approach for analyzing an economic process by seeing a system as a whole. In contrast, there is another approach that believes any system or scientific inquiry can be broken down into its basic components that tend to describe social phenomena solely in terms of psychological or individual properties. This commonly applied approach is called Reductionism[2] (Boulding, 1950: 3). As with ecology, these reductionist approaches cannot explain the system as a whole. General systems theory was promoted by Bertalanffy in the early 1940s. This approach complemented reductionism as another way of understanding phenomena. This theory is based on the principle that there is a series of regulations and processes common to all scientific systems that govern overall behavior. This means that it is possible to have access to a series of primary regulations and processes which define general system behavior despite their type (Farshadi, 1984: 25). So, according to this theory all systems have foundational rules. Generally, all systems are (at minimum) in the category of thermodynamic systems, in addition to their other characteristics, so that thermodynamic constraints and principles are useable in ecological and economic systems (Eriksson, 1991). In addition, an economy like an ecosystem is an open functioning system with real and measurable inputs, flows, and outputs of money, goods, services, or energy (Ogle, 2000: 31). Boulding (1993: 2) reinforces this interpretation when he says, “an economy … is what mathematicians call a ‘fuzzy set’. The boundary that divides what is in the economy from what is not may not always

[1] For more information can see Solow (1956, 1957); Swan (1956); Schumpeter 1942; Barro and Sala-i-Martin (1995); Krelle (1988); Krelle (1988); Lucas (1990); Mankiw, Romer and Weil (1992) and lots of other neoclassical economics.

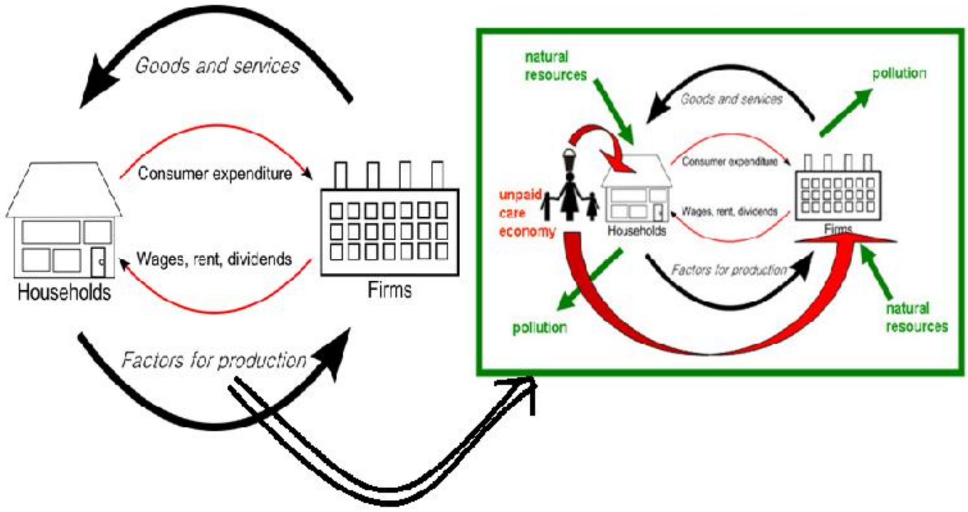
[2] See more Funtowics and Ravetz (1994), Patterson (1998)

be clear, but this does not mean that it is not real or important." Therefore, we can consider an economy as an ecosystem due to complex relationship of different parts that work together and perform an identifiable function. In a word, this is said that an economy is a mixture of flows and stocks with lots of interactions that is like a thermodynamic system. In addition, neoclassical theory does not regard thermodynamic laws.

The neoclassical theory of economic growth doesn't consider environment or energy as an important factor in production function and believes in the complete substitution of environmental and other factors (Solow,1956, 1957; Swan,1956; Schumpeter 1942; Barro and Sala-i-Martin,1995;Lucas, 1990; Mankiw et al., 1992). In fact, neoclassical economics rests on the assumption that natural resources are infinite and believes that economic growth can continually and constantly increase. This perspective is not held by most ecological economists. As shown by Pearce and Turner (1990), when analyzing the environment-economy interactions, production processes generate waste in each stage. Another similarity between ecological and economic systems, to which experts have paid attention more than before in recent years, is recycling. This means both ecological and economic systems have garbage that can be recycled and returned to the system. However, as shown by Ayres (2004: 31), "while most biomass is recycled fairly quickly, it is not true that there are no recycled wastes in nature". In other words, as Daly (2005: 8) said "the facts are plain and uncontestable: the biosphere is finite, non-growing, closed (except for the constant input of solar energy), and constrained by the laws of thermodynamics. "Natural resources can be measured and bequeathed. Ayres et al. (2014: 32) showed that "energy is a much more important factor of production than its small cost share may indicate". This shows that along the historical trend, a growing economy cannot safely be assumed. They showed two kinds of environmental constraints: hard and soft constraints. "Hard" constraints result from two facts. First, the degree of capacity utilization is always less than or equal to one because it is not possible to feed machines with more energy than technically feasible at their full utilization. Second, the technologically possible degree of automation should be less than the degree of automation; maximum value is again less than or equal to one. Furthermore, there are “soft” constraints pertaining to social, financial, organizational, or legal restrictions which also limit substitution possibilities over time. Haller and Hyland (2014: 20) and Costantiniand Paglialunga (2014: 13) in their empirical studies showed this weak sustainability and Tovar and Iglesias (2013: 16) showed the complementarity between energy and capital. So there are environmental material limitations in economics and ecological economists discussed these natural restrictions in economic growth by using systems and thermodynamic laws. In a sentence, it can be stated that the "revolution of ecological economy is the coordination between market and nature" (Brown, 2001: 9). Hence, we should see economy as a system that has its own environmental–technology constraints. In fact, we have technologies now that have some constraints for using environmental materials that means the scarcity of environment in our system. This kind of scarcity has been shown in Roegen's view.

Georgescu-Roegen (1970) showed numerous times that the standard economic paradigm— completely circular and self-sustaining along a closed network—incorrectly treated the economic network between production and consumption. It can be said, one of Georgescu-Roegen’s most important critics was his attempt to bring a physical-based systems view into economics, thereby changing economics from a conventional (monetary) circular one to a (partly physical) throughput one (Daly, 1995) (Figure 1).

Figure 1: Alteration a conventional (monetary) circular one to the (partly physical) throughput one



Source : Research findings

The latter view raised many essential questions (Ayres and Kneese, 1969; Ayres and Kneese 1989; Ayres and Nair 1984). The parallels between ecological growth and development processes and those in economics become more evident; a point stressed by Daly (1979, 1985, and 1987) and others. Kaberger and Mansson (2001) believe that an economic analysis that poses only supply–demand relationships and monetary costs is insufficient to deal with long-term sustainability. It is essential to recognize and include thermodynamic limits as well as the constraints on material transformations (Berry et al., 1978; Berry, 1979). In addition, Iran's pollutions and environmental destruction have been increasing recently. This leads to arising lots of constraints for economy and increasing entropy in Iran's complex system that will be discussed in this paper.

Summing up, an economy is an open system that has relations with an external, supplying and receiving environment. It can be modeled as a network of energy or goods and services inflows, through flows, and outflows that is based on thermodynamic laws. The first law of thermodynamic states that Energy is neither created nor destroyed, but turns from state to state. In this manner, it is possible to use the first law of thermodynamics to balance the production of goods and services and the waste in any period. The important thing in these network flows is that in each stage and in each part of process a lot of entropy and waste will arise. The amount of natural resources used is equal to the amount of waste generated for a system at steady-state. Some waste materials can be converted back to the environmental resources. Environmental materials and usable goods can be recycled.The second law of thermodynamic says that in a closed system, energy systems are falling and irregularities are arising. By not recycling all waste, the Second Law of Thermodynamics becomes relevant. These laws provide constraints that show to add the environment as a basic and important part of every economic network.

Aim of paper

In this paper, we view economy as a complex thermodynamic system in order to measure the entropy generation, specifically the trend in countries. Entropy is measuring the degree of energy dissipation in a system, i.e., measuring the spontaneous tendency of energy to degrade and be dissipated in the environment and in our model. Any closed system has tendency to increase entropy until final destruction. As in an ecosystem, order in the social and economic world can be maintained if anti-entropic operations are performed in it (Sanidass, 2008). As the entropy rule in economics indicates, the current economic system finally fails when total recycling is not possible. In this manner, energy becomes the ultimate limiting resource to economic activity such that low entropy energy contained in different natural resources becomes rare (Talberthet al., 2006). Another perspective on entropy is as a degree of uncertainty at a certain time for each system. One way to measure this is using information theory, specifically Shannon entropy. This theory is an explicit example of the process school that believes communication is the transfer of messages not the exchange of meaning (Fisk, 2008, p. 17). John Ackerlof, the 2001 Nobel Prize winner in economics, revived these discussions and information theory entered economic discussions (Ebadi, 2013).

Complex economic network systems comprise information of many energy or money (goods and services) inflows that are related to the resources and environmental issues.

To sum up, we gain a common platform for understanding and investigating an economy and ecosystem as complex systems based on thermodynamic laws (Jacobs, 2001). Based on systems theory and the thermodynamic laws the entropy of all closed systems is increasing. If a system grows and develops (i.e., complexifies), then it should not only increase the flow and efficiency of flows, but also decrease the entropy and increase the work capacity (i.e., exergy) and beneficial work gradients should be built and maintained. Economic networks are open, thermodynamic systems and thereby should be considered and investigated using tools suited for non-equilibrium systems (Kondepudi and Prigogine, 1998). An economic process is one that combines production factors of lower value into products with greater value using energy and material transformations. During this process, entropy will inevitably be generated. Economic production is utterly dependent on the availability of low-entropy inputs of natural resources (Daly and Cobb, 1989). When we analyze a system using resources and environmental issues, it is natural to start with thermodynamic laws. In fact, this paper wants to answer these questions: How much is the entropy index of Iran's economy? The Contribution of this paper is showing how can we estimate or calculate Growth, Development and Entropy in an Economic System Network. In fact with a new view it will see the macroeconomic network and show the thermodynamic constraints in Iran's economy.

2. Literature Review

Modern and neoclassical economic growth theory assumes that GDP growth per capita is driven by technological progress and capital investment, including knowledge investment, but does not pay attention to energy or other environmental factors (Romer, 1994; Aghion and Howitt, 1998; Barro and Sala-i-Martin, 2003). During the last two or three decades, the limitations of these economic growth models have been revealed and more studies have acknowledged the important crisis they have brought about. One of the most important criticisms is based on Georgescu-Roegen's view. Most studies concerning macro-social growth and development consider NicolasGeorgescu-Roegen to be the first that embedded economic growth theory into the natural environment and laws of thermodynamics. Georgescu-Roegen's basic criticism on the neoclassical theory is that every eaceconomic system in any time increases entropy. Georgescu-Roegen considers that neo-classical and standard economic models are based on the paradigm of Newtonian mechanics and don't take energy principles and also considering the matter destruction. He showed that we should take the thermodynamics paradigm into account and considered the Law of Entropy into economic model.

Daly (1997) believes the Solow-Stiglitz implicitly made an unreal assumption about capital and resources near perfect substitution—what Georgescu-Roegen aptly dismissed as a “conjuring trick”. “In the Solow-Stiglitz variant, to make a cake we need not only the cook and his kitchen, but also some non-zero amount of flour, sugar, eggs, etc”. Georgescu-Roegen (1971) with publication of “The Entropy Law and the Economic Process" has ensued a new level of debate regarding the role of the laws mass and energy conservation and entropy production (Krysiak, 2006). In particular, neoclassical and standard economic models cannot deal with irreversibility. On the microeconomic scale, Islam (1985) uses the second law of thermodynamics to show that the production is a processes cannot comply with assumptions necessary in the Cobb–Douglas equation. Ayres and Kneese (1969) on a macroeconomic level, have showed mass and energy balances into static input–output analysis. Subsequently, Perrings (1986) developed this analysis in models of linear dynamics, implying that these balance equations can lead to instabilities. The entropy index has been used in different studies that are summarized in the following. De Pascale (2012) showed the role of entropy in stable economic growth and criticized the neoclassic eeconomist. Ortiz Cruz et al (2012) measured the oil market efficiency by using entropy index and introduced a new way of efficiency measuring. Skene (2013) state the environmental alternative energy measuring by using the logistics entropy model. Also Zhou et al (2012) calculated environmental efficiency analysis of China's electric industry based on entropy model and Ramirez et al (2012) used multiple entropy method for market efficiency. Humans, by focusing on economic growth, use and transform environmental materials and convert them to waste and pollutants; thus, entropy in real economic systems is increasing. By considering the restrictions for the raw materials in nature, it is time to reassess infinite neoclassical economic growth and include entropy processes in economic systems modeling.

3. Methodology and data

3.1. Model

For discussing the flows and entropy generation in an economic system, one must define the boundary between the system itself and the environment and identify the stocks and flows within it. In fact, a network system is composed of a series of inflows between the components. This system also has some flows from and to external environment. The conceptual macro-economic model we employ here has 6 sectors as following: 1-Government, 2-Firms, 3-Financial market, 4-Households, 5-Environment, and 6-Foreign countries.

Our economic model adds the environment as endowments and energy sources that all parts of the system, especially firms, use for production of goods and services. As in macroeconomic models discussed, there are many flows between these components. For example, households supply the human labor to the firms and receive the wage as their income. The firm is managing all the inputs like labor from households, money and capital from the financial market, subsidy from government as capital and energy from the environment and some raw materials and machinery from foreign countries produce goods and services for the households. In other words, the underlying worldview is one of circular flows among members of economy: buying goods and services provides profits for firms which leads to revenue that can be used to buy inputs into the production sector. Household savings are financial sources that contribute to business investment in scale and efficiency which, in turn, results in outputs available to consumers. Other flows from financial sector are loans to people, government and firms. Households, in addition, saving money in banks, give tax flows to governments and surely take some subsidies flows from that and have some wastes to the environments directly. The government, in countries such as Iran, is the owner and manager of the environment including oil and gas energy sources, and hence it takes the material from the environment and sells it to foreign countries or domestic companies and, by these rents, has its own public purchases and flows. Foreign countries have some imports and exports to this system and have some money income and outcome flows.

In our model, an economic system gets energy and materials from environment and after a series of flow transfers between the economic sectors, finally produces waste material sent to the environment. We analyzed this model by accepting this reality that energy as an environmental resource and capital as a production factor are generally not substitutes, as assumed by production functions, but complements, thus production theory does not fully considers thermodynamic irreversibility. In this paper, it emphasize inputs flows go into the economy and waste flows come from it, which are considered by monetary values. For instance, sales as inputs into production sector by firms or for the consumption to households for welfare loss have monetary values. Internalization of externalities may be received by making markets for those flows, as has been tried, e.g., for water distribution or sulfur emissions (Baumol et al., 1994). The foregoing methods have focused upon particular system components, or subsystem aggregates, but ecosystem analysis and economic management are quite often concerned with the system is performing as a whole.

From the network point of view, the generation and evolution of the system can be summarized into two aspects: node changes and connection changes (Miao, 2007). The former represents the metabolism of the system components; the latter is on behalf of the metabolism of the system structure. Our economic system that is full of network flows is reliant on the environment. As shown by Domingos (2006), “the integration between economics and thermodynamics at the substantive level is of crucial importance because economic processes obey thermodynamic laws” and, hence, an economic theory must be coherent with thermodynamics laws. Accordingly, natural processes operate far from the thermodynamic with minimal internal entropy accumulation and thermodynamic loss and overall entropy production (Kamberger and Mansson, 2001).

In summary, the economic model of this paper is composed of 6 sectors with many flows between them in a state far from equilibrium. Each sector has its own stock, receives some input from other sectors, and generates output. These operations involve changing the energy and materials and formation, as well as breakdown of constructions. The transformation processes are of physical urgency dissipative, i.e., they consist the entropy production.

As described in ecological networks (Jorgensen and Fath, 2004; Ulanowicz, 2004; Kharrazi et al., 2014), flows are summed to a quantity referred to as total system through flow (TST). The economic equivalent of TST is GNP and, hence, for calculating entropy based on this model we have four aspects in the economic network:

1- Import and export Entropy
2- Respiration (i.e., dissipation)
3- Overhead or waste
4- Redundancy or, as we say, “second entropy”

In the context of societal processes, the laws of thermodynamics may be rephrased as: 1. Energy is neither consumed nor produced in economic operations2. Every economic activity results in an increase of total entropy. To prevent a prevalent misunderstanding, it must be stated that entropy does not consist of the macroscopic ‘disorder’ of everyday life. It is a physical, mainly microscopic, type of disorder. Notwithstanding, entropy is a macroscopic notion in the sense that it cannot be specified for a single or even a few types. In fact, entropy is a kind of energy that flows out of a system and because of this we have some disorder.

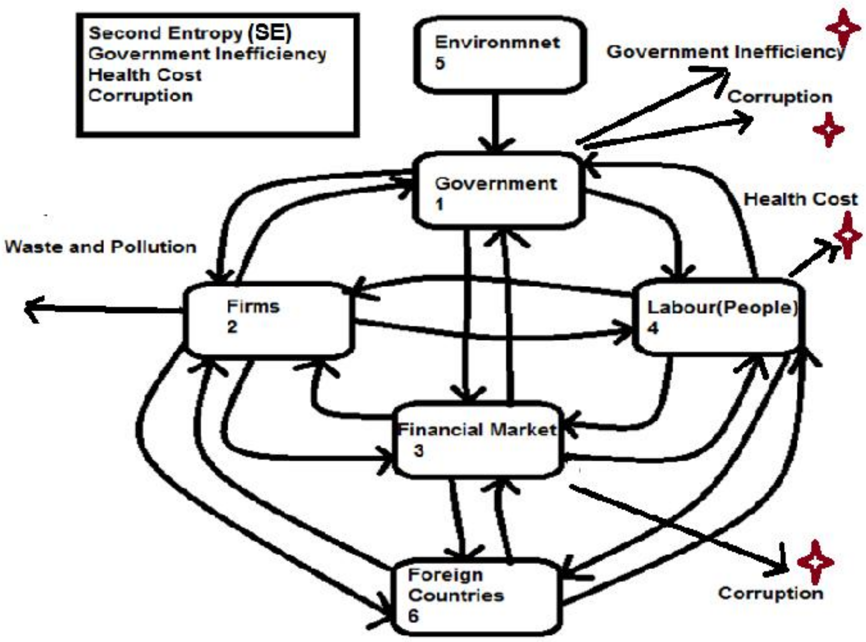
The first part is the entropy of one country with the others (foreign countries as external exchanges). Some relevant examples are wealth and human immigrations or net of goods, services and money transmits. In fact, if the net storage of money (capital) is negative, it means that some money goes out from country and we lose some of our energy. This is calculated as import and export entropy.

The second part, respiration, as a part of system entropy, means the amount of money or energy that systems and people need to be alive. A system just to remain stable needs some energy to keep that system alive. For example, we can take the poverty line for each person as the average respiration of system components. This part of energy also goes out the system for staying afloat and we lose this kind of energy. On the other hand, a system tends toward a stable situation to avoid uncertainty and volatility in the systems flows based on the Shannon entropy definition. So maintaining the current situation and not dropping from the present level is an action taken through decreasing the system's entropy.

The third are the residual uncertainty and waste of the system. In fact, each part of the system has some physical waste and some inefficiency that ensures some system energy is no longer accessible. For example, the firms produce wastes that go back to the environment and we can account the cost of recycling these wastes as part of entropy cost. Another example can be inefficiency of government that wastes the system energy and can be calculated by the difference of private and government efficiency parts as an entropy cost for a country.

The fourth part of entropy of a country is redundancy or, as we refer to it, "second entropy". Some energy or money that exits the system is not accessible even as waste, but rather, is some kind of entropy cost inside the system. Energy or money transmits but it bothers the society and is not useful for it. For example, decreasing the social capital and increasing crime in a country causes the creation of police and judicial agencies that this kind of action will increase the GDP and economic growth. As a result, in order to offer these services, there is some kind of transmitting tax on people. Some other examples are corruption in government institutions and financial markets, inefficiency of monopolies, and cost of diseases, health, medicine and accidents in one country. Another aspect of this kind of entropy is the inactive population of each society. In economies, people less than 16 or over 60 years old are generally inactive and can increase the system entropy as the heat of biomass. These situations are examples of second entropy, as they decrease the welfare of society although they contribute to growth.

Fig 2: Research Model, inflows in an economic complex system



Source: Research Findings

Table 1: The flows and stocks of macroeconomic complex system of Iran's economy

Sector	Stock (dollars)	Flow (dollars/time)
Government	Budgets	Subsidies to people and firms, government size* productivity difference (Second Entropy cost); and the cost of health and crimes (Respiration cost).
Firms	Assets	The tax to government, waste and pollution* cost of recycling or cleaning the air (using World Bank data), machinery depreciation (as Respiration cost), average wage*employees, deposit in bank
Financial	Assets	Loans to people, government and firms, corruptions (as Second Entropy cost), money outflows to the foreign countries
Labor	Active population * employment rate * annual income per capita	Deposits in banks, migrants' number * annual income per capita, taxes to government
Environment	Estimated capacity of oil, gas, forest, mines, etc.	Renting oil, gas, forests and mines
Foreign Countries	Sum GDP	Inflow of money, inflow of migrants *annual income per capita

*show multiplying
Source: research Findings

As shown in Table 1, our complex system model of Iran has 5 sectors; Government, Firms, Financial, Labor, Environment and Foreign Countries and lots of flows between them. Through the above conceptual model, we can see entropy in several areas. The most important part of the model shows the wastes firms generate including air, water, soil pollution. These wastes also include forest and other environmental destructions and finally domestic and industrial wastes. Other parts of entropy can be seen as respiration. We get the term “respiration” from ecology and in economics it is referred to as metabolism of economic system. This kind of energy is needed for being alive in a society and can be estimated by using a poverty line for the society. In fact, the whole population needs at least an equal poverty line to remain functionally alive. This kind of energy which comes out of the society is useless for the system except for keeping it alive.

In fact, the aim of introducing this model is showing the cost of an economic system. By seeing these wastes and pollution as entropy, we can go through the recycling processes. In other words, in this model, the real cost of the physical system will show itself and by this cost, recycling technology and research and development for protecting environment would be more easily accessible.

The second entropy includes (1) government inefficiency, (2) health and crime cost, and (3) corruption in a system. Therefore, the economic second entropy in a system is the sum of these 3 types of flows in the above model. The first part of second entropy is the efficiency difference between governmental institutes and private sector. This is calculated by multiplying government size and performance differences (1% at least). The second part of second entropy is health cost which shows problems in the society, but also the economic system needs. An increasing the health cost does not cause any further work for the system. The third part is some kind of governmental corruption that is not good for an economic system. It can be quantified by corruption index from the Freedom House institute. In the next section, factors affecting entropy will be shown mathematically.

3.2. Entropy

Svirezhev (2000) discussed in the open systems theory, the total change of entropy can be separated into two series:

$$dS(t) = d_i S(t) + d_e S(t) \tag{1}$$

Entropy, dS(t), is separated into internal entropy, $d_i D(t)$, and external entropy, $d_e D(t)$, where $d_i S(t) = dQ(t)/T(t)$, $dQ(t)$ shows the production of heat caused by processes that are irreversible, and T(t) is the temperature of the system. An analogy for temperature in economics can be inflation rate in a country. The value $d_e S(t)$ matches to the exchange processes entropy between the system and its environment. In fact, total heat production is composed of the following:

Entropy has inner heat change (di$S(t)$), which can be divided into system respiration (R) and system wastes (W). Wastes can be added to the environment (EW) or through the society (SW), so

$$d_i S(t) = R + EW + SW \tag{2}$$

In fact, total entropy is composed of this plus external entropy ($d_e S(t)$) that is produced by the relationship of systems sectors by foreign parts and two kinds of waste. It can be concluded from the above relations that entropy of a system depends on the initial and final situation of that system. In addition, entropy can exit through waste and pollution from the system and recycling can reduce the system entropy.

Summing up, we can say that in this model the two kinds are internal and external entropy. We have some recycling added to the system. Finally, the system entropy is based on the annual gross (total) and net primary production and the energy that is added to the system. In other words, entropy of a system depends on the waste material (difference of annual gross and net primary productions) and the amount of recycling (artificial energy). So from the model of Svirezhev(2000) and our model interpretation, by increasing the waste, we have more entropy and by increasing the recycling, the entropy will decrease.

3.3. Development and growth and Entropy in economic system

In the next section, Ulanowicz' approach will be used for calculating growth and development of a system (see, Ulanowicz (2000) and Scharler (2008)).For calculating growth in a system, we can use the joint probability that each event serves, as in Shannon's formula, as a weighing for incidence frequency of each happening (i.e., each co-occurrence of a_i and b_j). In fact, previous ecological studies using joint probability can be applied to a macroeconomic model in economic to show the growth and dissipation of energy in a system. In other words, a macroeconomic model like our research conceptual model in Figure1 can show growth and development of the model by using inflows and outflows in the system. The result is called average mutual information (AMI) or

$$AMI = K\sum_{i}\sum_{j} P(a_i, b_j)\ \log\left(\frac{(p(a_i/b_j)}{P(a_i)}\right) \tag{14}$$

AMI is the amount of uncertainty reduced by knowing b_j. Results are in units of *K* (Ulanowicz, 2000):

$$AMI = K\sum_{i,j}\left(\frac{T_{ij}}{T..}\right)\log\left(\frac{T_{ij}T..}{T_i.T._j}\right) \tag{15}$$

Some ecologists in this regard introduce network models. Of historical record in this regard was the far-reaching search during the 1960s for some linkage between system diversity and consistency (Woodwell and Smith, 1969). The whole matter was advanced by MacArthur (1955), who applied Shannon's Information Index to the flows in an ecosystem as,

$$H = -K\sum_{i,j}\left(\frac{T_{ij}}{T..}\right)\log\left(\frac{T_{ij}}{T..}\right) \tag{16}$$

Where *H* is the diversity of flows in the network, *k* is a scalar constant, and *T*. signifies the sum of T_{ij} over all combinations *i* and *j*. As said above, the development constraint is set by Shannon's diversity measure pertaining to the material transfers or flows. MacArthur used Shannon's diversity measure to the material flows in an ecosystem network to receive an index for the diversity of flows. *H* like the AMI can be multiplied by TST to scale the diversity of flows to the network in question. TST_*H* is named the development capacity, or development constraint:

$$C = TST\sum_{i,j}\left(\frac{T_{ij}}{T..}\right)\log\left(\frac{T_{ij}}{T..}\right) = \sum_{i,j} Tij\log\left(\frac{T_{ij}}{T..}\right) \tag{17}$$

As Scharler (2008) discussed, the development capacity is limited by two factors, namely TST and the number of compartments. This action is needed to decrease the number of compartments and therefore the number of flows. More sustainable systems are therefore believed to have higher *C* values compared to networks undergoing frequent perturbations. The initial complexity, *H*, consists of two parts. One is the AMI, showing the information gained by decreasing uncertainty and volatility in flow probability. It is a measure of the organized element of the system. The other is the residual part or residual uncertainty, or Hc (also named conditional diversity). Finally, based on Huang and Ulanowicz(2014) the growth and developments in such a system can be seen by this formula:

$$TST = \sum_{i,j} T_{ij} = T.. \quad (18)$$

“Growth, in economic terms, usually refers to the increase in total exchanges of flow medium” (Ulanowicz, 1986) which growth can be showed as any increase in TST.“Development is defined as an increase in organization, which is independent of the size of a system”(Ulanowicz, 1986). In a highly organized network, if it is considered that a flow has left compartment i at time t, then information about which compartment will take the flow at time t+θ is inside its flow structure. The more structured a network is, the more information it can provide. An ecological information-based measure named the average mutual information (AMI) estimates this organization, hence AMI can be used as an index of development(Ulanowicz,2014).The convexity of the logarithmic function guarantees that H≥AMI≥0(Ulanowicz, 2009,2014).H serves as an upper bound on AMI.

AMI measures the amount of flow diversity (H) that is encumbered by structural limits. It quantifies regular, orderly, coherent, and efficient actions in a network. Higher AMI values reflect tighter constraints on the movement of medium. Such structures are also considered to be highly efficient. Scaling H by TST results in the system development capacity that serves as an upper bound on system ascendency.“The difference between development capacity and ascendency can be regarded as redundancy, an attribute that is complementary (opposite) to ascendency” (Ulanowicz, 2014), such that R=C−A, where

$$A = TST * AMI = \sum_{i,j} \left(T_{ij}\right) \log\left(\frac{T_{ij} T_{..}}{T_{i.} T_{.j}}\right) \tag{19}$$

As above literature said, based on our model and the flows between the six sectors of our macroeconomic system, growth and development can be calculated.

Hc or Overhead as an Entropy Index

The residual uncertainty, Hc, when scaled by TST is also called the overhead. We can use overhead or waste as entropy in an economic network or in a physical system. In fact, unorganized, inefficient, and indeterminate elements of the flow structure is analyzed confidence for the network such that the four parts of imports, exports, respiration[3] and redundancy are portions of entropy in a system. For calculating entropy, we can use Shannon’s formula based on incomplete information and uncertainty. In other words, Shannon entropy based on information theory is a kind of uncertainty. Also, we can see entropy as an unorganized and inefficient flow that is depleted from the system like volatility in production function or volatility in liquidity or even exchange rate for the relation with the foreign part. Should the system become overly organized (high ascendency), it will also be prone to perturbations. Overhead consists of four components: imports overhead, overhead due to exports, respiration, and internal pathways. The combined overhead is showed by

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[3] As said before Respiration, as a part of system entropy means the amount of money or energy that system and people needs to be alive. For example we can take the poverty line for each person as average respiration of system components.

$$\text{Hc} = -k\sum_{i,j}\left(\frac{T_{ij}}{T_{..}}\right)\log\left(\frac{T_{2ij}}{T_{i}.T._{j}}\right) \tag{20}$$

Scaling *H*c to the system by replacing *k* with TSTYields

$$a = -\sum_{i,j}\left(T_{ij}\log\frac{T_{2ij}}{T_{i.}T_{.j}}\right). \tag{21}$$

Imports

The imports overhead is related to the number of pathways that originate outside the network and on the magnitude of the material transferred along them. By entering the imports in the system with fewer flows or compartments, ascendency will be more at overhead expense. Networks are expected to develop toward fewer import pathways. The formula for the overhead due to imports is as follows:

$$aI = -\sum_{j=1}(T_{0j})\ \log(T_{20j}/T_{0.}T_{.J}) \tag{22}$$

Where imports are regarded to originate in the fictitious compartment 0.

Exports

Similar to the imports overhead, the overhead due to exports is related to the pathways leaving the network. The export overhead reduces whenever there are more export pathways, lower transfer’s magnitude, or an uneven distribution of transferred amounts along the pathways

$$aE = \sum_{i=1}(T_{i}, n+1)\log\left(\frac{T_{2i}, n+1}{T_{i}.T._{j}, n+1}\right) \tag{23}$$

where exports are assumed to flow into a fictitious compartment*n*þ*1*.

Respiration (another part of export in a system)

Again, dissipation overhead, related to the environment lost magnitude, depends on the number of pathways and the magnitude of the distribution transferred. Losses through dissipation are in keeping with the second law of thermodynamics. The dissipation overhead is

$$ {}^{a}D = -\sum_{i=1} (T_i, n + 2) \log\left(\frac{T_{2i}, n + 2}{T_i . T._j, n + 2} \right) \tag{24} $$

where respiration is measured to flow into a fictitious compartment *n*þ*2*.

Redundancy

The fourth part of overhead is the internal transfers and measures the pathway redundancy. There are costs to the network in keeping redundant or parallel pathways. For one, there can be an increase in dissipation, whenever transfers happen not only along the most efficient way, but also along leakier pathways. Also, the stock transferred along several parallel routes might not ever end up at the right period at the consumer. According to Scharler (2008), redundancy is denoted by

$$ AMI = -K \sum_{i=1} \sum_{j=1} T_{ij} \log\left(\frac{T_{2ij}}{T_i . T._j} \right) \tag{25} $$

We can use overhead plus waste as entropy in an economic network. In fact, these four kinds of overhead plus waste can be another index for economic entropy.

- **Waste and pollution cost as an Entropy index**

Another way for seeing entropy like Georgescu-Roegen's physical throughput view as discussed is the ratio of waste and pollution to the GDP. This index shows the trend of damaging environment as economic entropy and can be seen as an economic entropy cost.

Summing up, it can be said that there are three kinds of entropy, firstly based on the physical systems approach, secondly by using an information approach, and lastly based on social entropy, considered the entropy cost of the system. Physical entropy is waste and pollution flows of an economic system. Information entropy is uncertainty of flows in a complex economic system. Social entropy is the second kind of entropy in this paper that includes (1) government inefficiency, (2) health and crime cost, and (3) corruption in a system.

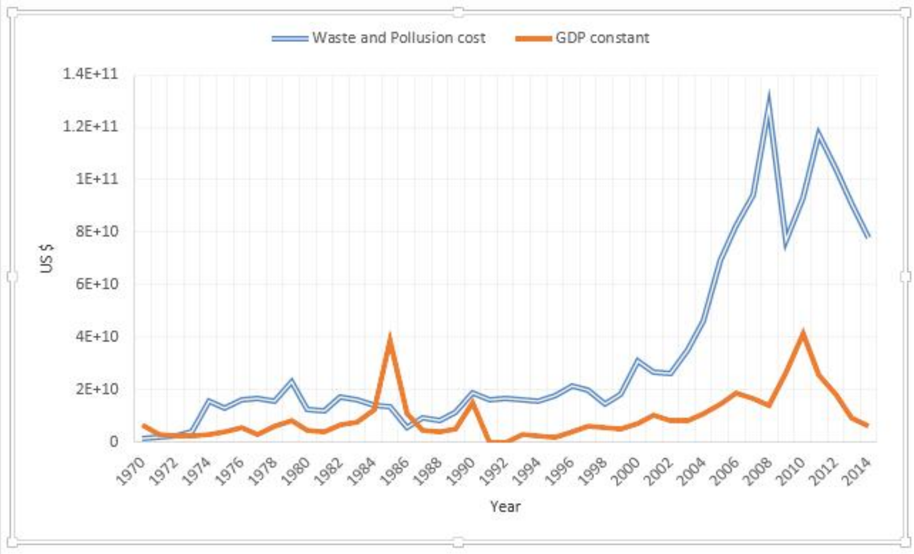
Data

In this paper, time series data for Iran economy is used for estimating growth, development, and entropy indices for the economic system during 1970–2014. This data has been gathered from World Development Index in the World Banks Statistics series. GDP constant is the real amount of gross domestic production of Iran that exists in time series format in World Banks Statistics series. Waste and Pollution Cost Data is the cost of recycling or cleaning the waste and pollution in the country. For the Government, stock is the Budget of government that is equal to income and cost of the government and flows are the subsidies to people and firms, government size multiplying productivity difference (1%); and the cost of health and crimes that are available in WDI. For Firms, stock is the total firm's assets and flows are the tax to government, waste and pollution multiplying to the cost of recycling or cleaning the air (using World Bank data ; machinery depreciation, average wage multiplying to employees and deposit in bank that all of them are available in WDI and central bank of Iran). For financial sector data, stock is the total financials assets and flows are the amount of loans given to people, government and firms, corruptions amount and money outflows to foreign countries that are available in WDI. The data for the labor and foreign Countries are also available in WDI. For Environment sector, stock is the estimated capacity of oil, gas, forest, mines, etc. and flows are the amount of renting oil, gas, forests and mines that are also available in WDI. All of the data is based on dollars and is constant based on the year 2005.

4. Results

In this section, the results of applying conceptual model in Figure 2 and based on waste and pollution cost as an Entropy index that is introduced previously. Figure3 shows the trend of waste and pollution costs and constant GDP of Iran.

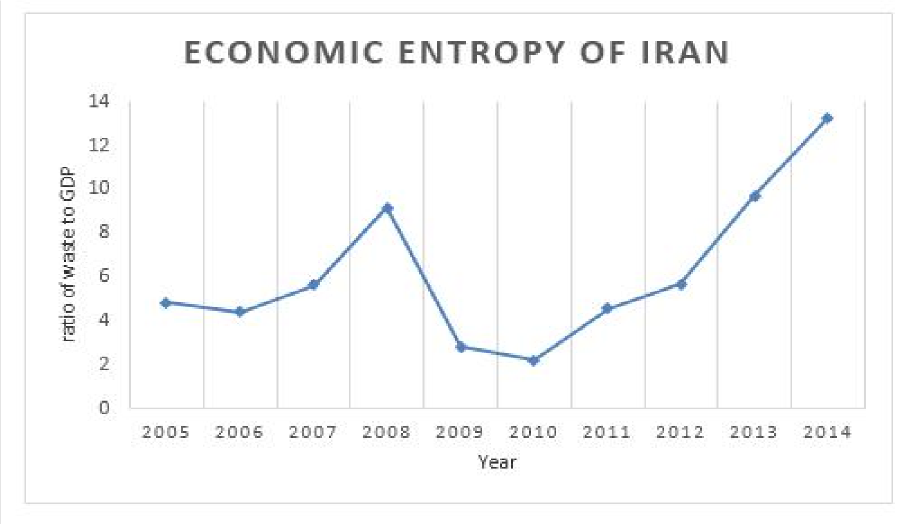
Fig 3: The trend of waste and pollution costs and the constant GDP of Iran; data gathered from WDI2014, World Bank



Source: Word Development Index, 2014

The trend of waste and pollution costs in Iran economy is increasing and there is a huge gap between waste and pollution costs and constant GDP in Iran. The ratio of waste and pollution cost is divided by the constant GDP amount. This ratio shows economic entropy based on Georgescu-Roegen’s view displayed in Figure 4.

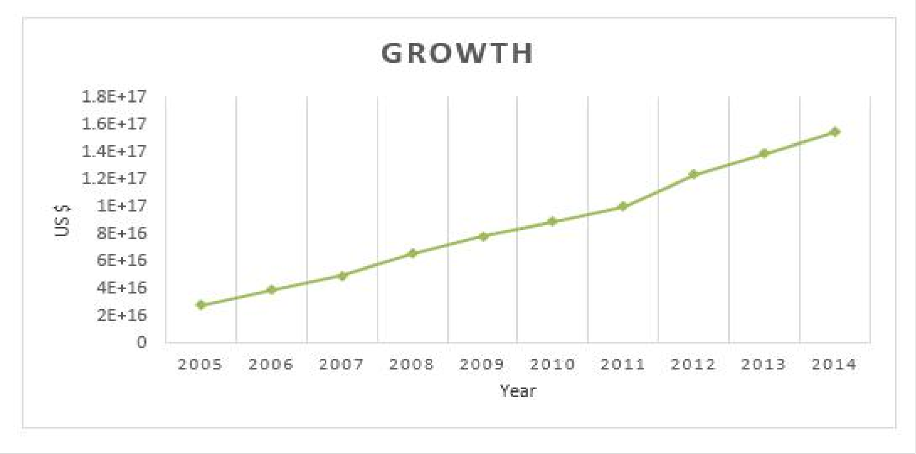
Fig 4: The ratio of waste and pollution cost divided by the constant GDP amount shows economic entropy



Source: Word Development Index, 2014

As it is shown in Figure (4), the economic entropy of Iran, based on the equation (17), is increasing and this implies that there have been changes to environmental materials (a production factor).

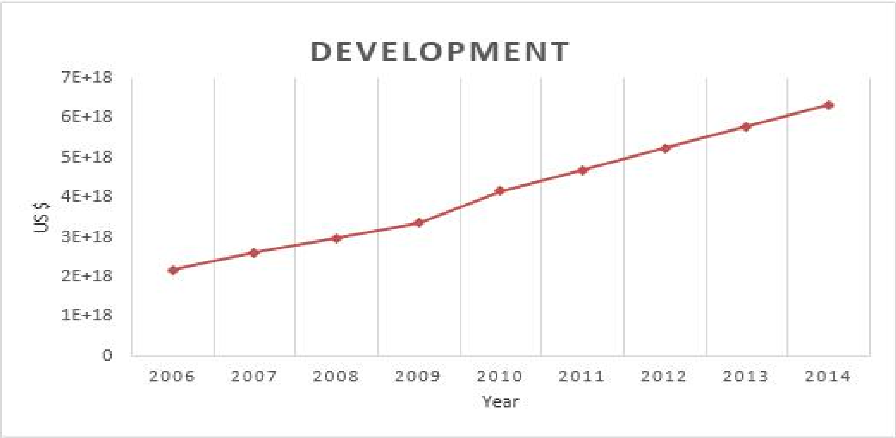
Fig 5: The trend of growth in Iran's economy of complex system



Source: Word Development Index, 2014

Growth, in economic terms, usually refers to the increase in total exchanges of flow medium (Ulanowicz, 1986). As shown in Figure 5, the trend is increasing. Figure 6 shows the development index based on equation (19) during the time period investigated.

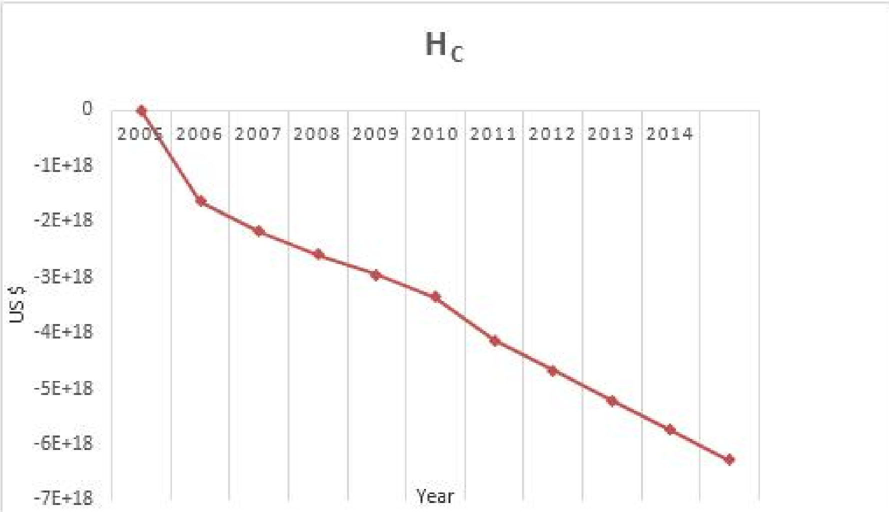
Fig 6: the trend of development in Iran's economy of complex systems



Source: Word Development Index, 2014

As discussed before AMI becomes a measure of development (Ulanowicz, 2014). AMI is increasing. Figure 7 is an entropy index. As mentioned before, entropy index includes several parts: overhead, imports, and exports.

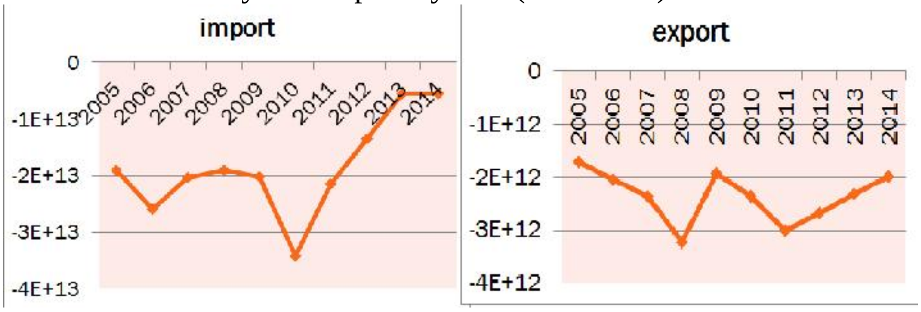
Fig 7: The trend of overhead or entropy index in Iran's economy of complex system



Source: Word Development Index, 2014

The overhead H_c , based on equation (21), shows a decreasing trend. The next figures are import and export trend based on equations (22, 23).

Fig 8: The trend of import and export in entropy index in Iran's economy of complex system (unit: US $)



Source: Word Development Index, 2014

This figure shows the import and export entropies have increasing trends, although export is flat as a whole. In fact, even by increasing environment capacity, under present management the environment will be destroyed and will disappear. For more interpretation, it can be said that both kinds of entropy, waste and pollution in physical model of economy or uncertainty in the complex system, in Iran's economy is increasing. In fact, if Iran's economic system had increased capacity of environmental material, it would still have experienced collapse of its economic complex system. Or uncertainty trend of the flows of the Iran's economic complex system is increasing. Using Shannon's entropy interpretation, it is said that the economic entropy of Iran's complex system is increasing as well. Human societies and natural ecosystems bear severe consequences due to an accelerating entropic juggernaut experienced as climate change and global capitalism (Rifkin, 2009). As Joon (2011) said, juggernaut metaphor implies the price we must pay for dissipating energy, not only by the unstoppable consumptive use of energy resources, but also by living systems for the maintenance of their organism.

5. Discussion and Conclusion

Some economists say that economic growth is one of the most important goals of an economy. Neoclassic economics says that economic growth can solve other problems like poverty, unemployment, over-population, etc., but we should pay attention to the environment and natural resources. As Daly believes, “Rather than the economy is a subsystem of the finite biosphere that supports it. When the economy’s expansion encroaches too much from its surrounding ecosystem, we will begin to sacrifice natural capital that is worth more than the man-made capital added by the growth.” He said that “Humankind must make transition to a sustainable economy… If we do not make that transition, we may be cursed not just with uneconomic growth but with an ecological catastrophe that would sharply lower living standards” (Daly, 2005). “Sustainability is a broad concept, with many definitions for differing disciplines” (Lems et al., 2004). The issue that is clear about consumption and waste material is that material consumption and waste production should be limited to an acceptable amount. This “acceptable level” shows that input material should not be used faster than the renewal input rate and waste production should not overstep the carrying capacity of the environmental ecosystem (Bakshi and Fiksel, 2003).Despite that several studies have considered entropy as an index for sustainability (Hornbogen, 2003; Wall, 2010), measuring this acceptable level has been difficult due to an absence of instruments, techniques, and understanding of the environment. As Kaberger and Mansson (2001) said “the limited stocks of our globe are relevant to the amount of different chemical elements that we may use”. Constraints to human use of materials are of two types namely input- and output- oriented. These two kinds of restrictions are resource scarcities that increase the cost of materials and the pollutions that society produces.

This shows that an economy like an ecosystem is a complex system, and we need to use a system's perspective of material flows and the relation between society and nature. Secondly, a paramount issue in Ecological Economics shows the relation between thermodynamics and economics. Simply, in each economic system the transition of energy or goods and services results in obligatory energy dissipation. Most precisely, the Thermodynamics Laws pertain to economy because economic tasks are entropic. “The integration between economics and thermodynamics at a substantive level is of crucial importance because economic processes obey thermodynamic laws and therefore a sound economic theory must be coherent with thermodynamics”(Čiegis and Čiegis, 2008). Borrowed from physics, entropy is defined as “a numerical way of measuring the grade of energy in a system” (Crowell, 2007). Another definition would be measuring the degree of energy dissipation in a system, i.e., measuring the spontaneous tendency of energy to degrade and be dissipated in the environment (Marchettini, 2008). Nothing is created, nothing is destroyed, and economic process is simply a large scale low-entropy transformation process.

6. policy implications

In this paper, we introduce a conceptual model using the basic flows in a macroeconomic network that could quantify the overall entropy for an economic system by focusing on the amount of wastes and other entropy generators. Furthermore, using a mathematical model and literature in ecology and macroeconomic view, growth, development, and entropy of an economy are calculated. Entropy in this paper is analyzed in three ways; the first part, thermodynamic-based, is entropy as a relevant measuring of the pollution to growth ratio. The second approach, information-based, is entropy as uncertainty in Iran economic system. The main results are as following:

The results indicate, as shown in Figure 4, the economic entropy of Iran is increasing and implies that the amount of environmental materials, as a production factor, is decreasing. With this perspective, we predict a declining economic growth trend in the future.

Also, the results of Iran’s economy in complex system indicate that the pollution and waste cost is really important for this economy and show effective constraints on economic growth in future that should be considered.

As Shown in Fig. 4, the ratio of the waste and pollution cost divided by constant GDP amount shows economic entropy and shown Fig. 8 is the trend of import and export in entropy index in

Iran’s economy of complex system (unit: US $). Different kinds of entropy in Iran's economy are increasing and indicate arising disorders and social cost in Iran's complex system. This has imposed lots of limitations on economic growth and development; so for decreasing entropy and social cost in Iran's economy the following items should be noticed:

- Decreasing air pollution, especially co2, by using new and better Technology for manufactures and cars
- Decreasing other kinds of pollution and using environment correctly and as little as possible.
- Decreasing uncertainty and risk in economy by having a long and correct programming in the country's development programs
- Increasing the social capital and decreasing the number of accidents that are kinds of entropy
- One of the most important kinds of entropy is inefficiency entropy based on which energy intensity is suggested to be reduced and the reverse should be done to the efficient use of energy. Using new kinds of energy and raising the price of energy regularly in order to reduce its consumption are suggested, too.
- Enhancement of administration transparency for decreasing transaction cost
- Miniaturize the government size for reducing inefficiency
- Reducing corruption in the economic system that can decrease the cost of system. In fact, although corruption in the first stage can facilitate administrative issues, in the next stage it can complicate the system and increase cost and entropy of the system.

Human societies and natural ecosystems bear severe consequences due to an accelerating entropic juggernaut experienced as climate change and global capitalism (Rifkin, 2009). As Joon (2011) said, “juggernaut metaphor implies the price we must pay for dissipating energy, not only by the unstoppable consumptive use of energy resources, but also by living systems for the maintenance of their organism”.

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