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The Role of Temperature in Economic Exchange - An Empirical Analysis

Abstract: As a synthesis of economics and physics and an attempt to apply the methods and models of statistical physics to economics, econophysics is presently a new, growing and very dynamic branch of modern science. Therefore, the subject of this paper is to analyse the relationship and interdependence between thermodynamics and economics, and it aims to show similarities, analogies and correspondence between the main categories, methods and models of thermodynamics on one hand, and economics on the other. The paper analyses the relation between economics and thermodynamics, as well as the probability distribution in the kinetic theory of gases corresponding to money, income and wealth distribution, connects entropy with utility and the principle of operation of the thermal engine with economic exchange. The final part of the paper empirically analyzes temperature differences in the exchange between Serbia and the selected EU countries. There are differences in temperature between Serbia and the group of selected countries. Results of the empirical analysis shows that the exchange between countries is based on principles of thermodynamics and that developed countries generate more profits and benefits from exchange.

Keywords: econophysics, thermodynamics, thermal machine, entropy, utility, the quantity theory of money

JEL classification: A12, C99

1. Introduction

Attempts to connect economics and physics are not new in the history of economic thought. One of the first examples of this kind is the work of William Petty who made the initial analogies between certain categories of economics and physics. The English classical political economics had certain parallels with Newtonian mechanics, while the Physiocratic Quesnay's analysis of economic reproduction pointed out the analogy of balance in nature and functioning of the circulatory system in the human body (Mimkes, J., 30). In the late 19th century, with the advent of the so-called Marginalist Revolution, economics began to use mathematical, quantitative methods of modern physics. Many leading economists were physicists, mathematicians or engineers by education, and Walras and Pareto conceptualised a model of general equilibrium theory according to the Newtonian model of natural laws applied in the physics of celestial mechanics. Jevons analysed the influence of sunspots to economic cycles, while Fisher, the student of the physicist Gibbs, made the analogy between the categories of physics and economic terms (Sharma, B.G. 40); the so-called Brownian motion in physics, which had been noticed for the first time by Einstein in the behaviour of particles within molecules, is also characteristic for the dynamics of the time series of stock market returns (Bachelier, L. 1900, 2) and known as "a process of random walk" (Jovanovic, F., et al., 2010, 21).

Econophysics is a new scientific discipline, which emerged at the end of the last century. The term was coined by E. Stanley, a physicist from the Boston University, in 1996. Econophysics applies methods of statistical physics and quantitative methods developed in physics to economic phenomena, primarily to the analysis and predictability of stock market behaviour, but increasingly to microeconomics, the theory of consumer's choice, agent-based models, macroeconomics, and the theory of production.

The typical methods and instruments of econophysics are the following:

- Statistical properties of stochastic processes;
- Boltzmann-Gibbs distribution, Lévy distribution, Pareto power law;
- The abandonment of the Gaussian theoretical framework typical of economic analysis (Portfolio optimization model by Markowitz, 1952, 27; 1959, 28) and the introduction of class models with probability distribution characterized by distribution tails, cluster variability and autocorrelation of returns;
- The abandonment of the theoretical framework with rational economic agents; introduction of a model with learning agents and the so-called 'zero intelligence' agents;

- According to econophysicists, the analysis of economic phenomena should be based on experience and not on the pre-given axiomatic assumptions of positivist models; facts should be preferred over theoretical and abstract structures that are not empirically based;

The most recent area in econophysics is thermoeconomics, which emerges as a synthesis of thermodynamics and economics. Being a discipline within physics, thermodynamics studies the interdependence of the four key values: pressure, volume, temperature, and entropy. In addition to the known laws of thermodynamics, this branch of physics focuses on thermodynamic heat engine, its efficiency, and reversible and irreversible processes. The synthesis of economics and thermodynamics is possible in three areas: 1) analogy between the values, 2) similarity of methods and models, 3) correspondence between thermodynamic and economic processes.

The objective of this paper is to show the interdependence, analogy and synthesis of economics and thermodynamics, in order to increase our knowledge of the functioning of economic processes based on theories and models of physics and thermodynamics and ensure their higher efficiency, as well as higher capability of economic science to estimate future outcomes. The paper presents comparative analysis of economics and physics - thermodynamics, in terms of categories, methods and models, including empirical verification of certain facts. In addition to the introduction, the paper consists of four sections. The correlation between economics and thermodynamics is analysed in the second section; the concept, role and importance of temperature in economics, together with the operating principle of the thermal engine both in physics and economics, are explained in the third part, while the fourth part consists of the empirical analysis of the role of temperature and operating model of thermodynamic and economic engine in international economic relations of Serbia with developed and less developed EU countries with which Serbia has significant economic exchange. It is followed by the conclusion and the list of references.

2. Literature review

The present correlation between economics and thermodynamics has been elaborated in numerous and dispersed literature, including theoretical articles, empirical research, papers in international seminars, books, and textbooks. Here are the most significant authors: J. Bryant (the book on thermodynamics and economics, 2012, 7; and the article 2010, 6), J. Mimkes (2006, 29, 30), Dragulescu and Yakovenko (2000, 13) Yakovenko and Rosser (2007, 36), Chakraborti and

Chakrabarti (2006, 9; 2012, 41), S. Prabakaran (2010, 34), (all the authors have published a series of papers related to the analogy between thermodynamics and the distribution of money, income and wealth), Dasari and Biswas (4), (parallels between electrodynamics and the economics; the literature in this field is particularly developed in India, which is the solid base of econophysics,), (Wang, Wu and Di) 2008, 48.) (Chinese authors on income distribution in the world), F. Jovanovic and C. Schinckus (the historians of econophysic thought, 2010, 21; 2010, 37; 2011, 38, 2013, 39), Smith and Foley (2007, 18), (on numerous parallels between thermodynamics, entropy, marginal utility and other areas of economics), T.A. dos Santos (2007, 44) (her doctoral thesis on the relationship of thermodynamics, economics and biology-physiology of living organisms), S. Bali, (2011, 3), the Russian authors Tishin and Baklitskaya (45), Valero and Cuadra (46) (thermoeconomics as a relation of ecology, physics and economics in the field of energy savings), as well as earlier authors: Georgescu - Roegen (pioneering work on the relationship of ecological economics and thermodynamics), Martinez and Alier, Mirowski, Baumgartner, Stern, Chen, Tribus and the others (Tania, A. 2007, 44; Mimkes, J., 2006, 29).

What are the basic analogies between categories and values of thermodynamics and economics?

- In the 17th century, Sir William Petty established the analogies between physical and economic values: bodies in physics - commodities in economics; concept of power in physics - human labour in economics; body movement - production; space in which bodies move - the market; (Dimitrijevic, B. et al., 2013, 12);
- In 1892, Irving Fisher wrote about the following analogies between economics and mechanics (dos Santos, 2007, 44):

In his book, Bryant (2012, 7) gave a set of physical symbols having their parallels in economics. Here are some typical ones:

Physics	Economics
Time	Time
Pressure	Prices per units
Number of molecules	Number of stock units
Temperature	Index of trading value
Energy Value	flow rate
Boltzmann constant	Productive content per unit
Volume Physical	production volume (GDP)
Temperature	GDP per capita; average selary
Entropy Marginal utility	production growth

A complete parallelism can be established between the kinetic theory of gases and the kinetic model of energy exchange on one side and the distribution laws that govern economics, as well as the behaviour of economic actors in the markets, on the other:

Table 1: Parallelism between the kinetic theory of gases and the distribution laws that govern the economics

Physics	Economics
Gas atoms, molecules	Economic actors
Physical particles	Assets of economic actors
Particle collision	Market exchange
Constant energy	Unchanged extent of wealth and money in a closed system
The same law of probability distribution manages gas energy in a closed system	Distribution of money, income and wealth behave according to the Boltzmann-Gibbs distribution and Pareto power law
Temperature in physics as an average kinetic energy of gas	Average amount of money, average wage, GDP p.c.
Maximum entropy	Maximum utility
Gases in a closed system behave according to the Theory of Random Processes	Stock market processes behave according to the random process defined in mathematical and physical statistics
Energy of gas is randomly distributed	Money, income, and wealth are randomly distributed

The principle of maximum utility in economics corresponds to the principle of minimum energy consumption in physics. It establishes a similarity between economics and molecular dynamics, and it was noticed by Einstein in the case of Brownian motion. In a closed system, particles of gas move randomly in the so-called random walk, and time-series of price indices behave the same manner. This feature is extremely important for the application of physical methods in economics. It is closely associated with the concepts of reversibility and stationarity of economic series and this is the area of basic criticism of economic statistical methods suggested to economists by econophysicists in the field of quantitative finance (Jovanovic, F. et al., 2010, 21).

3. Probability Distribution in Thermodynamics of Gas Kinetics and in Economics of Money, Income and Wealth - Theoretical approach

Statistical reversibility means that the time series are stationary - defined by the same process in time, allowing the application of principle of ergodicity and

Gaussian theoretical framework of normal distribution. However, time series of stock market returns are non-stationary (random walk process), so they are irreversible. This imposes the need for reducing these series to stationary (first, second difference series), or the use of the tools of statistical physics applying Boltzmann-Gipsovu probability distribution and Pareto power law, as better statistical models for the prediction and research of stock market phenomena. Such distributions were observed in the empirical analysis of time series of return on stock exchanges, as well as in the distribution of money, income and wealth, within individual countries (Yakovenko-Dragulescu, 2000, 17; Yakovenko-Rosser, 2009, 36; Chakraborti 2006, 9) and in the world economy as a whole.

There is an obvious correlation between the Ideal Gas Law (1) and the Equation of the Quantity Theory of Money (2) (which was defined by I. Fisher). Here are both equations:

$$PV = Nk_bT \tag{1}$$

$$PY = M\nu,\ \text{for } \nu = \frac{1}{k},\ k = \frac{1}{\nu},\ \text{is } PYk = M^d \text{ or } PY = M^d\,\nu \tag{2}$$

The meaning of the values is as follows: P - pressure in physics, prices in economics; V - volume; Y - production volume; v - velocity of money; N - number of molecules; k_b - Boltzmann constant (connecting the world of micro and macro physics and it could correspond to the velocity of money, or to the reciprocal velocity, the so-called Cambridge k); T - temperature in physics; temperature in economics is M/N (the average amount of money per actor), so the expression of NT in physics is analogous to the expression M (or M^d), the total amount of money, or money demand. So, there is a full analogy between the left side and the right side in both equations ($PV = PY$ and $Nk_bT = Mv$).

In further modifications, it is possible to show that there are significant following analogies:

$$PV = Nk_bT \tag{3}$$

$$PV = nRTP \tag{4}$$

$$n = \frac{N}{N_a} \tag{5}$$

$$R = N_a\, k_b \tag{6}$$

$$nR = Nk_b \tag{7}$$

$$n = \frac{N}{V} = \frac{N}{Y} \tag{8}$$

The meaning of the terms is as follows: N_a - Avogadro's number (the constant in physics, the number of molecules in one mole of gas); n - number of moles; R - universal gas constant, where the product of R and n equals the product of the Boltzmann constant and the number of molecules. In economics, the number n corresponds to the average number of products per one partial market; N_a is the number of partial markets, R is the average cost per one partial market, k_b is the price of a product, and N is the total number of products included in GDP. That way, the result of multiplying the price and the number of products in all partial markets is equal to the product of the average price and average number of products per one partial market. The multiplication Nk_bT (where T is the currency), corresponds to the nominal social product in the equation of the quantity theory of money! The expression (7) indicates that the product of the average price and the average number of products in all partial markets is essentially equal to the product of all the individual products and their prices. The expression (8) shows that the average number of products is equal to the quotient of the total number of products and the physical volume of production.

J. Bryant rightly observes that some differences between economics and thermodynamics certainly exist. In his model (2010, 6), N is the number of financial instruments, k is the nominal monetary standard, and T is the velocity of money (as a kind of system temperature). This relation was specified by Pickler, while the relationship of PV and PY was pointed out by P. Samuelson and J. Bryant (2010. 6). As a rule, economics is an open system in which all values vary in value (Y, P, v, M), and there is also inflation, which distorts the real values over time. The rising inflation over time is actually a form of entropy of money! With a series of transformations, Bryant showed that equality holds for:

$$\frac{dP}{P} = \frac{dN}{N} - n\frac{dV}{V} \tag{9}$$

where P is the price level, N is quantity of money, and V is GDP. Expressed by the rate of growth, this expression becomes:

$$\Pi = m - [n(y)] \tag{10}$$

This is the well-known Friedman's rule that the rate of monetary growth should be approximately equal to the growth rate of real GDP, if inflation is to be avoided.

An important area where there is a remarkable correspondence between thermodynamics and economics is the probability distribution of individual money income and wealth. **This is the same distribution law that follows the probability**

distribution of energy in gas atoms! The aforementioned analogy applies here, too: an economic system with a large number of subjects is like a gas system with a large number of particles, molecules, atoms and ions. Based on the principle of entropy, economic subjects are eager to maximize their utility, while physical systems incline toward a state with minimum energy expenditure. Such systems are best modelled by statistical equilibrium (which is better for research of essentially non-equilibrium systems as economic system) for larger samples. Probability distribution is in accordance with Gibbs-Boltzmann distribution according to the formula determined on the basis of empirical research:

$$P(\varepsilon) = Ce^{-\frac{\varepsilon}{T}} \tag{11}$$

where ε is energy, T – temperature, and C - normalizing constant. The formula for probability distribution of money at a one-level system (national economy) is as follows:

$$P(m) = Ce^{-\frac{m}{T}} \tag{12}$$

where m here is the amount of money (**money-energy**), and T = M/N is the average amount of money (in relation to population N), as temperature of the economic system.

Energy conservation law is applied in these models and the empirical conclusion is derived that the constant amount of energy (money, income) strives towards exponential probability distribution. However, there is a phenomenon observed here, which is typical for plasma physics, where the so-called "thermal" and "superthermal" part of plasma is noticed (Rosser, B. et al., 2009, 36), depending on temperature (an average amount of income). Namely, the larger part of the population with low income (lower temperature), behaves according to the exponential Boltzmann-Gibbs distribution, while a very small percentage of the population with high average income (higher temperature), behaves according to the Pareto power law (named after the economists Pareto who was first to apply concepts of physics to the study of economic and social phenomena). The Pareto power law is defined by the following formula:

$$P(\varepsilon) = \varepsilon^{-\alpha} \tag{13}$$

or in the version with an average income (r), the expression becomes:

$$P(r) = nr^{-\alpha} \tag{14}$$

Numerous empirical studies have confirmed that the distribution of the greater part of the population (97% - 99% within countries or between countries) is exponential, while for a very small percentage of the rich, it transforms to the Pareto power law. This indicates the non-uniformity - the inequality in income distribution in which a small part of the rich population (1-3%), has a larger share of money, wealth and income of the society. This kind of inequality is calculated by the famous Lorenz curve (named after the physicist Lorenzo), and the so-called Gini-coefficient accurately measures the level of non-uniformity. Thus, the share of the rich in income is calculated using the formula:

$$f = \frac{r - T}{r} \tag{15}$$

where r is the average income of the entire population, and T is the average income in the exponential part of the curve (for classes with lower incomes). Now, the Gini coefficient becomes:

$$G = \frac{1 + f}{2} \tag{16}$$

On the basis of the expressions (15) and (16), it is easy to show that f increases if the average income and the income of the rich increase, at the expense of the part of the income of the poorer section of society; in this case, the value of G increases, too, thereby increasing inequality in income distribution, which occurs when the value of the coefficient α decreases, since the Gini can be also calculated using formula:

$$G = \frac{1}{2a - 1} \tag{17}$$

This way, from the Boltzmann kinetic equation describing the time evolution of the probability of energy (money) emerges a law known as the Boltzmann-Gibbs distribution, as well as the Pareto distribution that is true for physical, biological and economic systems! Probability distribution based according to the Pareto power law is characteristic of the following occurrences:

- Global energy distribution
- Availability of limited resources,
- Stock market trade volume and the number of retailers in a given time interval,
- Share returns in the financial markets,
- Size and volume of capital and number of employees in companies,
- Quantity of rainfall during the year,

The Russian physicists Tishin and Baklitskaya emphasize the similar results in their work, citing the results of the empirical research (Bogdanov) of the distribution of wealth that completely relates with the Boltzmann-Gibbs-Maxwell equation in thermodynamics, which gives the share of gas molecules at a temperature T, whose potential energy is between E ± dE/2. This equation is:

$$\Delta F = \frac{e^{-\frac{E}{kT}}}{kT} \cdot \Delta E \tag{18}$$

There is a similar equation in economics that explains the proportion of people (ΔF) whose wealth is between ($D - \Delta D/2$) and ($D + \Delta D/2$), where D_a represents the average annual income in the United States:

$$\Delta F = \frac{e^{-\frac{D}{Da}}}{Da} \cdot \Delta D \tag{19}$$

It is obvious that the concept of income - D corresponds to the energy - E, while the proportion kT is analogue to the value Da.

4. Entropy in Thermodynamics and Economics

In statistical mechanics, entropy in an isolated system without temperature change is defined as a natural logarithm of the number of distinct microscopic states available to the system given the macroscopic constraints (constant energy). Thermodynamic entropy (according to Clausius) can be represented in several ways:

$$\text{a) } S = k\ln W,\ \text{ b) } \Delta S = \int \frac{dQ}{T},\ \text{ c) } \Delta S' = \int \frac{dQ}{k_B T} \tag{20}$$

Entropy is determined by the ratio of infinitely small quantity of heat received by a system (dQ) in relation to an infinitely small change of temperature T. In the case of c), the relationship with the Boltzmann constant, which normally connects temperature and energy of the physical system, is established as well. Entropy increase is followed by temperature decrease and increase of the system disorder.

In economics, entropy can be defined and measured in various ways:

- by increase of inflation and decrease of purchasing power of money,
- by interest rate increase, indicating the growth of money (energy) of the system,
- by decline of the average wage or the level of GDP p.c.

The logic of Carnotmapping process, operation principles of heat engines, laws of thermodynamics, Gibbs potential, Helmholtz free energy principle, and the like, can be applied to an economic system. This will be discussed in detail in the next chapter.

5. Operating Principle of the Heat Engine and the Role of Temperature in Economic Processes

5.1. Carnot Process and the Operating Principle of the Heat Engine

Here are the basic laws of thermodynamics and their economic interpretation:

The first law - the change in the internal energy of a closed thermodynamic system is equal to the amount of heat added to the system and the work spent on the system.

The second law - the total entropy of a closed thermodynamic system increases over time until a maximum value.

The third law - when a closed system approaches absolute zero, all processes and motion cease, and the entropy approaches a minimum value (zero).

The first law will be further explained later, but here is a simple economic interpretation: the money supply of a country (debt or grants) is partly spent on an increase of foreign exchange reserves, and partly on an increase of production volume (investments).

The second law: entropy of the economic system, measured by the inflation rate, rises at the level of the world economy as a whole, as well as at the level of individual countries.

The third law is only theoretically possible in economics. Namely, the system without money and without exchange ceases to function.

The first law of thermodynamics is usually formulated as follows:

$$Q = A + \Delta U \tag{21}$$

Q is heat, ΔU is the change of internal energy of the system, and A is the workload. The economic equivalent of this expression is: Q (M) is money entered into the country (for example, loan), ΔU (R) is the increase of foreign exchange reserves, or rise of the inflation rate, while the A (Y) is the increase of the physical production volume, due to the investment of the borrowed money:

$$Q(M) = A(Y) + \Delta U(R) \tag{22}$$

Workload can be decomposed into the expression A = P ΔV and it becomes clear that it is the product of prices and changes in production volume (nominal phrase). This expression indirectly shows the extent of the economic efficiency of the system, because it is desirable that the change of the component A is a consequence of the changes ΔV and not of price changes, which affects inflation and leads to increase of economic entropy. Friedman's monetary rule is also an aspect of the formulation of the first law of thermodynamics:

$$\pi = m - y \quad \text{and} \quad m = \pi + y \tag{23}$$

It means that the internal energy of the system (m) is the sum of the thermal energy (entropy, inflation) and work in the system (y, the increase of the physical volume of production).

Starting from the circular flow of economy, which was analysed by Quesnay in the 18th century, Mimkes, J. (2006, 29) formulated the first law of economics as the equality of the monetary cycle and production value. This is known in economics as Sey's market law, by which the sum of all commodity prices is equal to the value of manufactured goods.

The second law of thermodynamics can be represented in economics as follows:

$$DS = \frac{1}{T}\delta Q \tag{24}$$

The entropy is equal to the system surplus (profit, product surplus) relationship with the system temperature (average income); with a few changes the following proportion can be achieved:

$$\frac{\Delta P}{\delta T} = \frac{\delta S}{\delta V} \quad \text{and} \quad \delta P * \delta V = \delta T * \delta S \tag{25}$$

It means that the surplus multiplied by the average income (the right side of the equality) is equal to nominal gross domestic product growth (or total revenue), (left side of the equality).

Since Helmoltz potential (free energy surplus) is defined as:

$$Q = A + \Delta U \quad \text{and} \quad A = Q - \Delta U \tag{26}$$

A similar expression can be achieved in economics as:

$$(P\Delta V) = DF - (T\ dS) \tag{27}$$

where the system surplus equals the difference of total revenue (dF) and expenses (T dS) expressing the change of the system entropy.

Economy is the process of transformation of natural resources into commodities satisfying human needs and it is carried out as the Carnot process in four phases: the first phase is the production of goods; the second stage is their transportation to the market; the third phase is the sale of goods (exchange process); the fourth phase is consumption of purchased goods. These are the classic stages of reproduction: production - exchange - distribution - consumption. At the end of the cycle, the needs of final consumers and producers are satisfied (buyers receive goods, producers get money). The sum of total income is equal to the sum of the total expenditure. Yet, the system produces a surplus (profit), which is, on the one hand, the income factor, and on the other hand, the expenditure for the entrepreneurial functioning. Every Carnot process is a kind of heat engine, a heat pump, which works according to the principles defined by the first and second law of thermodynamics.[1] Water is taken from the river; its temperature is increased (using energy from the outside) and the space warming is enabled (the internal energy of the system is changed). The efficiency coefficient, i.e. utilization coefficient of heat engines μ is equal to the ratio of useful work and energy loaded into the engine. This is shown by the following equation:

$$\mu = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1} = 1 - \frac{T_1}{T_2} \tag{28}$$

where Q_1 is the energy entered into the system (heat engines, cylinder) and Q_2 is the energy taken out of the refrigerator, while T_1 and T_2 are the temperatures of the heat reservoir (source) and the refrigerator. The larger the difference between T_1 and T_2, the greater the efficiency of the heat engine. The economic heat machine works on the same principle!

The difference in the average temperature of the two systems is the surplus and it is the main driving force, but also an indicator of the efficiency of the economic system. This surplus is basically a profit, and the two economic systems can be: the economies of the two countries; the economic exchange within a country between the richer and the poorer classes; the exchange between the two compa-

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[1] An economic process can be compared with the internal combustion engine, which also represents a kind of thermodynamic machine. See Dimitrijevic, B. et al., 2008, 10.

nies in a single market and so on. The fridge temperature (T2) is always the temperature of the less developed country, the poorer part of the population or the company with a lower price or less economic power. What is the main source of surplus? Simply, it is the value transfer of natural resources from the a less developed economy to a more developed economy (minerals, oil, water, raw materials) or the exploitation of underpaid work (from the population with lower, towards the population with higher incomes).

5.2. Temperature in an Economic Process

Here are the economic values that can play the role of temperature:

1. An average amount of money according to the formula for the Boltzmann-Gibbs probability distribution;
2. An average salary seen in the Lorenz curve and the Gini-coefficient measurement;
3. G.D.P. p.c. for calculating the uniformity of distribution and the Gini-coefficient between countries and groups of countries in the analysis of international inequality and global inequality;
4. Terms of trade (price-level relationships) between different countries;
5. According to the quantity theory of money, money velocity is directly related to the inflation rate and entropy of money.

Here is an example of the economic engine based on the temperature difference. It is assumed that the exchange is carried out between the countries A and B. The wage in the country A is w_a = 50 monetary units, and in country B it is w_b = 200 monetary units. Based on the formula (35), the wage wa is equal to the temperature T_2, and the wage wb to the temperature T_1. It is easy to show that the efficiency coefficient is 75%; moreover, in the case of exchange between the richer and the poorer country, 80% of the profits benefits the richer country, i.e. the exchange profit of the richer country is three times bigger than the profit of the poorer country ((200 - 50) / 50)).

In relation to the Pareto power law, it has been accented that the difference in the level of average wages and salaries of the population with the lowest incomes determines the value of the Gini coefficient. Since it is about temperatures T_1 and T2, the higher the temperature difference, the greater the income distribution inequality and efficiency level of economic engine. Several important conclusions may be derived from the extensive research on this topic conducted by Branko Milanovic (2006, 31), such as: 1) the effectiveness of the economic engine rises after 1979-1980 (the epoch of Thatcher and Reagan), because of the increasing inequality between the richest and poorest countries in the world; 2) inequality also rises within countries (both developed and less developed); 3) the inequality rises within countries in transition, as well as the difference between these and the richest countries, in favour of the rich. The Pareto power law is valid for 1-3% of the population, while the law of exponential distribution refers to the 95-97% of the population.

If the difference in temperature levels between the two countries is larger, the efficiency of the economic engine is greater. This shows that the simplest exchange is carried out between countries with greater disparities in development, but also confirms the fact that the greater efficiency is achieved at the expense of wealth, manpower and resources of the less developed country - the operating principle of Carnot process. Therefore, the interest of the rich countries is the increased level of economic difference with less developed countries, as well as the cooperation with countries with more favourable exchange relations (greater temperature difference). In the US, the value of the exponent α decreased from 1.7 (in 1983) to 1.3 (2000) (Dragulescu, A. et al., 2000, 13), and in the income distribution tail (belonging to the affluent class) increased as much as 5 times (from 4% to about 20%). Also, the results of empirical research confirm another fact that is consistent with theoretical expectations: the level of inequality abruptly jumps and increases after major crises, such as the financial crisis of 2008. After major economic crises, recession, bankruptcies and stock market crashes, the richer become even richer!

Mimkes (2006, 29) pointed to another aspect of efficiency, which refers to the relation of total income (Y) - costs (C) (company level), or social product - expenditure (level of macroeconomics). Here is the relationship:

$$P_f = Y - C \tag{29}$$

where P_f is the surplus, or profit. The level of expenses and income can also be expressed by temperatures (average income and average costs), forming a relation of economic-thermal engine:

$$\mu = \frac{Y - C}{Y} = 1 - \frac{C}{Y} = 1 - \frac{T_2}{T_1} \tag{30}$$

If the temperature difference within the Carnot manufacturing process is bigger (internal effectiveness, profitability and productivity or more efficient model of economic development), the efficiency of the economic process rises as does the realized profit level or the growth rate of GDP. The same author (Mimkes, J., 2006, 29) even divided all the countries in exchange into six main groups, based on a profit-surplus share achieved during the exchange, which has important implications on tempo, dynamics and intensity of exchange between countries, and on the model and speed of economic growth. Some related conclusions and our own empirical research will be presented in the fourth chapter of the paper.

6. Temperature Differences and the Efficiency of Serbian Economic Exchange with the EU Countries - Empirical Analysis

The specific empirical analysis is done by comparing Serbia with seven European Union countries that have been selected according to the following criteria: a) two developed countries (Germany, Italy) that are Serbia`s major foreign exchange partners; b) three countries (Slovenia, Hungary, Slovakia), who have previously become members of the EU and are more developed from Serbia, with Hungary as a neighbouring country and Slovenia as a part of the former common state; c) Croatia and Romania that have recently become members of the EU are at the similar level of development as Serbia and are the neighbouring countries. Serbia has very significant and intensive foreign trade cooperation with most of the selected countries.

The chosen period was 2002-2012, in which all the selected countries already were or became the full members of the EU. The 10-year period is long enough to form time series, and it was interesting to compare whether there was a change in coefficient values after the outbreak of the economic crisis (the period from 2008 onwards).

The afore-defined temperatures were calculated for the three types of indicators: 1) GDP per capita was calculated in US dollars for each country based on the average exchange rate for the year; 2) The average salary in dollars for the year; At the same time, before the tables were formed, it was determined what was the lower (T_2) and the higher temperature (T_1) in each case, as the temperatures of the cold and hot reservoirs, in accordance with the principle of Carnot heat pumps.

Based on these definitions, the following types of coefficients - indicators were calculated (according to the methodology of Mimkes, but also of other authors, e.g. Yakovenko, Dragulescu, Chakraborti, etc.):

The maximum efficiency coefficient of Carnot heat pump is calculated by the following formula:

$$\mu = \frac{T_1 - T_2}{T_1} = 1 - \frac{T_2}{T_1} \tag{31}$$

where T_2 and T_1 are temperatures of the cold and hot reservoirs, respectively. The efficiency coefficient between the two countries (heat engine) indicates the utility level in exchange between the two countries - the tables 2 and 3 (for GDP per capita, average wages).

The data in tables should be read as indicators of these countries compared to Serbia on the principle of Carnot heat pumps.

Table 2: Maximum efficiency coefficient of Carnot heat pump for GDP p.c.

	Croatia	Romania	Hungary	Slovenia	Slovakia	Germany	Italy
2002	66.29%	71.49%	69.19%	82.64%	68.74%	91.72%	90.62%
2003	66.01%	66.22%	68.31%	82.11%	69.36%	91.10%	90.12%
2004	65.69%	64.22%	68.58%	81.30%	69.64%	90.41%	89.47%
2005	66.39%	64.39%	68.99%	81.01%	70.29%	89.89%	88.99%
2006	64.89%	65.28%	64.71%	79.68%	69.30%	88.81%	87.76%
2007	60.54%	59.90%	61.01%	77.49%	66.28%	86.94%	85.50%
2008	58.60%	58.60%	57.71%	75.95%	64.30%	85.28%	83.43%
2009	60.85%	64.73%	56.48%	77.14%	66.05%	86.35%	84.61%
2010	61.93%	68.79%	60.21%	77.84%	68.59%	87.45%	85.37%
2011	57.92%	64.67%	56.12%	75.29%	65.95%	86.37%	83.65%
2012	59.77%	70.10%	57.85%	76.00%	68.66%	87.57%	84.34%

Table 3: Maximum efficiency coefficient of Carnot heat pump for average wages

	Croatia	Romania	Hungary	Slovenia	Slovakia	Germany	Italy
2002	69.82%	20.18%	62.60%	81.40%	59.18%	91.10%	88.48%
2003	65.59%	29.77%	59.21%	79.72%	56.47%	89.75%	86.81%
2004	64.74%	27.56%	59.92%	79.36%	56.72%	88.83%	86.12%
2005	63.86%	12.57%	59.91%	78.87%	58.18%	88.06%	85.44%
2006	58.22%	13.81%	49.97%	75.11%	52.16%	85.39%	82.45%
2007	49.38%	13.07%	42.04%	69.82%	43.26%	81.51%	77.95%
2008	46.74%	15.71%	37.64%	67.81%	37.98%	79.32%	75.46%
2009	55.42%	4.41%	41.76%	73.44%	48.94%	82.61%	79.36%
2010	56.62%	0.92%	46.28%	75.47%	52.68%	83.47%	80.47%
2011	53.10%	0.96%	44.20%	74.39%	50.33%	83.08%	79.52%
2012	53.84%	1.04%	38.03%	76.87%	52.39%	82.81%	78.33%

$$r = \frac{T_1 - T_2}{T_2} \tag{32}$$

The return rates of other countries compared to Serbia (which typically has a lower temperature than all selected countries) are presented in tables 4 and 5 (for GDP per capita, average wages).

Table 4: Returns for GDP p.c.

	Croatia	Romania	Hungary	Slovenia	Slovakia	Germany	Italy
2002	196.68%	250.70%	224.55%	476.06%	219.92%	1108.03%	966.32%
2003	194.24%	196.04%	215.55%	458.91%	226.40%	1023.67%	912.27%
2004	191.49%	179.50%	218.24%	434.71%	229.38%	942.64%	849.42%
2005	197.53%	180.83%	222.49%	426.47%	236.58%	889.06%	808.60%
2006	184.80%	188.01%	183.40%	392.21%	225.73%	793.76%	717.04%
2007	153.41%	149.39%	156.49%	344.22%	196.56%	665.65%	589.80%
2008	141.53%	141.53%	136.46%	315.75%	180.11%	579.18%	503.62%
2009	155.4$^{4\%}$	183.52%	129$^{.80\%}$	337.45%	194.59%	632.46%	549.78%
2010	162.69%	220.40%	151.33%	351.36%	218.37%	696.52%	583.48%
2011	137.64%	183.01%	127.92%	304.75%	193.67%	633.41%	511.60%
2012	148.57%	234.50%	137.26%	316.69%	219.10%	704.67%	538.74%

Table 5: Returns for average wages

	Croatia	Romania	Hungary	Slovenia	Slovakia	Germany	Italy
2002	231.32%	25.29%	167.38%	437.56%	144.97%	1023.81%	768.25%
2003	190.59%	42.39%	145.16%	393.15%	129.74%	875.86%	658.37%
2004	183.58%	38.04%	149.49%	384.61%	131.07%	795.29%	620.42%
2005	176.69%	14.37%	149.45%	373.31%	139.15%	737.70%	586.88%
2006	139.36%	16.02%	99.89%	301.81%	109.01%	584.26%	469.94%
2007	97.54%	15.04%	72.53%	231.38%	76.24%	440.97%	353.46%
2008	87.75%	18.63%	60.35%	210.63%	61.24%	383.58%	307.58%
2009	124.3$^{3\%}$	4.61%	71$^{.69\%}$	276.58%	95.87%	474.97%	384.42%
2010	130.53%	0.93%	86.16%	307.62%	111.33%	504.93%	411.91%
2011	113.23%	0.97%	79.23%	290.40%	101.33%	491.16%	388.25%
2012	116.65%	1.06%	61.37%	332.26%	110.02%	481.60%	361.36%

The profit shares of Serbia and the selected countries in their mutual exchange are given in tables 7 and 8. Table 7 shows the shares of Serbia and other countries in total profit (thermal energy) generated by the exchange between the two countries, based on the values of GDP per capita.

Table 7: Profit share of the Republic of Serbia based on the values of GDP p.c.

	Croatia	Romania	Hungary	Slovenia	Slovakia	Germany	Italy
2002	0.25	0.22	0.24	0.15	0.24	0.08	0.09
2003	0.25	0.25	0.24	0.15	0.23	0.08	0.09
2004	0.26	0.26	0.24	0.16	0.23	0.09	0.10
2005	0.25	0.26	0.24	0.16	0.23	0.09	0.10
2006	0.26	0.26	0.26	0.17	0.23	0.10	0.11
2007	0.28	0.29	0.28	0.18	0.25	0.12	0.13
2008	0.29	0.29	0.30	0.19	0.26	0.13	0.14
2009	$0.^{28}$	0.50	0^{30}	0.19	0.25	0.12	0.13
2010	0.28	0.24	0.28	0.18	0.04	0.11	0.13
2011	0.30	0.26	0.30	0.20	0.25	0.12	0.14
2012	0.29	0.23	0.30	0.19	0.24	0.11	0.14

Table 8: Profit share of the Republic of Serbia

	Croatia	Romania	Hungary	Slovenia	Slovakia	Germany	Italy
2002	0.23	0.56	0.27	0.16	0.29	0.08	0.10
2003	0.26	0.59	0.29	0.17	0.30	0.09	0.12
2004	0.26	0.58	0.29	0.17	0.30	0.10	0.12
2005	0.27	0.53	0.29	0.17	0.29	0.11	0.13
2006	0.29	0.54	0.33	0.20	0.32	0.13	0.15
2007	0.34	0.53	0.37	0.23	0.36	0.16	0.18
2008	0.35	0.54	0.38	0.24	0.38	0.17	0.20
2009	$0.^{31}$	0.51	0^{37}	0.21	0.34	0.15	0.17
2010	0.30	0.50	0.35	0.20	0.32	0.14	0.16
2011	0.32	0.50	0.36	0.20	0.33	0.14	0.17
2012	0.32	0.50	0.38	0.19	0.32	0.15	0.18

6. Results and discussion

The results are consistent with theoretical expectations! For all three indicators, Serbia has a lower temperature than the selected countries (with just a few exceptions), and the principle of heat engine is achieved in accordance with the defined formulas and laws. The efficiency level of the exchange ratio (heat pump coefficient) depends on the temperature difference and it is lower for Serbia and the countries with smaller temperature difference (Croatia, Hungary, Romania) and higher for the countries with the bigger temperature difference (Germany and Italy). Tables 2, 3 and 4 can be read as the exchange between Serbia and Germany being more efficient (measured by this indicator) than the exchange between, for example, Serbia and Croatia.

The results in Tables 5, 6 and 7 are also consistent with the theoretical background. They show how much higher the returns of a more developed country are if compared with the less developed Serbia (having lower temperature). The higher the temperature difference and the efficiency coefficient for a given country in relation to Serbia, the higher the return level. For example, measured by the temperature of GDP per capita in 2012, it is 5.5 times and 1.5 times higher for Italy and Croatia, respectively, in comparison with Serbia.

The results in Tables 7 and 8 are also theoretically logical. As a less developed country, Serbia has a smaller benefit share (profit) in mutual exchanges with other countries having higher temperatures. The level of benefit rises for the richer countries than Serbia, as opposed to the countries with smaller temperature differences with Serbia.

If the results are analysed per years, it can be seen that in most cases, the position of Serbia has not been deteriorated after the outburst of the global economic crisis. As shown in other studies (Yakovenko, Roser), it was more logical to expect the Serbian position to deteriorate, but the results show that, according to these indicators, the crisis has significantly affected the EU member states, especially Hungary. Bearing in mind that Serbia currently (in 2014) applies harsh fiscal austerity measures and cuts wages, the inclusion of these data would reduce the relative position of Serbia, which was temporarily improved in the period 2008-2012.

In terms of share in profits and benefits, there are two groups of countries, if compared with Serbia. In the first group are Germany and Italy that virtually claim the entire benefit and have a strong interest to continue the intensive exchange in the future. This exchange is at a high level now, too, which is consistent with the theoretical model. In such an exchange, the standard of Serbia is not increased significantly, so it has an interest to move towards exchange with other countries. All the other countries are in the second group of countries because the profit share in Serbia is in the category 0 <r <0.5. It is the exchange between the countries where both sides have the exponential growth in living standards and are dependent on trade with the EU as a dominant affiliation.[2] Serbian interest is to increase the exchange with these countries, and simultaneously to seek for partner countries with the temperature difference in its favour.

7. Conclusion

The aim of the study was to demonstrate the interdependence, analogies and synthesis between economics and physics, especially thermodynamics. Therefore, numerous theoretical concepts, models, and methods applied in the modern thermodynamics on one hand and economics, on the other, have been comparatively analysed. There is the connection in the following three areas: 1) analogy between values, 2) similarity of the methods and models, 3) correspondence between thermodynamic and economic processes.

The paper has shown a correlation between the empirical probability distribution in kinetic theory of gases and distribution of money, income and wealth in economics. The similarity between entropy in thermodynamics and utility in economics has been also analysed. In particular, the analogies between the laws of thermodynamics and their application to economic processes have been demonstrated. All this is accompanied by appropriate references, research, empirical findings, and analogous application of formulas, methods and models.

The paper has paid particular attention to the research of connection and interdependence between the operating principles of the heat engine and the "economic engine" in exchange between two countries. The temperature in thermodynamics has fully adequate and comparable values in economics, e.g. an average amount of money, GDP per capita or an average wage in a country. Also, it is shown that the principle of exchange corresponds to the operation of the heat engine, with the key factor of the so-called temperature differences, i.e. the Carnot process. This explains the efficiency level, the realized level of returns, and the shares in profit-benefit in mutual exchange between different countries.

Using the methodology of J. Mimkes, this paper applied the empirical research on exchange between Serbia and the selected EU countries. The empirical studies are consistent with the theoretical expectations and confirm the analogy be-

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[2] The analysis of Mimkes, this is the case of the exchange between Germany and Japan, with the United States between them, as the dominant country in exchange.

tween economics and thermodynamics. By applying the formulas and methods of thermodynamics, it is possible to analyse specific parameters and indicators of economic exchange between countries with different temperature levels. The data show the high intensity of exchange with Germany and Italy, which can be explained by the model itself, as well as the fact that the exchange should be carried out with countries with less temperature difference, because Serbia achieves exponential growth of living standards then, even if it has a lower level of temperature in comparison with the observed countries. Also, the indirect conclusion of the research is that, in exchange, countries achieve the greatest benefit with those partners where the differences in wages or GDP are in their favour. Of course, if the trade with these countries is economically and geographically possible and compatible.

The results are encouraging for researchers, suggesting the need for further research on the relationship and interdependence of thermodynamics and economics, especially in the domain of empirical and applied areas.

References

1. Bachelier, L. (1995). *Theorie de la speculation*, reprint. Paris: J. Gabay.
2. Bali, S. (2011). Econophysics Thermoeconomics and Phynance. *Journal of International Social Research*, 18(4).
3. Biswas, K.A. Dasari, S. (2010). *An Economic analogy to Electrodynmics*. Shillong: BITS-Pilani Goa Campus.
4. Bouchand, J.P. (2008). Economic needs a scientific revolution. *Nature* 455(1181).
5. Bryant, J.A. (2010). *Thermodynamic Approach to Monetary Economics – A Revision An application to the UK Economy 1969-2006 and the USA Economy 1966-2006*. Harpenden: VOCAT International Ltd.
6. Bryant, J.A. (2012) *Thermodynamic Approach to Economics.Harpenden*: VOCAT International Ltd.
7. Bryant, J.A. (2010). *Thermodynamic Approach to Monetary Economics – A Revision An application to the UK Economy 1969-2006 and the USA Economy 1966-2006*. Harpenden: VOCAT International Ltd.
8. Burda, Z – Jurkiewicz, et.al. (2003). Is Econophysics a Solid Sciences? *Acta Physica Polonica B*, 34.
9. Chakraborti, A. (2006) *Econophysics: A brief introduction to modeling wealth distribution*. Vanarsi: Banaras Hindu University.
10. Dimitrijević, B. Fabris, N. (2009). *Makroekonomija*. Sremska Kamenica: Univerzitet Educons.
11. Dimitrijević, B. – Lovre, I. (2013) Essay on Monetary Policy and Economic Growth, Journal of *Central Banking Theory and Practice,* No.1, Podgorica: Central Bank of Montenegro
12. Dimitrijević, B. Djosević, M. (2013). Veza ekonomije i fizike – ekonofizika kao nova naučna disciplina i odgovor na svetsku ekonomsku krizu. *Zbornik: Globalna ekonomska kriza i poslovna ekonomija – izazovi teorije i prakse*, 4.
13. Dragulescu, A., Yakovenko, V.M. (2000). Statistical mechanics of money.*The European Physical Journal B*, 17.
14. Fama, E.F. 1965. Portfolio Analysis in a Stable Paretian Market. *Management Science11.3, Series A.*
15. Farmer, J.D. Shubik, M., Smith, E. (2008). Econophysics: the next physical science. *Physica A*.
16. Foley, K.D. Smith, E. (2007). Classical thermodynamics and economic general equilibrium theory. *Sfi Working paper*.
17. Gingras, Y. – Schinckus, C. (2012). Institutionalization of Econophysics in the shadow of physics. *Journal of the History of Economic Thought.*
18. Jovanovic, F. Schinckus, C. (2010). The History of Econophysics' Emergence: a New Approach in Modern Financial Theory. *Working Paper.*

19. Mantegna, R.N. Stanley, H.E. (2000). *An Introduction to Econophysics*. Cambridge: Cambridge University Press.
20. Markowitz, H.M. (1959). *Portfolio selection; efficient diversification of investments*, New York: Wiley.
21. Milanović, B., (2006). *Odvojeni svetovi. Merenje međunarodne i globalne nejednakosti*. Beograd: Fond Ujedinjenih nacija za razvoj.
22. Mimkes, J. A (2006). Thermodynamic Formulation of Economics. In Bikas, K., Chakrabarti, K., Chakraborti, A., Chatterjee, A. (Eds.). *Econophysics and Sociophysics: Trends and Perspectives*. Weinheim: WILEY-VCH VerlagGmbH & Co. KGaA.
23. Mimkes, J. (2011). *Introduction to Macro-Econophysics and Finance*. Paderborn: Paderborn University.
24. Prabakaran, S. (2010). The Study of Markets and Prices – The Thermodynamics Approach. *International Journal of Pure and Applied Physics*, 6 (3), 333-346.
25. Rosser, B. Yakoveno, V.M. (2009). Colloqium: Statistical mechanics of money, and income, *Reviews of Modern Physics*, 81.
26. Schinckus, C. (2010). Econophysics and Economics: sister disciplines? *American Journal of Physics*, 78.
27. Schinckus, C. (2011). What can Econophysics contribute to Financial Economics. *International Review of Economic.*
28. Schinckus, C. (2013). Introduction to econophysics: towards a new step in the evolution of physical sciences, *Contemporary Physics*, 54(1),
29. Sharma, B.G., Agrawal. S., Sharma, M., Bisen, D.P., Sharma, R. (2011). *Econphysics: A Brief Review of Historical Development*, Present Status and Future Trends. Raipur: Govt. Science College.
30. Sinha, S., Chakrabarti, B.K. (2012). Econophysics An Emerging Discipline, *Economic and Political Weekly*, 47(32).
31. Stanley, E., Nunes, A. (2000). Econophysics: What can Physicist contribute to Economics, *International Journal of Theoretical and Applied Finance.*
32. Tania A. dos S. C. e Sousa. (2007). *Thermodynamics as a Substantive and Formal Theory for the Analysis of Economic and Biological Systems*, research, Vrije Universiteit Amsterdam, Instituto Superior Tecnico, Lisboa.
33. Tishin, A. M. – Baklitskaya, O.B.(2008). *EconoThermodynamics, or the world economy "thermal death" paradox.*,Moscow: Lomonosow Moscow State University.
34. Valero, A., Cuadra, C.T. Thermoeconomic Analysis, Exergy, *Energy System Analysis and Optimization*, 2.
35. Yegorov, Y. (2007). Econo–physics: A Perspective of Matching Two Sciences. *Evolutionary and Institutional Economics Review.*

36. Wang, Y., Wu J,. Di Z. (2008). *Physics of Econophysics*. Beijing: Bejing Normal University.