THERMODYNAMICS OF STOCK MARKET

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Abstract. *The paper focused on linking the theory of thermodynamics with the factors of the stock market. The paper tried to show the working of the financial system, considering the stock market, by creating an analogy with the elements of the thermodynamics with the stock market. The four laws of thermodynamics universally accepted in the theory of physics. The zeroth law can determine the return from the market by the eagerness or participation of investors and the volume of shares traded in the market. The first law can measure the efficiency of the market. The second law can determine the randomness of the market, and finally, the third law can determine the randomness using the market capitalization for a specific time.*

Keywords: *Stock Market, Thermodynamics.*

I. Introduction

In physics, to measure temperature, one uses thermometers. These are special devices whose equations of state are known and calibrated; so by introducing the thermometer into contact with a body we may find the temperature of the body by a change of the state of the thermometer. As we will see, the (stock) markets may, to an extent, be considered as thermometers in economics.

In the case of economics, it may look as if the system is directed, citing Adam Smith, by an "invisible hand". At the time when Adam Smith was working on his book, the principles of thermodynamics were not known yet, so the "invisible hand" was interpreted in terms at hand, those of a mechanical metaphor. Adam Smith's conceptual model that identifies human interests with "forces" of the market gives really serious grounds for such an interpretation. Let us consider an "imaginary experiment" of Adam Smith a bit closer. Smith assumes that an increase of commodity prices brings about an increase in at least one of the price-making

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components i.e. the rent, workers' salaries, or profit giving a signal to actors, or rather forcing them, to change their behavior (to exploit more facilities, increase the offer of jobs or to expand manufacturing), and this change of behavior finally leads to the reduction of price. There is, however, one very weak spot in the "imaginary experiment" of Adam Smith. The only immediately accessible information for the market actors is the price. Whatever changes it up or down the reasons for this change are not immediately revealed to the observer. It is most often not clear to the buyer at all if the changes in the price were due to change-making factors (say, rise or fall of profit) or the reason was an increase in demand? Usually, such information is the seller's most guarded secret.

Gkranas et al (2004) presented the results of the analysis in the stock markets of Greece and Portugal. They recognized exponential laws at both the Athens Stock Exchange General Index (GD) and Lisbon's Main Index. This fact stimulated them to apply formalisms taken from physics about the study of macroscopic properties. Especially, they introduced the implication of Newton's law of cooling on these markets. The satisfying fit leads them to express a thermodynamic approach, in their effort to understand such complex behaviors.

Prabakaran (2010) stated that many researchers have attempted to viaduct their fields with others to gain insight into their own. In the past decade or so, physicists have begun to do academic research in economics. The paper was to present a phenomenological analysis for markets and prices with a thermodynamics approach. The main ambition of the study was fourfold namely: description of a thermodynamic model of economics with the simplest example, extend the thermodynamics approach to the study of markets and prices, the problem of the market equilibrium for the two markets with two items of goods and finally constructed the economic model with the actual market at a constant temperature.

II. Methods

The objective of this paper is to show the interdependence, analogy and synthesis of economics or finance 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.

2.1. Thermodynamic System

A thermodynamic system is one that can be described in terms of the thermodynamic state variables. The state variables of a thermodynamic system could be taken as a pair to be considered as Cartesian coordinates using any pair of quantities viz., pressure (P), volume (V), temperature (T), and entropy (S). The thermodynamic system in engineering is gas, vapor, steam, a mixture of gasoline vapor and air. In physics, thermodynamic includes besides the above systems like stretched wires, thermocouples, magnetic materials, electrical condensers, electrical cells, solids, and surface films (Lal&Subrahmanyam, 1991).

2.2. The Analogy between Thermodynamic and Stock Market

A thermodynamic system deals with some specific factors of basic physics, which are being analogous factors related to the stock market. The thermodynamic basic deals with the energy, temperature, heat, etc. similarly, the stock market deals with the expected return, inefficiency in the market, realized return, etc. respectively. In this perspective, an analogy between the theory of thermodynamics from physics and the stock market theory from finance has been illustrated below:

Thermodynamic	Stock Market
Energy (E)	Expected Return
Entropy (S)	Variability (Randomness) of Return
Temperature (T)	Change in Size of Return
Pressure (P)	The Eagerness of Investors in Exploiting Return
Work (W)	Realized Return
Heat (Q/H)	Inefficiency in the Stock Market
Force (U)	Trading by Investors for Return
Volume (V)	Volume of Share Traded
Heat Capacity (C_p)	Market Capitalization

2.3. Analog on Laws of Thermodynamics with Stock Market Variables

- **Zeroth Law**

The zeroth law of thermodynamics was formulated after the first and the second laws of thermodynamics have been enunciated. Thus, this law helps to define the term temperature of a system. This law states that if of three systems, A, B and C, A and B are separately in thermal equilibrium with C, then A and B are also in thermal equilibrium with one another (Lal&Subrahmanyam, 1991).

Then, if A and B are in thermal equilibrium, then

$\phi_1(P_A, V_A) = \phi_2(P_B, V_B)$………………..(i)

$P_B = f_1 [P_A, V_A, V_B]$

Again,

$\phi_2(P_B, V_B) = \phi_3(P_C, V_C)$………………..(ii)

$P_B = f_1 [V_B, P_C, V_C]$

From (i) and (ii), we get

$\phi_1(P_A, V_A) = \phi_3(P_C, V_C)$ ………………..(iii)

Thus, from (i), (ii) and (iii), we get

$\phi_1(P_A, V_A) = \phi_2(P_B, V_B) = \phi_3(P_C, V_C)$

Finally,

$\phi (P, V) = T$.

Therefore, in context to thermodynamic, the temperature of the body is determined by the pressure and the volume which can be reciprocal be interpreted in the context of the stock market as the change in the size of the return is determined by the eagerness of investors in exploiting return and volume of share traded at the stock market.

All neo-classical financial markets are based on the implicit assumption of stable equilibrium which creates difficulty for everyone to describe financial markets even to zeroth order using stationary distribution.

- **First Law**

Joule's law gives the relation between the work done and the heat produced. It is true when the whole of the work done is used in producing heat or vice versa (Lal&Subrahmanyam, 1991). James Prescott Joule an English physicist first propounded the concept of heat energy produced when electricity or current flow within an electric wire. Mathematically, the first law can be illustrated as:

$W = JH$

where,

W = Work Done

JH = Joule's Heat

$\delta H = dU + \delta W$

where,

δH = Quantity of heat supplied to the system

dU = The increase in internal energy of the molecules

δW = Amount of external work done

Again,

$_1H_2 = (E_2 - E_1) + {_1W_2}$

where,

$_1H_2$ = Heat transferred

$_1W_2$ = Work done

E_1 = Total energy of the system in state 1

E_2 = Total energy of the system in state 2.

Again, efficiency can be measured as;

Efficiency (ϑ) = $1 - \frac{E_2}{E_1} = \frac{_1W_2}{_1H_2}$.

The first law of thermodynamic can be tested in measuring the efficiency of the stock market for a specific time using the expected return, realized return and inefficiency in the market.

- **Second Law**

The Kelvin-Planck statement (or the heat engine statement) of the second law of thermodynamics states that it is impossible to devise a cyclically operating thermal engine, the sole effect of which is to absorb energy in the form of heat from a single thermal reservoir and to deliver an equivalent amount of work (Rao, 2001).

Furthermore, the second law has been defined in two parts by Kelvin and Clausius.

First part: It is impossible to obtain a continuous supply of work from a body by cooling it to a temperature below the coldest of its surroundings.

Second part: It is impossible to make heat flow from a body at a lower temperature to a body at a higher temperature without doing external work on the working substance (Lal&Subrahmanyam, 1991). Mathematically, the second law can be illustrated as:

$dS = \delta Q/T$

where,

S = Entropy

Q = Heat

T =Temperature.

Here, the law can be used in measuring the randomness of the stock market i.e. S with the help of using the inefficiency factors of the market, i.e. Q and change in the size of return from the market i.e. T.

- **Third Law**

The third law states that the entropy of a perfect crystal of any pure substance approaches zero as the temperature approaches absolute zero.

In Ludwig Eduard Boltzmann's definition, entropy is a measure of the number of possible microscopic states (or microstates) of a system in thermodynamic equilibrium, consistent with its macroscopic thermodynamic properties (or macrostate). At a microscopic level, the gas consists of a vast number of freely moving atoms, which occasionally collide with one another and with the walls of the container. The microstate of the system is a description of the positions and momenta of all the atoms. In principle, all the physical properties of the system are determined by its microstate. However, because the number of atoms is so large, the details of the motion of individual atoms are mostly irrelevant to the behavior of the system as a whole. Provided the system is in thermodynamic equilibrium, the system can be adequately described by a handful of macroscopic quantities, called "thermodynamic variables": the total energy *E*, volume *V*, pressure *P*, temperature *T*, and so forth. The macrostate of the system is a description of its thermodynamic variables (Brush, 1964).

However, the ultimate mathematical relation defined by the third law is:

$\lim_{T\to 0} S = 0$ .... (a)

where,

S = entropy which is expressed as J $s^{-1}K^{-1}$.

T = absolute temperature which is expressed in K.

It can also be written as:

$T \to 0 \Rightarrow S \to S_{min}$ .... (b)

Hence, we can say if the temperature approaches zero then the entropy approaches to its minimum value.

Another application of the third law of thermodynamics can be

$S = 2.303\ C_p \log T$............................. (c)

Using equation (c), the absolute entropy of any substance at a given temperature T can be determined. Here, C_p is the heat capacity of the substance at a constant pressure. Hence, the third law of thermodynamics can also be used to measure the randomness of the stock market i.e. S considering C_p, as the market capitalization for a specific time.

Thermodynamic entropy is always increasing. However, The entropy S(t) can never reach a maximum because the empirical density f(x,t) spreads diffusively without bound. This describes the loss of information about market returns (or prices) as time goes on. Hence, statistical equilibrium is impossible for market returns.

3. Conclusion

It can be agreed; that the stock market behavior can be analog with the theory of thermodynamics. Within physics, the phenomenological study of a macroscopic object is called thermodynamics. It is concentrated in the detailed study of change in the thermal state of macroscopic systems, basic dynamical constituents like atoms. The theory of thermodynamic stands in the system of thermodynamic equilibrium. The equilibrium between the supply and demand of the securities in the market determines the price. The law of thermodynamics deals with the energy conversion process equivalent to the stock market i.e., the capital is injected or invested in the market to generate the return. At the same time, the theory of thermodynamics states that the efficiency of a heat engine is determined through the work done by the system and the heat supplied to the system. Similarly, the efficiency of the stock market can be determined by the expected return and the realized return by the investors.

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