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Review Article

The Physics Principles and Mathematical Explanation of Supply and Demand - Returning to the Starting Point of Economic Research

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Abstract:
This manuscript presents a pioneering application of Newton's three laws and the principles of relativity to the study of fundamental theories in economics. By analogizing desires, utility, and prices to physical concepts, and integrating these concepts into the theoretical framework of natural sciences using mathematical language, the author has constructed a binary system and a ternary system for economic analysis. Based on this foundation, the laws of momentum conservation and energy conservation in social sciences are derived on a mathematical level. This manuscript argues that the fundamental theoretical principles in social sciences, represented by economics, are unified with those in natural sciences, represented by physics. The mathematical explanation of supply and demand in social sciences presented in this manuscript offers a perfect integration of the theoretical foundations of economics into the framework of physical principles. This opens up new research areas for future studies in social sciences.
Keywords: demand, supply, transaction frictions, econophysics, mathematical models of socio-economic systems, economic momentum conservation, economic energy conservation

1. Introduction

Can social sciences and natural sciences be unified under a single research framework? Can social sciences apply the axiomatic research paradigm of natural sciences? Economics, as one of the most axiomatic empirical disciplines within the social sciences, has established a dominant position through the application of axiomatic logic and extensive empirical methodologies. One of the key factors contributing to this phenomenon is the diversification of research methods in economics, as well as the wide-ranging use of mathematical models, which has facilitated the broad application of economics across the social sciences. However, the excessive reliance on mathematical model derivations that are not grounded in economic realities can hinder the exploration of theories of economic growth (Lawson, 2009; Romer, 2015). Therefore, while the theoretical methods of economics have been widely applied in other social science fields, many scholars(Gowdy, 2005; Kennet and Heinemann, 2006; Peters, 2019a; W. Brian Arthur, 2021) are reflecting on whether economics should be consistent with natural sciences in terms of logical frameworks and whether it can find one or several models based on economic foundations in all situations. In this regard, the research on complex economics(Colander *et al.*, 2004; Backhouse and Medema, 2009; Holt *et al.*, 2011a; Holt *et al.*, 2011b; Battiston *et al.*, 2016) has made many meaningful attempts to promote the theoretical integration of economics and physics.

In all visible physical research systems, whether the scope of research is global or local, and whether variables are continuous or discrete, there exist reciprocity and non-reciprocity(Fruchart *et al.*, 2021). So, it raises the question of whether the most fundamental elements of research in economics, such as supply and demand, also exhibit symmetry and symmetry breaking, conservation and non-conservation. Unfortunately, the physical principles behind these concepts and their mathematical explanations are often overlooked. Just as forces in physical systems can cause changes in the state of motion of objects, changes in supply and demand in the socio-economic sphere can also lead to changes in prices and transaction volumes.

Can such fundamental economic phenomena be modeled and analyzed through concise differential equations and dynamic models akin to Newton's three laws of motion, thereby extending the research framework of physics into the realm of socio-economic studies, rather than confining it solely to the properties of matter and energy in the physical world (Sinatra *et al.*, 2015) ? Furthermore, the basic elements observed in social sciences, represented by economics, such as prices, demand, supply, and institutions, have direct or indirect connections with individual desires or collective human consciousness. In other words, it is insufficient to explain economic phenomena, such as supply and demand, solely using classical mechanics principles. In this complex economics constructed based on physical principles, the subject of economic research is actually humans. Institutions, organizations, and markets seem to be the determined results of the quantum collapse of human psychological activities. From this perspective, the observable social, economic, and institutional evolution processes are formed by the interaction of human collective desires. Based on reflections on these natural laws and the laws of socio-economic development, the hypothesis proposed in this paper is that the reciprocity and non-reciprocity, equilibrium and non-equilibrium, conservation and non-conservation of these physical systems can be extended to more complex socio-economic activities and unified in an economic analysis framework based on physical laws.

2 Vector Analysis in Economics

2.1 Desires and Value

Desires play a crucial role in economic behavior as they drive individuals to seek satisfaction through the acquisition of goods and services. Desires can be seen as the underlying motivation behind economic choices. The motivation for consumer to consume goods stems from desires, which can be defined as "needs that are not satisfied". Desires stem from individuals' physiological and psychological needs. Human desires are diverse, and when one desire is satisfied, higher-level desires emerge. Although desires cannot be precisely measured, they can be judged by the maximum cost individuals are willing to pay to fulfill their wishes(Peters, 2019b) .

In economics, common key concepts such as price, quantity supplied, quantity demanded, transaction costs, transaction fees, and income are scalar variables without direction. Therefore, it is crucial to vectorize the most fundamental key concepts. Price represents the monetary manifestation of value and is a way to quantitatively analyze the value of goods or services. Since value is difficult to measure and to avoid getting caught up in conceptual debates, this paper will use price as an approximation for the value of goods or services.

Firstly, vectorizing the most important concept, price, is essential. For any research object X, which can be an individual, company, enterprise, region, or economy, if there is an outflow of funds, p is less than 0; if there is an inflow of funds, p is greater than 0. Secondly, analogizing the velocity in physics, desires for demand or supply are vectorized. Desire is a psychological or physiological state of "needing and not having", while demand desire refers to the motivation of consumers to possess the desired goods or services, either physiologically or psychologically. Supply desire refers to the motivation of suppliers to exchange the provided goods or services with equivalent value, either physiologically or psychologically. In this paper, desire is defined as the first derivative of value with respect to time.

$$i = \frac{\partial p}{\partial t} \quad (1)$$

The reason for using partial derivatives for price is that we only want to analyze the changes in value (price) over time. The mathematical explanation for supply desire or demand desire is the rate of change of value over unit time. For example, in any transaction process, the change in price over a certain period of time will cause a change in supply desire; and similarly, the change in price over a certain period of time will also cause a change in demand desire.

At the micro level, the subjects of supply or demand desire can include individuals, firms, or consumers. At the macro level, they can encompass organizations or countries. The choice of desire subject can be adjusted based on the research object. Based on the attributes of demand and supply, desires are expanded into demand desires and supply desires, with the mathematical expressions as follows:

$$i_D = \frac{\partial p_D}{\partial t} \quad (2)$$

$$i_S = \frac{\partial p_S}{\partial t} \quad (3)$$

Where i_D represents the demand desire of consumers for the desired goods and services, and p_D represents the maximum value that consumers are willing to give up for the desired goods and services. Similarly, i_S represents the supply desire of suppliers for the desired goods and services, and p_S represents the maximum value that suppliers are willing to give up for the desired goods and services. t denotes time. Desires encompass both supply desire and demand desire. It is evident that when the price of a particular good or service increases, the supply desire of suppliers increases, while the demand desire of consumers decreases. Conversely, when the price of a particular good or service decreases, or when the maximum value that consumers are willing to give up for the desired goods and services increases, the supply desire of suppliers decreases, and the demand desire of consumers increases.

2.2 Utility

Utility is a psychological phenomenon(Samuelson, 1938; Dana *et al.*, 2006) that cannot be precisely measured. It is a function of an individual's specific preferences(Peters, 2019b) and reflects the satisfaction or contentment an individual derives from a good or service. Clearly, utility is related to the desires of supply and consumers, and desires are a necessary but not sufficient condition for explaining the utility function. According to the ordinal utility theory, consumers do not weigh the exact magnitude of utility when making transactions; instead, they rank the utility of goods or services. These differences in utility can be explained by indifference curves.

Within a given time frame, utility is typically treated as a fixed scalar that represents the psychological desire of purchasing agents and consumers. At a macro level, the utility of essential goods for human survival can be approximated as a constant value, indicating that humans consistently derive utility from essential goods. Similarly, for an individual, the utility of a certain category of goods or services changes minimally over time. For example, the utility an individual derives from basic necessities remains relatively constant, but the demand or supply desires for these necessities fluctuate due to factors such as prices and living conditions. If an individual experiences significant psychological stimulation or is influenced by external stimuli, the utility can be adjusted using the principle of relativity. The modified formula is as follows:

$$u = \frac{u_0}{\sqrt{1 - i^2 / I^2}} \quad (4)$$

$$u = \frac{u_0}{\sqrt{1 - i^2 / I^2}} \quad (5)$$

$$I = i_{\max} \quad (6)$$

It is worth noting that the maximum value of demand or supply desire should be a large constant similar to the speed of light in physics. In other words, the quantitative value of demand/supply preferences approaches a very large number, meaning that it should be a bounded value._Therefore, from the formula, it can be deduced that the utility of an individual or a group for goods or services (any research object) remains constant in general. By substituting the mathematical expression of desire i and price into the modified utility equation, we can obtain:

It should be noted that the maximum value of demand or supply desire should be analogous to a very large constant like the speed of light in physics. Alternatively, the quantitative value of demand/supply desire approaches a very large number（I）, meaning this value is bounded. Here, u_0 represents the initial utility of the demander or supplier for the required goods and services. Meanwhile, u denotes the adjusted utility of the demander or supplier for the required goods and services. From the denominator part of Equation (4) $\sqrt{1-i^2/I^2}$, it is evident that the denominator asymptotically approaches 1.Therefore, based on these equations, we can deduce that the utility of an individual or group concerning goods or services (any research subject) remains unchanged under general conditions. Finally, by substituting the mathematical expressions of desire i and price into the adjusted utility equation, we obtain:

$$u = \frac{u_0}{\sqrt{1-(\frac{\partial p}{\partial t})^2 / I^2}} \qquad (7)$$

An interesting inference can be derived from equation (7): when the derivative of the price of a good or service with respect to time changes significantly, people's utility for that good or service will also change.

2.3 Supply Force and Demand Force

Introducing supply force and demand force, their mathematical expressions are as follows:

$$F = u\frac{\partial i}{\partial t} \qquad (8)$$

Where u represents the utility of consumers or suppliers for the desired goods or services, i represents the demand desire or supply desire of consumers or suppliers, and t represents time. In this equation, if there is a change in the utility of any individual for a certain good or service, the mathematical expression of supply force or demand force can be adjusted using the utility correction formula. Clearly, based on the attributes of demand and supply, the formulas can be written as:

$$F_S = u_S\frac{\partial i_S}{\partial t} \qquad (9)$$

$$F_D = u_D\frac{\partial i_D}{\partial t} \qquad (10)$$

Where F_S represents the supply force, u_S represents the utility of suppliers for the intended supply of goods or services, and i_S represents the supply desire of suppliers for the intended supply of goods or services. F_D represents the demand force, u_D represents the utility of consumers for the desired goods or services, and i_D represents the demand desire of consumers for the desired goods or services.

$$F = u\frac{\partial^2 p}{\partial t^2} \qquad (11)$$

From the equation, it can be seen that supply force F_S or demand force F_D is, in fact, the second partial derivative of the price of a certain good or service with respect to time within a given period. This reflects the response of suppliers and consumers to changes in the price of a certain good or service over time. If utility (u) is the derivative with respect to time and fluctuates significantly over time, the total differential expression of supply force or demand force is:

$$F = \frac{\mathrm{d}(ui)}{dt} \qquad (12)$$

Thus, time(t), price(p), and supply force or demand force are unified within the analytical framework of Newton's second law.

3. Demand Force and Supply Force in the Binary System Theory

3.1 Equilibrium and Non-equilibrium of Demand Force and Supply Force

The analysis of macroeconomic phenomena in economics is based on the concept of "equilibrium(Foley, 1975; Krusell and Smith, Jr., 1998; Blanchard, 2018)". However, the equilibrium concept in economics refers to the equilibrium of prices or quantities, which does not fully reflect the real economic processes(Veblen, 1898; Simon, 1957; Dubé *et al.*, 2009) . As a constantly evolving complex system, the system always evolves between states of equilibrium and non-equilibrium. In this context, equilibrium refers to the process by which the system returns to a relatively stable state after being disturbed by consumers, suppliers, or transaction frictions. This process of system reconstruction can be described as "resilience" (Simmie and Martin, 2010; Liu *et al.*, 2017), as Adam Smith referred to it as the invisible hand of the market. In this manuscript, the state of equilibrium between demand force and supply force is referred to as binary equilibrium. In a market where there are only suppliers and consumers, the mathematical interpretation of equilibrium state is given by:

$$\sum_{D_j=1}^{n} F_{D_j} + \sum_{S_k=1}^{n} F_{S_k} = 0 \qquad (13)$$

where F_{D_j} represents the demand force of individual j, and F_{S_k} represents the supply force of individual k. In the economic society, the equilibrium between suppliers and consumers refers to the property of maintaining the sum of demand force and supply force invariant under certain transformations within the economic system. These transformations are usually caused by changes in the desires and utilities of suppliers or consumers. The mathematical implication of the hypothesis of binary system equilibrium theory indicates that in a closed system, the sum of supply force and demand force remains constant. In the binary state, all supply forces and demand forces in the market interact with each other. Equilibrium is not about maintaining a fixed state; equilibrium is a dynamic process where the vector sum of supply force and demand force is zero. The level of equilibrium ability maintained by the economic system or market is determined jointly by supply force and demand force. The system's ability to absorb and handle various threats is referred to as systemic resilience, and the process of constructing systemic resilience aims to achieve various outputs(Trump *et al.*, 2020).

Similarly, the binary non-equilibrium state of suppliers and consumers can be derived as:

$$\sum_{D_j=1}^{n} F_{D_j} + \sum_{S_k=1}^{n} F_{S_k} \neq 0 \qquad (14)$$

In contrast to the equilibrium state, the non-equilibrium state refers to a condition in an economic system where the vectors of supply and demand forces are not equal to zero due to changes in the desires and utilities of suppliers or consumers. This means that after undergoing such transformations, there will be noticeable changes in supply force or demand force. Moreover, external forces are often the cause of changes in the equilibrium state of a system.

According to the hypothesis of binary equilibrium theory, fluctuations in demand force F_D can trigger fluctuations in supply force F_S, and likewise, fluctuations in supply force can also trigger fluctuations in demand force. Macro-economic models based on demand determinism(Keynes, 2018) and or supply-side economics models based on supply determinism are two aspects of the binary equilibrium theory where demand force and supply force interact with each other. Both demand determinism and supply determinism, which stand from different research perspectives on supply force and demand force, conclude that there is insufficient effective demand and the need to regulate supply in order to achieve a binary mechanical equilibrium. The binary mechanical equilibrium is a steady-state system of supply force and demand force. The transition from this steady-state system to a non-steady-state system is caused by $F_D + F_S \neq 0$ .Similarly, in the process of evolution from binary non-equilibrium to binary equilibrium, any market or organization will self-organize to an equilibrium state through the interaction of supply force and demand force.

By introducing supply desire and demand desire into the hypothesis of equilibrium between demand force and supply force in an ideal state, we obtain:

$$u_D \frac{\partial i_D}{\partial t} + u_S \frac{\partial i_S}{\partial t} = 0 \qquad (15)$$

The interpretation of equilibrium in terms of supply desire and demand desire is that it is the equilibrium of the product of the rate of change of utility and the rate of change of desire. In other words, the equilibrium between suppliers and consumers is the result of the combined effect of supply utility, supply desire, demand utility, and demand desire. In the example of the prisoner's dilemma game, both players have a desire(i) to minimize punishment and escape from prison, and escaping from prison provides a high utility(u) for both players. Therefore, this zero-sum game is also a result of the binary equilibrium between supply and demand.

In the process of transactions, supply desire and demand desire are unmeasurable. Therefore, by introducing supply price and demand price into the hypothesis of equilibrium between demand force and supply force in an ideal state, we obtain:

$$u_D \frac{\partial^2 p_D}{\partial t^2} + u_S \frac{\partial^2 p_S}{\partial t^2} = 0 \qquad (16)$$

The interpretation of equilibrium in terms of supply price and demand price is that it is the equilibrium of the product of the rate of change of utility and the rate of change of price. In other words, the equilibrium between suppliers and consumers is the result of the combined effect of supply utility, supply price, demand utility, and demand price. When supply and demand reach equilibrium, the equilibrium price for suppliers (p_S) may not necessarily be equal to the equilibrium price for consumers (p_D). This means that the equality of equilibrium prices in the Walrasian general equilibrium model and Marshallian partial equilibrium model is only a special case at the equilibrium point and does not hold universally. In the real economic world, there exists a point of equilibrium where supply and demand are balanced, denoted as $p_S \neq p_D$, but at this point, supply and demand are in equilibrium. It is worth noting that before introducing the concept of transaction frictions, the binary equilibrium also includes transaction frictions. However, these transaction frictions are endogenous to the transaction process between suppliers and consumers, and the magnitude of transaction frictions for suppliers is equal but opposite to that of consumers. Therefore, the hypothesis of binary equilibrium theory does not explicitly discuss the impact of transaction frictions on the system.

3.2 The Frictional Force in the Trading Process

Transaction costs in economics refer to the costs incurred during the process of exchanging goods, services, or assets(David and Han, 2004; Parker and Hartley, 2003; Grover and Malhotra, 2003; Williamson, 1987). These costs include not only monetary expenses but also non-monetary factors such as time, effort, and information asymmetry(Rindfleisch and Heide, 1997; Dyer, 1997). Transaction costs can arise from various sources, including searching for information, negotiating and enforcing contracts, monitoring and enforcing compliance, and resolving disputes. Coase argued that the existence of transaction costs leads to friction in economic processes, which is a key factor influencing economic performance. He further posited that firms arise because the transaction costs within firms are lower than market transaction costs(Coase, 1937).

To integrate the concept of transaction costs from economics into a physical analysis, this paper restructures and introduces the concept of frictional force in trading, with its mathematical interpretation as follows:

$$F_{\mu} = u\frac{\partial i}{\partial t} \quad (17)$$

$$F_{\mu} = u\frac{\partial^2 p}{\partial t^2} \quad (18)$$

Where, P is various forms of transaction costs, including endogenous transaction costs and exogenous transaction costs. F represents the frictional force in trading. u represents the utility of the transaction, and i represents the desire for the transaction. The sources of desire and utility in the frictional force F_{μ} are complex and can originate from supply-side entities, demand-side entities, market regulatory entities, as well as market institutions or transaction environments. Therefore, the generation of desire and utility in the frictional force can be directly produced by individuals or transmitted through institutional design or transaction environments created by individuals.

Frictional force is widely present in various real-world trading processes. The trading process mentioned here can also extend to a broad sense of trading processes, which not only include the trading process of goods and services but also encompass the non-price-measurable demands and contributions (supply) of emotions. Frictional force originates from three aspects. The first and second aspects of frictional force come from the supply-side and demand-side entities. For example, supply-side entities can induce demand-side entities through information asymmetry, resulting in inherent friction in the transaction process. The third aspect of frictional force comes from third parties, such as transaction costs brought about by different market institutions or transaction costs managed by the government. Firstly, we will introduce the frictional force caused by supply-side and demand-side entities.

$$F_{\mu_S} = u_s\frac{\partial^2 p_S}{\partial t^2} \quad (19)$$

$$F_{\mu_D} = u_D\frac{\partial^2 p_D}{\partial t^2} \quad (20)$$

The frictional force in trading can be caused by both supply-side entities and demand-side entities. Even in a research system that only involves supply-side entities and demand-side entities without third-party involvement such as the government, transactional friction still exists. This type of transactional friction can be caused by demand-side entities or supply-side entities. For example, in the principal-agent problem within a company, factors such as information asymmetry and moral hazards between agents and principals affect agent behavior. In the first type of principal-agent problem, the entrepreneurial talent of the agent can be considered as the traded good, with the agent as the supply-side entity and the principal as the demand-side entity. Clearly, the agent can deceive the principal using information asymmetry or by taking on moral risks to maximize their own interests, thereby creating transactional friction. Transactional friction caused by demand-side entities can also be illustrated using examples from the principal-agent problem. For instance, in the second type of principal-agent problem, stock financing can be considered as the traded good, with majority shareholders and principals as the demand-side entities, and the capital investments of all minority shareholders as the supply-side entities. It is evident that majority shareholders and principals can inflate stock prices by falsifying company profits, attracting minority shareholders to purchase company stocks, and subsequently cashing out at higher stock prices, thus harming the rights of minority shareholders. In this process, the demand-side entities create transactional friction. Both of these examples illustrate transactional friction deliberately caused by human factors. Even without deliberate human intervention, transaction costs such as search costs exist in the trading process of goods or services, and fluctuations in these transaction costs can generate transactional friction.

Similarly, in the trading process, there can be transactional friction caused by third parties other than supply-side entities and demand-side entities. In this paper, we refer to this as third-party transactional friction. Third-party transactional friction can be caused by non-supply-side entities and non-demand-side entities such as the government, political-economic environment, and market institutions.

$$F_{\mu_{third}} = u \frac{\partial^2 p_{third}}{\partial t^2} \quad (21)$$

Where, third-party transaction costs(p_{third}) refer to the costs imposed by any entities other than supply-side entities and demand-side entities that can influence the trading process. In most trading processes, the government is clearly one of the entities that can cause changes in transaction costs. In the real economic world, regardless of how the economic system is designed, there is always friction in the trading process. However, based on the mathematical interpretation of transactional friction in this paper, we can strive for a near-perfect trading process by balancing the frictional forces of supply-side entities, demand-side entities, and third-party entities, i.e., making a=b. This process of minimizing transactional friction can be represented as:

$$\int (F_{\mu_S} + F_{\mu_D} + F_{\mu_{third}})dt = 0 \quad (22)$$

In summary, the introduction of transactional friction allows for the complete integration of potential transactional frictions such as transaction costs, institutional costs, information asymmetry, and incomplete contracts into an analytical framework.

3.3 Equal Utility Balance Corollary

By substituting the mathematical expressions of demand force, supply force, and transaction friction force into Equation(23), we obtain:

$$\int (u_s \frac{\partial^2 p_S}{\partial t^2} + u_D \frac{\partial^2 p_D}{\partial t^2} + u_f \frac{\partial^2 p_{third}}{\partial t^2})dt = 0 \quad (24)$$

where the subscript u_s represents supply, u_D represents demand, and u_μ represents friction. If supply utility （u_s）, demand utility （u_D） and transaction friction utility （u_μ） are equal and non-zero（$u_s = u_D = u_f \neq 0$）, Of course, if u=0, then people would no longer pay attention to price changes. In summary, we have:

$$\int (\frac{\partial^2 p_S}{\partial t^2} + \frac{\partial^2 p_D}{\partial t^2} + \frac{\partial^2 p_{third}}{\partial t^2})dt = 0 \quad (25)$$

A significant corollary can be derived: For any set of goods or services with equal utility, the sum of the second-order partial derivatives of their prices with respect to time equals zero.

This can be generalized to the following form:

$$\int\left(\frac{\partial^2 p_1}{\partial t^2}+\frac{\partial^2 p_2}{\partial t^2}+....+\frac{\partial^2 p_n}{\partial t^2}\right)dt=0 \qquad (26)$$

For all goods or services lying on the equal utility curve, the sum of the second-order partial derivatives of their prices (p_1, p_2, ..., p_n) with respect to time equals zero. To facilitate its application, this important corollary is referred to as: the Equi-Utility Balance Corollary. The simple form of equi-utility balance is:

$$\int_1^n \frac{\partial^2 p_n}{\partial t^2}dt=0 \qquad (27)$$

4 The Equilibrium and Non-equilibrium Theory of Demand, Supply, and Frictional Forces in a Ternary System

The state of equilibrium between demand forces, supply forces, and frictional forces is referred to as the ternary system equilibrium state. In a ternary state market, the equilibrium among demand forces, supply forces, and frictional forces can be expressed as follows:

$$\sum_{D_j=1}^{n} F_{D_j}+\sum_{S_k=1}^{n} F_{S_k}+\sum_{\mu_m=1}^{n} F_{\mu_m}=0 \qquad (28)$$

Similarly, the mathematical expression for the non-equilibrium state of the ternary system involving supply forces, demand forces, and frictional forces can be derived as:

$$\sum_{D_j=1}^{n} F_{D_j}+\sum_{S_k=1}^{n} F_{S_k}+\sum_{\mu_m=1}^{n} F_{\mu_m}\neq 0 \qquad (29)$$

The key distinction between a ternary system market and a binary system market lies in the presence of third-party transactional friction generated by frictional forces in the trading process. Therefore, in the real world, the vector sum of forces among frictional forces, supply forces, and demand forces is zero. By introducing the desires of supply, demand, and friction into the hypothesis of equilibrium between demand forces, supply forces, and frictional forces under non-ideal conditions, we can obtain:

$$u_D\frac{\partial i_D}{\partial t}+u_S\frac{\partial i_S}{\partial t}+u_\mu\frac{\partial i_\mu}{\partial t}=0 \qquad (30)$$

After incorporating the desires of supply and demand, the mathematical interpretation of the ternary equilibrium theory is the balance between the rate of change of desires and the product of utilities. Since desires are unmeasurable in the trading process, we introduce prices into the hypothesis of equilibrium between demand forces and supply forces under ideal conditions, resulting in:

$$u_D\frac{\partial^2 p_D}{\partial t^2}+u_S\frac{\partial^2 p_S}{\partial t^2}+u_\mu\frac{\partial^2 p_\mu}{\partial t^2}=0 \qquad (31)$$

After incorporating the desires of supply and demand, the mathematical interpretation of the ternary equilibrium theory is the balance between the second derivative of prices with respect to time and the product of utilities. Similarly, the mathematical expression for the non-equilibrium state of the ternary system involving supply forces, demand forces, and frictional forces can be derived as:

$$u_D\frac{\partial^2 p_D}{\partial t^2}+u_S\frac{\partial^2 p_S}{\partial t^2}+u_\mu\frac{\partial^2 p_\mu}{\partial t^2}\neq 0 \qquad (32)$$

The non-equilibrium state of the ternary system forms the foundation of the “emergence” of economic and social phenomena.

5 The Conservation Hypothesis of Economic Momentum and Economic Energy

The momentum of an individual, denoted as M, who has demand or supply for a specific good or service with utility u and desire i, can be defined as:

$$M=ui \qquad (33)$$

The momentum modified by introducing the principle of relativity is as follows:

$$M=\frac{u_0}{\sqrt{1-i^2/I^2}}i \qquad (34)$$

In economics, momentum refers to the impact of supply forces, demand forces, and transactional frictional forces on a system over a certain period of time. Clearly, based on the attributes of supply and demand, the formulas can be written as:

$$M_S=u_S i_S \qquad (35)$$

$$M_D=u_D i_D \qquad (36)$$

where M_S represents the momentum of supply, u_S represents the utility of the goods and services intended to be supplied by the supply-side entity, i_S represents the supply desire of the supply-side entity; M_D represents the momentum of demand, u_D represents the utility of the goods and services desired by the demand-side entity, i_D represents the demand desire of the demand-side entity. Supply momentum and demand momentum reflect the accumulated effects of supply forces and demand forces over time, represented as vector equations that have both magnitude and direction. The frictional momentum caused by transactional friction(M_μ) can be expressed as:

$$M_\mu = u_\mu i_\mu \quad (37)$$

The brief derivation of the hypothesis of momentum conservation in economic activities is as follows. Within any short period of time (dt), supply forces and demand forces can be expressed as:

$$F = u\frac{di}{dt} \quad (38)$$

That is,

$$di = \frac{F}{u}dt$$

Taking the derivative of momentum M, we have:

$$dM = d(ui) \quad (39)$$

If the individual effects on the economic good are temporarily constant, we have

$$dM = d(ui) = udi = u\frac{F}{\mathrm{u}}dt = Fdt \quad (40)$$

That is,

$$M = Ft \quad (41)$$

By introducing time t into the ternary system equilibrium theory of supply forces, demand forces, and frictional forces, we obtain:

$$F_D\mathrm{t} + F_S t + F_\mu t = 0 \quad (42)$$

For a ternary equilibrium state system with an infinite number of demand-side entities, supply-side entities, and frictional entities, we have:

$$\sum_{D_j=1}^{n} F_{D_j} t + \sum_{S_k=1}^{n} F_{S_k} t + \sum_{\mu_m=1}^{n} F_{\mu_m} t = 0 \quad (43)$$

For any time, interval within the ternary system:

$$\sum_{D_j=1}^{n}\int_{t_1}^{t_2} F_{D_j} dt + \sum_{S_k=1}^{n}\int_{t_1}^{t_2} F_{S_k} dt + \sum_{\mu_m=1}^{n}\int_{t_1}^{t_2} F_{\mu_m} dt = 0 \quad (44)$$

And since $M = Ft$

we can state the hypothesis of momentum conservation in a closed ternary system as:

$$\sum_{D_j=1}^{n} M_{D_j} + \sum_{S_k=1}^{n} M_{S_k} + \sum_{\mu_m=1}^{n} M_{\mu_m} = 0 \quad (45)$$

The hypothesis of momentum conservation in a closed system can be simplified as:

$$\int_{k=1}^{n} M_k = 0 \quad (46)$$

This paper defines economic energy in economics as:

$$E = cMi \quad (47)$$

where c is a constant, M represents momentum, and i represents desire. For any closed system, there is energy generated by supply forces E_s , energy generated by demand forces E_D , and energy generated by frictional forces E_μ . According to the definition of economic momentum M, economic energy can also be expressed as:

$$E = cui^2 \quad (48)$$

By introducing the concept of economic energy into the ternary system theory, we obtain the hypothesis of energy conservation in a ternary system:

$$\int_{j=1}^{n} E_j = 0 \quad (49)$$

The law of energy conservation in economics corresponds to the synchronization between demand-side entities, supply-side entities, and frictional entities within a system. In any closed system, the vector sum of energy generated by supply forces E_s , energy generated by demand forces E_D , and energy generated by frictional forces E_μ is equal to zero. The energy generated by transactional friction E_μ is a form of loss, while the sum of energy generated by supply forces E_s and energy generated by demand forces

E_D represents the total social surplus of welfare. Demand forces, supply forces, and transactional frictional forces continuously evolve between equilibrium and non-equilibrium states, but in this process, the total economic energy and total economic momentum of a closed system remain constant.

6 Analysis of the Characteristics of Free Markets and Non-Free Markets

6.1 The Least Total Frictional Forces in Free Markets

Compared to non-free markets such as authoritarianism, free markets have the least total frictional forces F_{μ}, which is reflected in the second derivative of transaction costs over time being minimal. A free market is a market that minimizes transactional frictional forces. In a free market, goods and services are exchanged freely between demand-side entities and supply-side entities based on their value. The maximum value that demand-side entities are willing to pay equals the maximum value that supply-side entities are willing to receive. Price serves as the physical means of measuring the value of goods and services, so both buyers and sellers negotiate around the price of goods and services. In the bargaining process between supply-side entities and demand-side entities, neither party has sufficient power outside of the goods to interfere with the other party's supply or demand desires. Supply-side entities can only influence the purchasing desires of demand-side entities through the value of the economic goods they provide, while demand-side entities can only influence the supply desires of supply-side entities through equivalent exchange. The ultimate result is an exchange at a price that both supply-side entities and demand-side entities find acceptable.

The most significant characteristic of a free market is that neither supply-side entities nor demand-side entities can influence each other's supply and demand desires through mechanisms other than prices. Equally important is the fact that third parties other than supply-side entities and demand-side entities can also influence the trading process. The most notable examples in the real world are governments and market institutions. Governments can influence the trading process through direct participation or indirect participation. Direct participation refers to the government acting as either a demand-side entity or a supply-side entity. In the process of indirect participation, the government can use laws, regulations, administrative powers, and other means to increase or decrease transactional frictional forces, thereby creating frictional impulses (M) that affect the trading process and outcomes (transactional energy). It is worth noting that poverty and social inequality also reflect a form of energy, which is caused by fluctuations in supply forces, demand forces, or transactional frictional forces. If the non-acceptable energy state can be transformed into social surplus by regulating the triadic system composed of supply-side entities, demand-side entities, and frictional entities, transitioning the system from a non-equilibrium state to an equilibrium state.

In summary, the essence of a free market is a market that minimizes transactional frictional forces($F = u\frac{\partial i}{\partial t}$) among supply-side entities, demand-side entities, and frictional entities through the use of price mechanisms (p) and utility mechanisms (u). Additionally, the essence of a free market lies in the synergistic effect of price mechanisms (p) and utility mechanisms (u), minimizing the transactional frictional forces of supply-side entities, demand-side entities, and third-party entities ($\sum_{\mu_m=1}^{n} F_{\mu_m} = 0$).

6.2 The Maximum Impulse of Frictional Forces on the Demand and Supply System in Non-Free Markets

According to the hypothesis of triadic equilibrium theory in this paper, in non-free markets, there exists a significant total frictional force that cannot be balanced by the frictional forces of supply-side entities and demand-side entities. This can be mathematically explained as:

$$\int (F_{\mu_S} + F_{\mu_D} + F_{\mu_{third}})dt \neq 0 \qquad (50)$$

In a free market, there is a triadic equilibrium mechanism involving demand forces, supply forces, and frictional forces. However, the presence of authoritarian governments disrupts this equilibrium mechanism in free markets. Authoritarian governments manipulate free markets through barriers to entry, licensing, quota protection, tariff systems, and other unnatural means, exercising artificial control over transactional frictional forces and disrupting the balance between demand forces, supply forces, and frictional forces. An example from history is the administrative monopoly in the former Soviet Union, where the state's administrative power acted as third-party transactional frictional forces($F_{\mu_{third}}$). This kind of third-party transactional frictional force caused by the state's coercive power cannot be balanced by the frictional forces of demand-side entities(F_{μ_D}) and supply-side entities(F_{μ_S}), resulting in an imbalance at the national level($\lim_{t\to\infty}\left(F_{\mu_{third}}-(F_{\mu_S}+F_{\mu_D})\right)\neq 0$). Furthermore, this imbalance of total frictional forces $F_{\mu_{third}}$ cannot be intervened through anti-monopoly laws or anti-corruption measures because the implementer of the transactional frictional force (the Soviet government) determines the utility u and desire i of intervening in the market, which $F_{\mu_{third}}=u\frac{\partial i}{\partial t}$ has economic implications. In other words, from a holistic perspective, the balance of third-party frictional forces cannot be achieved by the implementer of the frictional forces, as the entity creating the frictional forces cannot eliminate them. The above analysis applies not only to the economic losses caused by administrative monopolies in the past Soviet era but also to any government intervention in free markets. Therefore, a necessary condition for judging whether the results of government intervention in the market are good or bad is whether the government is constrained by forces other than the government itself. In other words, whether the transactional frictional forces caused by the government can be balanced by the frictional forces of demand-side entities and supply-side entities.

The greatest resistance to the proper functioning of a free market is not the frictional forces of supply-side entities and demand-side entities, nor the frictional forces caused by transaction costs such as search costs during transactions. The greatest obstacle to the proper functioning of a free market should be the third-party transactional frictional forces resulting from administrative monopolies in industries such as oil, electricity, water resources, railways, and telecommunications, etc. In administratively monopolized industries, the operating entities of the industry refuse market competition and artificially manipulate transactional frictional forces to divert most of the social surplus towards the administrative monopolistic entities and privileged class. This manifests at the national level as an increase in the momentum($M=F_\mu t$) caused by third-party transactional frictional forces. According to the hypothesis of momentum conservation($F_D t+F_S t+F_\mu t=0$), the sum of momentum of demand-side entities and momentum of supply-side entities($F_D t+F_S t$) must decrease, leading to two economic consequences. First, there is a decrease in the total amount of social surplus, as the social wealth created by supply-side entities and demand-side entities(E_S+E_D) is consumed by the negative energy(E_μ) generated by transactional frictional forces. Second, there is a severe problem in the distribution of social surplus, with the majority of the surplus flowing towards the administrative monopoly class, leading to an increase in wealth disparity and exacerbation of social inequality. As the momentum ($M=F_\mu t$) caused by administrative monopoly frictional forces continues to increase, and the sum of momentum of demand-side entities and momentum of supply-side entities ($F_D t+F_S t$) continues to decrease, the system will eventually collapse or the entities will perish.

Finally, based on the law of energy conservation in social sciences, it can be concluded that, both in the past and in the future, the "negative energy" felt by the lower class in society will always balance out with the "positive energy" felt by the privileged class in non-free markets. From the perspective of the characteristics of economic development in the former Soviet Union, the fundamental cause of non-free markets is the maximization of transactional frictional forces through the exercise of administrative power. This process is an accumulation of the value (p) of goods and the utility of demand and supply (u) in economic mechanics over time and space. Transactional frictional forces caused by administrative monopolies or natural monopolies will inevitably generate economic frictional momentum, which in turn affects the fluctuation of economic energy. However, economic energy (E) and momentum (M) cannot be directly observed. Nevertheless, indicators in economics such as total social production level, total social surplus, GDP, and others can be used to approximate the measurement of economic energy. The transition from equilibrium to non-equilibrium and from non-equilibrium to equilibrium is a recurring process in complex social-economic systems. Regardless of the government's motives for intervening in the market being benevolent or not, it is crucial to assess whether the government is constrained by forces other than itself. In other words, whether the transactional frictional forces caused by the government can be balanced by the frictional forces of demand-side entities and supply-side entities.

7 Conclusion and Future Research

In this paper, by vectorizing price, demand, and supply in economics, and also applying the principle of relativity to mathematically explain the scalar characteristics of utility, and reconstructing a system of economic mechanics (Economic Mechanics) through demand force, supply force, and transaction friction, in a binary and ternary system equilibrium mechanics analysis system, this paper points out that the force is what changes the system equilibrium state, where demand, supply and friction forces can destroy the equilibrium state of the system; demand, supply and friction forces can also reshape the equilibrium state of the system. The disruption of the symmetry of the relationship of various elements in the system is the basis for the emergence of the system. So, the binary or ternary system equilibrium theory constantly presents the pairwise disruption (non-equilibrium) of a subject-diverse network, and the structural remodeling (equilibrium) brought about by symmetry disruption. Within this network-connected system, demand forces, supply forces, and friction forces will always create themselves in an evolving manner. So the system equilibrium theory hypothesis is neither a special case of economic equilibrium nor a complement to the neoclassical economic theory of equilibrium. This is because in the system equilibrium theory hypothesis constructed in this paper based on the principles of physics, the demand subject, supply subject and friction subject face high uncertainty and the law of increasing or decreasing economic output within the system are present.

Besides, the economic momentum and economic energy are expanded based on the system of economic mechanics, and it is pointed out that economic momentum and economic energy are the effect of demand force, supply force and friction force on the system in the time and spatial dimension. Economic energy can be expressed as both the “visible” social surplus and the “invisible” psychological feeling of happiness or pain. The modified economic mechanics model has a strong ability to explain social science problems. It is also possible to integrate economic analysis into the theoretical framework of the natural sciences, represented by physics. In this short mathematical model construction process, this paper attempts to integrate the basic logic of economics into the natural science research system represented by physics, which is of course a process of reinterpreting the basis of economics with the principles of physics and may provide a new research idea for the future research of economics.

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