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# Biophysical Study of Utility and Herding

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## Abstract

This study presents a biophysical perspective on the prevailing herding behavior observed in politics and finance. By reconceptualizing individual utility as the outcome of consuming a finite reservoir of internal energy –termed volition--over the course of life, this study develops a dynamic model of volition analogous to the linear cable equation for nerve impulses, informed by the Second Law of Thermodynamics. In particular, it identifies a threshold condition under which social learning can overpower the natural diminishing tendency of marginal utility implied by the Second Law. The analysis further examines the manifestations of herding in both political and financial contexts. In politics, the rise of populist anger, ideological fragmentation, and party polarization exemplifies such dynamics. In finance, herding appears when asset prices diverge sharply from their fundamental book values. An empirical illustration is provided by the extraordinarily high price-to-earnings ratios of leading AI firms such as Nvidia.

**Keyword:** herding behavior, social learning, entropy and evolution, dynamics of volition, biophysics of utility function

**JEL:** A12, D01, D91, G41

## Introduction

Every action carries intrinsic information, propelled by an underlying "inner energy." The consequences of these actions ripple outward from their epicenter—much like waves—transmitting information into the public sphere. This transmission, in turn, provokes further actions and reactions, perpetuating a cycle that facilitates the formation and evolution of herding behavior. This study provides a theoretical foundation for understanding this pervasive phenomenon as it manifests across economic, financial, and political domains.

*Foundation of Herding Theory*

Herding behavior occurs when individuals make decisions based on the observed actions of others, often disregarding their own private information. This phenomenon is a cornerstone of behavioral economics and game theory. In "A Simple Model of Herd Behavior" (Banerjee, 1992), herds form when individuals sequentially make decisions by ignoring private signals in favor of public behavior. Building on Banerjee with stronger formalization, Bikhchandani, Hirshleifer, and Welch (1992) introduce the concept of informational cascades, where early movers dominate group decisions despite subsequent better information. Chamley (2004) offers a deep theoretical foundation for rational herding. Even fully rational agents may herd due to the structure of information. Vives (2016) incorporates rational herding in markets with asymmetric information and endogenous prices. It shows how prices partially reflect dispersed signals.

Despite these rational frameworks, contemporary instability is often driven by demagogues and speculators who propagate demagogies to trigger blind allegiance. To justify these seemingly irrational behaviors, we look to Eyster & Rabin (2010), who show that "naïve herders" over-weight the signals of early movers, and Barberis et al. (1998), who link herding to excess volatility and market crashes. Angeletos & Pavan (2007) show that policy diffusion often exhibits herd-like patterns (e.g., tax policies, regulatory trends). Policymakers may suppress private beliefs to avoid signaling uncertainty.

*The Quantum Mind and Biophysical Laws*

In contrast with conventional economic thought, this study views decision-making as a conscious reaction to external stimuli, influenced by quantum mechanism. As illustrated in *Life on the Edge* (Al-Khalili & McFadden, 2014), the "quantum mind" is akin to an individual's volition--the undercurrent of mental power that flows through the physical body to form preference. To analyze this, we propose two fundamental principles that align human action with the laws of physics: The First Law of Human Behavior – all mental activities are driven by the quantum mechanics of the brain cell; The Second Law of Human Behavior – the dynamics of human behavior mimic nerve impulses reacting to external stimuli, as specified by the cable equation of the Ohmic model.

This study seeks to unify social and natural sciences by exploring the principles that yield orderly structures—from galaxies to consciousness—within a universe destined for decay. We contend that just as human life is finite, the phenomena of space and time are subject to the Second Law of Thermodynamics. Self-reflective individuals must navigate the tension of this finiteness, which ultimately shapes their utility function.

*Reconceptualizing Utility and Volition*

Unlike conventional axioms of completeness, transitivity and continuity, this study defines individual utility as the consumption of a finite "inner energy density" (volition) over a lifespan. By constructing a dynamic model of volition—using the linear cable equation for nerve impulses and incorporating Hebb's learning rule—we examine the forces driving marginal utility.

Key findings include: (1) Threshold Conditions--we derive the point at which social learning overpowers the natural diminishing tendency of marginal utility. (2) Acceleration and Depletion—unchecked herding causes marginal utility to accelerate excessively, potentially depleting social and economic resources. (3) Market Deviations—in fiancé, this is evident when asset prices deviate from fundamental book values. A current empirical example is the exceptionally high price-to-earnings (P/E) ratio of AI leaders like Nvidia. (4) Implications of Herding in Politics--the rise of populist anger, ideological fragmentation, and party polarization illustrates herding dynamics. These developments link global events with political tactics, revealing a profound and often subtle transformation in power and governance worldwide.

Finally, we highlight the dual roles of entropy and evolution. While entropy dictates predictability and decline, Darwinian mutation and human innovation disrupt this one-way trajectory. This study identifies the conditions under which human desire transcends the limits of diminishing marginal utility, generating the momentum necessary for market leadership and industry-wide transformation.

In the following we begin with the formulation of a dynamic equation that illustrates the movement of our mental volition:

## Dynamic Equation of Volition

In the following I am trying to formulate the movement and characterize the behavior of one's volition in line with the nature of quantum biology. To begin with I define "volition" (abbreviated as C) as something caused by the biochemical movement of ions across the membrane of one's nerve system. The interplay of physical and biochemical approaches to life science has borne significant fruits in interpreting how our nerve impulses work. I will not go to the details of this discussion. Instead, I will derive an equation of volition's movement in a more general sense.

Suppose we know the number of elements at each point along the x axis at time t, as N(x), where the elements can stand for the reservoir for one's volition and the distance x is measured along the conduit of our mental body like the yardstick that measures one's history of life or memory. How many elements will move across unit area from the point x to the point x+ε?

| | | |
|---|---|---|
| N(x) | : | N(x+ε) |
| x | : | $x+\varepsilon$ |

First of all, I assume that there is no other external force so that the elements will behave like a random walk. At time t+τ, half the element at x will have stepped across the dashed line from left to right, and half the elements at x+ε will have stepped across the dashed line from right to left. The net number crossing to the right will be

$$-\frac{1}{2}[N(x+\varepsilon)-N(x)].$$

If it turns out to be negative, there will be more elements crossing to the left than to the right. To obtain the net flux, I divide the net number above by the area normal to the x axis, $\omega$[1], and by the time interval, τ,

[1] $\omega$ is the cross-section area of the "volition" aqueduct, and measures the extent of one's mental strength or wealth at each point of his life.

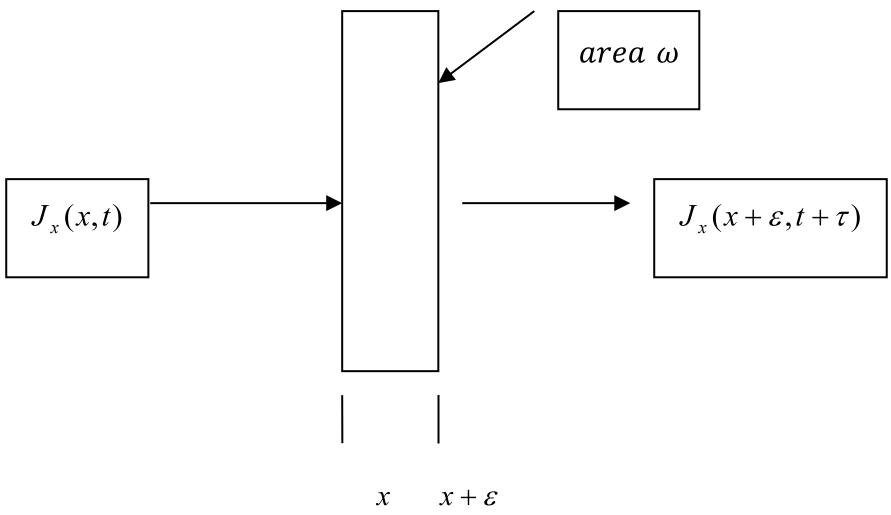
$$
\begin{aligned}
J_x &= -\frac{1}{2}[N(x+\varepsilon)-N(x)\}/\omega\tau \\
&= -\frac{\varepsilon^2}{2\tau}\frac{1}{\varepsilon}\left[\frac{N(x+\varepsilon)}{\omega\varepsilon}-\frac{N(x)}{\omega\varepsilon}\right] \\
&= -\frac{\varepsilon^2}{2\tau}\frac{1}{\varepsilon}[C(x+\varepsilon)-C(x)]
\end{aligned}
$$

Where $\varepsilon^2/2\tau$ is the diffusion coefficient denoting the tempo of one's life passage. We hereby define volition "C" as the density of reservoir constituting elements of energy or information at each point of life, that is, $C(x+\varepsilon)=N(x+\varepsilon)/\omega\varepsilon$ & $C(x)=N(x)/\omega\varepsilon$ are the densities or the number of elements per unit volume at the points $x+\varepsilon$ & $x$ respectively. In the limit $\varepsilon \to 0$, we obtain

$$J_x = -\frac{\varepsilon^2}{2\tau}\frac{\partial C}{\partial x}\ . \tag{1}$$

In other words, the net flux toward the wall with area ω at the location x is in a reverse proportion to the volition change at the point x.

Assume that the total number of elements is conserved as shown in Figure below.




Consider the box in the figure above. In a period of time $\tau$, $J_x(x)\omega\tau$ amounts of elements will enter from the left and $J_x(x+\varepsilon)\omega\tau$ elements will leave from the right. The volume of the box is $\omega\varepsilon$. If the elements are neither created nor destroyed, the number of elements per unit volume in the box must increase at the rate as follows:

Since $J_x(x+\varepsilon)=-\frac{1}{2}[N(x+2\varepsilon)-N(x+\varepsilon)\}/\omega\tau$,

$$[J_x(x+\varepsilon)-J_x(x)]\omega\tau = -\frac{1}{2}[N(x+2\varepsilon)-N(x+\varepsilon)+N(x+\varepsilon)-N(x)] = -\frac{1}{2}[N(x+2\varepsilon)-N(x)].$$

Therefore,

$$\frac{1}{2\tau}[C(t+2\tau)-C(t)]=\frac{1}{2\tau}[C(x+2\varepsilon)-C(x)]=\frac{\frac{1}{2\tau}[N(x+2\varepsilon)-N(x)]}{\omega\varepsilon}=-\frac{2}{2\tau}[J_x(x+\varepsilon)-J_x(x)]\omega\tau/\omega\varepsilon$$
$$=-\frac{1}{\varepsilon}[J_x(x+\varepsilon)-J_x(x)]$$

In the limit $\tau \to 0$ and $\varepsilon \to 0$, this means that

$$\frac{\partial C}{\partial t}=-\frac{\partial J_x}{\partial x} \tag{2}$$

An increase in the forward impulse will cause the depreciation of energy and the decline of volition. By substituting equation (1) into equation (2), we get the equation of volition's movement as

$$\frac{\partial C}{\partial t}=D\frac{\partial^2 C}{\partial x^2} \tag{3}$$

where $D\equiv\varepsilon^2/2\tau$ is the diffusion coefficient similar to the $\frac{(\lambda_{axon})^2}{\tau}$ in the linear cable equation for nerve impulse that embodies the Ohmic hypothesis, i.e.,

$$(\lambda_{axon})^2\frac{d^2v}{dx^2}-\tau\frac{dv}{dt}=v.$$

where $v$ is the difference between the interior potential of an axon and its quasi-steady value: $v(x,t)\equiv V(x,t)-v^0$.

This quasi-steady state potential $v^0$ can be derived from the Ohmic hypothesis by assuming that the sum of total charge fluxes to be zero. The axon's space constant term $\lambda_{axon}$ and time constant term $\tau$ are defined as

$$\lambda_{axon}\equiv\sqrt{ak/2g_{tot}};\quad \tau\equiv\mu/g_{tot},$$

where $a$ is the radius of the axon cylinder, $k$ is the fluid's electrical conductivity of the axoplasm, $g_{tot}=\sum_i g_i$, i.e., the summation of all ions' conductance per area of the axon membrane ($g_i$), and $\mu$ is a constant characteristic of the membrane material that measures the capacitance per area of the axon membrane. Letting $w(x,t)\equiv e^{t/\tau}v(x,t)$, the linear cable equation becomes

$$\frac{(\lambda_{axon})^2}{\tau}\frac{d^2w}{dx^2}=\frac{dw}{dt},$$

which has exactly the same form as our dynamic equation of volition. The derivation of the linear cable equation for nerve impulses above can be seen in Philip Nelson (2004, chapter 12).

We now turn to the discussion of diffuse with drift. When drift is included, the movement of element will be added by velocity $v_d$ which is caused by two distinct forces. The first force contributes a depreciating speed $v_e$ owing to the Second Law of Thermodynamics (see discussion and derivation of $v_e$ in the next section). The second force represents the mundane external force $F_x(=\lambda Y)$ with an attempt to slow down the passage of life. The latter two forces are represented by $v_d(=v_e-\lambda Y)$.

Once we add two forces into the elements in a distribution, a drift in the positive x direction will gain a velocity $v_d$, and the flux at any point x will increase by an amount $v_d \times C(x)$ in the $\varepsilon>0$ direction at that point x. Thus, equation (1) is modified to

$$J_x = -D\frac{\partial C}{\partial x} + v_d C \tag{4}$$

Following the same procedures as before, we derive the equation for volition's movement with drift, yielding

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} - v_d\frac{\partial C}{\partial x}. \tag{5}$$

According to Newton's second law, the application of an external force $F_x$ will change the velocity by an amount equal to $v_f = \frac{1}{2}\frac{F_x}{m}\tau$. An element at absolute temperature $T$ with mass $m$ and velocity $v_d$ along the x-axis has a kinetic energy of $mv_d^2/2$. Although this quantity fluctuates, its average value is given by $mv_d^2/2 = kT/2$, where $k$ is Boltzmann's constant. By substituting $D = \frac{\varepsilon^2}{2\tau}$, $v_d = \frac{\varepsilon}{\tau}$ and $mv_d^2/2 = kT/2$ into $v_d = v_e - v_f = v_e - \frac{1}{2}\frac{F_x}{m}\tau$, we can get $v_d = v_e - (D/kT)F_x$.

For an economic interpretation, consider an injection by the consumption of a specific good or service, denoted by Y. This injection increases the concentration of our inner energy or reduces the speed of volition depreciation, i.e., increases $\frac{\partial C}{\partial t}$, at the present time. In other words, when Y is accompanied by an external force $F_x$, it replenishes additional energy that counteracts the dissipation of initial inner energy, thereby reducing the speed of rightward impulse movement $v_d$ by an amount of $v_f\,(=\lambda Y)$. Thus, the resulting $v_d$ can be expressed as

$$v_d = v_e - \lambda Y \tag{6}$$

Here, $\lambda$ measures the characteristics of one's volition system—that is, how effectively volition can be preserved by the external force $Y$—and it is positively correlated with $D/kT$, i.e., $\lambda=D/kT$. By substituting equation (6) into equation (5), we obtain

$$\frac{\partial C}{\partial t}=D\frac{\partial^2 C}{\partial x^2}-v_d\frac{\partial C}{\partial x}=D\frac{\partial^2 C}{\partial x^2}-(v_e-\lambda Y)\frac{\partial C}{\partial x}. \tag{7}$$

## Consideration of Thermodynamic Law on the Drain of Volition

In addition to the external forces like $F_x$ or consumption goods Y that affects the flow of volition, there always exist an internal uncontrollable force that would constantly exhaust our innate energy according to the Second Law of Thermodynamics. From the Second Law, a measure of disorder called the entropy, denoted S, can be written as

$$S \equiv -k\sum_{j=1}^{M} P_j \ln P_j$$

where $k$ is Boltzmann's constant and $P_j$ is the probability of a particle j that would appear in an isolated container with M particles. This $P_j$ is like the concentration measure (i.e.,$C_j$) in our model[2]. Assume that we focus on the movement of a specific element j which is caused by an external force like consumption of good or service. Then the remaining M-1 elements can be kept intact. Then taking the differentiation of S yields

$$dS/dt=-k(1+\ln C_j)dC_j/dt$$

The dynamic change in entropy, i.e., $\frac{dS}{dt}$, can be reflected in the velocity $v_e$ for the movement of the internal energy concentration or volition (C) across the transmission medium (x) based on the following simplified equation: $\frac{1}{k(1+\ln C)}\frac{dS}{dt}=v_e\frac{dC}{dx}$. Accordingly, we obtain the impact of the Second Law on our volition as follows:

$$\frac{dC}{dt}=-\frac{1}{k(1+\ln C)}\frac{dS}{dt}=-v_e\frac{dC}{dx} \tag{8}$$

As we accumulate more energy from external consumption Y, it will lead to an increase in the degree of disorder or entropy and create a self-depreciation force $v_e$ that gradually drains the concentration of our volition according to equation (8).

[2] For simplicity we normalized the concentration C to be some value less than one in the discussion below.

## Consideration of Learning and Herding Effect

In 1949, Donald Hebb proposed that if input from neuron A consistently contributes to the firing of neuron B, then the synaptic connection from A to B should be strengthened. Hebb suggested that such synaptic modification could lead to the formation of neuronal assemblies that mirror the relationships experienced during learning. This principle, known as Hebb rule, has become foundational in research on synaptic plasticity and its role in learning and memory. For example, consider applying this rule to neurons that fire simultaneously during training due to an association between a stimulus and a response. These neurons would develop strong interconnections, such that the subsequent activation of a subset of them—triggered by the stimulus-- could provide sufficient synaptic drive to activate the rest, thereby eliciting the associated response.

Suppose a single postsynaptic neuron is influenced by multiple inputs, with their activities represented by $u_b$ for neuron $b = 1,2,..., N_u$. The dynamics of postsynaptic activity $v$, akin to the volition C described above, can be described by the Hebb learning rule as follows:

$$\gamma \frac{dv}{dt} = -v + \sum_{b=1}^{N_u} w_b u_b$$

where $\gamma$ is a time constant that governs the response rate, and $w_b$ the synaptic weight that describes the strength of the synapse from presynaptic neuron b to its postsynaptic neuron.

In this study, I extend and adapt the concept of Hebb rule to include all the relevant inputs contributing to lingering memory, which gradually consolidates into an stream of inertia that triggers herding behavior from $u_b$ with $w_b$ represents the strength of that memory's influence on volition. This learning effect—accumulated from cultural norms, social cues, or propaganda—serves as a theoretical foundation for how culture or propaganda shape individual decisions. Accordingly, this learning or herding effect introduces an additional driving force in the movement of volition, expressed as:

$$\frac{dC}{dt} = -\frac{1}{\gamma} C + \frac{1}{\gamma} \times \sum_b w_b u_b. \quad (9)$$

Combining equations (7), (8) and (9), we can obtain the complete equation for the dynamics of volition as:

$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2} + (\lambda Y - v_e) \frac{\partial C}{\partial x} - \frac{1}{\gamma} C + \frac{1}{\gamma} \times \sum_b w_b u_b, \quad (10)$$

where $\lambda=D/kT$.

In order to solve the nonlinear differential equation (10) above, we make the following simplifications for the learning effect by $\frac{1}{\gamma}(\sum_b w_b u_b - C)=f(C)=\frac{\beta C}{\gamma}$, where $\beta(>0)$ measures the extent of how the external force or consumption F enhances our habitual herding behavior and feeds back into long term memory via its impact on volition. Therefore, equation (10) can be rephrased as

$$\frac{\partial C}{\partial t}=D\frac{\partial^2 C}{\partial x^2}+(\lambda Y-v_e)\frac{\partial C}{\partial x}+C\beta/\gamma \qquad (10)'$$

## Converting Volition Equation into the Dynamics of Economic Behavior

Much of human culture--from artistic exploration to scientific discovery—has been driven by a worldly effort to reflect upon the finite nature of existence. The appeal of a natural law lies in its timelessness; our pursuit of enduring scientific principles stems precisely from the fact that our own lives are anything but eternal. The ultimate meaning of life, therefore, involves carrying forward the achievements of the past while opening new paths for the future, striving to make our allotted decades both splendid and lasting. In this sense, economic utility can be traced to an emotional desire to preserve fleeting moment and to the sheer intensity of that longing.

We define an individual's satisfaction, $\mu$ , as arising from the exertion of volition or energy against the natural flow of life. Ordinarily, an individual aspires to enjoy life within its finite span, seeking to enhance vitality over time by replenishing it with external energy inputs. Formally, this relationship may be expressed as $\mu\equiv\partial C/\partial x$. Let $v=dx/dt$ denote the passage velocity of life in accordance with natural law. However, this natural speed $v$ is perceived subjectively based on the injection of life's provisions (energy), with an additional influx of speed $v_d=v_e-v_f=v_e-\lambda Y$. Ultimately, the subjective velocity perceived by the individual becomes $v+v_d=v-\lambda Y+v_e$, which plays a critical role in shaping the variation in marginal utility (see corollary below).

The injection of external consumption ($Y$) affects internal energy density or volition $C$(t) through the drift of impulse (see Equation (4)). Any external force $Y$ that decelerates the forward movement of life is necessarily accompanied by a counteracting entropic exhaustion $v_e$, which accelerates life's passage according to the "two-step" entropic rule. Together with innate speed $v_e$, the overall impulse can be written as $J_x=-D\frac{\partial C}{\partial x}+v_d C$. This impulse drives the evolution of volition according to the dynamic equation $\frac{\partial C}{\partial t}=-\frac{\partial J_x}{\partial x}=D\frac{\partial^2 C}{\partial x^2}+v_d(-\frac{\partial C}{\partial x})$. Hence, an increase in $Y$ ultimately leads to an increase in $\frac{\partial C}{\partial t}$.

Since $\frac{\partial C}{\partial t}=\frac{\partial C}{\partial x}\times\frac{\partial x}{\partial t}=\mu(t)\cdot\ v$, it follows that $\mu(t)=\frac{\partial C}{\partial t}/v$. The greater the the exertion of volition (i.e., the larger $\frac{\partial C}{\partial t}$ resulting from injection $Y$ to slow $v_d$), the greater the resulting utility $\mu(t)$.

Furthermore, $\frac{\partial C^2}{\partial x^2}=\frac{d\mu}{dt}\cdot\ \frac{dt}{dx}=\left(\frac{1}{v}\right)\cdot\ \frac{d\mu}{dt}$. Combining these expressions, we rewrite equation (10)’ as

$$\mu(t)\cdot\ v(t)=\frac{D}{v(t)}\cdot\ \frac{d\mu(t)}{dt}+\mu(t)(\lambda Y-v_e)+[C\beta]/\gamma. \qquad (10)”$$

The solution to this differential equation becomes

$$\mu(t,Y)=(\mu(0)-A)\cdot\ exp\left[\frac{v(t)^2-v(t)(\lambda Y-v_e)}{D}\cdot\ t\right]+A \qquad (11)$$

where $A$ $(=\frac{C\beta}{\left[\gamma\ (v-\lambda Y+v_e)\right]})$ is a function of $Y$, and $\mu(0)$ is determined by the boundary condition at $t$=0.

The marginal utility for consumption $Y$ is then given by

$$\frac{\partial\mu(t;Y)}{\partial Y}=[\mu(0;Y)-A]\times exp\left[\frac{v^2-(\lambda Y-v_e)v}{D}\times t\right]\times(-\frac{\lambda vt}{D})$$

$$+\ \{1-\ exp\left[\frac{v^2-(\lambda Y-v_e)v}{D}\times t\right]\}\times\frac{C\beta\lambda}{[\gamma(v-\lambda Y+v_e)^2]}. \qquad (12)$$

For $\frac{\partial\mu(t;Y)}{\partial Y}$ to be positive, $\beta$ should satisfy the following condition:

$$\left\{\left(\frac{1}{exp\left[\frac{v^2-(\lambda Y-v_e)v}{D}\times t\right]}-1\right)\times D+v\times(v+v_e-\lambda Y)\times t\right\}\times\beta$$

$$>\ \mu(0)\times(vt)\times\gamma\times(v+v_e-\lambda Y)^2/C$$

Let $\Phi_1$ defined as (*) below:

$$\mathbf{\Phi_1}\equiv\frac{\left[\mu(0;Y)\left(\frac{vt}{C}\right)\right]\ \gamma\ \ (v-\lambda Y+v_e)^2}{D\left(\frac{1}{exp\left[\frac{v^2-(\lambda Y-v_e)v}{D}\times t\right]}-1\right)+(v-\lambda Y+v_e)vt)} \qquad \textbf{(*)}$$

## Conditions for Herding

The sufficient condition for positive marginal utility is $\beta>\Phi_1$. A violation of this condition (where $\beta<\Phi_1$) may occur due to an unusually high initial utility level, $\mu(0;Y)$. This might happen during a sudden technological breakthrough, such as those seen in high-tech stocks like Nvidia as illustrated in the section of herding in financial market below.

Next, we consider the impact of $\beta$ on the rate of change in the marginal utility of $Y$. The dynamics of the second derivative of utility proceed as follows:

$$\frac{\partial\mu^2(t;Y)}{\partial Y^2}=[\mu(0;Y)]\times exp\,[\frac{v^2-(\lambda Y-v_e)v}{D}\cdot\ t]\times\left(\frac{\lambda vt}{D}\right)^2+$$

$$A\times\{2\times exp\,[\frac{v^2-(\lambda Y-v_e)v}{D}\cdot\ t]\times(\frac{\lambda vt}{D})\times\frac{\lambda}{v+v_e-\lambda Y}+$$

$$\{1-exp\,[\frac{v^2-(\lambda Y-v_e)v}{D}t]\}\times\frac{2\lambda^2}{(v+v_e-\lambda Y)^2}-exp\,[\frac{v^2-(\lambda Y-v_e)v}{D}\cdot\ t]\times\left(\frac{\lambda vt}{D}\right)^2\}.$$

Let W represent the following term

$$W\equiv\{2\times exp\,[\frac{v^2-(\lambda Y-v_e)v}{D}\cdot\ t]\times(\frac{\lambda vt}{D})\times\frac{\lambda}{v+v_e-\lambda Y}+$$

$$\{1-exp\,[\frac{v^2-(\lambda Y-v_e)v}{D}t]\}\times\frac{2\lambda^2}{(v+v_e-\lambda Y)^2}-exp\,[\frac{v^2-(\lambda Y-v_e)v}{D}\cdot\ t]\times\left(\frac{\lambda vt}{D}\right)^2\}$$

Therefore, $\frac{\partial\mu^2(t;Y)}{\partial Y^2}>0$ implies that

$$[\mu(0;Y)]\times exp\,[\frac{v^2-(\lambda Y-v_e)v}{D}\cdot\ t]\times\left(\frac{\lambda vt}{D}\right)^2+\frac{C\beta}{\gamma(v+v_e-\lambda Y)}\times W>0,$$

or

$$\frac{C\beta}{\gamma(v+v_e-\lambda Y)}\times(-W)<[\mu(0;Y)]\times exp\,[\frac{v^2-(\lambda Y-v_e)v}{D}\cdot\ t]\times\left(\frac{\lambda vt}{D}\right)^2,$$

which implies that the sufficient condition for an increasing marginal utility is

$$\beta<\Phi_2\equiv\frac{[\mu(0;Y)]\times exp\,[\frac{v^2-(\lambda Y-v_e)v}{D}\cdot\ t]\times\left(\frac{\lambda vt}{D}\right)^2\times\gamma\times(v+v_e-\lambda Y)/C}{-W} \qquad (**)$$

Combining the conditions (*) and (**) above yields the following proposition:

*<u>Proposition</u>: When the impact of an external stimulus on internal learning mechanisms-captured by the parameter $\beta$ (characterizing the Hebbian learning response to volitional intensity C as $\sum_b w_b u_b - C = \beta C$)−falls within the range $\Phi_1 < \beta < \Phi_2$, an uncontrollable herding phenomenon may emerge, capable of engulfing the entire pool of economic resources.*

Here we implicitly assume that $\Phi_1 < \Phi_2$. If it happens that $\Phi_1 > \Phi_2$ (>0), the condition for a positive marginal utility (i.e., $\beta > \Phi_1$) also leads to a diminishing marginal utiitity ($\beta > \Phi_2$), erasing the possibility of herding. When $\beta$ is located outside the range of $[\Phi_1, \Phi_2]$ such that $\beta < \Phi_1 < \Phi_2$, we witness the situation of a negative but gradually increasing marginal utility, which is still likely to generate a herding behavior. If $\Phi_1 < \Phi_2 < \beta$, we observe the "normal" economic situation of positive but declining marginal utility.

Another critical factor influencing fluctuations in an individual's utility is the ultimate speed of volition movement, defined as $\theta \equiv v + v_d = v + v_e - \lambda Y$. According to equation (11), $\frac{\partial \mu}{\partial \theta} = \frac{\frac{\partial \mu}{\partial Y}}{\frac{\partial \theta}{\partial Y}} = -\frac{\partial \mu}{\partial Y} / \lambda$.

Thus, the condition for a positive marginal utility with respect to *Y*, i.e., $\frac{\partial \mu}{\partial Y} > 0$, implies $\frac{\partial \mu}{\partial \theta} < 0$. Consequently, satisfaction of the first part of the proposition, namely $\beta > \Phi_1$, also entails that an increase in $\theta$ will reduce an individual's utility:

*<u>Corollary:</u> Assuming that the marginal utility of consumption is positive (i.e., the individual's learning coefficient $\beta$ is greater than the threshold $\Phi_1$), an increase in the ultimate speed of volition movement over one's lifespan, i.e., $\theta = v + v_e - \lambda Y$, will result in a decline in the individual's utility, that is., $\frac{\partial \mu}{\partial \theta} < 0$. In other words, the subjective perception of the speed of one's life depreciation after compensated by any mundane effort from external energy injection ($\lambda Y$) is the primary driver for its utility diminishment.*

The term $v + v_e - \lambda Y$ plays a decisive role in shaping the rate at which utility diminishes because entropy, as Boltzmann demonstrated, governs the unfolding of all physical systems under the Second Law of Thermodynamics. Life, too, is subject to these fundamental principles: it both originates from and evolves through natural selection, while simultaneously obeying the dictates of entropy.

In the final chapters of *What is Life* (2012), Schrodinger explained that living organisms resist the rise of entropy by "feeding upon negative entropy"—a process he described as the entropic two-step. The injection of $\lambda Y$ represents this input of negative entropy, allowing life to preserve order against the universal tendency toward disorder. Organisms achieve this by consuming structured, low entropy resources (such as nutritious food and other energy-sustaining materials), oxidizing them to release usable energy, and channeling that energy into metabolic activities while exporting entropy to the environment in the form of waste and heat—the terms $v+v_e$. Ultimately, however, the two-step process still yields a net increase in disorder equal to $v+v_e-\lambda Y$.

According to equation (**), the impact of $v+v_e-\lambda Y$ on marginal utility is not straightforward. The Proposition above suggests that fluctuations in individual's marginal utility are governed more by the social learning coefficient $\beta$. When herding behavior expands excessively—corresponding to an abnormally large $\beta$— it can consume all available social and economic resources unless restrained by opposing forces such as the rise of competitive powers that check runaway collective behavior. However, the existence of these competing forces often leads to polarization within markets or societies, resulting in outcomes as oligopolistic economic structures or populist political regimes.

## Herding Behavior, Sovereignty, and the Political Economy of Global Imbalances

Political herding is cultivated through several channels: the mythologizing of history, the deployment of propaganda and anti-intellectualism to erode a shared reality, and the legitimization of racial or religious hierarchies. By exploiting resentment and prioritizing social order over individual freedom, these tactics entrench "us versus them" divisions.

These mechanisms operate through a feedback loop of representations and practices. Representations normalize practices that might otherwise seem unacceptable, while those practices retrospectively validate the original representations. For example, portraying immigrants as inherently dangerous legitimizes their confinement in prison-like centers; once they are behind bars, the confinement itself is cited as proof of their "danger".

*Geopolitical Implications*

When amplified by rigid notions of sovereignty and national identity, herding behavior profoundly reshapes contemporary geopolitics. This dynamic is vividly illustrated in the Taiwan conflict, where China's uncompromising sovereignty claims collide with the increasing resistance of Taiwan and the United States. Beneath this territorial dispute lies a deeper identity divide: two societies with fundamentally different understandings of their collective selves and their mutual relationships.

Three decades after their apparent triumph, liberal democracy and global capitalism face a crisis of legitimacy. This stems from a structural tension: Democracy grounds sovereignty in the principle of equal citizenship within national borders, whereas capitalism concentrates decision-making power in the hands of globally active private actors. This friction between nationally rooted egalitarian politics and globally driven inegalitarian markets has deepened partisan divisions in the United States and reignited ideological confrontation between capitalism and socialism. As public perception—fueled by rapid herding behavior—increasingly views governance as a tool for the elite, populist backlashes have intensified across the political spectrum.

*The Biology of Belief*

In *The Ideological Brain* (2025), Leor Zmigrod explores the biological foundation of political beliefs, revealing how the interplay between cognition and environment predisposes some individuals to rigid thought patterns. Ideologies formed through herding behavior provide psychological shortcuts--offering ready-made scripts and a sense of shared identity. Once entrenched, these ideologies reduce psychological flexibility and empathy.

From a biophysical perspective, this framework identifies how excessive political manipulation can lead to disastrous consequences. A recent example is the global turmoil triggered by the use of reciprocal tariffs. This represents a case of "hybrid herding" that disrupted deeply interdependent trade relations originally shaped by Adam Smith's principles of free trade.

*Economic Reliance and Social Fairness*

American consumers and producers have developed a habitual reliance on China's large-scale manufacturing—a pattern reminiscent of herding behavior. However, the benefits of global specialization are only sustainable when trade flows remain balanced. When the movement of goods or production factors--driven by unrestrained herding sentiment—tilts too heavily to one side, the gains of trade manifest as sharp disparities in welfare between exporters and importers, producers and consumers, and high-tech and low-tech sectors. These imbalances raise profound questions of social fairness and evolve into political fault lines. When exploited by opposition parties or demagogues, these tensions can escalate into widespread upheaval.

*The Digital Echo Chamber*

While political herding is a recurring historical force, the rise of social media has fundamentally altered its scale. Initially celebrated as a democratization of information, social media has instead facilitated the spread of propaganda and trapped users within powerful echo chambers. The rise and fall of empires, both East and West, attest to the destructive potential of unchecked herding. While these cycles explain the recurrent rhythms of history, the human cost of such disruption is profound—making early mitigation a global necessity.

## Herding in Financial Markets

Prechter & Parker (2007) argue that any robust model of finance must clearly distinguish the price behavior of financial assets from that of utilitarian goods. They propose that economic behavior is primarily mediated by the neocortex, which governs conscious thought, whereas financial behavior is largely driven by the limbic system and basal ganglia—areas responsible for unconscious emotions and impulses (Prechter, 1999; MacLean,1990; LeDoux, 1989).

Building on this insight, the present study seeks to bridge the gap between financial and economic models. We ground the formation of an individual's utility function—whether as a buyer, seller or investor--in the principle of humanity's finite lifespans and the innate drive to maximize instantaneous satisfaction through the expenditure of internal energy or volition.

Within this framework, stock price fluctuations are characterized by the variable $\mu$, defined as investors' subjective valuation of a company's intrinsic book value ($C$): $\mu \equiv +\partial C/\partial x$. The model examines how significant news or strategic initiatives ($Y$) influence both $\mu$ and $C$. The sensitivity of book value to such announcements is represented by $1/\gamma$, while the adjustment speed of book value or strategic intent is denoted by $v$. The parameter λ measures the effectiveness with which external factors ($Y$) influence the company's injection of impulses, which is usually opposite to the life's normal passage direction and proxied by a reversed change in the volume of trade ($\Delta(-J_x)$). Furthermore, D (where $D = -\frac{J_x}{\mu}$) represents the impulse propelling the company forward through price appreciation, and β measures the degree of herding behavior among investors.

In this model, $C$ denotes the book value per share, and its rate of change, $\partial C/\partial t$, is proxied by earnings per share (EPS). The market price of the stock, as perceived by investors, serves as a proxy for μ. Since $\frac{\partial C}{\partial t} = \frac{\partial C}{\partial x} \times \frac{\partial x}{\partial t} = \mu(t) \times v$, the velocity $v$ can be expressed as $\frac{\partial C}{\partial t}/\mu(t)$, or the ratio of EPS to stock price. We utilize trading volume as a proxy for the momentum required to reverse the impulse that might drive a firm toward insolvency ($-J_x$). Consequently, D ($=-\frac{J_x}{\mu}$) is approximated as the ratio of trading volume to stock price. The parameter λ is empirically estimated by regressing the change in trade volume ($\Delta(-J_x)$) on news announcement Y: $\Delta(-J_x)=-\widehat{v_e}+\hat{\lambda}\,Y+\epsilon$. Where $\widehat{v_e}$ is the estimate of $v_e$. The term $v+\widehat{v_e}-\hat{\lambda}\,Y$ serves as a critical driver for fluctuations in marginal utility.

The subsequent empirical analysis employs quarterly data for Nvidia, including earnings per share (EPS), stock price, trading volume, and book value per share over the past two years. The variable $Y$ is proxied by the surprise move in earnings (the ratio of reported EPS to expected EPS) at each quarterly reporting date. The raw data, along with the estimate of $\lambda$ and $v_e$, are presented below:

| | EPS | Stock Price | Vol. of trade | EPS (Report/Expect) | D | $v(t)$ | Book value/share |
|---|---|---|---|---|---|---|---|
| | $(=\partial C/\partial t)$ | (μ(t)) | (-J_x) in mill. | $Y(t)$ | (= -j_x/u(t)) | $(=\frac{\partial C}{\partial t}/u(t))$ | $C(t)$ |
| 21-Feb-24 | $0.52 | $67.45 | 690 | 0.52/0.46 | 10.2 | 0.0077 | $1.74 |
| 22-May-24 | $0.61 | $94.92 | 54 | 0.61/0.56 | 0.57 | 0.0064 | $2.00 |
| 28-Aug-24 | $0.68 | $125.57 | 448.1 | 0.68/0.65 | 3.57 | 0.0054 | $2.37 |
| 20-Nov-24 | $0.81 | $145.86 | 309.9 | 0.81/0.75 | 2.12 | 0.0056 | $2.39 |
| 26-Feb-25 | $0.89 | $131.28 | 322.6 | 0.89/0.84 | 2.46 | 0.0068 | $3.24 |
| 29-May-25 | $0.96 | $139.19 | 367.5 | 0.96/0.75 | 2.64 | 0.0069 | $3.44 |
| 27-Aug-25 | $1.04 | $181.60 | 235.5 | 1.04/1.01 | 1.3 | 0.0057 | $4.11 |

The regression of $\Delta(-J_x)$ over Y(t) yields $\Delta(-J_x)$= -220.77 + 131.89*Y(t). This results in $\widehat{v_e}$=220.77 and $\hat{\lambda}$=131.89.

Substituting these estimates into the model allows us to assess the impact of $\beta$ (specifically the ratio $\frac{\beta}{\gamma}$) on the estimated stock price at each reporting date. By minimizing the deviation between the estimated and observed stock price μ, we obtain $\beta\approx20$. While the estimated $\beta$ is below the critical threshold $\Phi_1$ (68.544) --indicating negative marginal utility—it is also less than $\Phi_2$ (95.273), implying that marginal utility is continuously increasing. These results suggest that Nvidia's stock price demonstrates pronounced herding behavior. This finding is further supported by Nvidia's exceptionally high price-to-earnings (PE) ratio, which averaged approximately 156 over the past two years.

The details of this estimation and derivation are summarized in the following table:

| t (quartery report date) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | Average |
|---|---|---|---|---|---|---|---|---|
| **Stock Price (μ)** | 67.45 | 94.92 | 125.57 | 145.86 | 131.28 | 139.19 | 181.6 | 126.55 |
| velocity (v) | 0.0077 | 0.0064 | 0.0054 | 0.0056 | 0.0068 | 0.0069 | 0.0057 | 0.00636 |
| **Book value (C)** | 1.74 | 2 | 2.37 | 2.39 | 3.24 | 3.44 | 4.11 | 2.75571 |
| Y (t) | 1.13 | 1.09 | 1.05 | 1.08 | 1.06 | 1.28 | 1.03 | |
| D | 10.2 | 0.57 | 3.57 | 2.12 | 2.46 | 2.64 | 1.3 | |
| $\nu_e$ | 220.77 | 220.77 | 220.77 | 220.77 | 220.77 | 220.77 | 220.77 | |
| **λ** | 131.89 | 131.89 | 131.89 | 131.89 | 131.89 | 131.89 | 131.89 | |
| $v(t) - \lambda(Y) + v_e$ | 71.742 | 131.89 | 131.89 | 131.89 | 131.89 | 131.89 | 131.89 | 123.297 |
| **β** | 50 | 30 | 4 | 11 | 15 | 15 | 15.5 | 20.071 |
| β/γ = β*λ | 6594.5 | 3956.7 | 527.56 | 1450.79 | 1978.4 | 1978.35 | 2044.3 | 2647.22 |
| A | 159.9402 | 60 | 9.48 | 26.29 | 48.6 | 51.6 | 63.705 | |
| v(t)[v(t)-λ(Y)+v_e] | 0.5524134 | 0.844096 | 0.71221 | 0.73858 | 0.8969 | 0.91004 | 0.75177 | |
| estimated μ | 67.45 | 92.75594 | 95.8742 | 143.344 | 129.63 | 140.431 | 184.024 | 121.93 |
| μ - estimated μ | 0 | 2.164064 | 29.6958 | 2.51628 | 1.6509 | -1.2407 | -2.4236 | 4.6232 |
| $\Phi_1$ | | 70.50918 | 162.245 | 74.3358 | 43.939 | 37.4669 | 22.7692 | 68.544 |
| W | | -3.41346 | -0.0286 | -0.8497 | -3.2015 | -6.5386 | -226.09 | -40.021 |
| $\Phi_2$ | | 95.26308 | 235.744 | 103.184 | 59.444 | 49.9257 | 28.0753 | 95.273 |

## Entropy and Evolution

Physicist Brian Greene (2020) highlights two fundamental forces shaping both the cosmos and human society: entropy and evolution. According to the Second Law of Thermodynamics, order inevitably yields to disorder. However, entropy possesses subtle qualities that allow physical systems to develop in intricate ways—often appearing to move against the entropic tide. In the wake of the Big Bang, particles destined for chaos instead organized into structured forms: stars, galaxies, and planets. Ultimately, these matured into the complex biological arrangements that sustain life. Parallel to this, Darwinian mutation and innovation provide organisms with the adaptability to temporarily resist decline and withstand intense external competition.

Just as biological mutation is vital for survival, innovation and creativity—driven by increasing returns to scale and the boundless nature of human desire—are indispensable to economic progress. While predictability and stability align with the "settling" dictates of entropy, mutation and innovation disrupt this one-way trajectory. Guided by Darwinian selection, these forces propel technological advancement and sustained prosperity. This study identifies the conditions under which human desire transcends the limits of diminishing marginal utility, generating the momentum to cultivate new market leaders or spark industry-wide revolutions.

Standard economic textbooks rely on two core assumptions to guarantee a general equilibrium:

diminishing marginal utility on the demand side and increasing marginal cost on the supply side. However, the prevalence of economies of scale has fostered enormous multinational corporations that command disproportionate market power, exacerbating global income inequality. This study raises a related concern that involves the encroachment of increasing marginal utility, fueled by herding behavior. When consumer preferences are amplified by aggressive marketing or mass media to the point that marginal utility surpasses a critical threshold, the economic system tilts toward the dominance of hegemonic firms. This introduces significant instability into the global economy, as the system moves away from a stable, distributed equilibrium.

## Conclusions: The Biophysical Perspective

Human life is a fleeting journey within a finite corporeal vessel, moving irreversibly along the arrow of time. What we categorize as joy and sorrow—or, in economic terms, utility and price—are expressions of the curvature of the tangential function tracing the body's motion through existence. The derivative of this life energy—representing the dynamics of marginal utility—arises from two sources: the entropy prescribed by the Second Law of Thermodynamics, and the acquired economic activities of production and consumption. Regardless of scientific advancement, all systems must yield to the destiny decreed by nature: the inexorable rise of thermodynamic entropy and eventual extinction.

This study offers a biophysical framework for understanding herding behavior in finance and politics. When social learning mechanisms grow so dominant that they overpower the natural tendency toward increasing marginal utility, the stability of the system is undermined. A primary example of the herding phenomenon is the irrational surge in stock prices driven by social learning within financial markets. The recent, persistently high price-to-earning ratios seen in AI stocks have raised significant concerns regarding a potential bubble and subsequent crisis.

In the political realm, Rebecca Lemov (2025) offers sobering insights into the fragility of truth. Democracy depends on a shared reality—a common grasp of the past that informs the future. Authoritarian factors and the mechanisms of surveillance capitalism deliberately seek to erode this foundation, dissolving collective self-awareness and leaving individuals disoriented and vulnerable. Whether these entropic forces in our social fabric remain manageable or spiral beyond control is the defining question of our era, demanding proactive measures and constant vigilance.

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