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DYNAMIC ECONOMIC PROCESS, ANIMAL SPIRITS, AND CHINESE QI

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Abstract

This study builds up a theoretical model to quantify the formation of Keynes' animal spirits. It derives the equations demonstrating why and how the herding behavior or the business cycle would conduct. We integrate the Western concept of spirits and the Chinese qi in our model to show that the internal force drives a human's motive to behave and bridges man's brain and action like hidden consciousness. After deriving the dynamic behavior of the qi movement, this study illustrates how one's marginal utility function evolves across time. This non-stationary marginal utility concept is closer to modern behavioral economics and would revolutionize the conventional utilitarianism-related economic models. Our model is applicable in the micro-context to a human being and is expandable in the macro-context to any artificial entity. We hope that the methodology underpinned in this study could open a new window for future research to better cope with the current intractable and turbulent economic environment.

Keywords: Animal spirits; Changing marginal utility; Human decision; Qi dynamics; Quantum mind.

INTRODUCTION

The economic foundation that underlies the forces driving our daily economic activities should not merely be a "constrained optimization" (Samuelson, 1948) but an "incremental improvement." In our mundane human history, evolution rather than revolution is the norm. From waking in the morning till the moment of sleep, we are busy thriving for the betterment of our lives, not just simply for accomplishing our dreams or lives' ultimate goals. The economic equilibrium that is supposed to be achieved from the intersection of demand and supply is too vague and flimsy a term to fathom for our ordinary people. We are all living in an instantaneous dynamic process, not aiming to jump toward our long-term destination in one giant step.

To thoroughly comprehend the recurrence of the global economic crises these days, acclaimed economists Akerlof and Shiller (2009) reassert the necessity of including the idea of animal spirits as the powerful psychological forces that influence the financial and economic performance and wealth of nations. Just as Adam Smith's invisible hand is the driving force in classical economics, John Maynard Keynes' animal spirits are the keynote to another view of the economy—a view that explains the underlying instability of capitalism. In 1936, when *The General Theory of Employment, Interest, and Money* was published, the political-economic spectrum were those who thought the old economics had gotten it right (Keynes, 1936). According to this classical economics, the private markets of their own accord and with no government interference would, "as if by an invisible hand," assure full employment.

However, in Keynes's view, the economy is not just governed by rational actors, who "as if by an invisible hand" will engage in any transaction to their mutual benefit as the classicists believed. Keynes argued that people with animal spirits have noneconomic motives and are not always rational in pursuing their economic goals. In Keynes' view, these animal spirits are the leading cause for why the economy fluctuates as it does. They would help set in motion an intellectual revolution that will change the way we think about economic depressions, unemployment, poverty, financial crises, and much more.

SPIRITS AND HUMAN BEHAVIOR

To probe into the origin of the animal spirit, we need to delve into the formation n of our decision-making via the impulse or response of our neural system toward the outside information input or shock. Numerous neuroscientific studies have all shown that our decision process is nothing but an effective transmission of the information at the molecular level, on a nanoscale, within living cells, and quantum mechanics is needed to explain the procession and storage of the information. In other words, our decision-making is driven by an invisible "quantum mind" to cope with the flow of information (Al-Khalili, 2014).

The idea of information derives originally from the realm of human discourse. It can be a purely abstract concept like a person's value system or moral standard. It also indirectly plays a physical role in the sphere of biology; a change in the information stored in an organism's DNA may produce a mutant offspring and alter the course of evolution. By and large, information itself has a casual power to make a difference in the world. The challenge to physical and social science is figuring out how to couple abstract information into our daily lives.

Dissatisfied with the existing economic doctrine that stresses the Nash equilibrium concept, this study intends to provide specific laws that could animate people's ideas and feelings and govern human decisions. These laws, which should not contradict the basic principles of physics and biology, are briefly phrased in the following:

- The First Law of Human Behavior – all the activities of the human's mind are driven by the quantum mechanics of human's brain cell;

- The Second Law of Human Behavior – the dynamics of human behavior should mimic our nerve impulses toward external stimulus as specified by the cable equation of the Ohmic model.

The internal information movement driven by our quantum mind is quite akin to Chinese qi (氣 or spiritual strength). This qi, meaning volition in Chinese, is the undercurrent of a human's mental power that flows freely within our physical body and plays a pivotal role in forming our preference. The internal force drives our intention or motive to behave, thus bridging our brain and action like our hidden consciousness.

Every time we go through the daily grind, trudging through our everyday activities, we de-energize ourselves. Our spirit is being drained away, and our bodies are inundated with exhausted qi instead. This exhausted and depreciated qi causes us to live poorly and out of balance that we easily get fatigued. If we continue living like this, our qi, hence spirit, will ebb away long before our physical life ended. The world of our experience consists of discrete things that typically interact poorly with one another. The fragile, imperfect relationships among human beings are good examples.

Balancing out different spheres of external distraction (i.e., the thermodynamic noises in the quantum world) helps to support our emotions and strengthen our qi. Many of us seek tranquility and alignment by withdrawing from the world temporarily, avoiding the various entanglements that draw out all sorts of uncomfortable feelings. Aside from taking a break, going on vacation or a retreat, or doing meditation, we can experience balance and alignment (or the so-called coherence in terms of quantum biology) always by modulating our impulsive desires and smoothing the ups and downs that come with too much anger or even too much joy.

After deriving the dynamic behavior of qi movement, this study illustrates how one's marginal utility evolves across time and somehow resolves the long-pending prisoner's dilemma. By converting the qi equation into the wave function in the format of quantum mechanism, this model can further explain the phenomenon of coherence or resonance that is the critical factor to dampen the adverse impact of external shock. It thus justifies the role played by culture to align the conflicting interests among game participants and facilitate more efficient economic development.

DYNAMIC EQUATION OF QI

In the following, we are trying to formulate the movement and characterize the behavior of qi in line with the nature of quantum biology. To begin with, we define "qi" (abbreviated as C) as something like the concentration of one's volition, which may be 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. We will not go to the details of this discussion. Instead, we derive an equation of qi'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 element can stand for the constituent of "qi" and the distance x is measured along the conduit of our mental body. How many elements will move across the unit area from point x to point $(x + \varepsilon)$?

$$N(x) : N(x+\varepsilon)$$

$$x : x+\varepsilon$$

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

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

This study builds up a theoretical model to quantify the formation of Keynes' animal spirits. It derives the equations demonstrating why and how the herding behavior or the business cycle would conduct. We integrate the Western concept of spirits and the Chinese qi in our model to show that the internal force drives a human's motive to behave and bridges man's brain and action like hidden consciousness. After deriving the dynamic behavior of the qi movement, this study illustrates how one's marginal utility function evolves across time. This non-stationary marginal utility concept is closer to modern behavioral economics and would revolutionize the conventional utilitarianism-related economic models. Our model is applicable in the micro-context to a human being and is expandable in the macro-context to any artificial entity. We hope that the methodology underpinned in this study could open a new window for future research to better cope with the current intractable and turbulent economic environment.

If it turns out to be negative, more elements will cross to the left than to the right. To obtain the net flux, J_x, we divide the net number above by the area normal to the x-axis, A[1], and by the time interval, τ,

[1] A is the cross-section area of the "qi" aqueduct. It is considered here for the sake of easy derivation. The final formulation of our "qi" equation will not depend on A.

$$J_x = -\frac{1}{2}[N(x+\varepsilon) - N(x)\}/A\tau$$
$$= -\frac{\varepsilon^2}{2\tau}\frac{1}{\varepsilon}\left[\frac{N(x+\varepsilon)}{A\varepsilon} - \frac{N(x)}{A\varepsilon}\right]$$
$$= -D\frac{1}{\varepsilon}[C(x+\varepsilon) - C(x)]$$

Where $D \equiv \varepsilon^2/2\tau$ is the diffusion coefficient, and $C(x+\varepsilon) = N(x+\varepsilon)/A\varepsilon \,\&\, C(x) = N(x)/A\varepsilon$ are the number of elements per unit volume at the points $x+\varepsilon \,\&\, x$ respectively. In the limit $\varepsilon \to 0$, we obtain the net flux, J_x:

$$J_x = -D\frac{\partial C}{\partial x} \quad (1)$$

Assume that the total number of elements is conserved, as shown in Figure 1 below.

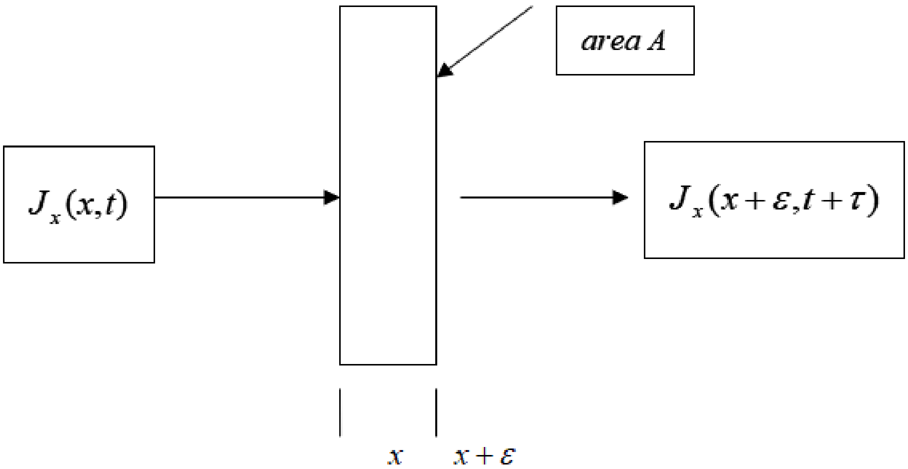

FIG 1. THE ELEMENTS MOVEMENT

Consider the box in Figure 1. In a period of time τ, $J_x(x)A\tau$ elements will enter from the left, and $J_x(x+\varepsilon)A\tau$ elements will leave from the right. The volume of the box is $A\varepsilon$. If the elements are neither created nor destroyed, the number of elements per unit volume in the box must increase at the rate

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

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

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

By substituting equation (1) into equation (2), we get the equation of qi's movement as

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

The equation (3) above is similar to the linear cable equation for nerve impulse that embodies the Ohmic hypothesis, i.e.,

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

where v is the difference between the interior potential of an axon and its quasi-steady value.

Letting $w(x,t) \equiv e^{t/\tau} v(x,t),$ the linear cable equation becomes

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

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

We now turn to the discussion of diffuse with drift. We compute the velocity at which an element drifts through the medium when exposed to an externally applied force. If all the elements in a distribution drift in the +x direction at velocity v_d, then the flux at point x must increase by an amount $v_d C(x)$. Thus equation (1) above becomes

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

The derivation of the equation of qi's movement with drift proceeds as before, giving

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

One example of v_d can be derived by imposing an external force F_x on the element that randomly walks with speed $v_x = \varepsilon / \tau$ initially. From Newton's second law, we know that $v_d = \frac{1}{2}\frac{F_x}{m}\tau.$ An element at absolute temperature T with mass m and velocity v_x on the x-axis has kinetic energy $mv_x^{\,2}/2$. This quantity fluctuates, but on average $mv_x^2/2=kT/2$, where k is Boltzmann's constant. By substituting $D=\varepsilon^2/2\tau, v_x=\varepsilon/\tau \,\&\, mv_x^2/2=kT/2$ into $v_d=\frac{1}{2}\frac{F_x}{m}\tau$, we can get $v_d=(D/kT)F_x$. For economic interpretation, the consumption of a specific good or service, Y, is deemed as the dispensation of qi and will decrease the concentration of qi at the present time and bring in an inverse external force, i.e., F_x, and a negative v_d as well. Therefore, we can write the above v_d as

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

as a result of consumption Y, and λ gauges the characteristics of one's "qi" system and should be positively correlated with D/kT .

After considering the natural depreciation of our life as tallied by an increase of entropy based on the second law of thermodynamics and the learning effect as addressed by the Hebb rule (see appendix 1), we can obtain the complete equation for the dynamics of qi as:

$$\frac{\partial C}{\partial t}=D\frac{\partial^2 C}{\partial x^2}+\lambda Y\frac{\partial C}{\partial x}-\frac{1}{Tk(1+\ln C)}\frac{dE}{dt}-C+\sum_b w_b u_b \tag{7}$$

where k is Boltzmann's constant, E and T are the energy and temperature of the system we are dealing with, respectively. In this study, we adopt and modify the concept of the Hebb rule to include all the relevant inputs in our memory that affect the reaction of our qi toward the specific activity u_b with w_b capturing the strength of that memory impact on qi. This learning impact from various memory sources provides the theoretical argument for how culture affects one's decision.

CONVERTING QI EQUATION INTO THE DYNAMICS OF ECONOMIC SATISFACTION

We define one's satisfaction (or happiness) μ as the underlying force that consumes (or depreciates) one's qi and moves against the normal direction of a life force. It can be written as $\mu\equiv-\partial C/\partial x$. Let $v=dx/dt$, which measures the normal speed of passage for one's life and is an inherent characteristic of one's qi system. For simplicity, we assume it maintains relatively constant in the process[2]. Then $\partial C/\partial t=-\mu(t)\cdot v$, and $\partial C^2/\partial x^2=-d\mu/dt\cdot dt/dx=(-1/v)\cdot d\mu/dt$. Putting all these together, we can rewrite equation (7) as

[2]It is assumed constant for simplicity. Otherwise, we need to solve a complicated partial differential equation.

$$\mu(t)\cdot v=\frac{D}{v}\cdot\frac{d\mu(t)}{dt}+\lambda Y\mu(t)+\frac{dE/dt}{Tk(1+\ln C)}+C-\sum_{b}w_b u_b \tag{8}$$

The solution for the above first-order differential equation is

$$\mu(t)=(\mu(0)-A)\cdot\exp[\frac{v^2-\lambda Yv}{D}\cdot t]+A$$

where

$$A=-f/(v-\lambda Y)=\left[\frac{dE/dt}{Tk(1+\ln C)}+C-\sum_{b}w_b u_b\right]/(v-\lambda Y) \tag{A}$$

and $\mu(0)$ is determined by the boundary condition at t = 0. We assume that the consumption of Y good or service happens in the very beginning, i.e., at t = 0. Hence, $\mu(0)$ is a function of Y and can be rewritten as $\mu(0;Y)$. As time goes on, $\mu(t)$ will become

$$\mu(t;Y)=(\mu(0;Y)-A)\cdot\exp[\frac{v^2-\lambda Y v}{D}\cdot t]+A \tag{9}$$

And the marginal satisfaction (utility) from the consumption of Y can be shown as follows:

$$\frac{\partial\mu(t;Y)}{\partial Y}=[\mu(0;Y)-A]\cdot\exp[\frac{v^2-\lambda Y v}{D}\cdot t]\cdot(-\frac{\lambda v t}{D})\ (>0) \tag{9'}$$

Let v be the normal speed of qi movement against the direction of depreciation (or consumption). In the case that the net impact of entropy and learning effect on the accumulation of qi is negative (i.e., f<0), ν must be greater than λY in such a way that A becomes greater than μ(0;Y). Otherwise, we would have a negative marginal utility from consumption of Y as shown in the marginal satisfaction from consumption Y above. In the case that the net impact of entropy and learning effect is positive (i., f>0), ν must be less than λY so that A>μ(0;Y) (otherwise marginal utility from Y would be negative.

When the consumption of Y is conducted repeatedly (instead of one shock happening at time 0), we can derive the property of declining marginal satisfaction (utility) as shown below:

$$\frac{\partial\mu^2(t;Y)}{\partial Y^2}=[\mu(0;Y)-A]\cdot\exp[\frac{v^2-\lambda Y v}{D}\cdot t]\cdot(\frac{\lambda v t}{D})^2 \tag{9''}$$

which is less than zero as long as $\mu(0;Y)-A<0$ is satisfied. In other words, in order to bring about the property conventionally assumed by our economics textbook, i.e., a positive and declining marginal utility, we need to satisfy the following biological assumption:

Biological Assumption for a Positive and Diminishing Marginal Utility:

(1) The influx of external input Y never exceeds the natural speed of qi movement ν so that $\nu > \lambda Y$;

(2) The net impact of entropy and learning effect on the accumulation of qi is sufficiently negative (i.e., f<0) so that A is greater than μ(0;Y).

Equation (9) describes the dynamic path of one's satisfaction from the one-time consumption at time 0. It shows that every economic activity has a lingering effect that will eventually sink into the sediment of our memory through the u_b in the above equation and exert its impact on our future interaction with the same or similar activity. This equation explicates the important role played by wealth, education, experience, culture, enthusiasm, and health condition through the parameters dE/dt, D, T, ν, w_b, u_b & λ in the digestion and consummation of one's satisfaction. Moreover, the entropic force that works by the second law of thermodynamics will boost our satisfaction through its natural dispersion of order and the consumption of our accumulated qi.

From equations (9') and (9") we can readily see that the greater A is, the greater the marginal utility becomes and the faster the marginal utility diminishes. According to the definition of A in equation (A) above, we can derive the following proposition:

Proposition 1: When the biological assumption holds, an increase in the growth of one's wealth (i.e., an increase in dE/dt) will result in a decline in one's marginal utility and an accelerating diminution in one's marginal utility from the consumption of Y.

Corollary 1: When the biological assumption holds, a reduction in one's enthusiasm or eagerness about the consumption of Y (i.e., a reduction in T) will result in a decline in one's marginal utility and an accelerating diminution in one's marginal utility from the consumption of Y.

Corollary 2: When the biological assumption holds, a relatively less experience or habit in consuming Y (i.e., a diminution in one's learning effect $w_b u_b$) will result in a decline in one's marginal utility and an accelerating diminution in one's marginal utility from the consumption of Y.

The proposition above provides a theoretical underpinning of how our marginal utility evolves owing to the effect exerted by the second law of thermodynamics (i.e., from the impact of dE/dt and T) and the impact of culture, education, habit, and experience (i.e., through the learning effect $\sum_b w_b u_b$). This property of ever-changing marginal utility paves the way of overcoming the inevitable outcome of the prisoner's dilemma that beleaguers our conventional economics. When one takes the initiative to cooperate, the experience of this benign intention observed by her opponent will gradually alter her marginal utility to become less diminishing or more treasure the long-term relationship. Therefore, both players are more willing to show the cooperative intention and dampen the incentive to violate the cooperative agreement or atmosphere thus developed.

Moreover, the implication of this evolving marginal utility will open the door of how one's behavior affects her opponents' attitude through the learning effect. The Nash equilibrium that becomes the cornerstone of modern economics will have since been revised. When one player chooses her best strategy in a game, she should no longer assume that her opponent's behavior or strategy be stationary in response to her offer. The consequence of any activity will imbue her opponent with a specific connotation of what it exactly means and bring in a change in the opponent's attitude (or marginal utility).

QI AND ECONOMIC SYSTEM

In modern economics, it has become standard practice to model agents as utility maximizers. Consumption is modeled by assuming that agents maximize utility over their lifetimes, or even over an infinite horizon that includes the lives of their descendants. Demand for money is the result of selecting an optimal portfolio of assets given the need to finance transactions and expectations of the future (King, 2016). This study basically modifies the conventional utilitarianism and challenges the notion of rational behavior upon which the micro-foundations in modern economics are constructed. The framework laid out in this model is closer to that of modern behavioral economics. Economic behavior is based on one's gut feeling, the biological reaction (or intuition) about how sensible people would behave according to his education, experiences, and lessons learned through observing behavior close at hand. As Keynes claimed in his *General Theory*, people's "animal spirit" and optimism or pessimism about unpredictable future is the predominant factor to cause the economic repercussion. This model intends to shed some light on this "animal spirit."

A conscious human being makes numerous economic decisions every day based on how her thinking framework is grated on the interaction of billions' neurons. Although thinking pattern differs dramatically from one another by one's distinct experience, heritage, and cultural background, a common trait would not deviate too much from the dynamic rule of evolution (or qi) as described in equation (7) above. This equation of qi can be interpreted more broadly in the following sense:

$$\frac{\partial C}{\partial t} - \sigma(C,t)\frac{\partial^2 C}{\partial x^2} - \alpha(C,t)\frac{\partial C}{\partial x} - f(C,t) = 0 \qquad (10)$$

Where $\sigma(C,t)$ characterizes the diffusion nature of the system and equals D in this model, $\alpha(C,t)$ depicts the external driving force upon this system and equals λY in this model, $f(C,t)$ reflects the inherent depreciating force in the absence of any outside disturbance and equals $-\frac{1}{Tk(1+\ln C)}\frac{dE}{dt}-C+\sum_b w_b u_b$ in this model.

By assuming a constant $v(t)=\frac{\partial x}{\partial t}$ for the simplification of interpretation, the dynamics of perceived satisfaction, $\mu=-\frac{\partial C}{\partial x}$, will then follow the following equation:

$$\mu(t)\cdot v(t)=\frac{\sigma}{v(t)}\cdot\frac{d\mu(t)}{dt}+\alpha\mu(t)-f \tag{11}$$

The solution for the above first-order differential equation is

$$\mu(t)=(\mu(0)-A)\cdot\exp[\frac{v(t)^2-\alpha v(t)}{\sigma}\cdot t]+A \tag{12}$$

where $A\equiv -f/(v(t)-\alpha)$, and $\mu(0)$ is determined by the boundary condition at t = 0.

An economic agent's behavior is driven by her gut feeling about the consequence of her economic decision. This gut feeling can be gauged by the repercussion on qi (equation 10) or satisfaction (equation 11). The impetus of economic activity is summarized in three factors: $\alpha, \sigma \,\&\, f$. α measures the average magnitude of external shock (force), which is likened to the government's economic stimulus or the rate of return for a portfolio choice in the example of an investment decision. σ reflects the dispersion or variance of the economic environment faced by a government or the return variance of an investment portfolio for an investor. One's memory, or the impact of culture on the decision object, is captured by the factor f. In addition, f manifests the natural depreciation force of one feeling as displayed in the second law of thermodynamics. The latter force leads to such economic phenomena as diminishing marginal utility, fad or herding behavior, and even the inexorable business cycle.

When we ignore the term $f(C,t)$, equation (10) reduces to the celebrated *Kolmogorov's forward equation*, the solution of which is

$$C(t,x)=\frac{1}{\sqrt{4\pi\sigma t}}\exp\left\{-\frac{[x-(x_0+\alpha t)]^2}{4\sigma t}\right\},$$

where x_0 is the initial value of $x(t)$ when t = 0. If we add the term $f(C,t)$ and simplify it to be $C \cdot \beta\,(<0)$, then the solution to equation (10) becomes

$$C(t,x) = \exp(-\beta t) \cdot \frac{1}{\sqrt{4\pi\sigma t}} \exp\left\{-\frac{[x-(x_0+\alpha t)]^2}{4\sigma t}\right\} \tag{13}$$

And the equation (12) above is a special case of equation (13) when we assume $x = v \cdot t$.

The equation (13) can be interpreted as the strength and resilience of an entity's growth potential and can be used as an alternative measurement of how the entity will evolve at time t when the subject maintains its current position x_0 at time t = 0. The entity can be an individual, financial derivative asset, society, corporation, country, or economic system. For example, if we interpret x_0 as a country's per capita wealth, then the qi (i.e., the degree of concentration or likelihood) that her per capita wealth would achieve the level x at time t is equal to C(t, x) as shown in equation (13).

The expression for C(t, x) is akin to the normal distribution with a mean equal to $x_0 + \alpha t$ and variance equal to σt, and magnified by a magnitude $\exp(-\beta t)$. The latter is the primary factor in gauging the degree of assurance for what a specific agent (an individual, a corporation, or a state) can achieve its objective (x) at time t through its effort of exerting Y. It is noted that

$$\beta = \frac{f}{C} = -\frac{\frac{dE}{dt}}{Tk(1+lnC)} * \frac{1}{C} - 1 + \frac{\sum_b w_b u_b}{C} < 0.$$

In the case of securing a country's higher standard of per capita wealth through its boosting economic policy (Y), we can readily derive the following proposition:

<u>Proposition 2</u>: The greater escalation of a state's wealth (i.e., an increasing dE/dt), the lesser hubbub in striking its specific public policy (i.e., a lesser degree in T),

<u>Corollary 3</u>: The more willing to learn the lesson from its history (i.e., a larger sum of $\sum_b w_b u_b$), the more likely for the state to secure its economic achievement through its policy inputs (Y).

Another analogy of this model is the implication on the pricing of a derivative asset. It is known that under the arbitrage-free condition, the diffusion differential equation associated with an asset price (F) that is derived from the underlying stock price (S) can be written as

$$\frac{\partial F}{\partial t} + \frac{1}{2} b^2 S^2 \frac{\partial^2 F}{\partial S^2} + rS \frac{\partial F}{\partial S} - rF = 0$$

when the diffusion process for the stock price is described by a geometric Brownian motion as $dS = aSdt + bSdW$. This diffusion differential equation is akin to our broadly defined dynamic equation of qi (equation 10) above as long as we interpret asset price F moves against the direction of qi (similar to the direction of consumption), σ to be $\frac{1}{2}b^2S^2$, α to be rS, and f to be $-r$F. The solution to this diffusion equation is the well-known *Black-Scholes Formula (*Bjork, 2004*).*

CONCLUDING REMARKS

This paper exemplifies how the Chinese qi, which is transfigured in the form of animal spirits in Keynes' study, can illustrate human behaviors and multifaceted economic phenomena. Economic behavior is nothing but one dimension of qi's manifestation in the macro-environment context. It presides over an economic man's behavior and underscores the market activities of our economic system. On the one hand, it is congruent and resonant with the thermodynamic theory of entropy and the Ohmic hypothesis of our nerve impulse (cable equation). On the other hand, it dictates how our desire evolves, how our inter-temporal investment decision is made, and underpins the Black-Scholes formula of derivative asset pricing.

The qi dynamics can be interpreted as one's indirect utility function that satisfies all the resource constraints confronted in the interconnected economic system. Or, more precisely, our human behavior is conducted in accordance with a partial differential equation with its coefficients determined in a complicated way by economic conditions as well as the natural law of entropy dissipation and an individual's personality and learning characteristics.

These qi dynamics are the same law that governs both our human behavior and the natural phenomenon. It not only echoes an individual's decision but also reins in a group's aggregate behavior with its coefficients adequately adjusted based on the nature of the group's economic system. Human history falls prey to the interaction of the market and morals. Chinese history of economic thought is fraught with moral disciplines while modern Western history emphasizes and treasures more on the market mechanism. Either moral or market has its own strength and weakness and will earmark a distinctive set of coefficients in qi's partial differential equation. How these coefficients are derived or adjusted from different settings of the economic system is worthy of our further study.

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APPENDIX 1: Consideration of Entropy and Learning Effect

According to thermodynamics, a measure of the disorder called the entropy, denoted S, is 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[3]. 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

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

According to the fundamental definition of temperature[4], T, we have the following relationship among entropy (S), energy (E), and temperature (T) as

$$T = (dS/dE)^{-1}.$$

If we bring a small system A into thermal contact with a big system B in equilibrium at temperature T, then B will stay in equilibrium at the same temperature (a is too small to affect it), but a will come to a new equilibrium, which minimizes the quantity $F \equiv E - TS$. The quantity F is called Helmholtz free energy of the subsystem. The minimum is the point where F is stationary when $\Delta F = 0$, which implies $T \cdot \Delta S = \Delta E$ as the one for the definition of T. When a subsystem is in a state of greater than minimum free energy, it can do work on an external load. The maximum possible work we can extract is $F - F_{\min}$. From the above equations, we can obtain another source of change in qi as

$$\frac{dC}{dt} = -\frac{1}{k(1+\ln C)}\frac{dS}{dt} = -\frac{1}{Tk(1+\ln C)}\frac{dE}{dt} \qquad \text{(A1)}$$

As we accumulate more energy (or economic wealth) E, it will create a self-depreciation force that gradually drains the concentration of our "qi" according to the second law of thermodynamics.

In 1949, Donald Hebb conjectured that if input from neuron A often contributes to the firing of neuron B, then the synapse from A to B should be strengthened. Hebb suggested that such synaptic modification could produce neuronal assemblies that reflect the relationships experienced during training. The Hebb rule forms the basis of much of the research done on the role of synaptic plasticity in learning and memory. For example, consider applying this rule to neurons that fire together during training due to an association between a stimulus and a response. These neurons would develop strong interconnections, and subsequent activation of some of them by the stimulus could produce the synaptic drive needed to activate the remaining neurons and generate the associated response. Consider a single postsynaptic neuron driven by N_u presynaptic inputs with activities represented by u_b for $b = 1,2,\ldots,N_u$, then the dynamics of postsynaptic activity v can be described according to the Hebb learning rule as

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

where γ is a time constant that controls the firing-rate response dynamics and w_b is the synaptic weight that describes the strength of the synapse from presynaptic neuron b to the postsynaptic neuron.

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

[4] The temperature T can be interpreted as the degree of enthusiasm toward the object entering into the qi system.

In this study, we adopt and modify the concept of the Hebb rule to include all the relevant inputs in our memory that affect the reaction of our qi toward the specific activity u_b with w_b capturing the strength of that memory impact on qi. This learning impact from various memory sources provides the theoretical argument for how culture affects one's decision. Accordingly, we have an additional source of thrust on the qi movement from this learning effect as

$$\frac{dC}{dt} = -C + \sum_b w_b u_b \tag{A2}$$

Combining equations (5), (6), (A1), and (A2), we can obtain the complete equation for the dynamics of qi as:

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} + \lambda Y\frac{\partial C}{\partial x} - \frac{1}{Tk(1+\ln C)}\frac{dE}{dt} - C + \sum_b w_b u_b \tag{A3}$$

APPENDIX 2: Human Spirit and Chinese Qi

The quantum life described according to the recent development of quantum biology can be reinterpreted by the Chinese "qi." The Righteous Qi poem written by Wen Tien-Shang, the Chinese scholar in Sung dynasty, once described the "righteous (or divine) qi" that permeates everywhere in the world in the following way[5]

As for the essence of all things, it is this that is life.
Below it generates the five grains;
Above it becomes the arrayed stars.
When it floats between Heaven and Earth, we call it ghosts and spirits;
When it is stored within a person's chest, we call that person a sage.

The notion of divine energies was hardly an unusual one in antiquity. It was a pan-Eurasian concept: in India, there was the notion of prana, or "breath," and in Greece, there was pneuma, or "breath of life," "soul," "spirit." All described a sense that some ineffable, unseen life force coursed throughout the cosmos and was responsible for the origins of life itself. Today many people would be skeptical that feelings of vitality come from divine energies. But the Chinese "qi" is a useful metaphor for what it would take to make us feel more alive.

Although qi exists in everything, there are infinite gradations of it. Rocks, mud, earth, and other inanimate parts of the cosmos are composed of a low and coarse qi—what we might call turbid qi. As qi becomes more highly refined, it becomes "vital essence" What sets vital essence apart from all else is that it exists only within things that have life. It is a life-giving force found in plants and animals. And finally, when qi is at its most ethereal and refined, it becomes divine qi. This sort of qi is so highly energized that it actually affects things around it. This qi is spirit itself. Spirit goes beyond a life-giving force; it gives living beings consciousness.

To hold the spirit within and not allow things to disorder our senses, we need to find an underlying Tao (道) in which everything is connected. The more these discrete things of the world interact with one another, resonating with one another, the closer they get to the Tao. These dynamics of qi reflect the interaction of Chinese Yin and Yang (Ritsema, 2005). We get closer to the Tao and increase our feelings of vitality when we cultivate the ability to remain balanced. The more stable we are, the more able we are to refine and hold on to the fresh qi.

We believe that we have created the first quantitative model to demonstrate the power of the Chinese qi. Chinese culture believes that qi is omnipresent and reflected into kaleidoscopic shapes of things and beings in the universe (天地有正氣, 雜然付流形). Equation (13) demonstrates the flexibility of our model, which is applicable not only in the micro-context to a human being but also is expandable in the macro-context to any artificial entity.

[5]See the translation of the poem and the illustration of "qi" by Puett and Gross-Loh (2016).