IN SEARCH OF CONSISTENCY IN AN ASYMMETRIC WORLD

Udayan Kumar BASU*

Abstract: *While nature loves symmetry inasmuch as many natural laws remain invariant under various transformations, description of the natural diversity warrants some kind of breakdown of symmetry. Such a breakdown of symmetry may be either explicit or spontaneous. Many significant developments have taken place in recent times in diverse fields of study. Algorithmic information theory has been formulated by Kolmogorov and others. Spontaneous breakdown of symmetry and its use in the standard model of particle physics, discovery of the Higgs Boson are all notable events. Work of Ilya Prigogine to accommodate biological self-organisation within the ambit of the second law of thermodynamics is also quite noteworthy. According to some, his principle of minimum entropy production has added a dynamic content to the second law of thermodynamics, which otherwise is viewed as a mere kinematic constraint. It appears that non-linear dynamics and the catastrophe theory of Rene Thom can play an important role to understand a sudden qualitative change of a dynamical system triggered by certain value of a parameter. Phase change of water subjected to external heating or change from a stable economy to one marked by trade cycles are examples of such sudden transitions. Advent of econophysics and behavioural finance has facilitated a new way of looking logically at the problems of finance and economics with the help of established physical laws as well as rigorous mathematical and statistical analyses. Importance of such an approach is evident from the sad plight of Louis Bachelier. In this article, it has been our effort to link up such apparently disjoint developments from diverse fields of study within the ambit of a single logically consistent framework.*

Keywords: *Symmetry, Invariance and Law of Conservation, Randomness, Complexity, Information Theory, Asymmetry, Explicit Breakdown of Symmetry, Spontaneous Breakdown of Symmetry, Goldstone Boson, Higgs Boson, Standard Model of Particle Physics, Principle of Minimality, Action in Classical Mechanics, Optical Path, Minimum Entropy Production, Statistical Mechanics, Self-Organisation, Genetic Code, Catastrophe Theory, Trade Cycle, Econophysics, Corporate Finance, Capital Budgeting Techniques, NPV, IRR, Parity, Speculation and Brownian Motion, Efficient Market Hypothesis, Market Correlation, Psychology, Behavioural Finance.*

* India, udayan_basu@yahoo.co.in

1. Nature Loves Symmetry

"Nature loves symmetry" is a very common statement in the world of physics. This is based on the fact that many natural laws (like the Newton's laws of motion) obey the requirements of symmetry. These laws, which hold good at my current location, continue to hold true if I move 100 metres or 100 kilometres to the north. If I now turn around and move away from north direction to east, south or west, the laws are still applicable with equal force. As a matter of fact, these are applicable even in outer space and on the moon. It means that these natural laws are invariant under translation and rotation. In other words, they exhibit translational and rotational symmetry.

Emmy Noether proved a theorem in 1915 (known as Noether's theorem) which links invariance under any continuous change to a conservation law. It states that if the Lagrangian function for a physical system is not affected by a continuous change (transformation) in the coordinate system used to describe it, then there will be a corresponding conservation law; i.e. there is a quantity that is constant. For example, if the Lagrangian is independent of the location of the origin then the system will conserve linear momentum. If it is independent of the base time then energy is conserved. If it is independent of the angle of measurement then angular momentum is conserved.

Besides these, certain properties of atomic nuclei may depend on the number of nucleons rather than the numbers of protons and neutrons and, but for the Coulomb force, neutrons and protons may appear similar. Based on this, a concept of charge invariance was proposed and Heisenberg mooted a new parameter isospin. Charge $Q = \frac{1}{2}(1 + k)$ where $k = 1$ for a proton and $k = -1$ for a neutron. Neutron and proton are considered two different states (isospin doublet) of the same elementary particle (nucleon) with different isospins. Certain properties remain invariant if k changes from 1 to –1 or vice-versa, leading to conservation of charge. Isospin, linked to $\frac{1}{2}k$, is the associated quantum number. Further, particles and antiparticles (like electron and positron) have identical masses, magnitudes of charge and lifetimes with difference in the signs of their charges. This has been linked to CPT (Charge, Parity and Time Reversal) invariance of the physical theories.

2. Absolute Symmetry can be Absolutely Uninteresting

Absolute symmetry may not be interesting at all. It may mean total void. If there is an object somewhere, translational and rotational symmetry would warrant existence of exactly identical objects all around and nothing else. No diversity of any type can thus be accommodated, although nature is full of all kinds of diversity. Even the domain of physical cosmology has what is known as the baryon asymmetry.

So, study of any meaningful scenario would require some kind of breakdown of symmetry, although the same set of physical laws may still prevail all over the universe.

Ask any electronics and telecommunication engineer. He too would narrate a similar story. An electromagnetic (pure sinusoidal) wave may be perfectly symmetrical but does not carry any information. For carrying information like news, music, movie etc., a signal /pulse has to piggyback the electromagnetic wave through what is called modulation. The receiver set receives the modulated carrier wave, demodulates to extract the signal and presents the same after suitable processing. So, for any information content, the perfect symmetry of an electromagnetic wave needs to be broken through the process of modulation.

Also, let us not forget the famous Charles Darwin propounding his theory of natural selection from a diverse pool of possibilities. In a world of perfect symmetry how can we have a diverse genetic pool to choose from?

As for information, it needs some degree of complexity that neither specified symmetry nor unspecified randomness can account for. According to the concept of algorithmic complexity formulated by Kolmogorov et al, the size of the minimal algorithm determines the degree of complexity. If one wants to write “God” 10000 times or to generate random 5 lettered combinations (not all of them are words in the dictionary), the algorithm may be trivial and rather small. However, the message coded in a single DNA using various combinations of the bases A, T, G and C (4 lettered genetic alphabet) is rather complex and very rich in information. Incidentally, in case of combinations of letters from say the English alphabet, certain human beings select the combinations that would carry some meaning, and optimality of such a selection process may always be an issue. In case of a DNA, however, selection from possible genetic combinations is done by nature itself.

3. Explicit Breakdown and Spontaneous Breakdown of Symmetry

The much-needed breakdown of symmetry can come about in two different ways – explicit breakdown and spontaneous breakdown.

Explicit breakdown means that the Lagrangian or Hamiltonian for the system includes a term that does not fulfil the requirement of symmetry. The impact of the asymmetric term is then calculated by employing perturbations of different orders.

On the other hand, in case of spontaneous breakdown of symmetry, the Lagrangian is still invariant under the transformation but the ground /vacuum state of the system is not.

4. Spontaneous Breakdown of Symmetry and Goldstone Boson

In relativistic quantum field theory, there is a theorem called Goldstone's theorem. According to this theorem, if there is an exact continuous symmetry of the Hamiltonian or Lagrangian defining the system, and this is not a symmetry of the ground/vacuum state (i.e. there is a spontaneously broken symmetry), then there must be at least one spin-zero massless particle called a Goldstone Boson. Boson, as we know, is a name given to the set of elementary particles with integral spin following the celebrated Bose Einstein Statistics (after Satyendra Nath Bose and Albert Einstein).

5. Higgs Boson or the God Particle

Goldstone's theorem is a crucial preliminary to understand the need for a Higgs Boson in the Standard Model theory of particle physics. Here mass for the Boson is generated through interaction/coupling between the fields. A suitable meson to complete the model for a unified field theory was thus in place. The question then was one of detection of the Higgs Boson, which was also named as the God Particle.

6. Experiments to detect Higgs Boson

The Higgs mechanism is generally described as a case of spontaneous symmetry breaking. This mechanism plays an important part in the

Standard Model of particle physics. It provides the theory with mass for the gauge Bosons of the weak interaction.

With a mass of more than 120 times that of the proton, the Higgs Boson became the second-heaviest particle. This large mass, combined with an extremely short lifetime (10^{-22} second) means that the particle cannot be found in nature. Its existence can be verified only by producing it in the laboratory. The first particle collider in history capable of producing Higgs Bosons in significant numbers was the Large Hadron Collider (LHC). The LHC accelerated protons to nearly the speed of light, giving each of them an energy of 6,500 giga electron volts, or GeV (at rest, protons have an energy of roughly 1 GeV; 1 GeV = 10^9 eV). These accelerated protons circulate through the LHC's 26.7-kilometer-long tunnel until they collide. Such encounters create a spray of particle debris – and in rare cases, the elusive Higgs Boson.

The Higgs Boson was eventually discovered on July 4, 2012 during a proton-proton collision, almost 50 years after first being proposed. Professor Peter Higgs received the 2013 Nobel for Physics and died on 08/04/2024.

7. Principle of Minimality in Nature

Successful use of spontaneous breakdown of symmetry to formulate the Standard Model of particle physics strengthened the case for a minimal breakdown of symmetry.

The principle of minimality had already been known in the field of physics. Path of least "Action" can solve problems of classical mechanics. According to Fermat's principle, minimality of optical path between two given points can lead to the laws of reflection and refraction (Snell's law).

Next, we consider the 2nd law of thermodynamics, which states that, for any isolated system, entropy can never decrease. Does it militate against the principle of biological evolution, which requires higher order of self-organisation? At the outset, we start by realising that life can be viewed as the condition/process of a thermodynamically open system characterised by self-organisation and growth. Being an open system, it is free to receive external supply of energy from the sun. Even plants require such supply in order to survive.

Also, it is not essential that increase of overall entropy has to mean increase of entropy everywhere. It is possible to look for a minimal increase of entropy along with a decrease of entropy locally. For instance, at the time of formation of crystal from a super saturated solution, crystal being an ordered structure, the entropy decreases locally. However, due to liberation of heat of crystallisation, the surrounding system becomes agitated leading to an increase of overall entropy.

Finally, the principle of minimum entropy production propounded by professor Ilya Prigogine (well known for his work in Statistical Mechanics) states that: The steady state of an irreversible process, i.e., the state in which the thermodynamic variables are independent of the time, is characterized by a minimum value of the rate of entropy production. As a part of his endeavour to reconcile physical laws with biological evolutions, professor Prigogine had pointed out, with the help of inter alia a detailed analysis of the "Benard problem", that it is possible to reach a new equilibrium state of a system using fluctuations once it is far removed from the erstwhile stable equilibrium state. As a matter of fact, such a phenomenon seems possible in case of non-linear systems having multiple steady states as the system is pushed from a particular steady state to the extremity of its stability zone. Bifurcation/Catastrophe, explained by the French mathematician Rene Thom (recipient of 1958 Fields Medal – often considered equivalent to the Nobel in mathematics), is also a similar phenomenon involving a sudden qualitative change of a dynamical system with continuous change of an external parameter (like sudden phase change of water at its boiling point when heat is added to it continuously from an external source). Similarly, economy of a country is at an equilibrium as long as its planned saving equals the planned investment. But, with certain change of a suitable parameter in a non-linear theory, the economy may bifurcate and undergo a sudden transition to a new state characterised by trade cycles.

Professor Prigogine received the 1977 Nobel for Chemistry and expired on May 30, 2003.

8. Integration of Physics & Mathematics with Finance & Economics

A. Econophysics

While writing a book on heat and thermodynamics in 1931, Professor M. N. Saha, a noted Indian scientist, discussed the Maxwellian distribution of velocity among gas molecules at a given temperature. As a footnote, he had mentioned there that the wealth distribution in a society should also follow a similar law.

This idea has since taken wings and a new subject named econophysics is now exploring new horizons in the field of finance and economics.

For instance, econophysics has already left its imprint in the area of Capital Budgeting Techniques. This is a very important and widely used concept under Corporate Finance/Project Finance which sets the criteria for evaluation of financial viability of any type of project. Some fundamental issues in this context have already been addressed in econophysics and it has been pointed out that:

(a). The number of IRRs (Internal Rate of Return) in any given scenario has nothing to do with the number of times the cash flows associated with the project change sign. A completely wrong concept that there would be as many IRRs for a project as the number of changes of signs of the associated cash flows was based on a wrong application of the Descartes Rule of Signs. Descartes Rule of Signs is of course absolutely correct. Unfortunately, some universities may still be teaching such wrong concepts under their syllabus for finance.

(b) The criterion for financial viability of a pure Borrowing Project should be NPV ≤ 0 and not NPV ≥ 0 where NPV stands for the Net Present Value of the project under consideration.

(c) With reference to a transformation that changes the signs of all the cash flows associated with a project leaving their magnitudes intact, NPV has a negative parity while IRR has a positive parity. This is fully consistent with the finding at point (b) above inasmuch as if NPV ≥ 0 is the criterion for financial viability of a lending project, that for the corresponding borrowing project cannot but be NPV ≤ 0.

(d) If all kinds of friction like payments to third parties (brokerage, syndication fee, taxes etc.) are ignored, the combined value of the counter parties having identical cost of capital remains constant during an investment/loan and borrowing activity. In other words, in a friction free world, the total value is conserved during such transactions involving counter parties with identical cost of capital.

B. Louis Bachelier and Albert Einstein

The French mathematician Louis Bachelier's work on random walk published in 1900 in his Ph. D. Thesis "*Théorie de la Spéculation*" predated Einstein's celebrated study of Brownian motion (in 1905) by as much as five years. Bachelier had worked out the distribution function for what is now known as the Wiener stochastic process (the stochastic process that underlies Brownian Motion) linking it mathematically with the diffusion equation. Seventy-three years before Black and Scholes wrote their famous paper in 1973, Bachelier had derived the price of an option where the share price movement is modelled by a Wiener process and derived the price of what is now called a barrier option (namely the option which depends on whether the share price crosses a barrier).

However, the pioneering nature of his work was recognized only after several decades, first by Andrey Kolmogorov and Leonard Jimmie Savage, who translated Bachelier's thesis into English and brought it to the attention of Paul Samuelson. The arguments Bachelier used in his thesis also predate Eugene Fama's efficient-market hypothesis (fetching a Nobel in economics in 2013), which is very closely related, as the idea of a random walk is suited to predict the random future in a stock market where everyone has all the available information. His work in finance is recognized as one of the foundations for the Black-Scholes model (fetching a Nobel in 1997). So, more than one Nobel and much more went past this unsung giant for no fault on his part. Mathematicians might have treated his choice of speculation as an affront for the subject while people of finance promptly put aside anything related to mathematics.

Basically, for any ideal i.e. perfectly efficient financial market (say a stock exchange), all price sensitive information is supposed to be already factored in the current price of a security (say an equity share). So, yesterday’s changes do not influence today’s prices and so on. This hypothesis of information efficiency of stock market would imply that each price change is independent of the last one and so on. In other words, a perfectly efficient financial market would require all correlation functions for non-zero time-lags to be zero. According to the Efficient Market Hypothesis (EMH), stocks always trade at their fair value on exchanges, making it impossible for investors to purchase undervalued stocks or sell overvalued ones. Fluctuations around such an equilibrium position are purely random in nature and akin to the Brownian motion. While absolute efficiency of a financial market may not be realisable, analysis reveals that markets have indeed gained in efficiency over time.

Louis Bachelier is now recognised internationally as the father of financial mathematics and the Bachelier Society, named in his honour, held its first World Congress in Paris in 2000 – on the hundredth anniversary of publication of his PhD thesis.

C. Statistics and Psychology with Finance and Economics

Daniel Kahneman was a professor of psychology, who exhibited that the principle of maximisation of utility in economics was not always true due to possible asymmetry in the approach of investors.

In sum, the logic can be demonstrated as follows:

In a bet, one could receive either an assured amount (100% probability) of Rs 40000 or Rs 100000 with 50% probability. The utility in case of the first option is Rs 40000 while that in the second case is Rs 50000. Number of surveys among diverse types of samples revealed a clear preference in favour of the assured amount of Rs 40000.

If both the percentages are now brought down by a factor of 50 i.e. amount of Rs 40000 with 2% probability and Rs 100000 with 1% probability, the survey reveals a majority to be in favour of Rs 100000. When the chances of success drop to low of 1% and 2%, the players like to bid for the higher amount. So, if we reduce the probabilities equally by keeping their ratio intact, the decision may change.

In other words, the basic norms of utility theory are violated inasmuch as:

(a) Investors do not always opt for the higher utility alternative.

(b) If the success rates for both alternatives are reduced proportionately keeping the ratio intact, the decision may still not remain unaltered.

He thus demonstrated how human decisions may systematically depart from those predicted by standard economic theory, indicating thereby that investors often act irrationally and assess their loss and gain perspectives in an asymmetric manner. The players in the financial market are seen as not strictly rational, but rather human and prone to cognitive biases. This observation has significant implications for diverse areas of finance.

This has led to advent of a new subject called behavioural finance.

Prof Kahneman received the 2002 Nobel for Economics and died on 27/03/2024.

9. Search for Consistency

Each subject deals with a small sub-set of the natural and/or social phenomena. But a broad logical framework may exist, which provides some ways to view the diverse developments in different fields of study collectively in a coherent and consistent manner. Let us try to discover the same.

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