The Story of Econophysics

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By

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PREFACE

I was unaware of the term "Econophysics" before November 2006 when I attended a lecture by Bikas Chakrabarti, a senior Professor at Saha Institute of Nuclear Physics (SINP, Kolkata) at Calcutta University. In fact, the word "Econophysics" was coined in 1995 at Calcutta University by Prof. H. E. Stanley of Boston University, USA, during an international conference. It had taken 11 years for me to realise the existence of such a field. Even 24 years after the birth of Econophysics, I still think many people are unaware of the subject. That is the reason why I was interested in writing this book, "The Story of Econophysics", which is non-technical in nature so that it can reach many people who have a background in neither Economics nor Physics.

As a first step to achieving this goal, I published my article entitled "Evolution of Econophysics" as a conference proceeding in Chapter 14 of the book, "Econophysics of Agent-Based Models" (pp. 235-285), edited by Frederic Abergel et al., published by Springer International Publishing, Switzerland, in 2014. Similarly, I authored another article published in Part IV, the Discussions and Commentary section of the book, "Econophysics and Data driven Modelling of Market Dynamics" (pp. 327-348), edited by Frederic Abergel et al., published by Springer International Publishing, Switzerland, in 2015. The present book, "The Story of Econophysics" is an extension of the above chapters. I also mentioned in the acknowledgement on page 284 of "Econophysics of Agent-Based Models" that this chapter forms a small part of a proposed book.

Chapter One of this present book deals with the background of the development relating to Economics and Physics, leading to Econophysics. For the interest of the readers, bio-boxes of the scientists are included. In Chapter Two, there are contributions from institutes, conferences and workshops, books and journal articles related to Econophysics, courses offered by some Universities, and awards given in Econophysics research etc. Chapter Three emphasises major research work relating to Econophysics. Furthermore, I have added the opinion of different people, views of newspapers etc. on this new subject in Chapter Four of this book. In Chapter Five, I present the results of a questionnaire I conducted with

leading Econophysicists regarding the impact of Econophysics. Chapter Six deals with the remarks of Prof. Bikas Chakrabarti in the concluding session of the Joint International Conference entitled "Econophys-2017 & Asia-Pacific Econophysics Conference (APEC)-2017", held in JNU and DU, New Delhi from 15 to 18 November 2017.

I am grateful to Prof. Bikas Chakrabarti, Ex-Director, Saha Institute of Nuclear Physics for his continued support and encouragement as I have been writing this book. I am thankful to all the scientists who sent their responses to my questionnaire. I extend my thanks to Springer Nature for allowing me to reuse my published work in this book. I am very grateful to my British editor, Eleanor Moore for proofreading and to Cambridge Scholars Publishing, UK for publishing this book.

Kishore C Dash
03.07.2019

CHAPTER ONE

ECONOPHYSICS NOW AND THEN

1.1 Introduction

Education systems originated in ancient times. However, people started learning to write around 3500 BCE. Basic communication skills, trading customs, language and religious practices were taught in Egypt between 3000 and 500 BCE. Vedic education consisted of proper pronunciation and recitation of the Veda, grammar and derivation, understanding of the secrets of nature, composition, versification of the rules of sacrifice, reasoning, including logic, the sciences, and the skills necessary for an occupation. There were five national schools in the capital city, Pi Yong, and four other schools for aristocrats and the nobility, including Shang Xiang in China during the Zhou Dynasty (1045-256 BC). Rites, music, archery, charioteering, calligraphy, and mathematics were taught in those schools. According to modern educational theorist Howard Gardner:

"Greek philosophers may have been the first to raise questions about the nature of matter, living entities, knowledge, will, truth, beauty, and goodness. In recent centuries, however, philosophy has steadily been yielding ground, enthusiastically or reluctantly, to empirical science" (Gardner, 2000, p. 1).

In India, formal education started before it did so in any other country. Sanskrit is the first language and the mother of many languages.

According to American historian, Will Durant (1885-1981):

> "India was the motherland of our race and Sanskrit the mother of Europe's languages. India was the mother of our philosophy, of much of our mathematics, of ideals embodied in Christianity.... of self-government and democracy. In many ways, Mother India is the mother of us all."

According to the magazine, *Forbes* (July 1987), the most suitable language for speech recognition by a computer was considered to be

Sanskrit. It is interesting to note that the principle of writing code was already there in the Sanskrit language in the work of Panini some 2500 years ago, as observed by western scientists.

1.2 Ancient Universities

The first university in the world was established in Takshasila (1000 BC to 500 AD) in present-day Pakistan. It became famous in 700 BC. There was no coordination of the teachers' work nor was there any external authority, such as that of a king who would govern his people. Every teacher had complete freedom and there was no obstruction to his work. Takshasila became the centre of higher education because several teachers who were recognised as authorities in their subjects resided there. One of the greatest achievements in the field of education was brought about by Nalanda University which was established in Bihar, India (425 AD-1205 AD) which was known as the Harvard of its times. Over 60 subjects were taught to more than 10,500 students in this university. Many foreign students were attracted to read in Nalanda.

1.3. Science

Another quotation follows from Grant Duff, British Historian of India*:*

> "Many of the advances in sciences that we consider today to have been made in Europe were in fact made in India centuries ago."

Some 1200 years before Sir Isaac Newton rediscovered the laws of gravity, Bhaskaracharya spoke about it in his Surya Siddhanta:

> "Objects fall on Earth due to the force of attraction of Earth. Therefore, the Earth, Planets, Constellations, Moon and the Sun are held in orbit by attraction."

Aryabhatta published his theory of the revolution of the Earth, a thousand years before Copernicus, which stated that the Earth revolves around the Sun:

> "Just as a person travelling in a boat feels that the trees on the bank are moving, people on the Earth feel that the Sun is moving."

Indians have even estimated the size of atoms in terms of units familiar to them as follows:

> "A tip of the human hair is divided into 100 parts and each part is in turn divided into 100 parts."

Seven colours of sunlight are mentioned in Rigveda; one quotation from Vedas supports these statements:

> "The Seven rays of the Sun are falling; there I live with my family."

These statements provide evidence of the assumption that the seven colours of sunrays were very well known, even during the Vedic period.

1.4. Economics (Arthashastra)

Chanakya, who is considered as the "Pioneer Economist of India" had written Arthashastra (*Science of Economics*), which is an extraordinary manual on statecraft and is read in Europe even today. Chanakya (350-283 BC) was the adviser and Prime Minister of Emperor Chandragupta and also an expert in economics, warfare, and commerce, and had served as a professor at the University of Takshasila (located in present-day Pakistan). In his work, Artha (wealth) is used in the sense of:

a. Material well-being
b. Livelihood
c. Wealth of Nations

Thus, Arthashastra is "the science of economics". It contains 15 books, which cover numerous topics on economics, government, administration, etc. It contains 380 shlokas. A shloka is a couplet of Sanskrit verse, especially one in which each line contains 16 syllables. The first five books deal with internal administration and the last eight with a state's relations with its neighbours.

"Arthashastra" had existed even before Chanakya, but all the works were lost.

1.5. Econophysics

Econophysics is a transdisciplinary research field, in which applying theories and methods originally developed by *physicists* are applied to the solving of problems in *economics*. *H. Eugene Stanley* coined the term "econophysics" in 1995 during a conference on statistical physics in Calcutta, which addressed the large number of papers written by physicists

on the problems of (stock and other) markets. *János Kertész* and *Imre Kondor* organised the first workshop on econophysics in Budapest in 1998. Some of the pioneer econophysicists are *H. Eugene Stanley*, Victor Yakovenko, Yi-Cheng Zhang, *McCauley*, Enrico Scalas, *Didier Sornette*, *Jean-Philippe Bouchaud*, *Bikas K Chakrabarti*, *Dirk Helbing*, *János Kertész* and Matteo Marsili.

Before the term was created in 1995, people from other fields had worked and applied their knowledge in the field of economics. The evolution of econophysics can be considered to have taken place in three different stages:

1. Pre-Classical era
2. Classical era
3. Modern era

1. Pre-Classical era – This can be considered as the period when there was no boundary between the study of different subjects. A philosopher was free to think and work in any field. There were no boundaries and no specialisations as there are today. There were no sharply defined fields. It was the pre-Newtonian era; there was no systematic physics and it was long before the development of social science (which started towards the third quarter of the eighteenth century).

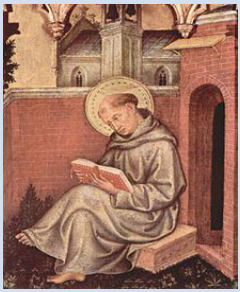
2. Classical era – This can be considered as the era after Newton during which many branches of science evolved. Later on, social sciences came into existence in different fields like economics, political science, sociology, etc. In this period, people were jumping from their mainstream subject to other branches, for example physical scientists were moving from their field to social sciences and vice versa. Natural sciences and social sciences are just like two sides of a river, which has no bridge. In this section, we shall deal with the jump and bridging the gap between natural sciences and social sciences.

3. Modern era – Finally, we describe the modern era of econophysics i.e., "institutionalised econophysics" after the word **"econophysics"** was coined by Professor H. Eugene Stanley, in Kolkata, India, in 1995. During this period, people worked in interdisciplinary fields, such as natural scientists who published papers, wrote books and convened workshops in the field of social sciences, thus bridging the gap between the two fields. We can say that bridges have been built over the river, so it is possible to cross the river and reach the other bank without the need to jump over.

1.5.1 Pre-Classical Era

1.5.1.1 Concept of just price

Bio Box 1.1



Thomas Aquinas (1225-1274)
Alma Mater - Cologne and Paris
Known For - Concept of just Price

Thomas Aquinas (1215-1274) According to Thomas Aquinas, an Italian theologist and writer on economic problems, "just price", a concept enunciated by him, means there is just sufficient to cover the *costs of production*, which includes the maintenance of a worker and his family. According to him, it is a kind of theft if one raises the price at a time of high demand.

1.5.1.2 Criticism of Just Price

***Duns Scotus* (1265-1308)** – Scotus, who was a philosopher from Scotland and a professor in Paris, Oxford and Cologne, is critical of the "just price" concept. He defended merchants. He argued, why one would trade if one did not make a profit? He said merchants were doing a social service by making goods available to the public and transporting them from one place to another.

1.5.1.3 The Medieval Concept of Money

Nicole Oresme (1320-1382). Nicole Oresme was a great philosopher before Copernicus, who did a lot of work in almost all fields during the fourteenth century. It is very interesting to note that he had an interest in science, social science, theology, cosmology and the like. Let us now go into his work in more detail:

Bio Box 1.2
Oresme's life

Born c. 1320-1325 in the village of Allemagne (today's Fleury-sur-Orne)

Alma Mater, College of Navarre, University of Paris

Subjects of Study – Arts, Theology

PhD – 1356

1369 – Started translation of the works of Aristotle at the request of Charles

Appointed Bishop of Lisieux – 1377

Nicole Oresme was a great philosopher of the later Middle Ages. He has worked and written on astronomy, philosophy, economics, mathematics, theology and physics.

Oresme's scientific work

Cosmology

According to Oresme, the heavens are in motion but not the Earth.

Mathematics

Tractatus de configurationibus qualitatum et motuum contains his important contributions to mathematics. He conceived the idea of rectangular coordinates and even the three dimensions. He applied his concept to local motion considering speed as length (latitude) and time as longitude, which gives distance travelled represented by area. The movement of a point in space can be figured out from his idea.

Fig 1.1 Portrait of Nicole Oresme

Economics

Oresme's manuscript *Treatise on the origin, nature, law, and alterations of money* delivers an insight into the medieval conception of money.

1.5.1.4 The Value of Money

Nicolaus Copernicus (1473-1543)

Copernicus was an adviser to King Sigismund of Prussia on monetary reforms and had participated in a discussion in East Prussia regarding coinage reform. His recommendations on monetary reform were being followed by the leaders of both Prussia and Poland. His article *Monetae cudendae ratio* in 1526 presented a version of Gresham's law 70 years earlier.

Bio Box 1.3
Nicolaus Copernicus
Portrait, 1580, Toruń Old Town City Hall
Born 19 February 1473 Toruń (Thorn), Royal Prussia, Kingdom of Poland
Died 24 May 1543 (aged 70) Frombork (Frauenburg), Prince-Bishopric of Warmia, Royal Prussia, Kingdom of Poland

Fields – Mathematics, astronomy, canon law, medicine, economics
Alma mater Kraków University, Bologna University, University of Padua, University of Ferrara

Known for Heliocentrism, Copernicus' Law
Signature

1.5.2 Classical Era

Mathematics is the oldest of all sciences and existed before Galileo Galilei (1564-1642). However, it is an analytical science. Physics, a science based on observations and experiments, would develop later on. The development of mathematics was probably due to the demands of astronomical studies. Astronomical studies had a deep impact on the development of physics, giving rise to the birth of classical physics which was achieved almost single-handedly by Sir Isaac Newton (1643-1727). However, people with a science background made a jump to social science during this era and we shall discuss their contribution to the field of economics, while remaining in their core field.

1.5.2.1 The Origin of the Gold Standard

Sir Isaac Newton (1642-1727)

Newton was a mathematician and physicist who was born in 1642 in Woolsthorpe in Lincolnshire. Systematic physics is considered to have originated from Newton. His apple story gives a good explanation of gravity. The entire field of classical mechanics is named after him as Newtonian physics. He is honoured as the greatest physicist of all times and generations. However, Newton was quite humble and had written in his own words:

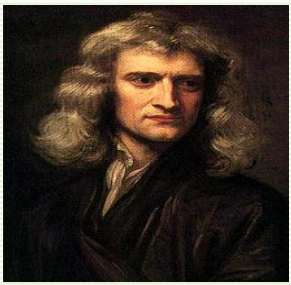
"I do not know what I may appear to the world, but to myself I seem to have been only like a boy playing on the sea-shore and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me."

Fig 1.2 Descendants of Newton's *apple tree*.

The Gold Standard

Newton's works were not just confined to physics or mathematics; rather he spent a precious 30 years of his life contributing to economics, by reforming the coinage of England. He was also the master of the mint, who valued gold over silver so that it became the standard in Great Britain. In 1696, he took charge as the warden, and in 1699, he became the Master of the Royal Mint until his death in 1727. During his 30 years at the Royal Mint, Newton brought a lot of reforms to the nation's coinage.

He is indeed a celebrated part of a distinguished history. Queen Anne knighted him in Cambridge in 1705 and he was buried in Westminster Abbey.



Bio Box 1.4
Sir Isaac Newton
Born 25 December 1642, *Lincolnshire*, England
Died 20 March 1727 (aged 84)
Kensington, Middlesex, England
Residence – England Nationality – English
Fields – Physics, mathematics, astronomy, natural philosophy, alchemy, Christian theology
Institutions – University of Cambridge, Royal Society , Royal Mint
Alma mater – Trinity College, Cambridge. Known for Newtonian mechanics, Universal gravitation, Infinitesimal calculus Optics, Binomial series, Newton's method, Philosophiæ Naturalis Principia Mathematica
Signature

Newton not only standardised Britain's coinage, but he also profited from it nicely as his remuneration was six hundred pounds a year. However, this was a time of expansion for England's economy, as merchants began trading all over the world. More coins were needed to keep up with the demand for trade. This could fetch him up to 1000 pounds a year as his salary. He was also able to prosecute 28 people engaged in counterfeiting coins.

Fig 1.3

1.5.2.2 The actuarial foundations of life assurance

Edmond Halley (1656-1742) He was the sponsor of Sir Isaac Newton's Principia, and the Editor of Philosophical Transactions. He was an Oceanographer, Meteorologist, Geophysicist, Inventor and Navigator and was quite famous for his research in determining longitude. Halley had predicted that a transit of Venus would occur in 1761 and it would be an ideal situation to make measurements from all locations of the Earth.

Bio Box 1.5
Edmond Halley – born in 1656 at Haggerston, London
Alma mater – St Paul's School and Queen's College, Oxford which he left in 1676 without a degree

Most influential work – to calculate the orbits of over twenty comets
1721– appointed Astronomer Royal and was the first to predict the return in 1758 of the periodic comet which now bears his name

Died in Greenwich on 14 January 1742

Besides astronomical inventions, he laid **the actuarial foundations of life assurance**.

Underwriters calculate risk and decide premiums based on statistics. In 1693, the astronomer Halley was the first to develop the mortality table. The problem was that the table had the same rate for all ages, which was corrected by Dodson in 1756.

Fig 1.4

Memorial of Halley

> "This memorial marks the comet's return in 1986, intercepted by the European spacecraft Giotto and built by British Aerospace."

1.5.2.3 Actuarial legacy

James Dodson (1705-1757) Besides being a mathematician, Dodson was an actuary and innovator in the insurance industry.

Bio Box 1.6
James Dodson

Born – 1705
Died – 23rd Nov, 1757
Work – Accountant and Teacher
Major contribution -The anti-logarithm canon (1742), The Calculator-1747
Field – Mathematics
Fellow of Royal Society – 1755
Elected Master of Royal Society - 1755

Actuarial legacy

Actuarial science is the study of assessing risk in the finance and insurance industries. Mathematics, statistics, economics, programming, etc. are different components of actuarial science. Premiums are calculated for long-term life insurance policies using mathematics, statistics, and deterministic models as a tool. Actuarial principles developed by Dodson

were used by The Equitable Life Assurance Society (1762). As Dodson was aged over 45, he was not considered for membership of the Amicable Life Assurance Society, so he formed a new society and built on the mortality tables developed by Edmond Halley in 1693.

His mathematical marvels are contained in *The Anti-Logarithmic Canon* published in 1742 consisting of all logarithms under 100,000 and *The Mathematical Miscellany* published in 1747, which contains analytical and algebraic solutions to a large number of problems in various branches of mathematics, as well as problems relating to insurances, annuities, etc.

1.5.2.4 The expected utility hypothesis and Bernoulli's formulation

***Daniel Bernoulli* (1687-1759)**

Daniel Bernoulli initiated his theory in 1738, in which he showed the mathematical relationship between uncertain outcomes like gambles (whether in money or other goods) with the probabilities of occurrence.

Bernoulli's formulation

Nicolas Bernoulli described the St. Petersburg paradox (involving infinite expected values) in 1713, which helped two Swiss mathematicians to develop the expected utility theory as a solution.

Daniel Bernoulli (Cousin of Nicolas Bernoulli), published *a New Theory on the Measurement of Risk* in 1738. Daniel used the probability for risk aversion and proposed a higher risk premium for low probability events.

Bernoulli's concept of marginal utility from many years ago is applied to economics now.

While Bernoulli's paper was concise and brilliant, the theory is seriously flawed. It was not until 2000 that the behavioural economist, Matthew Rabin finally mathematically proved that the utility of wealth cannot explain loss aversion and that attempts to use it in that way will fail. One of the flaws of Bernoulli's theory was that it lacked a reference point but it remained a dominant theory for over 250 years.

Bio Box 1.7
Daniel Bernoulli

Born	8 February 1700 in Groningen, Dutch Republic
Died	17 March 1782, Basel
Nationality	Swiss
Alma mater	Heidelberg University, University of Basel (M.D., 1721), University of Strasbourg
Known for	Bernoulli's principle, Thermodynamics, The early kinetic theory of gases,
Fields	Mathematics, physics, medicine

1.5.2.5 The Physiocrat's Model

Francois Quesnay (1694-1774)

Quesnay was a physician and surgeon who applied his ideas of blood circulation to economic circulation and accordingly his economic model is known as the Physiocrat's model. Quesnay was in his early sixties around 1750, and he became interested in economics. According to his thinking, the economic circle of commodities is similar to the circulation of the blood. According to Quesnay, the heart plays the same role in blood circulation as agriculture does in the social and economic system. Quesnay's argument about "unproductive labour" was one of his central propositions. Smith intended to dedicate *The Wealth of Nations* to Quesnay, had Quesnay not died before its publication. Quesnay said that the future of France depended on agricultural development and not on industry. Quesnay's economic theory is synonymous with the texts of today's mainstream neoclassical theory.

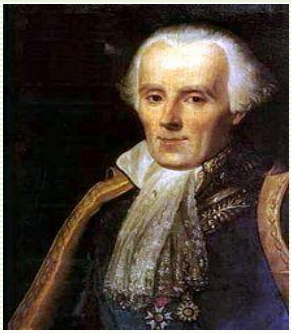
Bio Box 1.8

François Quesnay, after a portrait by Jean-Martial Frédou. Born June 4 1694 at Méré near Versailles
Died December 16, 1774 (aged 80) Versailles
Nationality – French
Field – Political economics

1.5.2.6 The Unpredictable Can Be Predictable

Pierre-Simon Laplace (1749-1827) Laplace, famous for his "Laplace's demon", was a mathematical physicist. In his *Essai Philosophique Sur les Probabilities* in 1812, he said that events that might seem random and unpredictable can be quite predictable and can be shown to obey simple power laws. Adolphe Quetelet studied the ideas of Laplace and went a step further by proving the existence of patterns in datasets ranging from economic to social problems.

Bio Box 1.9
Pierre-Simon, Marquis de Laplace
Pierre-Simon Laplace (1749-1827). Posthumous portrait by Madame Feytaud, 1842. Born 23 March 1749, Beaumont-en-Auge, Normandy, France. Died 5 March 1827 (aged 77), Paris, France
Nationality – French
Fields – Astronomy and Mathematics
Institutions – École Militaire (1769–1776)
Alma mater – University of Caen



1.5.2.7 Social Physics

Lambert Adolphe Jacques Quetelet (1796 – 1874)

Quetelet was a Belgian astronomer, who founded and directed the Brussels Observatory. He was also a mathematician, sociologist and statistician. He introduced statistical methods to the social sciences. He has contributed a lot to mathematics, sociology, criminology, etc.

Social Physics

Quetelet attempted to apply probability and statistics to social science and called it "social physics". He tried to understand the statistical laws involved in such phenomena as crime rates, marriage rates or suicide rates. He published his work in his book *Sur l'homme et le développement de ses facultés, ou Essai de physique sociale* in 1835 and its English version is entitled *Treatise on Man.*

Bio Box 1.10
Adolphe Quetelet
Born – 22 February 1796 Ghent, Belgium
Died – 17 February 1874 (aged 77) Brussels, Belgium
Nationality – Belgian
Fields – astronomer, mathematician statistician, sociologist
Institutions – Brussels Observatory
Alma mater – University of Ghent
Known for sociology

1.5.2.8 Science of Society

Auguste Comte (1798-1857) Comte studied in the École Polytechnique in Paris and then at the Medical School at Montpellier.

Comte published his work *A General View of Positivism* in 1865 in five volumes of which the first three contain the physical sciences, which were

already in existence. The other two volumes deal with social sciences. He is considered as the first philosopher of science. He was the first to distinguish between social science and natural science. Comte's classification of science is inorganic and organic physics. Astronomy, earth science and chemistry belong to inorganic physics, whereas biology and "sociologie" (physique sociologie) belong to organic physics. He neologised the term "Sociologie" in 1938. Comte had used the term "social physics" earlier but discarded it as it was used by others such as Quetelet.

Bio Box 1.11
Comte (1798-1857)
Born – 19 January 1798, Montpellier, France
Died – September 5, 1857 (aged 59) Paris, France
Alma mater – University of Montpellier, École Polytechnique in Paris
Notable ideas – Positivism, Sociology, Law of three stages, Encyclopaedic law

1.5.2.9 Monopolies

Antoine Augustin Cournot (1801-1877) Cournot was mainly a mathematician but also had an influence in economics and his application of mathematics to economic analysis is contained in his book *Researches on the Mathematical Principles of the Theory of Wealth* published in 1838. He was the first to draw supply and demand curves, 30 years before Alfred Marshall. According to his "One monopoly profit" theorem, "a monopolist can extract only one premium for being a monopolist, and getting into complementary markets does not pay". However, it is not applicable when

the monopolist's market is price-regulated (Baxter's Law). Nowadays, Cournot's work is recognised in econometrics. He is also credited as one of the sources of inspiration for Léon Walras and his equilibrium theory. He is well known for oligopoly theory – the Cournot competition in the field of economics.

Bio Box 1.12
Cournot

Born	28 August 1801, Gray, Haute-Saône, France
Died	31 March 1877 (aged 75), Paris, France
Nationality	French
Alma mater	Sorbonne University
Known for	Cournot competition, Oligopoly
Fields	Economics, Mathematics
Institutions	University of Grenoble

1.5.2.10 Marginalism

Léon Walras (1834-1910) Walras was a French mathematical economist. Before studying economics, he had studied mining engineering, and he had been a bank manager, a railway clerk and a novelist. Walras was in favour of the nationalisation of land. Being influenced by Cournot, he used mathematics in economics. Walras' work was too difficult for readers as it was mathematically complex. In the modern era, it is read extensively for its in-depth study of the market. To his credit, he was one independent enunciator of marginality theory. He is also considered as the father of the *general equilibrium theory* because of his work, *Elements of Pure Economics*, published in 1874 and 1877.

Walras' Law states that "considering any particular market, if all other markets in an economy are in equilibrium, then that specific market must also be in equilibrium". According to this law, excess market supply and demand must add up to zero. His thinking about equilibrium was very clear but to demonstrate the existence of equilibrium, his counting of equations and variables was severely flawed. In the 1950s, Kenneth Arrow and Gérard Debreu developed a new version of the argument.

In 1941 *George Stigler* wrote about Walras:

> "There is no general history of economic thought in English which devotes more than a passing reference to his work. … This sort of empty fame in English-speaking countries is of course attributable in large part to Walras' use of his mother tongue, French, and his depressing array of mathematical formulas". Whatever caused the U-turn of Walras' consideration in the US, the influx of German-speaking scientists – the German version of the *Elements* is from 1881 – after Hitler's rule was the initial start. To Schumpeter: "Walras is the … greatest of all economists. His system of economic equilibrium, uniting, as it does, the quality of 'revolutionary' creativeness with the quality of classic synthesis, is the only work by an economist that will stand comparison with the achievements of theoretical physics".

1.5.2.11 Stock Exchange Science

Jules Regnault (1834-1894)

Regnault was the first to use random walk theory and to suggest a modern theory of stock price changes. Based on statistical and probabilistic analysis, he tried to create a "stock exchange science". Later on, the famous economist *Louis Bachelier* used his hypotheses. He applied his financial theory and thus became rich. He tried to create "stock exchange science" using statistics and probability.

1.5.2.12 Entropy as a measure of volatility

Bio box 1.14
Rudolf Clausius
Born – 1822
Alma Mater – University of Berlin
Field – Physics

Clausius (1822-1888) Rudolf Clausius was born in 1822. He became a professor of physics, first in Zurich and then later in Würzburg and Bonn. According to Clausius, "heat does not pass spontaneously from a colder to a hotter body", which led to the Second Law of Thermodynamics. Another statement of the Second Law is that the entropy of an isolated system can never decrease: it can only either increase or remain constant. This principle was intensely controversial at that time, but Kelvin and Maxwell fought vigorously in its defence, and it was eventually accepted into the canon of Natural Law.

Entropy as a Measure of Volatility:

An alternative way to study stock market volatility is by applying concepts of physics. Significant literature has already shown this to be helpful in describing financial and economic phenomena. One measure that can be applied to describe the nonlinear dynamics of volatility is the concept of

entropy. In 1865, Clausius introduced this to explain the tendency of density, temperature, pressure and chemical gradients to flatten out and gradually disappear over time. On this basis, Clausius developed the Second Law of Thermodynamics.

1.5.2.13 Mathematical Method in Economics

William Stanley Jevons: Jevons, a natural scientist, was also a prolific writer on logic and economics. His book, *The Theory of Political Economy* (1871) was the beginning of the mathematical method in economics. He was the first person to enunciate the "final" (marginal) utility theory of value. This marked the opening of a new period in the history of economic thought. His marginal utility theory of value was explained in his book *General Mathematical Theory of Political Economy*. He had also published a book *A Serious Fall in the Value of Gold* in 1863. The theory of utility was practically formulated around 1860 and according to him, "philosophy would be found to consist solely in pointing out the likeness of things". According to him, economics is essentially a mathematical science. This led to the start of the Neoclassical Revolution in economics.

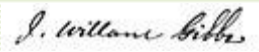
Applied economics: His opinion was that economics is a science. So, he wrote some works on practical economics like *A Serious Fall in the Value of Gold* (1863) and *The Coal Question* (1865), which recognised him as a writer of high rank. He wrote many other works such as *Money and the Mechanism of Exchange* (1875), a *Primer on Political Economy* (1878), *The State in Relation to Labour* (1882), *Methods of Social Reform* and *Investigations in Currency and Finance* (published after his death). In his work *Commercial Crises and Sunspots*, Jevons had studied the statistics relating to business cycles with sunspots. He argued that the weather depends on sunspots and crops depend on the weather, which may be the cause of the crises in the economy. He constructed a logical machine by means of which the conclusion derivable from any given set of premises could be mechanically obtained. He designed the "Logic Piano", a mechanical computer he designed and had built in 1869.

Bio Box 1.15
William Stanley Jevons

Born	1 September 1835, Liverpool, UK
Died	13 August 1882 (aged 46), Bexhill near Hastings, UK
Fields	Economics, Logic
Institutions	University College London 1876–80, Owens College 1863–1875
Alma mater	University College London

Known for Marginal utility theory

Notable awards – Rumford Prize (1880), Copley Medal (1901)



1.5.2.14 Statistical Mechanics

Josiah Willard Gibbs (1839-1903)

Gibbs is a great scientist who made a lot of contributions to the field of physics, chemistry, and mathematics. He invented the modern vector calculus. Gibbs was awarded the first American doctorate in engineering by Yale University.

Along with James Clerk Maxwell and Ludwig Boltzmann, Gibbs is considered to be one of the founders of statistical mechanics. Gibbs coined the phrase “statistical mechanics”, and introduced the term “phase space”.