1

The moving target

1.1 Invariance principles and laws of nature

The world is complicated and physics has made it appear relatively simple. Everything that we study in physics is reduced to a mathematical law of nature. At very small distances nature is governed by relativistic quantum field theory. At very large distances, for phenomena where both light speed and gravity matter, we have general relativity. In between, where neither atomic scale phenomena nor light speed matter, we have Newtonian mechanics. We have a law to understand and explain everything, at least qualitatively, except phenomena involving decisions made by minds. Our success in discovering that nature behaves mathematically has led to what a famous economist has described as "the Tarzan complex," meaning that physicists are bold enough to break into fields beyond the natural sciences, beyond the safe realm of mathematical laws of nature. Where did our interest in economics and finance come from?

From my own perspective, it started with the explosion of interest in nonlinear dynamics and chaos in the 1980s. Many years of work in that field formed the perspective put forth in this book. It even colors the way that I look at stochastic dynamics. From our experience in nonlinear dynamics we know that our simple looking local equations of motion can generate chaotic and even computationally complex solutions. In the latter case the digitized dynamical system is the computer and the digitized initial condition is the program. With the corresponding explosion of interest in "complexity," both in dynamical systems theory and statistical physics, physicists are attempting to compete with economists in understanding and explaining economic phenomena, both theoretically and computationally. Econophysics – is it only a new word, a new fad? Will it persist, or is it just a desperate attempt by fundless physicists to go into business, to work where the "real money" is found? We will try to demonstrate in this text that econophysicists can indeed contribute to economic thinking, both critically and creatively. First, it is important

to have a clear picture of just how and why theoretical physics differs from economic theorizing.

Eugene Wigner, one of the greatest physicists of the twentieth century and the acknowledged expert in symmetry principles, thought most clearly about these matters. He asked himself: why are we able to discover mathematical laws of nature at all? An historic example points to the answer. In order to combat the prevailing Aristotelian ideas, Galileo Galilei proposed an experiment to show that relative motion doesn't matter. Motivated by the Copernican idea, his aim was to explain why, if the earth moves, we don't feel the motion. His proposed experiment: drop a ball from the mast of a uniformly moving ship on a smooth sea. It will, he asserted, fall parallel to the mast just as if the ship were at rest. Galileo's starting point for discovering physics was therefore the principle of relativity. Galileo's famous thought experiment would have made no sense were the earth not a local inertial frame for times on the order of seconds or minutes.[1] Nor would it have made sense if initial conditions like absolute position and absolute time mattered.

The known mathematical laws of nature, the laws of physics, do not change on any time scale that we can observe. Nature obeys inviolable mathematical laws only because those laws are grounded in local invariance principles, local invariance with respect to frames moving at constant velocity (principle of relativity), local translational invariance, local rotational invariance and local time-translational invariance. These local invariances are the same whether we discuss Newtonian mechanics, general relativity or quantum mechanics. Were it not for these underlying invariance principles it would have been impossible to discover mathematical laws of nature in the first place (Wigner, 1967). Why is this? Because the local invariances form the theoretical basis for repeatable identical experiments whose results can be reproduced by different observers independently of where and at what time the observations are made, and independently of the state of relative motion of the observational machinery. In physics, therefore, we do not have merely *models* of the behavior of matter. Instead, we know mathematical laws of nature that cannot be violated intentionally. They are beyond the possibility of human invention, intervention, or convention, as Alan Turing, the father of modern computability theory, said of arithmetic in his famous paper proving that there are far more numbers that can be defined to "exist" mathematically than there are algorithms available to compute them.[2]

[1] There exist in the universe only local inertial frames, those locally in free fall in the net gravitational field of other bodies, there are no global inertial frames as Mach and Newton assumed. See Barbour (1989) for a fascinating and detailed account of the history of mechanics.

[2] The set of numbers that can be defined by continued fractions is uncountable and fills up the continuum. The set of algorithms available to generate initial conditions ("seeds") for continued fraction expansions is, in contrast, countable.

How are laws of nature discovered? As we well know, they are only established by repeatable identical (to within some decimal precision) experiments or observations. In physics and astronomy all predictions must in practice be falsifiable, otherwise we do not regard a model or theory as scientific. A falsifiable theory or model is one with few enough parameters and definite enough predictions (preferably of some new phenomenon) that it can be tested observationally and, if wrong, can be proven wrong. The cosmological principle (CP) may be an example of a model that is not falsifiable.[3] A nonfalsifiable hypothesis may belong to the realm of philosophy or religion, but not to science.

But we face more in life than can be classified as science, religion or philosophy: there is also medicine, which is not a completely scientific field, especially in everyday diagnosis. Most of our own daily decisions must be made on the basis of experience, bad information and instinct without adequate or even any scientific basis. For a discussion of an alternative to Galilean reasoning in the social field and medical diagnosis, see Carlo Ginzburg's (1992) essay on Clues in *Clues, Myths, and the Historical Method*, where he argues that the methods of Sherlock Holmes and art history are more fruitful in the social field than scientific rigor. But then this writer does not belong to the school of thought that believes that *everything* can be mathematized. Indeed, not everything can be. As von Neumann wrote, a simple system is one that is easier to describe mathematically than it is to build (the solar system, deterministic chaos, for example). In contrast, a complex system is easier to make than it is to describe completely mathematically (an embryo, for example). See Berlin (1998) for a nonmathematical discussion of the idea that there may be social problems that are not solvable.

1.2 Humanly invented law can always be violated

Anyone who has taken both physics and economics classes knows that these subjects are completely different in nature, notwithstanding the economists' failed attempt to make economics look like an exercise in calculus, or the finance theorists' failed attempt to portray financial markets as a subset of the theory of stochastic processes obeying the Martingale representation theorem. In economics, in contrast with physics, there exist no known inviolable mathematical laws of "motion"/behavior. Instead, economic law is either legislated law, dictatorial edict, contract, or in tribal societies the rule of tradition. Economic "law," like any legislated law or social contract, can always be violated by willful people and groups. In addition, the idea of falsification via observation has not yet taken root. Instead,

[3] The CP assumes that the universe is uniform at large enough distances, but out to the present limit of 170 Mpc h^{-1} we see nothing but clusters of clusters of galaxies, with no crossover to homogeneity indicated by *reliable* data analyses.

an internal logic system called neo-classical economic theory was invented via postulation and dominates academic economics. That theory is not derived from empirical data. The good news, from our standpoint, is that some specific predictions of the theory are falsifiable. In fact, there is so far no evidence at all for the validity of the theory from any real market data. The bad news is that this is the standard theory taught in economics textbooks, where there are many "graphs" but few if any that can be obtained from or justified by unmassaged, real market data.

In his very readable book *Intermediate Microeconomics*, Hal Varian (1999), who was a dynamical systems theorist before he was an economist, writes that much of (neo-classical) economics (theory) is based on two principles.

The optimization principle. People try to choose the best patterns of consumption they can afford.

The equilibrium principle. Prices adjust until the amount that people demand of something is equal to the amount that is supplied.

Both of these principles sound like common sense, and we will see that they turn out to be more akin to common sense than to science. They have been postulated as describing markets, but lack the required empirical underpinning.

Because the laws of physics, or better said the known laws of nature, are based on local invariance principles, they are independent of initial conditions like absolute time, absolute position in the universe, and absolute orientation. We cannot say the same about markets: socio-economic behavior is not necessarily universal but may vary from country to country. Mexico is not like China, which in turn is not like the USA, which in turn is not like Germany. Many econophysicists, in agreement with economists, would like to ignore the details and hope that a single universal "law of motion" governs markets, but this idea remains only a hope, not a reality. There are no known socio-economic invariances to support that hope.

The best we can reasonably hope for in economic theory is a model that captures and reproduces the essentials of historical data for specific markets during some epoch. We can try to describe mathematically what has happened in the past, but there is no guarantee that the future will be the same. Insurance companies provide an example. There, historic statistics are used with success in making money under normally expected circumstances, but occasionally there comes a "surprise" whose risk was not estimated correctly based on past statistics, and the companies consequently lose a lot of money through paying claims. Econophysicists aim to be at least as successful in the modeling of financial markets, following Markowitz, Osborne, Mandelbrot, Sharpe, Black, Scholes, and Merton, who were the pioneers of finance theory. The insurance industry, like econophysics, uses historic statistics

and mathematics to try to estimate the probability of extreme events, but the method of this text differs significantly from their methods.

Some people will remain unconvinced that there is a *practical* difference between economics and the hardest unsolved problems in physics. One might object: we can't solve the Navier–Stokes equations for turbulence because of the butterfly effect or the computational complexity of the solutions of those equations, so what's the difference with economics? Economics cannot be fairly compared with turbulence. In fluid mechanics we know the equations of motion based on Galilean invariance principles. In turbulence theory we cannot predict the weather. However, we *understand* the weather physically and can describe it qualitatively and reliably based on the equations of thermo-hydrodynamics. We understand very well the physics of formation and motion of hurricanes and tornadoes even if we cannot predict when and where they will hit.

In economics, in contrast, we do not know any universal laws of markets that could be used to explain even *qualitatively* correctly the phenomena of economic growth, bubbles, recessions, depressions, the lopsided distribution of wealth, the collapse of Marxism, and so on. We cannot use mathematics systematically to explain why Argentina, Brazil, Mexico, Russia, and Thailand collapsed financially after following the advice of neo-classical economics and deregulating, opening up their markets to external investment and control. We cannot use the standard economic theory to explain mathematically why Enron and WCom and the others collapsed. Such extreme events are ruled out from the start by assuming equilibrium in neo-classical economic theory, and also in the standard theory of financial markets and option prices based on expectations of small fluctuations.

Econophysics is not like academic economics. We are not trying to make incremental improvements in theory, as Yi-Cheng Zhang has so poetically put it, we are trying instead to replace the standard models with something completely new. Econophysics began in this spirit in 1958 with M. F. M. Osborne's discovery of Gaussian stock market returns, Benoit Mandelbrot's emphasis on distributions with fat tails, and then Osborne's empirically based criticism of neo-classical economics theory in 1977, where he suggested an alternative formulation of supply and demand behavior. Primarily, though, world events and new research opportunities drew many physicists into finance. As Philip Mirowski (2002) emphasizes in his book *Machine Dreams*, the advent of physicists working in large numbers in finance coincided with the reduction in physics funding after the collapse of the USSR. What Mirowski does not emphasize is that it also coincides, with a time lag of roughly a decade, with the advent of the Black–Scholes theory of option pricing and the simultaneous start of large-scale options trading in Chicago, the advent of deregulation as a dominant government philosophy in the 1980s and beyond, and

in the 1990s the collapse of the USSR and the explosion of computing technology with the collection of high-frequency finance data. All of these developments opened the door to the globalization of capital and led to a demand on modeling and data analysis in finance that many physicists have found fascinating and lucrative, especially since the standard theories (neo-classical in economics, Black–Scholes in finance) do not describe markets correctly.

1.3 Where are we headed?

Economic phenomena provide us with data. Data are analyzed by economists in a subfield called econometrics (the division of theory and data analysis in the economics profession is Bourbakian). The main tool used in the past in econometrics was regression analysis, which so far has not led to any significant insight into economic phenomena. Regression analysis cannot be used to isolate cause and effect and therefore does not lead to new qualitative understanding. Worse, sometimes data analyses and model-based theoretical expectations are mixed together in a way that makes the resulting analysis useless. An example of regression analysis is the "derivation" of the Phillip's curve (Ormerod, 1994), purporting to show the functional relationship between inflation and employment (see Figure 1.1). To obtain that curve a straight line is drawn through a big scatter of points that don't suggest that any curve at all should be drawn through them (see the graphs in McCandless (1991) for some examples). Econometrics, regression analysis, does not lead to isolation of cause and effect. Studying correlations is not the same as understanding how and why certain phenomena have occurred.

International and governmental banks (like the Federal Reserve) use many-parameter econometric models to try to make economic forecasts. Were these models applied to something simpler, namely the stock market, you would lose money by placing bets based on those predictions (Bass, 1991). In other words, the models are too complicated and based on too few good ideas and too many unknown parameters to be very useful. The falsification of a many-parameter econometric model would require extremely accurate data, and even then the model can not be falsifiable if it has too many unknown or badly known parameters. So far, neither econophysicists nor alternative economists (non neo-classical economists) have come up with models that are adequate to dislodge neo-classical economic theory from its role as king of the textbooks. An aim of this book is to make it clear to the reader that neo-classical theory, beloved of pure mathematicians, is a bad place to start in order to make new models of economic behavior. This includes the neo-classical idea of Nash equilibria in game theory. In order to avoid reinventing a square wheel, it would be good for econophysicists to gain an overview of what's been done in economic theory since World War II since the advent of both game

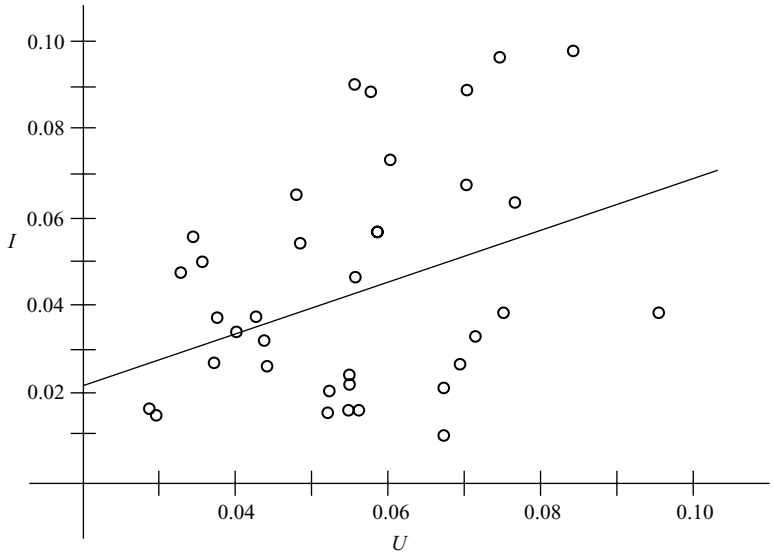

Figure 1.1. The data points represent the inflation rate I vs the unemployment rate U. The straight line is an example from econometrics of the misapplication of regression analysis, because no curve can describe the data.

theory (which von Neumann abandoned in economics) and automata (which he believed to be a fruitful path, but has so far borne no fruit).

The main reason for the popularity with physicists of analyzing stock, bond, and foreign exchange markets is that those markets provide very accurate "high frequency data," meaning data on a time scale from seconds upward. Markets outside finance do not provide data of comparable accuracy. Finance is therefore the best empirical testing ground for new behavioral models. Interesting alternative work in modeling, paying attention to limitations on our ability to gather, process, and interpret information, is carried out in several schools of economics in northern Italy and elsewhere, but so far the Black–Scholes option pricing model is the only falsifiable *and* partly successful model within the economic sciences.

But "Why," asked a former student of economics, "do physicists believe that they are more qualified than economists to explain economic phenomena?[4] And *if* physicists, *then* why not also mathematicians, chemists, and biologists, all other natural scientists as well?" I responded that mathematicians do work in economics, but they tend to be postulatory and to ignore real data. Then I talked with a colleague and came up with a better answer: chemists and biologists are trained to concentrate on details. Physicists are trained to see the connections between seemingly different

[4] Maybe many citizens of Third World countries would say that econophysicists could not do worse, and might even do better.

phenomena, to try to get a glimpse of the big picture and to present the simplest possible mathematical description of a phenomenon that includes as many links as are necessary, but not more. With that in mind, let's get to work and sift through the evidence from one econophysicist's viewpoint. Most of this book is primarily about that part of economics called finance, because that is where comparisons with empirical data lead to the clearest conclusions.

2

Neo-classical economic theory

2.1 Why study "optimizing behavior"?

We live in a time of widespread belief in an economic model, a model that emphasizes deregulated markets with the reduction and avoidance of government intervention in socio-economic problems. This belief gained ground explosively after the collapse of the competing extreme ideology, communism. After many decades of rigorous attempts at central planning, communism has been thoroughly discredited in our age.

The winning side now advances globalization via rapid privatization and deregulation of markets.[1] The dominant theoretical economic underpinning for this ideology is provided by neo-classical equilibrium theory, also called optimizing behavior, and is taught in standard economics texts. Therefore it is necessary to know what are the model's assumptions and to understand how its predictions compare empirically with real, unmassaged data. We will see, among other things, that although the model is used to advise governments, businesses, and international lending agencies on financial matters, the neo-classical model relies on presumptions of stability and equilibrium in a way that completely excludes the possibility of discussing money/capital and financial markets! It is even more strange that the standard equilibrium model completely excludes the profit motive as well in describing markets: the accumulation of capital is not allowed within the confines of that model, and, because of the severe nature of the assumptions required to guarantee equilibrium, cannot be included perturbatively either. This will all be discussed below.

Economists distinguish between classical and neo-classical economic ideas. Classical theory began with Adam Smith, and neo-classical theory began with

[1] The vast middle ground represented by the regulation of free markets, along with the idea that markets do not necessarily provide the best solution to all social problems, is not taught by "Pareto efficiency" in the standard neo-classical model.

Walras, Pareto, I. Fisher and others. Adam Smith (2000) observed society qualitatively and invented the notion of an Invisible Hand that hypothetically should match supply to demand in free markets. When politicians, businessmen, and economists assert that "I believe in the law of supply and demand" they implicitly assume that Smith's Invisible Hand is in firm control of the market. Mathematically formulated, the Invisible Hand represents the implicit assumption that a stable equilibrium point determines market dynamics, whatever those dynamics may be. This philosophy has led to an elevated notion of the role of markets in our society. Exactly how the Invisible Hand should accomplish the self-regulation of free markets and avoid social chaos is something that economists have not been able to explain satisfactorily.

Adam Smith was not completely against the idea of government intervention and noted that it is sometimes necessary. He did not assert that free markets are always the best solution to all socio-economic problems. Smith lived in a Calvinist society and also wrote a book about morals. He assumed that economic agents (consumers, producers, traders, bankers, CEOs, accountants) would exercise self-restraint in order that markets would not be dominated by greed and criminality. He believed that people would regulate themselves, that self-discipline would prevent foolishness and greed from playing the dominant role in the market. This is quite different from the standard belief, which elevates self-interest and deregulation to the level of guiding principles. Varian (1999), in his text *Intermediate Economics*, shows via a rent control example how to use neo-classical reasoning to "prove" mathematically that free-market solutions are best, that any other solution is less efficient. This is the theory that students of economics are most often taught. We therefore present and discuss it critically in the next sections.

Supra-governmental organizations like the World Bank and the International Monetary Fund (IMF) rely on the neo-classical equilibrium model in formulating guidelines for extending loans (Stiglitz, 2002). After you understand this chapter then you will be in a better position to understand what ideas lie underneath whenever one of those organizations announces that a country is in violation of its rules.

2.2 Dissecting neo-classical economic theory (microeconomics)

In economic theory we speak of "agents." In neo-classical theory agents consist of consumers and producers. Let $x = (x_1, \ldots, x_n)$, where x_k denotes the quantity of asset k held or desired by a consumer. x_1 may be the number of VW Golfs, x_2 the number of Phillips TV sets, x_3 the number of ice cream cones, etc. These are demanded by a consumer at prices given by $\boldsymbol{p} = (p_1, \ldots, p_n)$. Neo-classical theory describes the behavior of a so-called "rational agent." By "rational