Economics, Econometrics and Modelling in Economics

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When talking about the methodology in economic sciences, I have always found it utterly inadequate to focus attention only on these special fields without seeing them in a much broader perspective. Therefore, it was inevitable that I included in the field of vision of this paper some branches of science of economics as well.

Several ancient philosophers made various economic observations. Aristotle was concerned with transactions aimed at monetary gain and the wealth they yielded. The *Arthaśāstra*[1] is a treatise on statecraft and economic policy which identifies its author by the names Kautilya and Viṣṇugupta, who are traditionally identified with the Mauryan minister Canakya. The traditional identification of Kautilya and Viṣṇugupta with the Mauryan minister Canakya would date the *Arthaśāstra* to the 4th century BC. *Arthaśāstra* argues for an autocracy managing an efficient and solid economy. It discusses the ethics of economics and the duties and obligations of a king. The scope of *Arthaśāstra* is, however, far wider than statecraft, and it offers an outline of the entire legal and bureaucratic framework for administering a kingdom, with a wealth of descriptive cultural detail on topics such as mineralogy, mining and metals, agriculture, animal husbandry and medicine. The *Arthaśāstra* also focuses on issues of welfare (for instance, redistribution of wealth during a famine) and the collective ethics that hold a society together. Medieval Muslims also made contributions to the understanding of economics. In particular, Ibn Khaldun of Tunis (1332–1406) wrote on economic and political theory in his *Prolegomena*. Niccolö Machiavelli (1469–1527) in his book *The Prince* was one of the first authors to theorize economic policy in the form of advice. Anders Chydenius (1729–1803) a Finnish priest published a book called *The National Gain* in 1765, in which he proposed ideas of freedom of trade and industry and explored the relationship between economy and society.

Adam Smith, Economist and Philosopher (1723–1790), published *An Inquiry into the Nature and Causes of the Wealth of Nations* in 1776 which examined in detail the consequences of economic freedom. It covered such concepts as the role of self-interest, the division of labour, the function of markets, and the international implications of a laissez-faire economy. *Wealth of Nations* established economics as an autonomous subject and launched the economic doctrine of free enterprise. Smith laid the intellectual framework that explained the free market and still holds true today. He is most often recognized for the expression 'the invisible hand', which he used to demonstrate how self-interest guides the most efficient use of resources in a nation's economy, with public welfare coming as a by-product. To underscore his laissez-faire convictions, Smith argued that state and personal efforts to promote social good are ineffectual compared to unbridled market forces.

In the 19th century, Karl Marx synthesized a variety of schools of thought involving the social distribution of resources, including the work of Adam Smith, as well as socialism and egalitarianism, and used the systematic approach to logic taken from the philosopher Georg Wilhelm Friedrich Hegel to produce *Das Kapital*. His work was the most widely adhered-to critique of market economics during much of the 19th and 20th centuries. Marxist economics is based on the labour theory of value.

Turning now to the more specifically subject matters, it is inevitable that I should begin by making a brief survey of the development of the science of economics as much as I know. In the middle of the 19th century, John Stuart Mill (1806–1873) in his famous work *Principles of Economics* laid down the general principles of the theory of value and price. In Mill's *Principles*, the ideas of Adam Smith, David Ricardo (1772–1823) and Thomas Robert Malthus (1766–1834) had been knit together into an organic, logically and seemingly complete whole.

The economic theory was completely renewed in the years between 1870 and 1890 when a number of Austrian

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economists headed by Karl Menger (1840–1921) undertook a systematic study of the human wants and their place in a theory of prices. Similar thoughts were expressed also by the Swiss Léon Walras (1834–1910) and the Englishman Stanley Jevons (1835–1882). This was the first breakthrough since Stuart Mill. The Englishman Alfred Marshall (1842–1924)[2] subsequently did much to combine the technological viewpoint and the cost of production viewpoint. This led to what we now usually speak of as the neo-classical theory. Neither the classicists nor the neo-classicists did much to verify their theoretical results by statistical observations. The reason was partly that the statistics were poor, and partly that neither the classical nor the neo-classical theory was built out with the systematic statistical verification in view. A crucial point in this connection is the quantification of the economic concepts, i.e. the attempts at making these concepts measurable. There is no need to insist on what quantitative formulation of concepts and relations has meant in the natural sciences.

John Maynard Keynes (1883–1946)[3] is doubtlessly one of the most important figures in the entire history of economics. In 1930, Keynes brought out his heavy, two-volume *Treatise on Money*, which effectively set out his theory of the credit cycle. In it, the rudiments of a liquidity preference theory of interest are laid out. He revolutionized economics with his classic book, *The General Theory of Employment, Interest and Money* (1936). This is generally regarded as probably the most influential social science treatise of the 20th century; in that it quickly and permanently changed the way the world looked at the economy and the role of government in society. The heroic entrepreneurs are resurrected in *The General Theory*. Investment, in the Keynesian system, is an independent affair contingent upon finance and the 'animal spirits' of entrepreneurs.

In the 1930s, Professor Jan Tinbergen (1903–1994)[4,5] devised the first macro-economic model ever. In this model, the focus of economic analysis was no longer on the abstract relation between individual goods and prices. Instead, it was shifted to the concrete relationships between economic aggregates like total income, consumption and investment. His work involved the statistical observation of theoretically founded concepts, namely mathematical economics working with concrete numbers. In his Nobel lecture of December 12, 1969, Professor Tinbergen discussed the experience he had with the method of model building as a contribution to economic science and the prospects for its further application. First of all he reminded of the essential features of models. In his opinion they are: (i) drawing up a list of the variables to be considered; (ii) drawing up a list of the equations or relations the variables have to obey, and (iii) testing the validity of the equations, which implies the estimation of their coefficients, if any. As a consequence of especially (iii), the econometricians may have to revise (i) and (ii) so as to arrive at a satisfactory degree of realism of the theory embodied in the model. Then, the model may be used for various purposes, that is, for the solution of various problems. The advantages of models are, on one hand, that they force the econometricians to present a 'complete' theory that is a theory taking into account all relevant phenomena and relations and, on the other hand, the confrontation with observation, that is, reality. The utility of models goes beyond their didactic value. They are a real and essential element in the preparation of well-coordinated policies. But they cannot do this job all by themselves. Models constitute a *framework* or a *skeleton* and the flesh and blood will have to be added by a lot of common sense and knowledge of details. Again, as a framework they can be of vital importance. The framework as being referred to supplies the main ingredients for coordinating government policies at the level of a central government.

The models should have widening scope to specify optimum socio-economic orders. Optimization is not a new subject, of course. Mathematical programming models are now widely used, both on the level of the production unit and on higher levels. Scientific development took place along various tracks. Among the most sophisticated we have, in recent years, dynamic models for long periods, such as developed by Edmund S. Phelps (Nobel Prize in Economic Sciences in 2006) in his analysis of intertemporal tradeoffs in macroeconomic policy and those developed by Tjalling C. Koopmans[6,7,8] in his work for the contribution to the theory of optimum allocation of resources. Among the results attained by these authors are the limits set to our freedom to choose some parameters which we might have thought we are free to choose, such as the time discount occurring in a preference function. For some value intervals of this parameter, Koopmans has shown that no preferential ordering of the various conceivable development paths is possible. Results such as these belong to the really fundamental features of economic science.

Professor Ragnar Frish[9] (1895–1973) observed, 'Deep in the human nature there is an almost irresistible tendency to concentrate physical and mental energy on attempts at solving problems that *seem to be unsolvable*. Indeed, for some kinds of active people only the seemingly unsolvable problems can arouse their interest. Other problems, those which can reasonably be expected to yield a solution by applying some time, energy and money do not seem to interest them. The English mathematician and economist Stanley Jevons (1835–1882) dreamed of the day when we would be able to *quantify* at least some of the laws and regularities of economics. Today, since the breakthrough of econometrics, this is not a dream anymore but a reality. Econometricians of 60s to 80s had strikingly supreme intelligence to solve seemingly unsolved problems of covering man and money so that we can have the present state of the art.

The list of variables and the equations and/or bounds that are introduced, constitute the core of the model. It may be linear or non-linear.

While building models the questions are frequently asked:

Should we build a road between points A and B in the country? Should we promote investments that will give employment to many people, or should we, on the contrary, promote such investment which will save labour? Should we aim at a high rate of increase of the gross national product, or should we put more emphasis on a socially justified distribution of it? Should we aim, above all, at keeping the price level under control or should we sacrifice the stability of the price level and put more emphasis on the increase of the gross national product (in real terms)? Should we sacrifice a part of the increase of the total gross national product in order to be able to increase the living standards of one specific social group, say fishermen or industrial workers? Should we put more emphasis on things that have up to now not been included in the statistical concept of the gross national product? For instance, should we try to avoid air-pollution and all the kinds of intoxications that may be caused by refuse and waste (a problem that must be studied in its totality as a problem of circulation of matter in society, much in the same way as we study inter-industry relations in an input-output table)? Should we assess economic value to an undisturbed nature? etc.

If we should ask the experts to produce a list of feasible alternatives for the development path of the economy, a list that would be comprehensible enough to cover even very approximately all these various specific questions, the list of possible development path would have to contain a large number of alternatives.

Ever since Sir William Petty (1623–1687) began recording economic data in 17th century Britain, empirical work has always played an important role in economics for two reasons: namely, economists think that (1) economic insights can be gained by careful examination of the data (the 'inductive approach') and (2) existing economic theories can be validated or falsified by comparing their claims against empirical data (the 'theoretical approach'). The inductivist approach has a long history: from data Clement Juglar (1819–1905) saw in financial tables evidence for a credit-driven cycle. Similarly, H L Moore (1869–1958) used the inductive approach to argue for a weather and astral-driven cycle. However, the theoretical approach was also used as far back as Charles D'Avenant (1656–1723) and Henry Charles Fleeming Jenkin (1833–1885). Economists had attempted to fit data to demand curves. This was the particular skill of H L Moore who attempted to fit data to Leon Walras's demand equations. In 1877, Walras published *Elements of Pure Economics*, a work that led him to be considered the father of the general equilibrium theory. The problem that Walras set out to solve was that even though it could be demonstrated how individual markets behaved, it was still unknown how goods interacted with each other to effect supplies and demands. Walras created a system of simultaneous equations in an attempt to solve problem. He recognized that while his system might be correct, the number of unknowns combined with the lack of information made it unsolvable. Henry Schultz (1893–1938) and Paul H Douglas (1892–1976) carried this work on into the 1930s. Similar work was carried out in Britain by Arthur C Pigou (1877–1959) and in Germany by Jacob Marschak (1898–1977).

Professor Simon Kuznets (1901–1985)[10] is credited with revolutionizing econometrics, and his work is credited with fuelling the Keynesian Revolution. His most important book is *National Income and its Composition (1919–1938)*. Published in 1941, it is one of the historically most significant works on Gross National Product. His work on the business cycle and disequilibrium aspects of economic growth helped launch development economics.

Naturally, the empirical recording and analysis of the business cycle spilt over into collecting and analyzing all sorts of empirical data—notably, the collection of national income accounts (output, investment, etc.), which became the primary activity of Simon Kuznets.

Naturally, theoretical treatises on the business cycle, such as those by J A Schumpeter, D H Robertson, A C Pigou and G Haberler had been accompanied the presentation of empirical data, but they could not have said to be adopting the second 'theoretical approach' entirely because they used no proper statistical inference methods to do so.

The inductive approach was severely criticized by George Yule, Eugene Slutsky, Ragnar Frisch and Tjalling C Koopmans. This resulted in a rebirth of the theoretical approach and thus econometrics as we know it. The theoretical approach had been first applied usefully to business cycles by Jan Tinbergen in the late 1930s after the appearance of the *General Theory* of Keynes. Tinbergen used statistical methods, such as linear regressions to estimate the parameters of the Keynesian relationships.

Galvanized into action, a great leap forward was achieved with the 'probabilistic approach' to econometrics as proposed by Trygve Haavelmo.[11] Thus, formal textbook econometrics was born.

The econometric boom was on. The work of the Haavelmo, Tinbergen and Ragnar led to development of estimation techniques for systems of simultaneous equations, such as the Klein-Goldberger model of Keynesian macroeconomics.

The statistical models of the working of the economy of the nation or of corporate enterprises are not proposed as formulae of all the secrets of the complex real world of matter and money in a single equation. The models would attempt to provide as much information about future or about unknown phenomena as can be observed from the historical records of observable and measurable facts. They provide information about the quantitative properties of the economic variables in the future. Any information of a qualitative nature that is available should be used by the econometrician in drawing inferences about the real world from his models.

Professor Paul A Samuelson[12] is considered one of the founders of modern neoclassical economics. He has not only simply rewritten considerable parts of economic theory but has also shown the fundamental unity of both the problems and analytical techniques in economics, partly by a systematic application of the methodology of maximization for a broad set of problems. Professor Samuelson in his Nobel Lecture on December 11, 1970 euologized the mathematical models for using Pontriagin's Maximum Principle in analytical economics. He observed, 'Well, today, under the guise of operational research and managerial economics, the fanciest of our economic tools are being utilised in enterprises both public and private.' In a small essay, 'How I became an economist' on September 5, 2003 , Professor Samuelson said, 'So after all, as I look back in my ninth decade over my long career in economics, I realize that all those incidents of good luck have to be understood against the background of fundamental trends in economic history. Mine has been a grandstand seat from which to observe most of a century of basic economic history. Bliss it was to be in the forefront of the revolutions that have changed economics forever.'

The modelling processes wholly depend on real life data. For Professor Wassily Leontief,[13, 14] explanations of economic systems must be grounded on facts. Theory follows as an instrument that helps explain facts. Professor Leontief's dedicated preference for what can be observed rather than what can be imagined, coupled with an insistence on practical applications, led him to his greatest achievement, the invention and elaboration of input-output analysis (IOA). Professor Leontief used a familiar metaphor to describe the special ability of IOA to bring together micro and macro-ecnomics: 'It has often been said that in economics one must make a choice between detailed description of individual trees or aggregative description of the entire forest. Input-output analysis is an application of the modern system approach that permits us to describe the forest in terms of individual trees. It provides the means for observing and analyzing simultaneously the quantitative relationships between hundreds and even thousands of variables while preserving throughout all the operations the identity, the name and address, of each of them.'

Professor Friedrich August von Hayek[15] tried to penetrate more deeply into the business cycle mechanism. Perhaps, partly due to this more profound analysis, he was one of the few economists who gave warning of the possibility of a major economic crisis before the great crash came in the autumn of 1929. Professor von Hayek showed how monetary expansion, accompanied by lending which exceeded the rate of voluntary saving, could lead to a misallocation of resources, particularly affecting the structure of capital. Often economic science comes in close contact with social science. As is evident when Professor Gunnar Myrdal[16] said, 'The blunt truth is that without rather radical changes in the consumption patterns in the rich countries, any pious talk about a new world economic order is humbug.' Mainly by directing most of his research on economic problems in the broadest sense, particularly the negro problem in the USA and the poverty of the developing countries, Professor Myrdal has sought to relate economic analysis to social, demographic and institutional conditions. Professor Myrdal has attached great importance to the monumental work, *An American Dilemma: The Negro Problem and Modern Democracy* (1944). It is primarily in this massive work of scholarship that Myrdal has documented his ability to combine economic analysis in a broad sociological perspective.

Professor Leonid Kantorovich has done his most important scientific work in the field of normative economic theory, i.e., the theory of the optimum allocation of resources. As the starting point of his work in this field, he has studied the problem of how available productive resources can be used to the greatest advantage in the production of goods and services.

Professor Koopmans has in a series of works, primarily, *Analysis of Production as an Efficient Combination of Activities*, developed the activity analysis. Within this theory, new ways of interpreting the relationship between inputs and outputs of a production process are used to clarify the correspondence between efficiency in production and the existence of a system of calculation of prices. This shed a new and interesting light on the connection between the normative allocation theory and the general equilibrium theory.

Professor Milton Friedman[17] is the twentieth century's most prominent economist advocate of free markets. Professor Friedman's name is chiefly associated with the renaissance of the role of money in inflation and the consequent renewed understanding of the instrument of monetary policy. The strong emphasis on the role of money should be seen in the light of how economists for a long time almost entirely ignored the significance of money and monetary policy when analyzing business cycles and inflation. Professor Friedman's findings on the comparatively great relevance of the quantity theory in explaining developments is, in fact, built on the premise that the demand for money is very stable.

From 1970s, international trade and international capital movements have become widely spread. Professor Bertil Ohlin's classic work, *Interregional and International Trade* has brought him recognition as founder of the modern theory of international trade. He has developed a theory that demonstrates which factors determine the pattern of foreign trade and the international division of labour on the one hand, and on the other, shows what effect foreign trade has on the allocation of resources, price relations and the distribution of income.

Professor James Meade[18] in his major work, *The Theory of International Economic Policy* has demonstrated the effects of economic policy on foreign trade and penetrated the problems of stabilization policies. His analysis has particularly concentrated on the conditions necessary for internal and external balance. He has also shown why and how a successful stabilization policy must take into account not only the level of total demand for goods and services but also relations between prices and costs. These achievements have made Professor Meade the leading pioneer in the field of international macro-theory and international economic policy.

Professor Herbert A Simon[19, 20, 21] has made pioneering research into the decision-making process within economic organizations. His name is associated, most of all, with publications on structure and decision-making within economic organizations, a relatively new area of economic research.

Influenced by the organizational research that was being conducted in other social sciences, economists have started to look at the structure of companies and at the decision-making process in an entirely new way. Professor Simon's work was of utmost importance for this new line of development. In his epoch-making book, *Administrative Behavior* (1947), and in a number of subsequent works, he described the company as an adaptive system of physical, personal and social components that are held together by a network of intercommunications and by the willingness of its members to cooperate and to strive towards a common goal.

From the sixth decade of the last century problems of developing countries came in the international forefront. Professor Theodore W Schultz[22] and Professor Sir Arthur Lewis did pioneering research into economic development research with particular consideration of the problems of developing countries.

Professor Schultz was an agricultural economist to start with, and in the thirties and forties, presented a series of studies on the crises in American agriculture, and then later took up agricultural questions in various developing countries throughout the world. His best known works from this period are *Agriculture in an Unstable Economy* (1945) and *Production and Welfare of Agriculture* (1949). His most trail-blazing book was *Transforming Traditional Agriculture* (1964). The main characteristic of Schultz's studies in agricultural economics is that he does not treat agricultural economy in isolation, but as an integral part of the entire economy. Schultz's analytical interest has been focused on the imbalance between relative poverty and underdevelopment in agriculture compared to the higher productivity and the higher income levels in industry and other urban economic activities.

Professor Lewis was a leading figure and pioneer in developing country research. He has tackled issues which are basic to the causes of poverty among populations in the developing world and to the unsatisfactory rate of economic development.

Professor Schultz's work primarily concentrates on a number of strategic questions related to conditions for efficiency in the employment of production resources. Professor Schultz attaches crucial importance to vocational skills, schooling, research and its application. He is a pioneer in research on 'human capital', a field which has been expanding rapidly since the end of the fifties. The efficiency and development of agriculture, is also in Professor Lewis's opinion, of vital importance for the situation and growth of the developing countries. Professor Lewis has focused attention on the dual nature of developing country economies, the tension between a large, dominating and stationary agricultural sector and a dynamic industrial sector.

The creation of economic models and their applications to the analysis of economic fluctuations and economic policies are in the favourite domain of econometricans. The building of econometric models has attained a widespread universal use.

Professor James Tobin[23,24] has made substantial contributions in such widely differing areas as econometric methods and strictly formalized risk theory, the theory of household and firm behaviour, general macro theory and applied analysis of economic policy. His most outstanding and significant research contribution belongs to the theory of financial markets and their relation to consumption and investment decision, production, employment and prices. Professor Tobin's studies constitute a major breakthrough in the integration of real and financial conditions in central economic theory.

Portfolio selection theory is used to study households' and firms' decisions to hold different real and financial assets, and, simultaneously, incur debts. Professor Tobin shows how these decisions are governed by weighing risk and expected rate of return. Unlike many other theorists in the field, Professor Tobin did not confine his analysis solely to money but considered the entire range of assets and debts.

With an excellent background of analytical methods, Cybernetics in Modelling in Financial Engineering has become a strong contender of economic sciences. By definition, Cybernetics deals with the purposeful analysis of complex system with a view to ascertain control mechanism in accordance with optimally designed decision processes.

Financial engineering, the most computational intense subfield of finance, has only come to be recognized as a formal profession over the last four or five years. During that time, the International Association of Financial Engineers (IAFE) has been instrumental in helping to define the profession and in promoting the creation of financial engineering research programmes. Technological sciences recently reveal the revolution in financial services. For more than a half-century statistics and technical analysis have been the technologies of choice for financial analysts. However, it was not until the introduction of the Hamiltonian-Jacobi-Bellman and Black-Scholes[25] differential equation in the mid-70s that more advanced forms of mathematics were used in the field of finance. Since that time there has been a tremendous expansion in the application of mathematics and other engineering technologies to the field of finance. In 1973, Fischer Black and Myron Scholes published their groundbreaking paper, 'The Pricing of Options and Corporate Liabilities'. Not only did this specify the first successful option of pricing formula, but it also described as a general framework for pricing other derivative instruments. This paper launched the field of financial engineering. The use of mathematics has been spurred by the availability of low-cost computers and supercomputers. In addition there has been a luminous gathering of engineers, mathematicians, and physicists into the finance and investments industry. Many of these professionals are excited about the opportunities to apply their quantitative and analytical skills in new ways. And finally there is the explosive growth in the financial markets in volume, numbers and types of securities offered, and their internationalization under GATT and WTO regimes which has required the intensive use of engineering technologies for development of highly skillful computerized software.

The future of the continuing convergence of the fields of finance and engineering into a new era of computational intelligence and its application in the financial services arena has been envisaged. There are neural nets that emulate the Black-Scholes equation with better out-of-sample performance than the original equation. Commercially available software using genetic algorithms provide superior results for portfolio asset allocation. Moreover today's computational intelligence methodologies can forecast the inflation rate to 95 per cent accuracy. The interest in application of the ingredients of computational intelligence to finance has been growing steadily.

Three factors are largely responsible for this mighty achievement. The first is the simple fact that the financial system is becoming more complex over time. This is an obvious consequence of general economic growth and development in which the number of market participants, the variety of financial transactions, and the sums involved also grow. As the financial system becomes more complex, the benefits of more highly developed financial technology become greater and greater and, ultimately indispensable. The second factor is the set of professional developments in the quantitative modelling of financial markets, e.g., financial technology, pioneered over the past three decades by the giants of financial professionals: Fischer Black[25], D A Cox[26], J Lintner[27], H Markowitz[28], R C Merton[29], and others. Their contributions laid the remarkably durable foundations on which all of modern quantitative financial analyses are built. The third factor is an almost parallel set of technological breakthroughs in computer technology, including hardware, software, and data collection and organization. Precisely, Professor Merton's work in the continuous time of mathematics of finance serves as one of the cornerstones on which the profession of financial engineering is built. Professor Merton redefined modern financial economics definitively, and helped to launch a multi-trillion-dollar industry that is still enjoying double-digit growth. While the methods and techniques range broadly, from optimal control and filtering to neural networks to nonparametric regression, the topics are all sharply focused on financial applications. In this way, financial engineering is following a path not unlike those of the engineering disciplines in their formative stages: applications tend to drive the technology, yet research and development are characterized by an intellectual entrepreneurialism that cuts across many different methodologies.

Post graduate programmes are being offered by engineering schools and mathematics departments, though some are being offered by business schools. The understanding and mitigation of risk are increasingly important aspects of modern finance. Running on the speed and capacity of the Internet and other information technologies, the world's financial markets have grown dramatically in size, interconnectedness and complexity. With more opportunities available, investors are more willing to accept the risks associated with entrepreneurial ventures to create new financial products and services. But the combination of technological innovation and globalization that created the new economy also brings new sources of risk to financial markets.

Financial engineering is a multidisciplinary field that combines finance, mathematics and statistics, engineering and computer science. The related areas in these fields are financial markets, mathematical finance and econo-physics and computational finance. Quantitative and analytical principles and methods are critical in understanding financial instruments in financial markets today, so that the new discipline of financial engineering has evolved. Financial engineering requires a composite of skills. For example, the methodology of science and mathematics has been used in financial engineering areas such as derivative pricing and hedging, portfolio management and risk management. Stochastic calculus helps financial engineers to price exotic options and to hedge the risks. Advances in Monte Carlo simulation have been applied to risk management. For selecting optimal portfolios, optimization techniques have been applied to the asset and liability management problem. The neural networks and genetic algorithms used in engineering and physical science fields have been applied to forecasting future prices for trading and investment.

The domain of knowledge includes financial markets, financial products and processes, price and hedge modelling, investment technology, risk analysis, computational methods, and data support systems for trading. When institutions create desired pay-off patterns that manage risk for their clients or use options and futures to hedge the products they sell, they are engaging in financial engineering.

A distinct professional category called financial engineers is needed by financial institutions to develop new financial products, to customize and trade them, to monitor risk exposure to books of complex derivatives, to devise hedging schemes and to search for arbitrage opportunities in the markets.

A wide range of businesses offer career opportunities for financial engineers, including:

- commercial and investment banks
- brokerage and investment firms
- insurance companies
- accounting and consultancy firms
- treasury departments of non-financial corporations
- public institutions such as federal government agencies, state and local governments, municipalities and international organizations
- software and technology vendors that provide products and services to the financial industry.

The rapid assimilation of new methodology into practice is both a result of and reason for this interdisciplinarity. Financial engineering encompasses most realistic model-building. A model building procedure will now be outlined. The procedure follows in three stages: 1) Preliminary Structure Determination, 2) Parameter Estimation, and 3) Diagnostics. These stages are not disjoint, for in reality the results of any one may alter the results of another and thus require a repeated application of some or all of the previous stages. Experience has shown that the actual construction of a model involves repeated cycling through the stages.

The specification of a model almost exclusively involves purely economic considerations. The model may be used as an aid in economic analysis, policy simulation, or policy optimization, but each case imposes special demands on the specification. The result of such considerations generally determines the overall size of the model, the number of inputs and outputs, and the definition of these variables. In addition, the outputs of the model are usually decomposed into two types: the endogenous variables which are outputs of dynamic equations, called behavioural equations and variables which are outputs of non-stochastic equations, called definitional equations. A choice must be made as to the use of variables in current price (inflated) or constant price (deflated). The economic specification stage can be summarized as one in which the following information is determined:

1) The specific purpose of the model, thereby fixing the overall size; and hence, an enumeration of all the outputs and their type and an enumeration of all the inputs and their type.

2) The output definitions, whether it is explained by a behavioural equation together with all its explanations (inputs to the equation), or whether it is determined by a definitional identity.

The second stage is the most challenging of the two.

This stage combines the use of *a priori* economic information, hypothesis testing techniques, and cross-correlation analysis from the black box approach. In econometric terminology, the word 'structure' denotes a complete definition of the functional or stochastic relationships between all of the endogenous and exogenous variables. The specific meaning of structure can be ascertained by examining each equation of the structural form. Before accepting the results of any estimation, they must be tested for their adequacy. The auto- and cross-correlation functions for the model residuals constitute important diagnostic checks. The last diagnostic to be employed is perhaps the most important, namely, the model's forecasting performance. After having successfully met the other diagnostic checks a model is not accepted until it has demonstrated its ability to forecast. Forecasts are then made with each model from the end of its sample period up to the present, using the (historical) observed inputs over this period. Thus, forecasts are obtained outside of the sample period. Such simulations more closely approach reality and serve as a good guide in judging the model's adequacy in forecasting the unknown future. This gives additional insight into the time-invariance of the model structure. The modelling procedure described above was designed to incorporate three concepts. First, employment is made of all available *a priori* information provided by thus eliminating beforehand the possibility of expending effort on fruitless searches for non-existent relationships (interconnections). Second, the basic philosophy of the 'black box' approach is then applied allowing the data to decide the exact dynamic structure. Thus, complex (statistically unsubstantiated) structures are automatically eliminated. Third, diagnostics are continually employed which are designed to both reveal inadequacies and indicate how improvements can be made.

In conclusion let me quote from the 1982 Economics Nobel lecture of Professor George J Stiglar, 'The central task of an empirical science such as economics is to provide general understanding of events in the real world, and ultimately all of its theories and techniques must be instrumental to that task.'

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