Contributions to Economics

Paolo Savona
Rainer Stefano Masera *Editors*

Monetary Policy Normalization

One Hundred Years After Keynes' Tract on Monetary Reform

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Editors
Paolo Savona
Emeritus LUISS Guido Carli University
Chairman Consob
Rome, Italy

Rainer Stefano Masera
Economics Faculty
Marconi University
Rome, Italy

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This work is the result of an initiative
taken by Rainer S. Masera and Paolo Savona
who dedicate it to Paolo Baffi
Unforgettable Mentor

Contents

Purpose of the Initiative

Paolo Savona

Abstract This Preface explains the purpose of the collected essays on "normalization" of monetary policy after the unexpected rise of inflation. It shortly examines the problems related to the increasingly involving of money creation in guaranteeing financial stability, in the development of data science and Fintech, in the weakness of forecasts based on econometric models, in the irreconcilability of legal treatment of common and civil law regimes in front of interfungible operations on global markets, in the creation of the digital euro and ongoing changes in the geopolitical-economic utility function. All these factors require a re-examination of the interpretative models of how the markets for real and financial goods function, and empirical implementation which raise doubts about the possibility of a normalization of monetary policy, if we mean a return to the principle on which rests the independence of the monetary authorities, i.e., the stability of prices. The analysis starts from Keynes' proposal in his 1924 book entitled A Tract on Monetary Reform that the authors consider the beginning of modern theory of money and want to celebrate the ongoing centenary.

Keywords Money normalization · Financial stability · Data science · Fintech · Forecast models · Legal regimes · Digital euro · Geopolitical-economic function

1 Introduction[1]

After the rise in inflation at the end of 2021, the world's major central banks began to question whether they could return the monetary policy to the guidelines that had been in place until the global financial crisis of 2008. They also wondered, but to a

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P. Savona (✉)
Emeritus LUISS Guido Carli University, Chairman Consob, Rome, Italy
e-mail: p.savona@consob.it

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more modest extent, why they made the mistake of considering the increase in prices a short-run phenomenon that had emerged after a long period of deflation.

This volume is devoted to the examination of the many interconnected questions of this desired normalization, starting with the role of technological innovations in the management of the currency and of financial markets (derivatives and cryptocurrencies), the involvement of monetary policy in the financial crises (mainly by accepting public debts as collateral), and the great repricing needed for central banks and the world economy.

Then the analysis approaches the problem of how flexible money should be and the importance of the predictive instruments for the related policy choices, focusing the attention on the progress made by languages for scientific research, specifically the one dedicated to analyzing the working of the economy.

The last three papers are then dedicated to paramount features of the problem: the possible adoption of a digital euro, the impact of different law regimes (civil or common), and the digital innovations in geopolitical relations, particularly in welfare and warfare.

This Introduction will present some of the ideas that the authors have freely developed in their contributions.

Paragraphs 2 and 3 give a brief history of the institutional steps made to define the monetary policy rules that, one crisis after another, dominated the post-WWII economic scenario in the West, characterized by recovery and growth, until the end of the Bretton Woods agreement and of the dominance of the US dollar for international uses. This history is an indispensable starting point to understand the present attempt at "normalizing" the monetary policy.

Paragraph 4 analyzes the "permissive" monetary policy implemented in different ways by the FED and the ECB after the 2008 financial crisis, caused by abuses in the use of derivative contracts. This benign neglect policy for the economy is known as Quantitative Easing (QE) and became possible because of the existence of deflationary pressures. Today the situation is reversed, and inflationary tendencies prevail due to the sudden recovery in world demand as the health pandemic subsided and, since February 2022, the war in Ukraine.

Paragraph 5 testifies that a similar policy attitude of benign neglect was applied toward cryptocurrencies. This question is here considered part of the more extensive and complex problem of normalization that cannot be solved without a specific and clear position on the decentralized accounting technologies in use (blockchain and DLT).

Paragraph 6 deals with the central theme of the languages used in scientific research, in general or specifically in economics (as John Stuart Mill did). The search for monetary policy normalization is intertwined with the problem of the language needed to reach the necessary knowledge to make informed choices. After the dissatisfaction in the use of econometric methods, the possibility should be evaluated to use Artificial Intelligence, notably machine learning.

Paragraph 7 treats the issue of the legal basis within which the current monetary and financial surveillance system operates.

Paragraph 8 closes the analysis by placing all the formerly identified problems in a more general context, delineated by philosophers of information technologies, who take into account the implications that these questions have on human relations, in particular in the labor market and changes in geopolitics.

Lastly, the Preface offers some preliminary conclusions on the questions raised and on the possibility of monetary policy normalization.

2 Monetary Policy as Defined by the Bretton Woods Agreement of 1944

At the turn of the twentieth century the Governors of the two most important central banks in the world, the Bank of England (BoE) and the American Federal Reserve (FED) promoted some International Monetary Conferences. At the time, Norman Montagu of the BoE was the most influential central banker because of the centrality of the British currency in the world.

The purpose of these Conferences was to establish an international monetary regime and define in it the role of central banks, with particular attention to their independence from governments and parliamentary acts. This important issue was addressed based on the principle of no taxation without representation, the foundation of representative democracy that had found explicit consideration in the American Constitution.

The first three Conferences (1878, 1881, and 1892) discussed the impact of the excess of American silver on the prevailing bi-metallic monetary regime. After WWI the discussion resumed in 1920 in Brussels and in 1922 in Genoa, proposing the "decalogue of a good central banker" and the rules of the gold-exchange standard. This important stage in the definition of a monetary institutional architecture corresponded to a period of monetary and financial turmoil which culminated in 1922–1923 with the Great German Inflation. In 1925 a new Conference in Locarno debated the rules for converting metal and paper money, while the last conference, held in London in 1925, saw the creation of the Gold Block. This last coalition of countries, still maintaining the gold exchange, collapsed in 1931 with the crisis of the Sterling, which added new turmoil to those created by the 1929–1933 Great American Crisis and Depression. WWII then brought, obviously, a new wave of monetary and financial disorder.

The 1944 Bretton Woods Agreement can be considered the natural continuation of those Conferences in a different economic and logical contest. Indeed, the need for international monetary coordination remained on the political agenda, but above all in the agenda of economists, driven by J. M. Keynes's ideas published in 1924 (*A Tract on Monetary Reform*) and in 1930 (*A Treatise on Money*). In these volumes Keynes suggested to reconsider the "neoclassical theory of money"; the two volumes of the *Treatise* were presented with a curious annotation that he was publishing a

text that he no longer agreed with, but which would have been useful to be meditated by his colleagues. The two publications were taken as a reference analysis of this book not only because we are near the centenary of the first Keynesian publication—that we want to commemorate—but also because the ideas expressed there remain of importance in the ongoing discourse on the "normalization" of the monetary policy. After these treatises, Keynes began his gestation of the *General Theory* (1936) that would revolutionize the conception of how the economy works, including money, introducing policies to avoid the stagnation of aggregate demand and labor unemployment.

The *General Theory* marks the transition from the neoclassical theory to the Keynesian theory of money as the basis for orientation of economic policy decisions. The main change concerned the conception of how savings are formed—reversing the timing of its decision from ex ante to ex post—shifting analysis from autonomous choices to income-based micro or macro choices. This new conception justified the shift of the instrument of monetary policy from the quantity of money put in circulation to controlling the interest rate. The change in interpretative paradigm has led to a similar change in the neoclassical theory that, under the pressure of the Chicago School, transformed into what is known as monetarism.

3 From the Collapse of the Bretton Woods System in 1971 to the Global Financial Crisis of 2008

The monetary and financial turmoil culminated in the Great Crisis of 1929–33, brought the stability of the monetary meter and the management of finance to the center of economic policy action, with important institutional innovations, such as national banking laws and the creation of financial surveillance authorities (as the Security and Exchange Commission). The crisis of the Sterling in 1931 called for a redefinition of the interfungibility agreements between sovereign currencies so that, despite the disturbances caused by WWII, leading political and intellectual groups in the United Kingdom and the United States devoted more attention to monetary problems, as the basis of the proper functioning of the financial market and as such of economic development.

Even before the end of the world war, in 1944 these considerations led the representatives of 44 countries to meet at Bretton Woods (USA) to lay down the cornerstones of a Treaty that bears the name of the place where it was defined and played a role, which I consider decisive, in the creation of the monetary and financial environment conducive to post-war world growth.

The leading character of this meeting was Keynes, who had very clear ideas on the importance of the institutional architecture of money for attaining full employment, an objective that had become part of the utility function of the economic policy of the participants of the Bretton Woods regime.

The agreement reached at Bretton Woods was the result of compromises, including the refusal to create a currency for international use other than national currencies (the bancor proposed by Keynes), to be assigned to the management of a world central bank (the International Monetary Fund—IMF). Instead, it was agreed that the international currency should have been the American dollar convertible into gold at fixed prices (35 dollars per troy ounce); the IMF was supplemented by the creation of a World Bank to propitiate the growth of economically backward countries.

Subsequently, a continuous effort was made to strengthen the money-creation powers of the IMF, arriving in 1968 to the birth at Rio de Janeiro of the Special Drawing Rights (SDRs), but they were subjected to such constraints that they could not compensate for the defects shown by the dollar for international use. In 1971 the agreement reached at Bretton Woods was unilaterally suspended by the US.

A long period of inflation and monetary disturbances followed during which the development of alternative instruments was practiced to the excess. One such instrument was the derivatives, which were supposed to better manage financial risks, while at the same time, they created new ones. In 2008 the world entered in new great financial crisis, which induced the main central banks to intervene to avoid the consequences that had afflicted the economy in the past, such as those of the Great Crisis of half a century earlier.

4 Quantitative Easing (2009–2012), the Resurgence of Inflation (2021), and the Search for Normalization

The financial crisis of 2008 compared to the other crises experienced in the past had one peculiarity, the presence of higher public debts. The United States dealt with the situation by resorting to greater monetary creation which spread everywhere in the world, but public debts were affected by the crisis, inducing a change of orientation to privilege financial stability. This policy, which took the name of Quantitative Easing, was made possible by the prevalence of a deflationary tendency of the economy. Since the countries adhering to the euro had constraints to intervene to support public debts, the effects of the crisis tended to spread, becoming systemic. The collapse of the European currency became a real possibility. The European Central Bank (ECB) took longer than the FED to accept the necessity of an expansion of the quantity of money and to change its policy approach, but nonetheless, after buffer interventions, in 2012 it switched to practices that were equivalent to that of the American QE.

The new stabilizing financial operations operated effectively, but the quantity of money needed was determined on the basis of immediate needs, without taking into account longer-term effects. The errors of evaluation were induced by the prevalence of a deflationary condition, which the forecasting models based on econometric logic projected to persist in the long run. When the sudden recovery of aggregate demand following the end of the health lockdown occurred, forecasts continued to be

mistaken, and inflation continued to find further fuel in the new constraints imposed by the outbreak of the war in Ukraine and in the increase in energy prices.

At the end of 2021, it was clear that an inflationary wave had started that could be contained with a strong restriction, which would have caused serious problems for the stability of banks and finance. To avoid this unwelcome outcome, monetary policy was hesitant, but in the second half of 2022 all central banks dealt with the excessive quantities of money created, reducing them, and increasing the interest rates, but moderately.

This policy was called an attempt at "normalization," that is, an attempt to recover the tasks assigned to monetary policy in the past. Governments and banks that had largely benefited from the abundance of money at near-zero rates bore the brunt of the inflationary crisis, increasing the burdens on public debt to protect real growth and reducing risks of default on credit.

5 Grafting Cryptocurrencies onto the Dynamics of the Money and Financial Market

Since 2009, on this already complex framework, a rapid, disorderly, and unregulated growth of cryptocurrency has been grafted, starting with the success of Bitcoins. Bitcoins were created with a quantity constraint, so that a price increase could follow from even small increases in demand, a feature that, for no other reason than likeness, spread to other cryptocurrencies. The creation of legal money has always been the result of a real or financial operation with a creditor in front of a debtor, while the creation (or mining) of cryptocurrency has no debtor/creditor relationship behind it, but instead an external voluntary intervention accepting it. In this way, it is the market that gives a cryptocurrency its "legitimation." The creation of a cryptocurrency is a technological game that needs the legal system to be transformed into a real debt/credit creation. A benign neglect attitude of the authorities with respect to this unofficial market cannot be justified.

The attraction exerted by these new "virtual" instruments that have a mere digital consistency has represented a convenient alternative for savers who suffered losses on their investments in the 2008 global financial crisis. Bitcoins were a conventional currency or, as many believed, a financial asset "with a market" able to guarantee its liquidity if accepted in payment or transformed into another "traditional" asset (legal money, bonds, stocks, or others financial instruments). The rapid growth of their price was well represented by the following exemplification: at the beginning, a Bitcoin would buy you a pizza, and after ten years the entire "pizzeria" (the shop). Today the price of a Bitcoin fluctuates at a level that corresponds to less than 50% of the maximum value ever reached before.

People would think, at some point, that any form of cryptocurrency was a form of investment that could generate profits without doing anything, but there is no free lunch, as many have ascertained since, paying the cost of their illusion. In the

beginning, and very often even today, the authorities considered cryptos a minor problem, mainly because of the modest size of the total value they represented in respect to that of legal money and of traditional financial assets, but a snowball can turn into an avalanche despite its small initial size.

My position has always been that the problem was not the cryptocurrencies in themselves, but the type of accounting on which they were based: the Blockchain or the Distributed Ledger Technology (DLT), self-certifying decentralized operations by the owners of these virtual assets without the intervention of external operators. The main difference between the type of decentralized accounting is that Blockchains are permissionless, while DLTs are permissioned if third parties (intermediaries or official authorities) have the keys to know the content of the individual wallets. The use of decentralized accounting is currently limited, but it is becoming widespread and can cover all financial transactions, with a high probability that also legal money will be kept in such a form. A major source of concern regarding this technology is the connected disintermediation of bank deposits from the circuit of monetary creation, changing their legal and economic nature. Another is, in democracies, the threat to the privacy of citizens, which is difficult to guarantee in the infosphere.

These technological innovations for money and financial assets change the way the economy works, raising the need for an "economic theory with cryptocurrencies" that could offer new and more efficient predictive tools for the decision-making process of monetary and fiscal policies. Econometric models no longer seem capable of helping the authorities in deciding what they should do to control inflation and how to react to stagnation, causing them to proceed "by observing data." This data is then simply based on past trends and shown in an average dimension without an indicator of its frequency distribution to check its significance. As a consequence, more accurate day-by-day calculation based on AI algorithms is needed to change the statistical apparatus that is available for economic policy choices. The need for "economics with cryptocurrency" so becomes the search for "economics with machine learning," a technique to understand how a system works or, if you prefer, how it is possible to improve economic forecasts for monetary and fiscal policy choices. While this new economics is still in the making, at present economic policy decisions are a perilous balance act between three different goals, inflation targeting, growth stimulation, and social welfare. Juggling all of these objectives at once needs expert hands.

6 The Role of Languages and Paradigms Used in Scientific Research as the Main Problem of Information Technologies

The innovations that make up the Infosphere have a technological heart made of explanatory languages and protocols. Distinguished scientists who have developed scientific languages, from Newton to Leibnitz, and who have pursued the goal of universal language for scientific research or developed machines that propitiate its

advancement, like Galileo with his telescope, passed down to us the task of creating logical and physical tools suitable for the scientific purpose. The leap toward machine languages can be traced back to the contributions of Ada Lovelace and Alan Turing, which paved the way, in the second half of the twentieth century for advances in intercommunication ranging from the protocol Arpa (1958) to Arpanet (1969) and to the Internet (1989), the base for the www-world wide web (1991), which allowed an extraordinary world exchange of knowledge among scientist and common people. Science made significant progress when the common natural language was substituted by machine language, known as NLP, Natural Language Processing, then to the Internet of Things and shortly after to the Internet of People (the Avatars), giving an irreversible push to the creation of humanized robots, driven by artificial intelligence methods.

Adopting machine language opens up the possibility of using different protocols, as well as different machine languages. In finance, this diversification concerns self-certifying decentralized accounting, such as DLT, which has particularly significant effects on the legal architecture of monetary and financial markets. In fact, national currencies could lose the ability to interchange with one another, as could already happen between the digitized US dollar and the Chinese crypto yuan. To avoid this, the interchangeability should be extended from traditional financial instruments with centralized accounting to virtual ones with decentralized accounting.

7 The Impact on the Governance of Money and Finance of Common Law and Civil Law Regimes

It is well known that there cannot be a well-functioning market without a legal system that lays down the rules that operators must respect. Given the rapid evolution of the technological innovations applied to money and finance, choosing the form that best suits an ever-changing world is particularly significant. The common law regime is the one that best and promptly adapts to changes because the body of laws is formed through the judgments of judges. Consider that the rules that were formed in economics are the result of the pioneering work conducted by the Roman *pretores* (hence also Roman law), who judged case by case, elaborating constantly evolving common solutions. The civil law regime—which literature considers, I believe unjustly, the daughter of Roman law—is instead the transposition of legal reflections and experiences into legislative dictates, where judgments have margins of interpretation linked to the imperfections of the legislative dictate and the ability of judges to identify innovative spaces.

The coexistence between the two regimes should be guaranteed by international conventions, inevitably not binding, and by the freedom of the contracting parties to choose the desired regime for any of their conflicts. It is no coincidence that the prevailing choice is for the Anglo-Saxon common law regime, but above all the use of conciliation bodies, often private, whose decisions are less bound by codified

rules. One of the problems that has arisen with cryptos is that operators in the sector make customers sign agreements in which decisions in case of conflict are resolved by bodies chosen by them.

In this process of implementation of Fintechs, it has been observed that civil law regimes are sliding toward forms of common law decided by the judiciary at different levels on the basis of general legal principles concerning traditional economic activity and not a virtual reality in continuous evolution.

The numerous initiatives for the international standardization of financial phenomena do not directly address this problem, but reconcile the various instances indicated.

8 The Implications for Humans of the Application of Information Technologies to Economic Activity

A considerable part of the debate on technological innovations is centered on their effects on human coexistence, pitting the human brain against the artificial brain. On this line are those who reject computer applications because they do not intend to subject the human being to the will of a machine or run the risk of a rebellion of robots, ignoring that the artificial brain is born from applications of the ways of functioning of the human brain, to enhance it and, if this rebels, it means it has been instructed to do so. Man is the crooked wood of humanity, not the machines he invents.

Certainly, the spread of infotechnologies forces man to adapt and can cause isolation, disturbances, or ordinary life crises. However, if we think that the use of the infinite mobile apps has been quickly internalized in their behavior even by people of a modest level of education, the objection that the man–machine relationship increases the already serious social problems, seems an exaggeration. However, if we think about the metaverse, namely the transformation of all realities into virtualities, the infosphere, and the chatbots, that is, the provision of answers to every problem or curiosity based on processing AI algorithms without knowing the underlying technologies, the problem moves to the educational level, a problem that we have been facing for centuries; at least since the start of the industrial revolution that changed ways of life and social organizations.

These experiences generated both the most inviting democracies and the most terrible dictatorships, a problem on which disputes are still open. History goes on and technological innovations can be delayed, but not eliminated. There will always be someone who will carry them out. So, we need scientists and entrepreneurs, but also just as many educators. It will be on education and not only on machines that the future of mankind will be founded.

9 Conclusion: Is the "Normalization" of Monetary Policy Possible?

Given the historical heritage of markets and the intertwining of technological developments, "normalization" of the monetary policy is an old unsolved problem with new connotations.

The theoretical dispute over the tasks assigned to the central bank to be implemented independently provided content for the international monetary conferences mentioned and has generated in practice two policies: one which limited the objectives to price stability and was rooted in neoclassical economic logic; the other which also assigned the objective of real growth, near to Keynesian logic. The practical implementation was directed toward the first solution in Europe and the second in the United States, assuming in the first case a form of regulatory rigidity and in the second a practical application that, only in the seventies of the last century had a mathematical formulation known as Taylor rule.

In the aftermath of the 2008 crisis, it became clear that the aim of monetary stability in both directions, deflation/inflation, could not be pursued without financial stability and the protection of real growth. Because of its objective function and common law type of regulatory framework, the US moved rapidly, with QE, toward monetary policy involvement in financial stability, while the EU was much slower, paying a higher cost in terms of credit insolvencies and corporate bankruptcies. As has already been mentioned, the problem of the magnitude of this intervention was underestimated because of the deflationary environment in which it was implemented. As was the consideration that once the health component of deflation, the one born from the spread of Covid, ceased, there would have been a sudden growth in aggregate supply and demand with effects on prices. The first impact was caused by the recovery of energy demand in 2021, to which in early 2022 that of the invasion of Ukraine by Russia was added.

The forecasting instruments based on econometric logic showed their limitation and contributed to the errors, especially in the timing of intervention, committed by monetary authorities, that have accentuated and prolonged inflationary effects.

The temporal chain of economic policy choices testifies to this state of affairs which, instead of developing in the correct direction, that is, identifying what can be done, has been directed toward the search for institutional and personal responsibilities, neglecting the external ones of economists and governments, which are no less important. The outcome is as indicated: central banks are trying to recover the orthodoxy of their utility function in its dual configuration, which for simplicity of exposition we have defined as neoclassical and Keynesian, and governments react by forcing fiscal policy in the opposite direction to that necessary in an inflationary environment, that is, by trying to amend the damages it causes instead of tracing the causes. This inversion has been termed "normalization," meaning a shift from unconventional monetary policy toward conventional interest rate policy.

Put in these terms, the problem of normalization does not address the real problem: how to protect citizens from the unfair tax of inflation and ensure the continuation—and, if possible, improvement—of real growth: two faces of the same coin.

The answers to these questions that were given in the past, from which central banks have deviated under the impetus of the global financial crisis of 2008, has been that monetary stability cannot be achieved without simultaneous financial stability on the side of public and private debt, and protection of real growth, to avoid credit defaults. The limits of central bank intervention were given by the nature of individual crises, especially banking crises: if they arose from liquidity shortages, they could be addressed with the injection of the monetary base; If, on the other hand, they were crises of insolvency, then the units had to fail, accompanying this implementation so that it could be carried out in an orderly manner, that is, without overflowing on the other units. These limits could be overcome, because of the conclusion reached with the Radcliffe Report of 1931 (born after the British Sterling crisis) and reiterated by the following surveys like that carried out by the OECD in the 1960s, that money lacks direct effect on real growth but is important in determining expectations. Since the beginning of QE policies, but especially in this phase of normalization centered on interest rates, this characteristic of monetary choices has been incisively confirmed in the dependence of stock market trends and of the spreads on government bond yields on the statements and practical behavior of central bankers. A problem of communication and real decision with different effects compared to the past.

If this knowledge were relevant, it would follow that a normalization that ignored the role played by the spectators in simultaneously achieving a balance between monetary, financial, and real stability, would not solve the problem of how to deal with inflation and support real growth. To achieve this difficult equilibrium two rules of the monetary policy apply the first, supported by Karl Brunner, one of the leading theoreticians of monetarism who simultaneously analyzed the problems of money and of credit, that the main problem of inflation is not having it, but when you run into it you need to be very careful about how to get out of it so as not to cause greater damage; the second is that the knowledge tools to decide the quality and quantity of choices can no longer be limited to those developed by econometrics, but must experiment with more advanced solutions using artificial intelligence techniques.

Economics and Money. Political and Epistemological Perspectives of Connecting and Fault Lines: A Fil Rouge from Keynes to Digitization

Rainer Stefano Masera

Abstract To assess the theoretical and normative consequences of the digitization process in money, finance, and defense, a deeper understanding of the underlying methodological reference frameworks of statistics, probability, economics, and social sciences is needed. This paper addresses the problem by looking at the relationship between inductive and deductive approaches in research methodology and at the century-old distinction between measurable objective risk and uncertainty underlined by J. M. Keynes and F. Knight. Assessing the right theoretical framework will be paramount to choose an adequate normative approach in respect to the danger of contagion between the phygital domains, the crypto world, and the traditional financial system.

Keywords J. M. Keynes · Cryptocurrencies · Bancor · Phygital · Financial system

1 Introduction

A central—nonmainstream, but with distinguished precedents—tenet of this paper is that economic and monetary theories and policies arise from experience and should be confronted with experience (Hicks, 1977). Economic analysis is intertwined with politics, social sciences, statistics, and mathematics. The two-way links with these sciences are strong, but changing over time, partly because of technological advances and structural trends.

Human knowledge, society, philosophy, law, and sciences are undergoing constant reshape. Digitization (the process of converting information from a physical into a digital format) has become the fundamental driver of transformation in modern societies and economies. The world is undergoing a radical redesign. The opportunities are large. But so are the risks of political and policy mistakes.

R. S. Masera (✉)
Economics Faculty, Marconi University, Rome, Italy
e-mail: r.masera@unimarconi.it

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Equally important changes took place in the past few centuries with waves of technological innovation, wars, depressions, inflation, reconstruction, and population/economic growth.

A remarkable insight of past developments to "take wings into the future" was offered by J. M. Keynes (1930a, 1930b) in a relatively little known (and quoted[1]) essay, where he developed a positive long-term view on the readjustment process, including the reabsorption of unemployed labor.

In times of global uncertainties and profound political, social, and economic changes, the evolving threads must be adapted to the underlying processes under review, to events which have come about, and are expected to take place. From this perspective, it will be argued that the part of economic theory which is in constant search of one timeless "general theory of economic equilibrium", with self-correcting markets, may turn out to be misleading.

Economics is not an exact science (and even sciences like physics can hardly be referred to as "exact" in the traditional sense of the term); it cannot be neatly encapsulated in mathematical models. Walras (1874), Arrow (1951, 1972), Arrow & Debreu (1954) gave a formal mathematical answer to issues originally analyzed by Adam Smith. See also Hicks (1934).

Pioneering reflections on general equilibrium theory are due to Von Hayek (1937, 1948, 1994). He criticized the passive price-taking behavior adopted in the Walrasian framework, and, more generally, the supposed self-regulating of a market economy. He also indicated that economics must not be considered in isolation but should be instead analyzed in terms of the interplay with social and institutional factors.

Hayek was convinced, as Hicks after his IS-LM model, that a merely mathematical formulation of general equilibrium could prove deceptive. Hayek's approach was modeled in his analysis of the market economy as an information gathering and process system. This represents a path-breaking frame of reference for the digital revolution.

He pioneered the analysis of complex adaptive systems, by referring to a dynamic vision of the emerging economics of information. His work is correctly regarded as an anticipation of large-scale information treatment and of market algorithms. Hayek therefore represents the link with the digital new deal, the use of Artificial Intelligence, and the risks to democratic systems posed by the control of information (Quarles, 2019 and Sect. 8 below).

He is therefore critical of the neoclassical model advanced to explain how free markets left to themselves can coordinate the different desires and talents to promote a stable full employment system, and of its assumptions: individual rationality, market clearing, perfect competition, perfect information, and "rational" expectations.[2]

[1] Notably in comparison with the near-exclusive emphasis on the alleged short-termism of Keynesian analysis (1923) ("in the long run we are all dead").

[2] Arrow recognized that the rarefied assumptions implied "real problems" in finding any use of his general equilibrium model. See Arrow in Machina and Viscusi (2014).

2 Macroeconomic Processes: Mathematical, Statistical, and Probability Theories

Following the mathematical formalization of Keynes' General Theory (1936), offered by the Hicksian IS-LM framework (1937), the macroeconomic analysis was generally set in terms of systems of simultaneous equations (Modigliani, 1944; Tobin, 1981). Macroeconomic models were translated into econometric forecasting models.

This leads to the issue of ergodicity and stationarity in statistical and probability application to economics and to the extension of statistical techniques designed for experiments to the non-experimental data which often represent the reference in economics (Box 1).

Box 1: Ergodicity and Stationarity: From Physics to Economics

Ergodicity and stationarity play a crucial role in the analysis of issues relevant to statistics, probability, and economics.

Ergodicity. The concept of ergodicity was introduced by Ludwig Boltzmann (1898), a German physicist who studied problems of statistical mechanics and thermodynamics (observation of trajectories in the study of the kinetic theory of gases). In an ergodic system, by observing single trajectories, one can define hypotheses about the behavior of the whole system. If observed for a sufficiently long period, one trajectory is representative of the system as a whole. At the cost of some oversimplification, it is possible to say that the same result is obtained whether the system's values are averaged over time and space.

The ergodic theory was extended and refined by Birkhoff (1931), and Neumann (1932); they underlined the relevance of these issues for physics, chemistry, engineering, and other sciences. The mathematical and statistical concepts developed in terms of the deterministic "rational mechanics" approach in physics are closely intertwined with the neoclassical economic equilibrium models. In this process: "the ergodic hypothesis was essential to extending statistical techniques designed for experiments to the non-experimental data of concern in economics" (Poitras & Heaney, 2015).

Stationarity. From the perspective of statistics, stationarity refers primarily to the distribution of the reference random variables. In a stationary process, all the random variables have the same distribution function. More specifically, the statistical description of the process does not change if we shift all time instants.

Ergodicity and stationarity are two different concepts, with some common characteristics. Specific attention can be drawn to one key aspect. The essence of the "mean ergodic theorem" can be viewed in the equality of ensemble and time averages. This equality is necessary to the concept of stationary stochastic process.

The transposition of the models of ergodicity and stationarity to economics—with clear implications also for the treatment of risk and uncertainty (Boxes 2 and 3)—requires great care and attention. Two key references are Machina and Viscusi (2014) and Kay and King (2020).

A non-technical explanation was offered by Hicks (1979, 121): "When we cannot accept that the observations, along the time series available to us, are independent we have, in strict logic, no more than one observation, all of the separate items having to