

ROBERT M. SOLOW

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Robert M. Solow is one of the major proponents of the neoclassical synthesis (the synthesis of standard neoclassical microeconomics and Keynesian macroeconomics). In the vanguard of this theoretical orientation is a quintet of distinguished economists: P. A. Samuelson, J. Hicks, J. Tobin, F. Modigliani and Solow himself. It is worth noting that each of them is a Nobel laureate. Solow was awarded the Nobel Prize for Economics in 1987 for his contri-



butions to the theory and measurement of economic growth.

His pioneering work in the field of growth theory had a profound effect on the further development of economics and instigated a discussion on the factors ensuring economic growth and, more importantly, a completely new explanation of how technological progress contributes to the growth of national income and social wealth.

Robert Merton Solow was born in Brooklyn, New York on 23 August 1924. His parents were the children of immigrants. Educated in the neighbourhood public schools of New York City, he was, as he himself has said, taught by a devoted teacher to read the great 19th century French and Russian novelists and to take ideas seriously. In 1940 he won a scholarship to Harvard University where his first studies were in sociology, anthropology and elementary economics. At the end of 1942 he left university and joined the U.S. Army. He served briefly in North Africa and Sicily and then for the duration of the war in Italy, until his discharge in 1945.

Upon returning to Harvard in 1945 he decided to continue with economics. This came about thanks to a meeting with Wassily Leontief, who became his teacher, guide and friend and who taught him the spirit and substance of modern economic theory. As his research assistant, Solow produced a set of capital-coefficients for the input-output model.

Having become interested in statistics and probabilistic models, Solow spent a year studying them at Columbia University in 1949-1950. He was at the same time working on his Ph.D. thesis, which addressed the modelling of changes in the size distribution of wage income using interacting Markoff processes for employment-unemployment and wage rates. The thesis was awarded the Wells Prize at Harvard, along with which the author

was offered publication in book form and \$500 (in 1951 prices) once the thesis was ready to be printed. Nevertheless, the thesis was not published and the cheque was not cashed. Solow explained that after rereading the text, he realised he could do better. In the end, however, he never returned to this work.

In 1950 Solow was offered and accepted an Assistant Professorship in the Economics Department at the Massachusetts Institute of Technology. After initially teaching courses in statistics and econometrics, he focused his research on macroeconomics for what he himself has called a geographical reason – he was given an office next to Paul Samuelson, who had already written a well-known textbook on economics. Daily contact with Samuelson and conversations on economics, politics and ordinary life, eventually drew Solow back to "straight" economics and he discovered in himself an instinctive macroeconomist.

Apart from his research and teaching, Solow has been involved in practical activities in the government sector. In 1960 – 1961 he served on President John F. Kennedy's Council of Economic Advisors, and later he was part of a government commission examining the problems of welfare recipients. For five years in the late 1970s Solow was a director of the Federal Reserve Bank in Boston. He has also been engaged in a range of topical controversies and discussions.

Theory of economic growth

At the end of the 1950s a majority of economies were experiencing fast economic growth generated by demand deferred from the war period and by the need to restore the war-torn economies. The economic sciences also responded to this situation. In the United States the question of economic growth was being addressed mainly by Solow, J. Kendrick and E.

Denison. They were nicknamed "economic archaeologists" since they were attempting to "dig up" the source of economic growth.

Solow's main contribution is an elaboration of neoclassical growth theory. His first pioneering work was the article "A Contribution to the Theory of Economic Growth" (1956), in which he developed a neoclassical-type mathematical model of long-run growth based on criticisms of the Keynesian Harrod-Domar



model (regarding the fact it was a single factor model where the sole growth factor was capital accumulation). Solow abandoned the standard Keynesian assumption of a fixed ratio between production factors and introduced a ratio variable. The basis of growth in his model was, on the one hand, the substitution of labour by capital and, on the other hand, technological progress, which he considered to be a key determinant of growth in the long run.

Solow drew on the Cobb-Douglas production function, which expressed the functional dependence of national product growth on labour growth and on capital growth. Developed by the mathematician Charles W. Cobb and the economist Paul Douglas at the end of the 1920s for the U.S. economy, this production function is represented as follows:

$$Y = A \cdot L^a \cdot K^b$$

$$a + b = 1$$

where:

- A – a constant determined by the effect of other factors not directly expressed in the function,
- L – labour input,
- K – capital input,
- a – an elasticity coefficient for labour's share of output; it indicates the percentage change in the product when, ceteris paribus, the volume of labour changes by 1%,
- b – an elasticity coefficient for capital's share of output; it indicates the percentage change in the product when, ceteris paribus, the volume of capital changes by 1%.

Solow's contribution was to extend the Cobb-Douglas production function with a third factor of growth – technological progress, which he understood as operating autonomously in time. For him, technological progress is an exponential function of time. As a result he came to a modified version of the Cobb-Douglas production function:

$$Y = A \cdot L^a \cdot K^b \cdot e^{rt},$$

where e^{rt} represents the effect of technological progress (r) in time (t) on economic growth.

In contrast to the Harrod-Domar model, the Solow growth model took into account labour-capital substitution, in other words the change in production technique as a response to changes in relative prices of labour and capital.

Solow attempted to quantify the effect of individual factors on the pace of growth. In an article entitled "Technical Change and the Aggregate Production Function" (1957), he carried out an empirical analysis of the long-term growth of the U.S. economy. The key to economic growth in the period 1909-1949 was, according to him, technological progress rather than

the traditional production factors of labour and capital. He asserted that, in the mid-20th century, 87.5% of labour productivity was the result of "technological changes" and only 12.5% could be attributed to conventional growth in the number of workers and capital equipment. He construed technological progress in quite broad terms – including, for example, the increasing educational qualifications of workers and the more effective organisation and management of production – and, understandably, in the narrow sense too. Solow's conclusion represented an immediate revolution in both economic science and economic policy. The importance of investments took a lower profile, as economists and politicians gave priority to technical progress and how to go about accelerating it.

Solow in his initial reasoning worked with disembodied technological progress, which is not tied to the replacement of old equipment with new. Such technological progress has the character of an exogenous quantity, not related to the introduction of production factors into the production process. On this basis, the view spread that the main agent of growth is investment in people and science, rather than investment in capital, which led to a certain underestimation of capital accumulation.

Solow later developed the hypothesis of embodied technological progress, in other words technical progress which is embodied in capital goods (in machines of various ages). In a work entitled "Investment and Technical Progress" (1960), he disaggregated capital according to its age structure and therefore also according to its technical level. Embodied technological progress reckons on the fact that older production equipment is gradually replaced with new and improved equipment. Each new generation of investments is more productive than the last. In this case, technological progress is factored into the growth indicator of capital itself. In such an understanding of technological progress, capital as a share of economic growth is substantially higher at the expense of disembodied technological progress.

The "Solow residual" – the rate of technological change that explains the difference between real income growth and growth explicable by growth in labour and capital – is considered by many to be a key element of the new economics since it reflects the overall efficiency with which labour and capital are used. There may be various origins of the efficiency growth – innovations, technological changes, management methods, organisational changes, more efficient methods of organising production and services, and so on.

Theoretical literature was dominated up to the mid-1970s by the neoclassical theory of long-run economic growth that Solow and his followers had developed. (The most notable opposition to it came in the



form of the post-Keynesian growth models of N. Kaldor, J. Robinson, et al.) Interest in the theory waned as a result of the turbulence related to the oil crisis, stagflation, etc. (It is no wonder that business cycle theories that had previously been out of fashion enjoyed a renaissance at this time.) From the mid-1980s the problems of long-term growth once again began to take a more important place in macroeconomic research – the newer research is well known as endogenous growth theory (Robert Lucas, Paul Romer).

The productivity paradox

On the subject of computers, Solow made the following observation in 1987: "You can see the computer age everywhere but in the productivity statistics." The fact that new information technologies have hardly registered in productivity growth has been termed "the productivity paradox". The author's doubts about whether new computers and information technologies actually increase productivity in individual sectors are based on the fact that its growth since the mid-1970s has been slowing down. It appears that the enormous investments in information technologies are not having the desired effect of increasing productivity growth in the economy as a whole.

Solow at the same time suggests two possible explanations for this paradox. It may, on the one hand, be due to the time lag between the introduction of new technology and the effect it has on economic growth. On the other hand, the productivity paradox could be caused by a change in the character of national economies. This concerns the fact that there is a transition taking place from the old economy, based on the automated production of goods and mechanisation of agriculture (with efforts in automation having ensured average annual growth of between 3% and 4% over the past hundred years), to the new economy. The feature of this economy is that, as a result of innovations, manufacturing employs even fewer people and workers are therefore moving into the service sector, which is not reporting substantial productivity growth (less than 1% per year on average).

Solow's contribution to the development of the Phillip's curve

Solow also devoted himself to macroeconomic questions concerning the problems of inflation, unemployment and selecting an appropriate economic policy. In the field of Keynesian macroeconomics he attracted attention mainly with an article entitled "Analytical Aspects of Anti-Inflation Policy" (1960), co-written with Samuelson. Here the authors analysed the causes of inflation, drew a distinction between

its demand and supply impulses, and, most notably, modified the classic Phillips curve by replacing the rate of change of nominal wages with the rate of inflation. In their concept, the Phillips curve modified in this way illustrated the link between the rate of unemployment and the rate of inflation. Resembling the original Phillips curve in shape, slope and position, this form of the Phillips curve is today the one most frequently used in economic literature.

This modification led to a conclusion with interesting implications for economic policy, in particular, that the desired low unemployment (sought by the Keynesians) is linked to the undesired growth in prices – inflation. The extent of unemployment may be influenced by fiscal and monetary policies. The government has a certain room for manoeuvre: it faces a choice of two "evils" – high unemployment and high inflation – between which there is scope for substitutability. In this regard Solow focused on the selection of an appropriate economic policy.

According to Solow and Samuelson, price level stability should be achieved where the rate of unemployment stands at 5.5% (5% – 6%). They calculated that an unemployment rate of 3%, which was then considered an objective of economic policy, would result in an annual inflation rate of between 4% and 5%. Nowadays these conclusions sound exceptionally optimistic. It should be added, however, that the authors themselves warned about their conclusions only being applicable for the next few years since a change in economic policy could shift the Phillips curve. Today we take the view that the 1970s stagflation represented a concurrent worsening of both the key indicators and excluded the room for manoeuvre as being a way to increase inflation still further. Not only has the Phillips curve shifted rightwards and upwards, it has also lost its characteristic slope. A new interpretation of the Phillips curve was provided by Milton Friedman.

Other contributions of Solow

It was in the 1970s that the ecological issues came to the centre of public attention. As an expert in the interpretation of the factors affecting long-run economic growth (in other words, basic production resources and technological progress), Solow entered into this discussion while at the same time exposing a number of ecological myths. For example, he rejected the opinions of the Club of Rome members who advocated zero growth (Forrester) and who maintained that we could no longer rely on technological progress to solve our problems. Solow argued that the only basis for overcoming ecological problems was economic growth and the technological progress which creates new economic resources or saves on existing resources.



Solow also gave a lot of attention to analysing the labour market and the problem of unemployment. He understood unemployment to be involuntary, a position typical of Keynesian economists. As to why the labour market is distinct from other markets, he considered the main reasons to be non-economic ones, including social patterns and principles of appropriate behaviour (for example, unemployment assistance, household management, etc.). These reasons, according to him, prevented the easy creation of such wage rates that would "clear" the labour market or that would adjust more quickly to changed conditions.

Solow – Keynesian economist

Even though the Solow growth model has pronounced neoclassical (in other words non-Keynesian) features, Solow himself is a substantially Keynesian economist. Holding the Keynesian position in key respects, he sees the current problem of the market economy in terms of unemployment, he rejects the monetarist doctrine, and he advocates active intervention by the government in the economy. He made highly critical comments about the economic policies of U.S. President Ronald Reagan and U.K. Prime Minister Margaret Thatcher. That said, he also criticised the effectiveness of Keynesian-style intervention, for example, the anti-recession measures pursued in the U.S. in the late 1960s, including the regulation of interest rates and fiscal policy.

The human side of Solow

Colleagues describe Solow as an unpretentious, good and witty person. In personal matters he is known for his moderation. Unlike many of his colleagues he never tried his luck as a stock market speculator. It was typical that he still kept his office next to Samuelson even after being awarded the Nobel Prize.

Solow is regarded as a skilful debater. His language and reasoning are elegant and sharp-witted, so much

so that his intellectual opponents are often led into cul-de-sacs. Commenting on an address given by Milton Friedman in the late 1960s, he said: "Another difference between Milton and myself is that everything reminds Milton of the money supply. Well, everything reminds me of sex but I keep it out of the paper."

Solow's enthusiasm for economics and his sense of humour are renowned. He is also aware that economics is very difficult to get across to the public. In a press conference given after his Nobel Prize award, he remarked: "The attention span of the people you write for is shorter than the length of one true sentence."

We will conclude with the dictum that Solow used to round off his Nobel Prize lecture: "You never know if you have gone as far as you can until you try to go further."

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Major works of R. Solow

Solow's main field of interest was macroeconomics where his approach was based on the construction of models based on microeconomic principles. His research work was published mostly in journal articles and in the chapters of collective publications.

His most important works include:

- Contribution to the Theory of Economic Growth (1956, Príspevok k teórii ekonomického rastu).
- Technical Change and the Aggregate Production Function (1957, Technický pokrok a celková funkcia výroby).

- Nature and Sources of Unemployment in the USA (1964, Povaha a zdroje nezamestnanosti v USA).
- Capital Theory and the Rate of Return (1965, Teória kapitálu a výnosová miera).
- Price Expectations and the Behavior of the Price Level (1968, Očakávaná vývoja cien a správanie cenovej hladiny).
- Growth Theory: an Exposition (1969, Teórie rastu: výklad).
- The Labor Market as a Social Institution (1990, Trh práce ako sociálna inštitúcia).
- Work and Welfare (1998, Práca a prosperita).