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The Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 1995

[Robert E. Lucas Jr.](#)



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Advanced Information

The Scientific Contributions of Robert E. Lucas, Jr.

The Royal Swedish Academy of Sciences

October 1995

During the 1970s macroeconomics was rapidly and thoroughly transformed: the rational expectations hypothesis was developed and applied, an equilibrium theory of business cycles emerged, and the problems in macroeconomic evaluation of economic policy and their solutions were clarified. This evolution is mostly due to the contributions of one researcher: Robert E. Lucas, Jr. This report elaborates on that development and Lucas's contributions to it. Lucas has also made significant contributions to other research fields than macroeconomics. These are covered only very briefly.

1. The rational expectations hypothesis

Agents' expectations about the future are obviously important for many of their current decisions. Therefore the development of the economy is to a considerable degree affected by current expectations about future developments. One example is wage formation, where expectations about future inflation and labor demand strongly affect the contracted wage for the contract period, which in turn strongly influences realized inflation. Bond rates and other asset prices are further obvious examples. Interest rates vary with expected future inflation, since bondholders want to be compensated for the depreciation caused by inflation. Stock prices are influenced by expected future dividends and capital gains. Firms' and households' investment in capital and saving in financial assets are then influenced by these asset prices and expected future returns, incomes, and taxes.

In spite of their importance, expectations long received very superficial treatment in economic analysis. A couple of decades ago it was not unusual to assume exogenous or even static expectations, for instance such that the expected future price level was equal to today's price level, regardless of the development of the economy. In some cases expectations were expressed as an arbitrary function of observed variables. So-called adaptive expectations were an improvement. They imply that expectations of the future are mechanically adjusted to previous expectation errors: if today's price level exceeds previous expectations of today's price level, today's expectations of the future price level are adjusted upwards in proportion to the error. Such expectations imply, however, that agents mechanically repeat previous errors without ever realizing how primitive their method is; these expectations are only backward-looking. Rational expectations are instead truly forward-looking and imply a much more sophisticated, and more realistic, way of forming expectations; agents learn from their mistakes and use their intellectual capacity to understand the way the economy works.

The rational expectations hypothesis is best described as the consistent application of the hypothesis of rational behavior to individuals' and firms' behavior in genuinely dynamic situations, with uncertainty about the future, imperfect information and costly information gathering. The hypothesis does not imply that all agents have the same information, or that all agents know the 'true' economic model; it simply means that agents use available information in the best way and collect further information only if the expected benefit exceeds the cost.

Expressed in this way the rational expectations hypothesis is easy to grasp and no more controversial than the usual rationality hypothesis in static situations. But it is often technically difficult to apply the hypothesis in economic analysis; the consequences of the hypothesis are frequently dramatic, for instance in regard to the effects of stabilization policy.

John Muth (1961) was the first to formulate the rational expectations hypothesis in a precise way. He used it in a study of the classic cobweb phenomenon. Muth's analysis was restricted to a single market in partial equilibrium. The importance of the rational expectations hypothesis became apparent when Lucas extended the hypothesis to macroeconomic models and to the analysis of economic policy.

In a series of path-breaking papers, starting with Lucas (1972b), he extended and applied the hypothesis to general equilibrium situations. Especially, he demonstrated that it could successfully be applied to the study of economic policy. In this undertaking, an important development was to look at economic policy, not as in previous literature as a series of independent actions, but as systematic behavior, an implicit or explicit rule, with both predictable and unpredictable components. For instance, monetary policy by a central bank is often more productively seen as the continuous adjustment of policy instruments to observed variations in inflation and unemployment, than as just a series of

independent adjustments. Lucas realized and explained the far-reaching consequences of endogenous rational expectations formation, especially for the effects of changes in economic policy and for econometric evaluation of economic policy. He later applied the hypothesis to several other fields than macroeconomics and economic policy.

Lucas also developed operational methods to solve general equilibrium systems with rational expectations. These methods are now standard in economic analysis (see below). Without such methods, the implications of the rational expectations hypothesis would probably have been restricted to general insights about the importance of expectations, rather than precise and operational statements in specific situations.

The rational expectations hypothesis is by now accepted as the standard frame of reference and the starting point for later studies of expectation formation, for instance with bounded rationality, limited computational capacity, and gradual learning. This role is similar to that of the Arrow-Debreu model of general equilibrium on a set of complete markets as the starting point for later work on incomplete markets, transaction costs, and imperfect competition.

2. An equilibrium theory of business cycles

A considerable part of Lucas's research has been devoted to an equilibrium theory of business cycles. After the Second World War business-cycle research was dominated by Keynes' followers. Business cycles were seen as disequilibrium phenomena. Disequilibrium here refers to the assumption that important variables in the analysis, for instance prices and wages, are exogenously fixed and not explained endogenously in the model. This meant that the supply of labor in the labor market and the supply of goods in the goods market might be rationed. In some cases prices and wages were assumed to be mechanically adjusted to the level of excess supply in each market, such that price and wage inflation was a decreasing function of the rate of unemployment: the so-called Phillips curve. The Keynesian approach was rightly criticized for *postulating* such relations without giving them rigorous theoretical explanations. The critique carried special weight since it showed that the Keynesian approach in effect assumed agents to behave consistently against their own best interests.

Even if the Phillips curve lacked a satisfactory theoretical explanation, by the end of the 1960s it had substantial empirical support. It was generally interpreted as implying a long-run tradeoff between inflation and unemployment: the authorities in a country could achieve a long-run reduction in unemployment by pursuing a more expansionary stabilization policy leading to higher inflation. This interpretation was criticized by Milton Friedman and Edmund Phelps, who emphasized that the interpretation disregarded the effects of expectations: If expectations were adjusted to higher inflation, the Phillips curve would shift and the long-run tradeoff between unemployment and inflation would vanish; the long-run Phillips curve would become vertical and the long-run, 'natural', unemployment rate would be independent of inflation. Friedman and Phelps assumed adaptive expectations in their critique. However, with such expectations, unemployment can still be permanently reduced, if inflation is allowed to increase steadily over time.

Using the rational expectations hypothesis, Lucas (1972b) presented the first theoretically satisfactory derivation of a short-run sloping and long-run vertical Phillips curve. In the model he constructed, agents have imperfect information and cannot unambiguously distinguish whether a local price increase is due to rising demand for their own product or a general increase in the price level because of an expansion of the money supply. In contrast to previous disequilibrium analysis, this was an example of consistent *equilibrium analysis* in the sense that all important variables were determined in

the model, that the variables controlled by agents were set according to their objectives, and that the agents had rational expectations about the future development of the model's variables. Lucas formulated the model's equilibrium as a functional equation for the functions describing the responses of the model's endogenous variables to exogenous random disturbances, and he also solved the functional equation. (1) Lucas showed that it is rational for the producers in the model to interpret a proportion of each price increase as caused by increased demand and therefore to increase output somewhat. Econometric estimation on time series generated by the model would then result in a positive relation between inflation and employment. However, any attempt to exploit this relation and, by more expansionary monetary policy, permanently increase employment would be fruitless and only result in more inflation.

(1) Expectations are modeled as a function describing how prices are expected to depend on exogenous disturbances. This expectation function results in a pricing function describing how the actual prices depend on the exogenous disturbances. The expectation function is hence mapped into the space of pricing functions; this results in the relevant functional equation. The solution to the functional equation is a fixpoint where the expectation function and the pricing function coincide. Such a solution indeed exists, since the functional equation can be shown to be a contraction mapping.

During the 1970s governments and central banks allowed inflation to take off in a number of countries. As predicted by Friedman, Phelps, and Lucas, the short-run Phillips curves shifted such that no permanent gain in employment could be achieved.

This was the first example of a rigorous equilibrium business cycle model with endogenous rational expectations. The model's main importance eventually derived from its role as a methodological example. The actual explanation of business cycles in the model, imperfect information about the money supply, has not been considered too convincing, because precise information about the money supply is easily accessible. Although disturbances to money demand and money supply multipliers can be difficult to observe, it has not been possible to demonstrate empirically that imperfect information about monetary aggregates is an important explanation of business cycles.

After Lucas's pioneering contribution, equilibrium business cycles rapidly became a dynamic research area. A large number of followers in the 'real business cycles' literature have emphasized real disturbances in productivity rather than monetary disturbances as a cause of business cycle variations. More recently, monetary disturbances have received new interest. The typical working method in the equilibrium business cycle literature is to begin by formulating a consistent stochastic equilibrium model, and then calibrate or estimate the model parameters, using earlier estimates of central parameters or new estimates of the model's more specific relationships. Thereafter the model is evaluated according to how well it can reproduce actual historical time series. The model is in a way used as a laboratory, where postulated relations and subtheories are tried out. (2)

(2) See for instance the papers collected in Cooley (1995).

Lucas's work has adhered to an easily stated principle: The models should be explicit and complete, in the sense that all important variables should be determined endogenously through interaction between rational agents with rational expectations in a specified environment. This implies an insistence on completeness in the theoretical analysis that, in principle, is accepted by most researchers in

economics. In practice, this insistence may be very difficult to achieve, especially since many macroeconomic problems require analysis of dynamic situations with explicit uncertainty.

The equilibrium theory of business cycles was initially developed under the maintained assumptions of completely flexible prices and instantaneous equilibria with perfect competition on goods and factor markets. These assumptions have sometimes, erroneously, been regarded as a necessary and integrated part of the equilibrium business cycle approach. Lucas's approach is indeed consistent with sticky prices and market imperfections. In a discussion of models with predetermined prices that are fixed during a specific contract period, Lucas wrote (1980b, p. 712): "If...contract length is viewed as emerging from a decision problem solved by agents, then these models, so elaborated, would be equilibrium models."

Lucas's approach hence appears completely consistent with frictions and imperfections. However, it insists that they not be *postulated*, that is, introduced in an arbitrary way, but instead be *explained* as a result of agents' decisions and interaction in their environment. Interpreted this way, Lucas's methodological approach has been accepted by almost all macroeconomists, even if the application of it is very demanding and often encounters practical problems. It appears as if the most progress in modeling frictions and imperfections has been made when this methodological principle has been followed, for instance in the new-Keynesian literature on sticky prices (see the contributions collected in Mankiw and Romer (1991)). Lucas's general approach has indeed become a prototype for practically all modern researchers in macroeconomics.

3. Macroeconometric evaluation of economic policy

The 'Lucas critique' - Lucas's contribution to macroeconometric evaluation of economic policy - has received enormous attention and been completely incorporated in current thought. Briefly, the 'critique' implies that estimated parameters which were previously regarded as 'structural' in econometric analysis of economic policy actually depend on the economic policy pursued during the estimation period (for instance, the slope of the Phillips curve may depend on the variance of non-observed disturbances in money demand and money supply). Hence, the parameters may change with shifts in the policy regime. This is not only an academic point, but also important for economic-policy recommendations. The effects of policy regime shifts are often completely different if the agents' expectations adjust to the new regime than if they do not. Nowadays, it goes without saying that the effects of changing expectations should be taken into account when the consequences of a new policy are assessed - for instance, a new exchange rate system, a new monetary policy, a tax reform, or new rules for unemployment benefits.

When Lucas's seminal article (1976) was published, practically all existing macroeconometric models had behavioral functions that were in so-called reduced form; that is, the parameters in those functions might implicitly depend on the policy regime. If so, it is obviously problematic to use the same parameter values to evaluate other policy regimes. Nevertheless, the models were often used precisely in that way: Parameters estimated under a particular policy regime were used in simulations with other policy rules, for the purpose of predicting the effect on crucial macroeconomic variables. With regime-dependent parameters, the predictions could turn out to be erroneous and misleading. For instance, the same change in a central bank's instrumental interest rate can have very different effects in different regimes. Such phenomena, which might superficially be interpreted as a complex and strange property of the economic system, are given a relatively simple and intuitive explanation in the light of Lucas's result.

Expressed in this way, the point is easy to grasp. But to establish it in a convincing and rigorous way required deep insights into the relationship between typical behavior functions in macroeconomic models and the result of dynamic optimization in microeconomic models of economic behavior. With these insights, Lucas could theoretically convince his contemporaries as well as later economists that three crucial building blocks of traditional macro models, the consumption function, the investment function and the Phillips curve, had parameters that were regime dependent.

A simple version of Lucas's result is very easy to demonstrate for the Phillips curve. Assume that employment, l_t , and inflation, π_t , in period t follow the relation

$$l_t = \alpha(\pi_t - E_t\pi_{t-1}) + \bar{l},$$

where α and \bar{l} are positive constants, and $E_t\pi_{t-1}$ denotes agents' rational expectations in period $t-1$, given the information available in period $t-1$, about inflation in period t . As mentioned above, Lucas (1972b) provides a rigorous derivation of this relation.³

Assume now that a given monetary policy results in the following stochastic process for inflation,

$$\pi_t = \bar{\pi} + \epsilon_t,$$

where $\bar{\pi}$ is a given constant average inflation rate and ϵ_t is an identically and independently distributed exogenous disturbance with mean zero and constant variance. Then expected inflation is given by $E_{t-1}\pi_t = \bar{\pi}$, and employment will fulfill

$$l_t = \alpha\pi_t - \alpha\bar{\pi} + \bar{l},$$

with average employment

$$E[l_t] = \alpha\bar{\pi} - \alpha\bar{\pi} + \bar{l} = \bar{l}.$$

(3) As shown in modern macroeconomic textbooks, the same relation can be derived in several different ways. One situation is when nominal wages for period t are set one period in advance in period $t-1$, in proportion to expectations of the period t price level. If realized inflation then exceeds expected inflation, the realized real wage will be lower. If labor demand is decreasing in the real wage, employment will then be higher.

Time series of employment and inflation generated by this simple model economy will show a positive relation between employment and inflation. It may then be tempting to try to increase the average employment level, by running a more expansionary monetary policy that results in more inflation. Assume therefore that monetary policy is changed to a more expansionary stance and results in a new stochastic process for inflation.

$$\pi_t = \hat{\pi} + \epsilon_t,$$

where $\hat{\pi} > \bar{\pi}$. Now expected inflation is given by $E_{t-1}\pi_t = \hat{\pi}$; inflation expectations are adjusted upwards. Employment will obey

$$l_t = \alpha\pi_t - \alpha\hat{\pi} + \bar{l},$$

and average employment will be

$$E[l_t] = \alpha \hat{\pi} - \alpha \hat{\pi} + \bar{l} = \bar{l}.$$

Thus more expansionary policy just leads to more inflation, but does not increase average employment.

Lucas's contribution was also an implicit call for a new research program. This program involves formulating and estimating macroeconomic models with parameters that are independent of the policy regime, so that they can be used for evaluating alternative policies. The principle is again easy to state. The models should be formulated in terms of policy-independent parameters, for instance describing households tastes and firms technology. These parameters can then be estimated with specially developed econometric methods. In practice, as emphasized above, it is often quite difficult to follow this principle. Nevertheless, the principle has been successfully applied in a number of cases, such as investment behavior's dependence on depreciation rules, taxation, and access to subsidized investment funds; consumption behavior's dependence on taxes and transfers; labor supply's dependence on wages, taxes, and unemployment benefits.

Lucas's pioneering contributions have actually created a new subfield within econometrics: rational expectations econometrics. Here, the theoretical analysis of the consequences of rational expectations is used to identify the most suitable methods for estimating relations and models where expectations are key components. Some early contributions are collected in Lucas and Sargent (1981).

4. Other contributions

In addition to his work in macroeconomics, Lucas has made significant contributions to a number of other research fields, such as investment theory (Lucas and Prescott (1971)), financial economics (Lucas (1978)), monetary theory (Lucas (1980a), Lucas and Stokey (1987)), dynamic public economics (Lucas and Stokey (1983)), international finance (Lucas (1982)) and, most recently, economic growth (Lucas (1988)). In these fields Lucas's work has been of great importance, given research a new direction, and generated a large new literature.

One of these contributions concerns asset pricing. Lucas (1978) solved the first model of asset pricing in a general equilibrium with rational expectations. This work is one of the most influential in financial economics and has become the starting point for a whole new literature that tries to integrate financial economics and macroeconomics. Lucas showed that asset prices can be expressed as a function of the economy's state variables, which is the solution to a functional equation that arises from a combination of an equilibrium assumption and a first-order condition for the agents' individual decision problem. This method has become standard in financial economics.

Another example is the field of endogenous growth which, after two or three seminal papers - one of which is by Lucas (1988) - has quickly become a large and rapidly developing area. In previous growth literature, the long-run growth rate was exogenously determined. In the new growth literature, the economy's growth rate is endogenously determined because accumulation of physical capital, human capital and new technological know-how does not lead to diminishing returns. A large group of followers have been extending this literature.

5. Summary

Robert Lucas is the economist whose work has had the greatest impact on the development of macroeconomics and macroeconometrics since 1970. His work has brought about a rapid and

revolutionary development: the application of the rational expectations hypothesis, the emergence of an equilibrium theory of business cycles, and the macroeconomic evaluation of economic policy. Lucas has also made major contributions to several other fields of economics.

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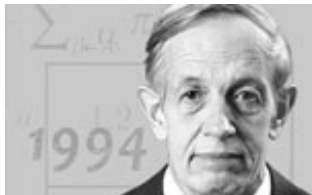
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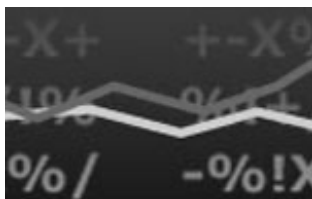
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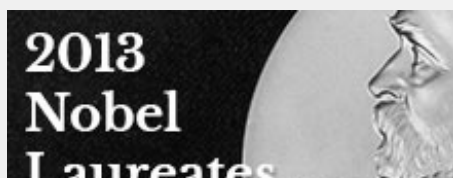
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