

## Nobel Laureate Robert E. Lucas, Jr.: Architect of Modern Macroeconomics

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### **Abstract**

In 1995, Robert E. Lucas, Jr., was awarded the Nobel Prize in Economic Sciences. This review places Lucas' work in a historical context and evaluates the effect of this work on the economics profession. Lucas' central contribution is that he developed and applied economic theory to answer substantive questions in macroeconomics. Economists today routinely analyze systems in which agents operate in complex probabilistic environments to understand interactions about which the great theorists of an earlier generation could only speculate. This sea change is due primarily to Lucas.

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In the late 1960s and early 1970s, Robert E. Lucas, Jr., wrote a number of papers which have rightly been revered as modern classics. For this body of work, Lucas received the Nobel Prize in Economic Sciences in the fall of 1995. The purpose of this review is to place Lucas' work in a historical context and to evaluate the effect of this work on the economics profession. In writing this review, I have benefited greatly from Lucas' (1996) Nobel lecture and from the essay of Thomas Sargent (1996) which was written to kick off a conference held at the Federal Reserve Bank of Minneapolis to celebrate the 25th anniversary of the publication of Lucas' (1972) seminal paper, "Expectations and the Neutrality of Money."

Lucas' work is sometimes heralded as revolutionary, marking the beginning of the end of Keynesian economics and the birth of rational expectations economics. This tendency to mark all key developments in economics as revolutionary is popular enough, but in my view, it is a misreading of the history of economic thought. My thesis is that Lucas' work is very much a part of the natural progress of economics as a science. Scientific progress arises from the interaction between theory and data and the desire to have one unified theory to account for the observations at hand. The search for such a theory proceeds by developing specific abstractions, or *models*, to understand specific observations. These abstractions then lead to the development of a more general theory, which in turn leads to discarding models which are inconsistent with data and to the development of better models. Lucas' central contribution was to develop and apply economic theory to specific questions in macroeconomics and to make obsolete one class of models. With trenchant vigor and uncommon grace, Lucas argued that economic theory could be used to illuminate old and puzzling substantive questions.

Lucas' contributions are both methodological and substantive. The methodological contribution is to illustrate how one goes about constructing dynamic, stochastic general equilibrium models to shed light on questions of substantive economic interest. The substantive contribution is to develop and analyze a specific mechanism by which monetary instability leads to fluctuations in output and inflation. It is hard to overemphasize the contribution to method. Economists today routinely analyze systems in which agents operate in complex probabilistic environments in order to understand interactions about which the great theorists of an earlier generation could only speculate. This sea change is due in substantial part to Lucas.

### **The Theoretical Foundations of Macroeconomics**

By the 1960s, the models used in macroeconomics described the aggregate economy as consisting of a system of equations: one equation to describe consumption, one to describe investment, one to describe money demand, and so on. Each of these equations was loosely thought of as arising from a deeper formulation of individual or firm decision making. This approach was attractive because the models were mathematically explicit and the parameters of the equations could be estimated using the powerful econometric procedures that had been developed in the postwar era under the influence of the Cowles Commission. These macroeconomic models were widely used for answering questions such as, How does the conduct of monetary policy affect output, inflation, and unemployment? A growing

consensus in economics viewed these models as fitting the behavior of the U.S. economy and as suitable for generating answers to policy questions; for an expression of this confidence, see Franco Modigliani's (1977) presidential address to the American Economic Association. At the same time, the desirability of making specific the relationship between macroeconomic models and microeconomic theory was widely recognized. That is, macroeconomics needed theoretical foundations.

The chief difficulty in developing these foundations was that macroeconomic questions necessarily involve dealing with dynamics and uncertainty. An individual choosing how much to spend today is necessarily making a choice of how much to consume in the future. Investment decisions are based on the expectations of future returns. These and other decisions are fraught with risk. Furthermore, they are based on anticipations of prices that will prevail in the future. How does one model this decision making and the way in which anticipations are made and revised?

Economic theory is about developing frameworks that can be used to analyze such situations. The theory has at its base two fundamental postulates. First, individuals act purposefully to achieve the ends they seek, and this feature can best be captured in models where agents maximize a well-defined objective function. Second, since outcomes depend upon the actions of everyone in society, agents must form expectations about the actions of others and, indeed, expectations about the expectations of others, and so on. This feature can be captured by the notion of *equilibrium*.

The equilibrium postulate is a convenient and powerful way of summarizing these expectations and ensuring consistency in decision making. As the name suggests, *equilibrium* is the rest point of a system, and it was conventional to think of this rest point in terms of quantities and prices. However, this conventional view is not particularly helpful in thinking about a world which is continually buffeted by shocks. In such a world, the sensible way to think about decision problems is as formulating decision rules or contingency plans for choosing actions which depend upon agents' information. The central theoretical breakthrough of the last 50 years is that economists now think of equilibrium as a rest point in the space of decision rules. This breakthrough appeared in the most theoretical and abstract reaches of the discipline in the work of John Nash (1950) in game theory and the work of Kenneth Arrow (1951) and Gerard Debreu (1959) in the theory of competitive equilibrium. Lucas is perhaps the foremost recent developer and expositor of this view. Thinking of equilibrium as a rest point in the space of decision rules has given economists the conceptual framework to analyze a bewildering variety of environments in which dynamics and uncertainty play central roles.

The contrast between the theoretical foundations of the 1960s-style macroeconomic models and those of modern models is stark; the book edited by Thomas Cooley (1995) is a collection of papers which illustrate the style of modern macroeconomic modeling. The earlier generation of macroeconomic models was frequently rationalized as representing the equilibria of static general equilibrium models together with tacked on dynamics representing slow wage and price adjustment to shocks. The parameters describing the speed of adjustment were not derived from

maximizing behavior. The notion that people setting wages and prices will not react rationally to the expected future state of the economy, or will react in a mechanistic way, is fundamentally at odds with the maximization postulate. It was well understood that this was not a happy state of affairs. Resistance to conventional economic theory came in substantial part because equilibrium models were thought to be inconsistent with high rates of unemployment.

Thus, the macroeconomics of the 1960s and early 1970s needed firm theoretical foundations, and the great contribution of Lucas and others (including Robert Barro, Edward Prescott, Sargent, and Neil Wallace) lies in the attempt to reformulate old questions in the language of economic theory. In doing so, these theorists clarified the questions for which macroeconomic models could provide reliable answers and the questions for which such models could not provide reliable answers. More important, these theorists laid out a research program for studying substantive questions in macroeconomics. Modern economic models apply economic theory consistently. These models also have a surprising ability to reproduce observations that were thought to be inconsistent with equilibrium, including unemployment, underutilization of capital, and fluctuations in economic aggregates.

In the next sections of this review, I focus on two papers by Lucas: his 1972 paper “Expectations and the Neutrality of Money” and his 1976 paper “Econometric Policy Evaluation: A Critique.” These papers were explicitly cited by the Royal Swedish Academy of Sciences in awarding Lucas the Nobel prize.

## Expectations and the Neutrality of Money

### *The Setting*

By the late 1960s, there was a consensus among macroeconomists that the Phillips curve was a central feature of business cycles. A. W. Phillips (1958) plotted the rate of growth of nominal wages against the unemployment rate for the United Kingdom and showed that these variables were negatively associated. Subsequent analyses focused on the relationship between the rate of change of a broad index of prices of goods and services—that is, the inflation rate—and the deviations of gross national product, or output, from a trend. A stable relationship of this kind has immediate policy implications. It suggests that monetary authorities can lower unemployment at the cost of a somewhat higher inflation rate and can reduce the inflation rate only by incurring the cost of higher unemployment.

However, Milton Friedman (1968) and Edmund Phelps (1968) soon mounted powerful theoretical arguments against these policy recommendations. They argued that economic theory suggests that sustained inflation can have no effect because people care about real quantities, not nominal ones. Once people anticipate sustained inflation, they will adjust their pricing, employment, and job search decisions in ways that take inflation into account, rendering the inflation irrelevant to real economic decisions. These considerations suggest that sustained inflation cannot lead to a permanent reduction in unemployment. Friedman emphasized that expectations adjust slowly to permanent changes in the inflation rate. This slow adjustment implies that unemployment can be temporarily low when the economy is stimulated by, say, expansionary monetary policy. But eventually the monetary expansion will filter through

to the economy in higher prices, and unemployment will return to the level determined by underlying real forces. Phelps (1970), in his introductory essay to a marvelous volume, sketched out a formulation in which informational imperfections lead people to believe that overall price changes reflecting monetary fluctuations are instead relative price changes favoring the industry or sector in which they are employed. The stage was set for Lucas to flesh out this sketch in the language of modern economic theory.

### *The Question*

In “Expectations and the Neutrality of Money,” Lucas (1972) asks one of the oldest questions in economics: How do changes in the conduct of monetary policy affect inflation, output, and unemployment? At least since David Hume in 1752 (in Rotwein 1970), economists have struggled with this question, and it continues to occupy center stage two and a half centuries later. The evidence is unambiguous in one respect: Business cycle booms are times in which the growth rate of monetary aggregates is higher than average, and contractions are times in which the growth rate of monetary aggregates is lower than average. A central question in macroeconomics is whether monetary policy can and should be used to moderate business cycle fluctuations. It is the kind of question that the data alone cannot answer. Models are needed.

Lucas made a substantive and a methodological contribution in his 1972 paper. The substantive contribution is to develop and analyze a specific mechanism by which monetary instability leads to fluctuations in output and inflation. In this mechanism, people with limited information confuse monetary disturbances with relative price movements, so that monetary fluctuations lead to aggregate output fluctuations. The methodological contribution is to illustrate how one goes about constructing dynamic, stochastic general equilibrium models to shed light on questions of substantive economic interest.

Lucas set his argument in a framework originally introduced by Paul Samuelson (1958). In this overlapping generations framework, people live for two periods, so that in any period the economy always has people of two age groups, the young and the old. At the end of each period, the old die, the young become old, and a new generation is born. There is only one good. Only the young can work and produce the good, but both young and old people like to consume it. The good cannot be stored. In this highly stylized economy, current and future generations can all be made better off if they could devise some mechanism to transfer part of production in every period to those who are old. One obvious such institution is social security, and indeed, modern analyses of social security programs use the overlapping generations model as a point of departure.

Samuelson (1958) noted that other institutions could also perform much the same function. In particular, intrinsically useless pieces of paper, called *money*, could provide the old with a claim to part of the output produced by the young. Each generation of young people willingly gives up part of what they produce for pieces of paper, because they think that future generations will exchange these pieces of paper for goods. Suppose that the number of pieces of paper, or the *stock of money*, is fixed and held by the initial generation of old people and that each generation of young people is identical. The simplest way of thinking about this kind of economy is that people behave competitively;

that is, they take the price of goods in terms of money as unaffected by their individual decisions on how much to produce and consume. Old people supply all the money they possess and consume what the market provides. Young people have a more interesting problem. In choosing how much of their production to supply to the market, they need to forecast the value of money when they are old. The value of money, of course, depends upon the decisions of the next generation and therefore upon the forecasts that will be made by the next generation. Rational decision making by today's young requires forecasting the forecasts of others.

It is here that the notion of equilibrium allows analysis of an apparently intractable problem. In this unchanging world, the notion of equilibrium requires that expectations of future prices, or forecasts, be the same as the prices that actually prevail. An equilibrium, then, is a price in each period and a choice by young people in each period of how much to sell to the market, given the price when they are young and the price when they are old, such that the amount of money brought by old people into the market is the same as the amount of money young people want to carry into the future. This last requirement is sometimes described as a *market-clearing condition*.

This kind of monetary economy shares a feature with all sensibly formulated economies. The units in which prices are quoted have no effect on the outcomes people care about. If we split up dollar bills into pennies and quote prices in pennies rather than dollars, it is obvious that all that happens is that prices are multiplied by a factor of 100. This property is called *zero-degree homogeneity* of prices. An implication of zero-degree homogeneity is that if we double the number of dollar bills once and for all in the hands of the initial generation of old people, all that happens is that prices double in all periods. Monetary economies with this feature are said to display *neutrality*. More generally, money is said to be *neutral* if a proportionate change in all nominal, or dollar-denominated, quantities in all periods is associated with a proportionate change in all prices and no change in real quantities. In Samuelson's (1958) economy, a one-time change in the number of dollars held by the initial generation of old people leads to a proportionate change in all nominal quantities and in all prices, so that monetary injections of this kind are neutral.

Monetary injections of other kinds may or may not be neutral. Suppose, for example, that a monetary authority expands the quantity of money at a constant rate and does so by continually handing out money to old people in a lump-sum fashion, that is, independently of the amount of money any particular old person may have. One would expect this kind of injection to lead to a constant increase in the price of goods, that is, to *inflation*. In this kind of a world, young people see that the purchasing power of money will be diminished by the time they are old, and this reduced reward to work today leads to a fall in their willingness to work and in output. That is, inflation induced by ongoing monetary expansions of this kind acts much as a tax does. The inflation tax is an important feature of actual economies, but in this context, it leads to the implication that anticipated expansions in the stock of money depress current economic activity. Lucas, remember, is seeking to create a framework in which a current expansion in the stock of money first creates a surge in real

activity, as the evidence suggests actually occurs, but is neutral in the long run. For this purpose, the inflation tax argument works in exactly the wrong way.

However, there are other ways of injecting money into the economy which lead to continuing inflation but do not alter real decisions about how much to produce and consume. Consider, for example, handing out money to old people in exact proportion to the amount of money they have carried over from the past. Monetary injections of this kind are neutral because they do not change the rate of return to holding money. With injections of this kind, the negative effect of inflation on willingness to work is exactly undone by the higher return associated with the proportionate transfer.

### *The Answer*

To make the informational mechanism play a central role, Lucas assumes that transfers are proportional. Consider a situation in which these transfers are random. The interesting feature of this economy is that even if the young do not know the size of the monetary transfer in the current period, money is still neutral. The reason is that in competitive markets, the young generation can observe the price of goods before making their production decision. Therefore, in equilibrium, the prices reveal the size of the monetary transfer. As a result, in equilibrium, prices simply rise in each period by the amount of the transfer, and real allocations are completely unaffected.

The central economic idea that Lucas wants to formalize is that monetary disturbances lead to movements in prices that people interpret as meaning that the present is a favorable time to produce. The elegant formulation Lucas chooses is one in which trade occurs in "two physically separated markets" (1972, p. 103). Specifically, think of the economy as two islands, each with an equal number of old people. The overall number of young people is fixed, but they are divided randomly between the two islands in a given time period. Suppose for the moment that the stock of money is fixed for all time. Young people who find themselves on an island with few young people will find that the price of the good they sell is high, since there are few producers. This temporarily high price signals to them that they should produce a relatively large amount. Young people assigned to the other island find a low price and choose to produce little. In this economy, output on one island is higher than average, and output on the other island is lower than average. There is no particular reason that total output should exactly be equal to its average value, so in this sense output will fluctuate over time, depending on the exact assignment of young people. However, these fluctuations seem to have little to do with business cycles, since a key feature of the business cycle is that essentially all sectors of the economy move together.

Now consider adding monetary disturbances to this economy. A higher than average transfer induces prices to rise on both islands. Consider the problem facing a typical young person. Prices could be high because of the monetary disturbance, in which case the best thing to do is not to respond in terms of production decisions, or prices could be high because there are relatively few people on the island, in which case the best thing to do is to produce more. If a producer does not know why the price is high, the optimal decision is a mix of these extremes, so that output in both islands rises relative to the case when there was no

monetary disturbance. Thus, in this economy, prices are higher than average precisely when output is higher than average—and this is precisely when the rate of growth of the money supply is higher than average. Prices and output are lower than average when the rate of growth of money is lower than average. Notice, however, that if the size of the monetary disturbance is known, there is no scope for confusion about the source of the price increase, and monetary disturbances are neutral. The model requires that we draw a sharp distinction between *anticipated* monetary fluctuations, which are neutral, and *unanticipated* fluctuations, which induce output movements.

Lucas (1972, p. 119) also uses the model to argue for a particular sense in which the best monetary policy is one in which the monetary authority follows a “*k*-percent rule,” in which the rate of growth of the quantity of money is constant. At this point it is best to quote from the conclusion to the paper (Lucas 1972, pp. 121–22):

This paper has been an attempt to resolve the paradox posed by Gurley (1961), in his mild but accurate parody of Friedmanian monetary theory: “Money is a veil, but when the veil flutters, real output sputters.” This resolution has been effected by postulating economic agents free of money illusion, so that the Ricardian hypothetical experiment of a fully announced, proportional monetary expansion will have no real consequences (that is, so that money *is* a veil). These rational agents are then placed in a setting in which the information conveyed to traders by market prices is inadequate to permit them to distinguish real from monetary disturbances. In this setting, monetary fluctuations lead to real output movements in the same direction.

In order for this resolution to carry any conviction, it has been necessary to adopt a framework simple enough to permit a precise specification of the information available to each trader at each point in time, and to facilitate verification of the rationality of each trader’s behavior. To obtain this simplicity, most of the interesting features of the observed business cycle have been abstracted from, with one notable exception: the Phillips curve emerges not as an unexplained empirical fact, but as a central feature of the solution to a general equilibrium system.

### *The Legacy*

The demonstration that a Phillips curve could emerge in an economic model with rational agents is at one level an impressive display of technical wizardry. The key to the technical contribution is that prices are thought of as *functions* of the state of the economy, where the state is the stock of money and the distribution of young people across islands. This notion has its antecedents in the work of Arrow (1951), Debreu (1959), John Muth (1961), and Lucas and Prescott (1971). Muth advanced the principle of rational expectations as a model-building device: the idea is that the expectations attributed to economic agents in a model should be the same as those implied by the model. More generally, the rational expectations hypothesis is that agents use available information in the best way.

It took some time before this principle was widely used in economics. Once it began to be used, however, it took the field by storm for three reasons. First, unlike the alternatives, the notion of rational expectations adds no free parameters but, instead, imposes restrictions across equations. In contrast, for example, the notion of adaptive expectations involves adding free parameters to describe how expectations are formed and revised. Second, rational

expectations is consistent with individual maximization, since it rules out the existence of obvious profit opportunities. Third, the equilibrium point of view practically forces one to use rational expectations. Once prices and choices are thought of as functions of the state of the economy, one is forced to impart beliefs to economic agents about how the state evolves and therefore beliefs about the model of the economy held by agents in our models. Today, it seems hard to imagine starting anywhere else.

Some of the most interesting recent theoretical work involves studying how agents learn; a good introduction to this literature is Sargent 1993. Specifically, one question that many authors have attempted to study is whether agents who start off with beliefs other than those implied by rational expectations will eventually come to hold rational expectations. Another line of research assumes that people are boundedly rational and asks whether such economies will eventually look like economies with fully rational agents. The starting point for both literatures is a rational expectations equilibrium.

With the model in “Expectations and the Neutrality of Money,” Lucas emphasizes the distinction between anticipated and unanticipated changes in the stock of money. In this sense, the approach represents a difference, and I think an advance, over the distinction between the long run and the short run which both Friedman and the Keynesian literature emphasized. The specific formulation led to a long and misdirected debate over whether rational expectations implies that anticipated monetary policy could have no real effects. It is abundantly clear from the model that neutrality of anticipated monetary policy depends critically upon the manner in which money is injected. Other ways of injecting money have effects on output. For example, if monetary injections were made in a lump-sum manner, the inflation tax would affect the behavior of output. However, we have good reason to believe that these effects are likely to be small. In any event, the economy will respond quite differently to anticipated and unanticipated changes in the stock of money.

This contribution of “Expectations and the Neutrality of Money” led to an extensive empirical literature. (See, for example, Sargent 1976 and Barro 1977.) In “Some International Evidence on Output-Inflation Tradeoffs,” Lucas (1973) noted that a key implication of the 1972 paper is that when monetary fluctuations become very volatile, agents will pay no attention to the price signal when making their decisions. This immediately suggests that countries with volatile inflation rates should have less volatile output. The international evidence lent some support to this view. The distinction between the effect on output of anticipated and unanticipated changes in the stock of money was also tested for U.S. time series data by many economists, notably Sargent and Barro. The evidence here is mixed, and it is fair to say that the effects of price surprises appear to be weak.

The idea that informational limitations play a central role in how monetary policy affects output in the real world has largely fallen by the wayside. In part, this is because of the evidence from U.S. time series. The main reason, however, is that it seems quite difficult to use this mechanism to generate persistent effects of monetary shocks on output. In developed economies like the United States, information about economywide outcomes is readi-

ly and quickly available. It may be reasonable to suppose that people are confused about the sources of price changes for perhaps two or three months, but it seems difficult to see how people could continue to be misinformed for two or three years. Since business cycle fluctuations last at least that long, this mechanism is not persuasive as a model of business cycles.

One especially interesting logical descendant of “Expectations and the Neutrality of Money” is Finn Kydland and Prescott’s (1982) “Time to Build and Aggregate Fluctuations.” Both papers take seriously the ideas of focusing on one key driving force behind business cycle fluctuations, of using the best economic theory available, and of taking the implications of the theory seriously. Substantively, however, it is difficult to imagine two papers more at odds with each other. In 1972, Lucas modeled business cycles as an avoidable consequence of erratic monetary policy. In 1982, Kydland and Prescott modeled business cycles as the efficient response of the economy to technology disturbances. Neither paper’s substantive message has been accepted by the profession at large, but the methodological contributions are overwhelming. It is hard to pick up a recently published paper in macroeconomics that does not routinely use the notion of rational expectations equilibrium, and dynamic, stochastic general equilibrium models in the style of these papers have become the workhorses of modern macroeconomics.

What, then, is the legacy of “Expectations and the Neutrality of Money”? The paper is a contribution to method. It led to a simple reduced-form model of output fluctuations which continues to be widely used in the time-consistency literature and in positive models of central bank policy. Along with the work of Friedman and Phelps, the paper contributed to the demise of the belief that there was a long-run trade-off between unemployment and inflation for policymakers to exploit. The great inflation of the 1970s was surely due in part to the economics profession’s acceptance of the Phillips curve, just as the great disinflation of the 1980s and 1990s was due in part to the profession’s acceptance that the long-run Phillips curve is vertical (or perhaps even slopes upward). In this, as in so much else, ideas have profound consequences.

### **Econometric Policy Evaluation: A Critique**

The process of integrating economic theory into macroeconomics has fundamentally altered the profession’s perspective on a variety of questions. Most notably, it has discredited the usefulness of 1960s-style macroeconomic models for answering a variety of policy questions. For example, suppose we want to ask how the behavior of the U.S. economy would change if the Federal Reserve System were to adopt a policy of maintaining the growth rate of the money supply at 4 percent per annum. Using parameter estimates in a macroeconomic model generated from a time period when the Federal Reserve was pursuing a completely different policy makes sense if one believes these parameters would not change under a different policy regime. The problem is that economists have every reason to believe that parameters in such models are a mongrel of the way in which people’s expectations are formed and of underlying features of the economy, such as preferences and technology. Expectations depend upon the nature of the policy regime in place and therefore are likely to

change systematically with the regime. This is the substance of the 1976 *Lucas critique*.

In some ways, the Lucas critique has had a more substantial impact than did “Expectations and the Neutrality of Money” (1972). In part, this is due to the simplicity of the examples Lucas used in the critique to make his point. But the greater impact of the critique stems from the fact that it uses entirely conventional theoretical formulations to criticize the use of macroeconomic models in policy evaluation. Economists have long understood that economic models cannot sensibly be used for policy evaluation unless one has confidence that the structure of the model and its parameters are likely not to change under alternative policies. The typical macroeconomic model is a system of equations which are interpreted as describing the behavior of the people, the firms, and the government in the economy. When such models are used for evaluating alternative policies, they implicitly presume that the parameters of the equations will be invariant with respect to alternative policies. However, as Lucas (1976, p. 25) wrote in a later paper: “*Everything we know about dynamic economic theory indicates that this presumption is unjustified*” (emphasis in original). The argument behind this bold claim is that the equations in macroeconomic models are implicitly based on decision rules which specify what people will do, given the state of the economy. However, these decision rules depend on their expectations of future policies, which in turn surely depend on the kinds of policies chosen in the past. If policymakers choose policies in a new manner, surely people’s expectations about future policies will change, and their decision rules will also.

The distinction between structural and reduced-form parameters and warnings about using reduced-form models for policymaking were well known in economics far before Lucas. (See, for example, the work of Jan Tinbergen, 1952, and Jacob Marschak, 1953.) The value of the critique lies in its use of graphic examples to illustrate the argument and the alternative program it advocated. The first example Lucas uses is one based on Friedman’s permanent income hypothesis. Friedman (1957) hypothesized that consumption is a function of *permanent income*, which is defined as that constant flow which yields the same present value as an individual’s expected present value of actual income. Friedman also posited that permanent income is a weighted average of past incomes. Muth (1960) then showed more rigorously that a particular stochastic behavior of income over time, together with optimal forecasting by agents, implies that the best estimate of permanent income is an exponentially weighted average of past incomes. This stochastic process for income is given by the sum of a highly *persistent* part (a random walk) and a very *transitory* part (an independent random variable). Muth showed that the weights on past incomes depend on the relative variabilities of the two components; for example, if the transitory part has large variance, rational individuals attribute income fluctuations to the transitory part, and thus, the weight on current income is low. In terms of the relationship between consumption and income, this theory gives consumption as a function of current and past incomes, where the weights depend upon the relative variabilities. From an econometric point of view, one can obtain the relationship between

consumption and income from historical data by running a regression.

Lucas used this framework to make his point that this kind of regression relation cannot be used to uncover parameter values which are invariant across some interesting policy experiments. Consider a policy which supplements the individual's income by a constant amount forever. If this policy is known to the individual, it is clear that permanent income rises by the amount of the supplement and consumption rises in proportion to permanent income. Traditional uses of macroeconomic models regard the relationship between consumption and income as given by the historical data and use the estimated relationship to forecast the implied time path of the expected change in consumption. This relationship implies that expected consumption will gradually rise. The theory, however, says that consumption should rise immediately and that expected consumption should be permanently higher immediately. This apparent conflict between the implications of a widely accepted theory and conventional procedure has had a lasting effect on the profession.

Lucas used other examples to make the point that conflicts of this variety are pervasive. One example concerns the effect of a temporary investment tax credit to stimulate economic activity in recessions. It makes the point that anticipations of an investment tax credit, while the proposed credit is moving through the political process, may induce firms to postpone investments and, thereby, may accentuate the very recession the policy is designed to eliminate.

The real value of the critique lies in the clearly articulated research program it envisions. This research program involves specifying a structural model as well as the policy regime under which the economy is thought to operate. A *policy regime* is simply a function which prescribes the policies for each state of the economy. Economic agents in the model are thought of as knowing the policy regime. Data can then be used to uncover the regime as well as the details of the model. Policy evaluation, then, consists of evaluating the properties of the model under alternative policy regimes. This contribution has led directly to a vast literature on rational expectations econometrics (for example, Lucas and Sargent 1981).

The research program has also had a profound impact on the old argument over rules versus discretion in economic policymaking. Friedman (1968) has been perhaps the most prominent proponent of the view that economic and especially monetary policy should be constrained by rules that specify policy as an explicit function of the state of the economy. His arguments are primarily based on the practical view that discretionary policymaking has led to bad outcomes and that economists and policymakers do not know enough about the structure of the economy for discretionary policy to work well. Lucas' argument is based on the view that economists simply have no hope of understanding the effect of policies unless we think of policies as choosing among alternative rules.

Consider, for example, the question, Should the Federal Reserve raise interest rates next quarter? Answering this question requires that we know how future expectations will change in response to this action. If the current policy regime prescribes that the Federal Reserve should raise interest rates, then it is clear that we can forecast the ef-

fects of this action. If it does not, then we need to know how private agents will react to an apparent change in the regime. The problem is that we have no way of knowing what the new regime is. Private agents may even view this action as simply erratic monetary policy, and it is not clear that policy exercises which involve introducing noise are desirable.

Economists can, however, offer sensible policy advice when it comes to choosing among alternative policy rules, which are ways in which actions should be chosen depending upon the state of the economy. From this perspective, the question economists can answer should be posed as, Is raising interest rates next quarter part of a rule for the conduct of monetary policy that will lead to good outcomes on average? It should be emphasized that the point that economists can offer sensible advice only when it comes to choosing among alternative rules in no way implies that proposals such as Friedman's, that the stock of money should grow at 4 percent a year, are necessarily optimal. For example, John Taylor (1979) developed a model with staggered wage-setting in which a monetary policy rule which reacts to the state of the economy is better than a fixed money growth rate rule.

The perspective that policies should be thought of as rules has also led to an influential research program which uses game-theoretic techniques to understand the relative advantages of rules and discretion in policymaking. Beginning with the seminal contributions of Kydland and Prescott (1977) and Guillermo Calvo (1978), this literature thinks of discretionary policy as a situation in which the actions in each period are required to be optimal for the policymaker relative to other possible actions. This criterion generates policies as rules. It turns out, however, that the rules for policymaking implied by this procedure can be dominated in an average sense by other policies. Put differently, the policymaker can be made better off by committing to follow future policies. The simplest example is the payment of ransom to hostages. If a government could credibly commit never to pay ransom, it is possible that kidnappers would choose never to take prisoners hostage. The problem, of course, is that once hostages are taken, it may well be optimal to pay the ransom to save the hostages' lives. This issue shows up in economic situations as well. Consider, for example, the problem of default on government debt. Since revenues to pay interest on such debt typically must be raised from taxes that distort private decisions, it is optimal to default on government debt and promise never to do so again. Obviously, nobody would buy such debt if the promises were not believed. This example, then, illustrates the importance of being able to commit to an action (not to default on the debt) even though one would like to deviate from the committed action later. The models used in the rules versus discretion literature do not provide simple answers. However, taking economic theory seriously, as Lucas did, has led to an enormously influential and rich research agenda.

### Other Contributions

Lucas has made significant contributions to a number of fields in economics including financial economics (1978), monetary theory (1980a, Lucas and Stokey 1987), public finance (Lucas and Stokey 1983), international economics (1982), and, most recently, economic growth (1988). In

every area, his work has set new standards and generated a large new literature. Here, let me discuss only a few of my favorites.

The work of Lucas and Leonard Rapping (1969) is, quite simply, a classic. Lucas and Rapping tried to understand why employment fell so dramatically during the Great Depression and rose so dramatically during World War II. Central to their argument is the idea that households work more hours when wages are temporarily high and fewer hours when wages are temporarily low. In the jargon of economics, the intertemporal elasticity of labor supply is high. Labor economists and macroeconomists to this day continue to argue over the size of this elasticity. It plays a central role in any model which attempts to understand the fluctuations of employment over the business cycle. Lucas and Rapping used a form of adaptive expectations in their model, but emphasis on intertemporal labor supply substitution continues in Lucas' own work and in much other work on business cycles.

Lucas 1978 is one of the most influential papers in financial economics. Here Lucas showed how asset prices could be expressed as a function of the economy's state variables and that this function is the solution to a functional equation that arises from individual optimization and market-clearing. This elegant characterization is now routinely used in the asset-pricing literature.

The field of economic growth has been a growth industry in the last decade. In the so-called new growth literature, the long-run growth rate is determined by the accumulation of physical capital, human capital, and technological know-how. In this area, Lucas (1988) has made powerful arguments that human capital accumulation has important external effects and that learning by doing plays an important role in the process of human capital accumulation.

In many ways, my personal favorite of Lucas' work is "Methods and Problems in Business Cycle Theory" (1980b), which is a piece on methodology in economics. In general, I am hostile to methodological pieces; I prefer to read about work that has been done rather than be preached at about how to do it. However, the basic premise of this engaging article is that, as scientists, economists are limited by the tools at their disposal rather than by their ability to make verbal conjectures about how the world works. Lucas argued that improvements in economic theory and computational abilities have been driving forces in the postwar transformation of economics into a quantitative science. Lucas (1980b, pp. 709–10) wrote that "Our task as I see it . . . is to write a FORTRAN program that will accept specific economic policy rules as 'input' and will generate as 'output' statistics describing the operating characteristics of time series we care about, which are predicted to result from these policies." And how are we to build this FORTRAN program? "Progress in economic thinking means getting better and better abstract, analogue economic models, not better verbal observations about the world" (Lucas 1980b, p. 700).

## A Summing Up

Robert E. Lucas, Jr., is the preeminent macroeconomist of the last 25 years. Even when academic macroeconomists disagree over substantive questions, most work today under a common set of standards that define high-quality work. We use similar equilibrium concepts, econometric

techniques, and models of policymaking. This agreement over method is due in substantial part to Lucas. The logical structure of his arguments has been central in this methodological victory, although the flair and grace of his writing and his ability to craft persuasive examples to make telling points have played important supporting roles.

Sargent (1996, p. 536) has written that "the late 1960s were good times to be a young macroeconomist." Ideas and controversies were in the air. There was a general feeling that economic science was on the verge of making sharp quantitative statements about a host of issues. The late 1990s seem to me to be even better times. The controversies are just as pronounced, but the sophistication of our theoretical tools and our abilities to make quantitative assessments are now vastly greater. Progress has by some measure been slow over the last three decades, but it is sobering to think how much slower it would have been without Lucas' contributions.

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†*Author's note:* I first got to know Bob Lucas when I, as a graduate student at Carnegie-Mellon, was fortunate enough to spend a year at Chicago. I still have not gotten over being treated as an equal. I am pleased to have this opportunity to acknowledge my intellectual debt. Bob is a charming and delightful person, but you do want to be thoroughly armed in any debate with him. His rhetorical skills are formidable beyond belief, and since he reads widely and majored in history, it is tough to win a debate with him. I haven't, as yet, but I keep trying. A marvelous autobiography is available through the home page of the Nobel Foundation (<http://www.nobel.se>). I highly recommend it.

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