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THE ECONOMETRICS OF THE GENERAL EQUILIBRIUM APPROACH TO BUSINESS CYCLES

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ABSTRACT

The founding fathers of the Econometric Society defined econometrics to be quantitative economic theory. A vision of theirs was the use of econometrics to provide quantitative answers to business cycle questions. The realization of this dream required a number of advances in pure theory—in particular, the development of modern general equilibrium theory. The econometric problem is how to use these tools along with measurement to answer business cycles questions. In this essay, we review this econometric development and contrast it with the econometric approach that preceded it.

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Early in this century American institutionists and members of the German historical school attacked—and rightfully so—neoclassical economic theory for not being quantitative. This deficiency bothered Ragnar Frisch and motivated him, along with Irving Fisher, Joseph Schumpeter, and others, to organize the Econometric Society in 1930. The aim of the society was to foster the development of quantitative economic theory—that is, the development of what Frisch labeled *econometrics*. Soon after its inception, the society started the journal *Econometrica*. Frisch was the journal's first editor and served in this capacity for 25 years.

In his editorial statement introducing the first issue of *Econometrica* (1933), Frisch makes it clear that his motivation for starting the Econometric Society was the "unification of theoretical and factual studies in economics" (p. 1). This unification of statistics, economic theory, and mathematics, he argues, is what is powerful. Frisch points to the bewildering mass of statistical data becoming available at that time, and asserts that in order not to get lost "we need the guidance and help of a powerful theoretical framework. Without this no significant interpretation and coordination of our observations will be possible" (*ibid.*, p. 2).

Frisch speaks eloquently about the interaction between theory and observation when he says "theory, in formulating its abstract quantitative notions, must be inspired to a larger extent by the technique of observation. And fresh statistical and other factual studies must be the healthy element of disturbance that constantly threatens and disquiets the theorist and prevents him from coming to rest on some inherited, obsolete set of assumptions" (*ibid.*). Frisch goes on to say that

> this mutual penetration of quantitative economic theory and statistical observation is the essence of econometrics. (*ibid.*, p. 2).

To summarize the Frisch view, then, econometrics is quantitative neoclassical theory with a basis in facts.

Forty years after founding the Econometric Society, Frisch (1970) reviewed the state of econometrics. In this review he discusses what he considers to be "econometric analysis of the genuine kind" (p. 163), and gives four examples of such analysis. None of these examples involve the estimation and statistical testing of some model. None involve an attempt to discover some true relationship. All use a model, which is an abstraction of a complex reality, to address some clear-cut question or issue.

It is interesting to note that, in his 1933 editorial statement, Frisch announced that each year *Econometrica* would publish four surveys of "the significant developments within the main fields that are of interest to the econometrician" (*ibid.*, p. 3). These fields are general economic theory (including pure economics), business cycle theory, statistical technique, and, finally, statistical information. We find it surprising that business cycle theory was included in this list of main fields of interest to econometricians. Business cycles were apparently phenomena of great interest to the founders of the Econometric Society.

Frisch's (1933) famous, pioneering work, which appears in the Cassel volume, applies the econometric approach he favors to the study of business cycles. In this paper, he makes a clear distinction between sources of shocks on the one hand, and the propagation of shocks on the other. The main propagation mechanism he proposes is capital-starting and carry-on activities in capital construction, both of them features of the production technology. Frisch considers the implications for duration and amplitude of the cycles in a model that he calibrates using available micro data to select the numerical values for the parameters. Making the production technology with capital accumulation a central element of the theory has its parallel in modern growth theory.

There are many other papers dating from the thirties that study business cycle models. In these papers, however, and in those of the forties and fifties, little progress was made beyond what Frisch had already done. The main reason was that essential theoretical tools, in particular Arrow-Debreu general equilibrium theory, statistical decision theory, modern capital theory, and recursive methods had yet to be developed. The modern electronic computers needed to compute the equilibrium processes of dynamic stochastic model economies were also unavailable. Only after these developments took place could Frisch's vision be carried out.

In this paper, we review the development of econometric business cycle theory, with particular emphasis on the general equilibrium approach (which was developed later). Crucial to this development was the systematic reporting of national income and product accounts, along with time series of aggregate inputs and outputs of the business sector. Section 1 is a review of this important development in factual studies. In Section 2 we review what we call the system-of-equations approach to business cycle theory. With this approach, a theory of the business cycle is a system of dynamic equations which have been measured using the tools of statistics.

Section 3 is a review of the general equilibrium approach to business cycle theory. General equilibrium models have people or agents who have preferences and technologies, and who use some allocation mechanism. The crucial difference between the general equilibrium and the system-of-equations approaches is that which is assumed invariant and about which we organize our empirical knowledge. With the systems-of-equations approach, it is behavioral equations which are invariant and are measured. With the general equilibrium approach, on the other hand, it is the willingness and ability of people to substitute that is measured. In Section 4 we illustrate the application of econometric applications of the general equilibrium approach to addressing specific quantitative questions in the study of business cycles. Section 5 contains some concluding comments.

1. *National Income and Product Accounts*

An important development in economics is the Kuznets-Lindahl-Stone national income and product accounts. Together with measures of aggregate inputs to the business sector, these accounts are the aggregate time series that virtually define the field of macroeconomics—which we see as concerned with both growth and business cycle fluctuations. The Kuznets-Lindahl-Stone accounting system is well-matched to the general equilibrium framework because there are both household and business sectors, with measures of factor inputs to the business sector and of goods produced by the business sector, as well as measures of factor incomes and expenditures on products.

An examination of these time series reveals some interesting regularities—in particular, a number of ratios which remain more or less constant. These growth facts led Robert Solow to develop a neoclassical growth model which simply and elegantly rationalized these facts. Solow's structure was not fully neoclassical, however, because the consumption-savings decision was behaviorally determined rather than being the result of maximizing behavior subject to constraints. With the consumption-savings decision endogenized, Solow's growth model does become fully neoclassical, with agent's maximizing subject to constraints and market clearing. This structure can be used to generate time series of national income and product accounts.

Aggregate data present other features that are of interest to economists, such as the more volatile movements in the time series. During the fifties and sixties, neoclassical theory had not evolved enough to allow economists to construct computable general equilibrium models with fluctuations. Lacking the necessary tools, economists adopted an empirical approach and searched for laws of motion governing these variables. They hoped this research procedure would result in empirically determined laws which would subsequently be rationalized within the neoclassical paradigm. In the natural sciences, for example, empirically determined laws have often subsequently been rationalized at a deeper theoretical level, and it was hoped that this would also be the case in macroeconomics. In the following section we briefly review the econometrics of this approach to business cycle fluctuations.

2. The System-of-Equations Approach

Tjalling Koopmans, who was influenced by Frisch and might even be considered one of his students, argued forcefully in the late forties for what he called the econometric approach to business cycle fluctuations. At the time, it was the only econometric approach. The general equilibrium approach to the study of business cycles had yet to be developed. But since the approach Koopman advocated is no longer the only one, another name is needed for it. As it is the equations which are invariant and measured, we label this approach the system-of-equations approach.[1]

In the thirties, there were a number of business cycle models or theories. These logically complete theories were a dynamic set of difference equations that could be used to generate time series of the aggregate variables of interest. Notable examples include Frisch's model in Cassel's volume, Tinbergen's (1935) suggestions on quantitative business cycles, and the Samuelson's (1939) multiplier-accelerator model. One problem with this class of models is that the quantitative behavior of the model depended upon the values of the coefficient of the variables included in the equations. As Haberler (1949) points out in his comment on Koopmans' (1949) paper, the stock of cyclical models (theories) is embarrassingly large. Give any sophomore "a couple of lags and initial conditions and he will construct systems which display regular, damped or explosive oscillation . . . as desired" (p 85). Pure theory was not providing sufficient discipline, and so it is not surprising that Koopmans advocated the use of the statistics discipline to develop a theory of business fluctuations.

System-of-Equations Models

As Koopmans (1949, p. 64) points out, the main features of the system-of-equations models are the following: First, they serve as theoretical exercises and experiments. Second, the variables involved are broad aggregates, such as total consumption, the capital stock, the price level, etc.. Third, the models are "logically complete, i.e., they consist of a number of equations equal to the number of variables whose course over time is to be explained." Fourth, the models are dynamic, with equations determining the current values of variables depending not only on current values of other variables but also on the values of beginning-of-period capital stocks and on lagged variables. Fifth, the models contain, at most, four kinds of equations, which Koopmans calls *structural equations*. The first type of equations are *identities*. They are valid by virtue of the definition of the variables involved. The second type of equations are *institutional rules*, such as tax schedules. The third type are binding *technology constraints*, that is, production functions. The final type are what

Koopmans calls *behavioral equations*, which represent the response of groups of individuals or firms to a common economic environment. Examples are a consumption function, an investment equation, a wage equation, a money demand function, etc.. A model within this framework is a system-of-equations. Another requirement, in addition to the one that the number of variables equal the number of equations, is that the system have a unique solution. A final requirement is that all the identities implied by the accounting system for the variables in the model hold for the solution to the equation system; that is, the solution must imply a consistent set of national income and product accounts.

Statistical Measurement of Equations

The behavior of these models depends crucially on the numerical magnitudes of the coefficients of the variables and of the time lags. This leads to attempts to estimate these parameters using time series of the variables being modeled. Given that the estimation of these coefficients is a statistical exercise, a probability model is an additional completeness requirement. For that purpose, a residual random disturbance vector typically is added, with one component for each behavioral equation. For statistical completeness, the probability distribution of this disturbance vector must be specified up to some set of parameters. Only then can statistical methods be applied to estimating the coefficients of the behavioral equations and the parameters of the disturbance distribution. The crucial point is that the equations of the macroeconometric model are the organizing principle of the system-of-equations approach. What is measured is the value of the coefficients of the equations. The criterion guiding the selection of the values of the coefficients is essentially the ability of the resulting system of equations to mimic the historical time series. The issue of which set of equations to estimate is settled in a similar fashion. The criterion guiding the selection of equations is in large part how well a particular set can mimic the historical data. Indeed, in the sixties a student of business cycle fluctuations was successful if his particular behavioral equation improved the fit of, and therefore replaced, a currently established equation.

The Rise and the Fall of the System-of-Equations Approach

With the emergence of a consensus on the structure of the system of equations that best described the behavior of the aggregate economy, the approach advocated by Koopmans became totally dominant in the sixties. This is well-illustrated by the following statement of Solow's, quoted by Brunner (1989, p. 197):

> I think that most economists feel that the short run macroeconomic theory is pretty well in hand . . . The basic outlines of the dominant theory have not changed in years. All that is left is the trivial job of filling in the empty boxes [the parameters to be estimated] and that will not take more than 50 years of concentrated effort at a maximum.

The reign of this system-of-equations macroeconomic approach was not long. One reason for its demise was the spectacular predictive failure of the approach. As Lucas and Sargent (1978) point out, in 1969 these models predicted high unemployment would be associated with low inflation. Counter to this prediction, the seventies saw a combination of both high unemployment and high inflation. Another reason for the demise of this approach was the general recognition that policy-invariant behavioral equations are inconsistent with the maximization postulate in dynamic settings. The principal reason for the abandonment of the system-of-equations approach, however, was advances in neoclassical theory that permitted the application of the paradigm in dynamic stochastic settings. Once the neoclassical tools needed for modeling business cycle fluctuations existed, their application to this problem and their ultimate domination over any other method was inevitable.

3. The General Equilibrium Approach

A powerful theoretical framework was developed in the fifties and sixties that built upon advances in general equilibrium theory, statistical decision theory, capital theory, and recursive methods. Statistical decision theory provided a logically consistent framework for maximization in a dynamic stochastic environment. This is what was needed to extend neoclassical theory, with its maximization assumption, to such environments. Another crucial development was the extension of general equilibrium theory to dynamic stochastic models, with the simple yet important insight that commodities could be indexed not only by type, but also by date and event. This important insight was made by Arrow and Debreu (1954), who had important precursors in the work of Hicks (1939) and, particularly, in that of Lindahl (1929)—who had previously effectively extended competitive theory to dynamic environments. Subsequently, recursive methods, with their Markovian structure, were developed. These methods simplified the use of this dynamic framework and, in particular, its extension to stochastic general equilibrium analyses. (See, for example, Stokey and Lucas 1989).

Perhaps just as important as the development of tools for carrying out aggregate equilibrium analysis was the access to better and more systematic national income and product accounts data. In his review of growth theory, Solow (1970) lists the key growth facts which guided his research in growth theory in the fifties. These growth facts were the relative constancy of investment and consumption shares of output, the relative constancy of labor and capital income shares, the continual growth of the real wage and output per capita, and the lack of trend in the return on capital. Solow (1956), in a seminal contribution, developed a simple model economy that accounted for these facts. The key to this early theory was the neoclassical production function, which is a part of the general equilibrium language. Afterwards the focus of attention shifted to preferences, with the important realization that the outcome of the Cass–Koopmans optimal growth model could be interpreted as the equilibrium of a competitive economy in which the typical consumer maximizes utility and the markets for both factors and products clear at every date.

General Equilibrium Models

By general equilibrium we mean a framework in which there is an explicit and consistent account of the household sector as well as the business sector. To answer some research questions, one must also include a sector for the government, which is subject to its own budget constraint. A model within this framework is specified in terms of the parameters that characterized preferences, technology, information structure, and institutional arrangements. It is these parameters that must be measured, and not some set of equations. The general equilibrium language has come to dominate in business cycle theory, as it did earlier in public finance, international trade, and growth. This framework is well-designed for providing quantative answers to questions of interest to the business cycle student.

One of these important questions, which has occupied business cycle theorists since the time of Frisch and Slutzky, is how to determine which sources of shocks give rise to cycles of the magnitudes we observe. To provide reliable answers to this and similar questions, abstractions are needed that describe the ability and willingness of agents to substitute commodities, both intertemporally and intratemporally, and within which one can bring to bear statistical or factual information. One of these abstractions is the neoclassical growth model. This model has proven useful in accounting for secular facts. To understand business cycles, we rely on the same ability and willingness of agents to substitute commodities as those used to explain the growth facts. We are now better able than Frisch was more than fifty years ago to calibrate the parameters of aggregate production technology. The wealth of studies on the growth model have shown us the way. To account for growth facts, it may be legitimate to abstract from the time allocation between market and nonmarket activities. To account for business cycle facts, however, the time allocation is crucial. Thus, good measures of the parameters of household technology are needed if applied business cycle theory is to provide reliable answers.

The Econometrics of the General Equilibrium Approach

The econometrics of the general equilibrium approach was first developed to analyze static or steady-state deterministic models. Pioneers of this approach are Johansen (1960) and Harberger (1962). This framework was greatly advanced by Shoven and Whalley (1972), who built on the work of Scarf (1973). Development was impeded by the requirement that there be a set of excess-demand functions, which are solved to find the equilibrium allocations. This necessitated that preference and technology structures have very special forms for which closed-form supply and demand functions existed. Perhaps these researchers were still under the influence of the system-of-equations approach and thought a model had to be a system of supply and demand functions. These researchers lacked the time series needed to estimate these equations. Given that they could not estimate the equations, they calibrated their model economy so that its static equilibrium reproduced the sectoral national income and product accounts for a base year. In their calibration, they used estimates of the elasticity parameters obtained in other studies.

Their approach is ill-suited for the general equilibrium modeling of business fluctuations because dynamics and uncertainty are crucial to any model that attempts to study business cycles. To apply general equilibrium methods to the quantitative study of business cycle fluctuations, we need methods to compute the equilibrium processes of dynamic stochastic economies, and specific methods for the stochastic growth model economy. Recursive competitive theory and the use of linear-quadratic economies are methods that have proven particularly useful. These tools make it possible to compute the equilibrium stochastic processes of a rich class of model economies. The econometric problem arises in the selection of the model economies to be studied. Without some restrictions, virtually any linear stochastic process on the variables can be rationalized as the equilibrium behavior of some model economy in this class. The key econometric problem is to use statistical observations to select the parameters for an experimental economy. Once these parameters have been selected, the central part of the econometrics of the general equilibrium approach to business cycles is the computational experiment. This is the vehicle by which theory is made quantitative. The experiments should be carried out within a sensible or appropriate model economy that is capable of addressing the question whose answer is being sought. The main steps in econometric analyses are as follows:

defining the question; setting up the model; calibrating the model; and reporting the findings.

Question

To begin with, the research question must be clearly defined. For example, in some of our own research we have looked at quantifying the contribution of changes in a technology parameter, also called Solow residuals, as a source of U.S. postwar business cycles. But we refined it further. The precise question asked is how much variation in aggregate economic activity would have remained if technology shocks were the only source of variation. We emphasize that an econometric, that is, quantitative theoretic analysis, can be judged only relative to its ability to address a clear-cut question. This is a common shortcoming of economic modeling. When the question is not made sufficiently clear, the model economy is often criticized for being ill-suited to answer a question it was never designed to answer.

Model Economy

To address a specific question one typically needs a suitable model economy for addressing the specified question. In addition to having a clear bearing on the question, tractability and computability are essential in determining whether the model is suitable. Model-economy selection depends on the question being asked. Model-economy selection should not depend on the answer provided. Searching within some parametric class of economies for the one that best fits some set of aggregate time series makes little sense. Unlike the system-of-equations approach, no attempt is made to determine the true model. All model economies are abstractions and are by definition false.

Calibration

The model has to be calibrated. The necessary information can sometimes be obtained from data on individuals or households. An example of such information is the average fraction of discretionary time household members who are, or who potentially are, labor market participants actually spent in market activity. In many other cases, the required information easily can be obtained from aggregate nonbusiness-cycle information. The task often involves merely computing some simple averages, such as growth relations between aggregates. This is the case for inventory-output and capital-output ratios, and long-run fractions of the various GNP components to total output, among others.

In some cases, history has provided sufficiently dramatic price experiments which can be used to determine, with a great deal of confidence, an elasticity of substitution. In the case of labor and capital as inputs in the aggregate business production function, and also in the case of consumption and leisure as inputs to household production, the large real-wage increase over several decades in relation to the prices of the other input, combined with knowledge about what has happened to the expenditure shares on the respective inputs, provides this kind of information. Because the language used in these business cycle models is the same as that used in other areas of applied economics, the values of common parameters should be identical across these areas and typically have been measured by researchers working in these other areas. One can argue that the econometrics of business cycles described here need not be restricted to general equilibrium models. In fact it is in the stage of calibration where the power of the general equilibrium approach shows up most forcefully. The insistence upon internal consistency implies that parsimoniously parameterized models of the household and business sector display rich dynamic behavior through the intertemporal substitution arising from capital accumulations and from other sources.

Computational Experiments

Once the model is calibrated, the next step is to carry out a set of computational experiments. If all the parameters can be calibrated with a great deal of accuracy, then only a few experiments are needed. In practice, however, a number of experiments are typically required in order to provide a sense of the degree of confidence in the answer to the question. It often happens that the answer to the research question is robust to sizable variations in some set of parameters and conclusions are sharp, even though there may be a great degree uncertainty in those parameters. At other times, however, this is not the case, and without better measurement of the parameters involved, theory can only restrict the quantitative answer to a large interval.

Findings

The final step is to report the findings. This report should include a quantitative assessment of the precision with which the question has been answered. For the question mentioned above, the answer is a numerical estimate of the fraction of output variability that would have remained if variations in the growth of the Solow residual were the only source of aggregate fluctuation. The numerical answer to the research question, of course, is model dependent. The issue of how confident we are in the econometric answer is a subtle one which cannot be resolved by computing some measure of how well the model economy mimics historical data. The degree of confidence in the answer depends on the confidence that is placed in the economic theory being used.

4. *Two Applications to Business Cycle Theory*

We illustrate the econometrics of the general equilibrium approach to business cycle theory with two examples. The first example, credited to Lucas (1987) and to Imrohoroglu (1989), addresses the question of quantifying the costs of business cycle fluctuations. An important feature of the quantitative general equilibrium approach is that it allows for explicit quantitative welfare statements, something which was generally not possible with the system-of-equations approach that preceded it. The second example investigates the question of how large business cycle fluctuations would have been if technology shocks were the only source of fluctuations. This question is also important from a policy point of view. If these shocks are quantitatively important, an implication of theory is that an important component of business cycle fluctuations is a good, not a bad.

Costs of Business Cycle Fluctuations

The economy Lucas uses for his quantitative evaluation is very simple. There is a representative or stand-in household and a random endowment process of the single consumption good. The utility function is standard, namely, the expected discounted value of a constant relative risk aversion utility function. Equilibrium behavior is simply to consume the endowment. Lucas determines how much consumption the agent is willing to forgo each period in return for the elimination of all fluctuations in consumption. Even with an extreme curvature parameter of 10, he finds that when the endowment process is calibrated to the U.S. consumption behavior, the cost per person of business cycle fluctuations is less than one-tenth of a percent of per-capita consumption.

This model abstracts from important features of reality. There is no investment good, and consequently no technology to transform the date t consumption good into the date t+1 consumption good. As the costs of fluctuation are a function of the variability in consumption and not in investment, abstracting from capital accumulation is appropriate relative to the research question asked. What matters for this evaluation is the nature of the equilibrium consumption process. Any representative-agent economy calibrated to this process will give the same answer to the question, so it makes sense to deal with the simplest economy whose equilibrium consumption process is the desired one. This is what Lucas does. Introducing the time-allocation decision between market and nonmarket activities would change the estimate, since the agent would have the opportunity to substitute between consumption and leisure. The introduction of these substitution opportunities would result in a reduction in the estimated cost of business cycle fluctuations as leisure moves countercyclically. But, given the small magnitude of the cost of business cycle fluctuations, even in a world without this substitution opportunity, and given that the introduction of this feature reduces the estimate of this cost, there is no need for its inclusion.

In representative-agent economies, all agents are subject to the same fluctuations in consumption. If there is heterogeneity and all idiosyncratic risk is allocated efficiently, the results for the representative and heterogeneous agent economies coincide. This would not be the case if agents were to smooth consumption through the holding of liquid assets as is the case in the permanent income theory. Imrohoroglu (1989) examines whether the estimated costs of business cycle fluctuations are significantly increased if, as is in fact the case, people vary their holdings of liquid assets in order to smooth their stream of consumption. She modifies the Lucas economy by introducing heterogeneity and by giving each agent access to a technology that allows that agent to transform date t consumption into date t+1 consumption. Given that real interest rates were near zero in the fifty-odd years from 1933 to 1988, the nature of the storage technology chosen is that one unit of the good today can be transferred into one unit of the good tomorrow. She calibrates the processes on individual endowments to the per-capita consumption process, to the variability of annual income across individuals, and to the average holdings of the liquid asset--also across individuals. For her calibrated model economy, she finds the cost of inflation is approximately three times as large as that obtained in worlds with perfect insurance of idiosyncratic risk. But three times a small number is still a small number.

Technology Shocks as Source of Fluctuations

One source of shocks suggested as far back as in Wicksell (1907) is fluctuations in technological growth. In the sixties and seventies, this source was dismissed by many as being unlikely to play much of a role in the aggregate. Most researchers accepted that there could be considerable variation in productivity at the industry level, but they believed that industry-level shocks would average out in the aggregate. During the eighties, however, this source of shocks became the subject of renewed interest as a major source of fluctuations, in large part supported by quantitative economic theory. The question addressed, then, was how much would the U.S. postwar economy have fluctuated if technological shocks were the only source of aggregate fluctuations?

Our selection of a model economy to address this question follows. First we extended the neoclassical growth model to include leisure as an argument of the stand-in households's utility function. Given that more than half of business cycle fluctuations are accounted for by variations in the labor input, introducing this element is crucial. Next we calibrated the deterministic version of the model so that its consumption-investment shares, factor income shares, capital output ratios, leisure-market time shares, and depreciation shares matched the average values for the U.S. economy in the postwar period. Throughout this analysis, constant elasticity structures were used. As uncertainty is crucial to the question, computational considerations led us to select a linear-quadratic economy whose average behavior is the same as the calibrated deterministic constant elasticity of substitution economy.

We abstracted from public finance considerations and consolidated the public and private sectors. We introduced Frisch's (1933) assumption of time-to-build new productive capital. The construction period considered was four periods, with new capital becoming productive only upon completion, but with resources being used up throughout its construction. Given the high volatility of inventory investment, inventory stocks were included as a factor of production. We found, using the variance of Solow residuals estimated by Prescott (1986), that the model economy's output variance is 55 percent as large as the corresponding variance for the U.S. economy in the postwar period.

In the early eighties, there was much discussion in the profession about the degree of aggregate intertemporal substitution of leisure. The feeling was that this elasticity had to be quite high in order for a market-clearing model to account for the highly volatile and procyclical movements in hours. This discussion may have started with the famous paper by Lucas and Rapping (1969). Realizing that the standard utility function implied a rather small elasticity of substitution, they suggested the possibility that past leisure choices may directly affect current utility. Being sympathetic to that view, we considered also a non-time-separable utility function as a tractable way of introducing this feature. When lags on leisure are considered, the estimate of how volatile the economy would have been if technology shocks were the only disturbance increases from 55 to near 70 percent. But, until there is more empirical support for this alternative preference structure, we think estimates obtained using the economy with a time-separable utility function are better. Unlike the system-of-equations approach, the model economy which better fits the data is not the one used. Rather, currently established theory dictates which one is used.

Probably the most questionable assumption of this theory, given the question addressed, is that of homogeneous workers, with the additional implication that all variation in hours occurs in the form of changes in hours per worker. According to aggregate data for the U.S. economy, only about one-third of the quarterly fluctuations in hours are of this form, while the remaining two-thirds arise from changes in the number of workers (Kydland and Prescott 1989, Table 1).

This observation led Hansen (1985) to introduce the Rogerson (1988) labor indivisibility construct into a business cycle model. In the Hansen world all fluctuations in hours are in the form of employment variation. To deal with the apparent nonconvexity arising from the assumption of indivisible labor, the problem is made convex by assuming that the commodity points are contracts in which every agent is paid the same amount whether that agent works or not, and a lottery randomly chooses who in fact works in every period. Hansen finds that with this labor indivisibility his model economy fluctuates as much as did the U.S. economy. Our view is that, with the extreme assumption of only fluctuations in employment, Hansen overestimates the amount of aggregate fluctuations accounted for by Solow residuals in the same way as our equally extreme assumption of only fluctuations in hours per worker lead us to an underestimation.

In Kydland and Prescott (1989), the major improvement on the 1982 version of the model economy is to permit variation both in the number of workers and in the number of hours per worker. The number of hours a plant is operated in any given period is endogenous. The model also treats labor as a quasi-fixed input factor by assuming costs of moving people into and out of the business sector. Thus, in this model there is what we interpret to be labor hoarding.

Without the cost of moving workers in and out of the labor force, a property of the equilibrium turns out to be that all the hours variation is in the form of employment change and none in hours per worker. In that respect, it is similar to Hansen's (1985) model. For this economy with no moving costs, the estimate is that Solow residuals account for about 90 percent of the aggregate output variance. For this economy with moving costs, we calibrated so that the relative variations in hours per worker and number of workers matched U.S. data. With this degree of labor hoarding, the estimate of the fraction of the cycle accounted for by Solow residuals is reduced to 70 percent.

A widespread and misguided criticism of our econometric studies (for example, McCallum, 1989) is that the correlation between labor productivity and the labor input is almost one for our model economy while it is approximately zero for the U.S. postwar economy. If we had found that technology shocks account for nearly all fluctuations and that other factors were unimportant, the failure of the model economy to mimic the data in this respect would cast serious doubt on our findings. But we did not find that the Solow technology shocks are all-important. We estimate that these technology shocks account for about 70 percent of business cycle fluctuations. If technology shocks account for 70 percent, and some other shocks which are orthogonal to technology shocks account for 30 percent, theory implies a correlation between labor productivity and the labor input near zero. Christiano and Eichenbaum (1990) have established this formally in the case that the other shock is variations in public consumption. But the result holds for any shock that is orthogonal to the Solow technology shocks. The fact that this correlation for our model economy and the actual data differ in the way they do adds to our confidence in our findings.

The estimate of the contribution of technology shocks to aggregate shocks has been found to be robust to several modifications in the model economy. For example, Greenwood, Hercowitz, and Huffman (1988) permit the utilization rate of capital to vary and to affect its depreciation rate, while all technology change is embodied in new capital; Danthine and Donaldson (1989) introduce an efficient-wage construct; Cooley and Hansen (1989) consider a monetary economy with a cash-in-advance constraint; and Rios-Rull (1990) uses a model calibrated to life cycle earnings and consumption patterns. King, Plosser, and Rebelo (1988) have non-zero growth. Gomme and Greenwood (1990) have heterogenous agents with recursive preferences and equilibrium risk allocations. Benhabib, Rogerson, and Wright (1990) incorporate home production. Hornstein (1990) considers the implications of increasing returns and monopolistic competition. In none of these cases is the estimate of the contribution of technology shocks to aggregate fluctuations significantly altered.

5. Concluding Remarks

Econometrics is by definition quantitative economic theory—that is, economic analyses which provide quantitative answers to clear-cut questions. The general equilibrium econometric methodology is centered around computational experiments. These experiments provide answers to the questions posed in the model economies whose equilibrium elements have been computed. The model economy selected should quantitatively capture people's ability and willingness to substitute and the arrangements employed which are relevant to the question. We base our quantitative economic intuition on the outcome of these experiments.

The dramatic advances in econometric methodology over the last 25 years have made it possible to apply fully neoclassical econometrics to the study of business cycles. Already there have been several surprising findings. Contrary to what virtually everyone thought, including the authors of this review, technology shocks were found to be an important contributor to business cycle fluctuations in the U.S. postwar period.

Not all fluctuations are accounted for by technology shocks, and monetary shocks are a leading candidate to account for a significant fraction of the unaccounted-for aggregate fluctuations. The issue of how to incorporate monetary and credit factors into the structure is still open, with different avenues under exploration. When there is an established monetary theory, we are sure that general equilibrium methods will be used econometrically to evaluate alternative monetary and credit arrangements.

Footnotes

[1] Koopmans subsequently became disillusioned with the system-of-equations approach. When asked in the late seventies by graduate students at the University of Minnesota in what direction macroeconomics should go, Koopmans is reported by Zvi Eckstein to have said they should use the growth model.

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