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Real Business Cycles: A Selective Survey

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It is now more than ten years since the publication of Kydland and Prescott's first paper on real business cycles (RBC). RBC theories rationalize fluctuations in key real macro variables as the natural outcome of the competitive economy where individuals make optimal, intertemporal resource allocation decisions in response to stochastic shifts in the production technology. We use a simple model to bring out the salient features of this methodology and present a selective survey of work in this area over the last decade.

It is now more than ten years since the publication of Kydland and Prescott's first paper on real business cycles.[1] Their early work has stimulated an impressive body of research. This paper presents a selective survey of the developments in this field over this period.

There can be different ways of describing the distinguishing tenets of real business cycle (RBC) theories. For instance, Stockman (1988, p. 24) says, "the purpose of real business cycle (RBC) models is to explain aggregate fluctuations in business cycles without reference to monetary policy." Perhaps more fundamentally, it is the following central implication of RBC theories that has attracted attention: Fluctuations in aggregate output, as well as employment, are not a manifestation of coordination failure in some markets, but a natural outcome of the competitive economy where rational individuals make optimal, intertemporal resource allocation decisions in response to stochastic shifts in the production function.

Another aspect of these models is the fact that they are dynamic, general equilibrium models of the economy, and they generate empirical predictions for a wide array of macroeconomic variables. This is in contrast to most earlier analyses, which focused upon describing the behavior of a subset of the economy. Thus, these models aim to fulfill Lucas's (1977) requirement for understanding business cycles: "One exhibits understanding of business cycles by constructing a *model* in the most literal sense: a fully articulated artificial economy which behaves through time so as to imitate closely the time series behavior of actual economics" [sic] (p. 11).

In a sense, RBC models are the descendants of the models of Lucas (1975) and Barro (1976). Elements that are common to these models include the role of intertemporal substitution, the emphasis on individual optimization, as well as the requirement that markets clear—in the sense that no unexploited gains from trade are permitted. These elements distinguish both kinds of models from the traditional Keynesian theories of the business cycle.

However, RBC models diverge sharply from Lucas-Barro type models when it comes to the sources of macroeconomic fluctuations. Whereas the earlier models focused on the role of monetary shocks in causing business cycles, RBC models assign the primary role to shocks to production technology. It is this combination of assumptions about the economy's structure (i.e., optimizing individuals, perfect competition, and clearing markets) and the source of shocks (primarily, shocks to technology) that suggests that macroeconomic fluctuations represent optimal responses, and—in the absence of externalities—also makes it difficult to see how stabilization policy can lead to improvements in welfare.

RBC models also differ from the business cycle models of Lucas and Barro in the production technology they assume. Specifically, these models employ the production structure contained in the Solow growth model. However, the fact that these models allow endogenous saving and labor supply decisions places fewer restrictions upon the dynamic behavior of key macroeconomic variables (such as income, investment, etc.) than traditional growth models do, and therefore allows us to study business-cycle-like movements in this artificial economy.

This paper is organized as follows. Section I lays out a simple, intertemporal model to illustrate the key elements of an RBC model. This model is then solved and the solutions used to derive relationships between different variables. The next section discusses how the predictions from an artificial RBC economy are compared to the data and how well these models perform. Section III surveys research aimed at incorporating money into these models. Section IV reviews some of the criticisms made against these models, while the last section offers an appraisal and some concluding comments.

I. A Simple Intertemporal Model

We will analyze a simple two-period model, where many agents with identical preferences and endowments reside in the economy. This makes the economy-wide equilibrium outcome exactly the same as that for the individual, and allows us to analyze the behavior of the economy in terms of the behavior of a representative agent. Assume that each individual's preferences can be described by

$$U(c_t, l_t) = \frac{(c_t l_t^A)^{1-\gamma}}{1-\gamma},$$

where c_i and l_i denote consumption and leisure in period i.[2] For simplicity we assume that $\gamma = 1$, so that the utility function becomes

$$(1) \qquad U(c_t, l_t) = \log c_t + A \log l_t,$$

where $A > 0$. Each individual makes allocation decisions in periods one and two to maximize the two-period objective function,

$$(1)' \qquad U(c_1, l_1) + \beta\, U(c_2, l_2).$$

where β is the rate at which individuals discount tomorrow's utility. For simplicity, we set $\beta = 1$ below.

We assume that each individual begins period 1 with an endowment of k_1 units of capital. Each individual has to choose how much to consume and invest (c_1, i_1), and how much time to spend in leisure or work (l_1, n_1). These decisions will depend on the prices of leisure (that is, the wage rate) and rental capital, determined in the factor market and taken as given by individuals in the economy. Equations (2) and (3) embody these decisions and the relevant constraints on each set of decisions:

$$(2) \qquad c_1 + i_1 = w_1 n_1 + r_1 k_1$$

$$(3) \qquad l_1 + n_1 = 1.$$

Here w_1 is the wage rate and r_1 is the capital rental rate. Equation (2) states that the sum of the individual's consumption and investment (or saving) must equal the sum of her income from labor and capital. Equation (3) simply normalizes total hours to equal 1.

The individual does not invest in capital formation in period 2. However, she still has to make the leisure-labor choice. Equations (4) and (5) describe these decisions for period two:

$$(4) \qquad c_2 = w_2 n_2 + r_2 k_2$$

$$(5) \qquad l_2 + n_2 = 1.$$

The evolution of the individual's capital stock from period 1 to 2 is given by

$$(6) \qquad k_2 = (1 - \delta) k_1 + i_1,$$

where δ denotes the depreciation rate for one period. For simplicity, we assume that capital is used up each period, so δ is set to one. Consequently, $i_1 = k_2$ in our model.

Consumers make allocation decisions to maximize (1)' subject to the constraints (2)-(6). This will give rise to the following set of equations that describe the necessary conditions for the consumer's optimum:

$$\begin{aligned}
&\frac{\partial u_1}{\partial c_1} - \lambda_1 = 0\\
&\frac{\partial u_1}{\partial l_1} - w_1\lambda_1 = 0\\
&-\lambda_1 + r_2\lambda_2 = 0 \qquad (7)\\
&\frac{\partial u_2}{\partial c_2} - \lambda_2 = 0\\
&\frac{\partial u_2}{\partial l_2} - w_2\lambda_2 = 0
\end{aligned}$$

Here λ_1, λ_2 are Lagrange multipliers associated with constraints (2) and (4), respectively, and measure the shadow price of consumption in the two periods.

Assume that there are as many firms as individuals. Each firm maximizes one-period profit, given by

(8) $$\Pi_i = Y_i - w_i N_i - r_i K_i,$$

where Y denotes the firm's output, while N and K respectively denote the labor and capital employed by the firm. Firms are assumed to employ input factors in competitive factor markets, so that factor prices (measured here in terms of output) are taken as given. These firms employ an identical production technology given by the constant elasticity of substitution (CES) function

$$Y = [\alpha_1 N^{-\rho} + \alpha_2 (Kz)^{-\rho}]^{-\frac{1}{\rho}}$$

where the good Y can either be consumed or invested. Here α_1 and α_2 are the respective shares of labor and capital, and ρ is the elasticity of substitution between the two. The z_is denote capital specific technology shocks. For simplicity again, we assume that $\alpha_1 = \alpha_2 = -\rho = 1$, so that the production function becomes

(9) $$Y_i = f(N_i, K_i, z_i) = N_i + K_i z_i.$$ [3]

We further assume that there is no uncertainty in this economy, so that z_1 and z_2 are known when agents make decisions at the beginning of period 1.[4]

Given this structure for the economy, our aim is to derive a system of equations that expresses the endogenous variables as functions of the exogenous technology shocks and predetermined capital stock variables that describe the state of the economy. Solving the first order conditions (equation (7)) will give rise to individual decision rules that relate individual consumption-saving and leisure-labor decisions to the set of variables that are taken to be exogenous to an individual consumer, such as the wage and capital rental rates for both periods and aggregate capital stocks in each period.

For the next stage we exploit the structure of the model economy. First, the constant returns to scale technology and perfect competition assumptions imply that factor prices will be set equal to marginal products. Thus, in our simple model, we will obtain $w_i = 1$ and $r_i = z_i$, for $i = 1, 2$.

These conditions, together with the first order conditions above (equation (7)), imply certain specific relationships between the decision variables (that is, c_1, n_1, i_1, etc). Thus, we obtain

(10a) $$c_2 = r_2 c_1$$

(10b) $$l_i = A c_i,$$

$$\text{for } i = 1, 2.$$

The first equation shows the equilibrium tradeoff between consumption today and tomorrow. It states that in equilibrium the marginal utility of \$1 of consumption today must equal the marginal utility of \$$r_2$ of consumption tomorrow. Similarly, (10b) presents the equilibrium tradeoff between consumption and leisure. This tradeoff is determined by the parameter A, which represents the utility derived from leisure relative to that derived from consumption. The equation shows that at the optimum the individual equates the marginal utility of consumption with the marginal utility of leisure.

Then, we impose the market clearing conditions. Specifically, in equilibrium the demands for labor and capital will equal the respective supplies (i.e., $N = n$ and $K = k$), and total output will be exhausted (i.e., $y = c + k$). As a result, we obtain a system of equations that describes the evolution of the equilibrium values over time:

$$\begin{aligned}
n_1 &= D_1\{2 + A(1 - k_1 z_1 - z_2^{-1})\}\\
c_1 &= D_1(D_2 + z_2^{-1})\\
i_1 &= k_2 = \frac{1}{2}\,(D_2 - z_2^{-1}) \qquad (11)\\
n_2 &= D_1\{2 + A(1 - z_2 D_2)\}\\
c_2 &= D_1(1 + z_2 D_2),
\end{aligned}$$

where $D_1 = 1/2(1 + A)$ and $D_2 = (1 + k_1 z_1)$. We now use our model and these results to discuss some of the key issues in the RBC literature.

Intertemporal Choices

The intertemporal nature of the decision is immediately clear in (11). The equilibrium outcome of the first period is directly dependent on the state of the economy in the second period, and vice versa. The reason for these intertemporal linkages is easily seen from (10a). Because the individual equates the marginal utility of consumption in both time periods, any change in consumption (or in consumption possibilities) in one period will also affect consumption in the second. For similar reasons, any change in leisure in one period will also lead to a change in leisure in the next period.

It is easiest to understand the adjustments taking place by examining how individuals react to the two technology shocks in the model. Consider first the response to a change in z_1. From (11) we have

$$\frac{\partial n_1}{\partial z_1} = -D_1 A k_1 < 0 \tag{12}$$

$$\frac{\partial n_2}{\partial z_1} = -D_1 A k_1 z_2 < 0.$$

Recall that the z_is affect the productivity of capital (and in equilibrium equal the real interest rate). Further, since the productivity of capital is independent of labor supply, a higher z_1 is equivalent to getting a larger endowment of capital in the first period. In other words, an increase in z_1 has a pure wealth effect. Theory tells us that individuals should react by reducing labor supply in both periods. (12) shows that a large realization of z_1 unambiguously lowers n_1. It will also lower n_2 as long as z_2 is positive, a requirement that does not seem too stringent when it is recalled that z_2 $(=r_2)$ is the gross rate of return on investing in the first period.

Higher wealth should also imply an increase in consumption. In our model, (10a) shows that any change in the equilibrium level of leisure (and hence labor supply) must be accompanied by a change in consumption. This can be confirmed from (11) as well

$$\frac{\partial c_1}{\partial z_1} = D_1 k_1 > 0$$

$$\frac{\partial c_2}{\partial z_1} = D_1 k_1 z_2 > 0.$$

The effect of an increase in z_2, however, is quite different from that of an increase in z_1. Again from (11)

$$\frac{\partial n_1}{\partial z_2} = \frac{AD_1}{z_2^2} > 0$$

$$\frac{\partial n_2}{\partial z_2} = -AD_1D_2 < 0.$$

Thus, a large z_2 unambiguously lowers n_2 because of the wealth effect. However, it has the opposite effect on n_1. Note that this change in n_1 occurs without any change in the wage rate. This is because an increase in the productivity of tomorrow's capital stock makes it desirable to have a larger capital stock tomorrow. One way to increase tomorrow's capital stock is to increase work effort and produce more today, so that more can be invested.

The other way is to reduce consumption today, since the rewards to deferring consumption have gone up. Specifically,

$$\frac{\partial c_1}{\partial z_2} = -\frac{D_1}{z_2} < 0$$

$$\frac{\partial c_2}{\partial z_2} = D_1 D_2 > 0$$

Thus, an increase in the productivity of tomorrow's capital stock leads to increased investment today; this higher investment is obtained by reducing consumption and by increasing work effort.

Thus, changes in intertemporal opportunities cause individuals to alter both consumption and leisure. These intertemporal considerations remain central as the time horizon is extended from our simple two-period framework to the infinite horizon models typically used in RBC analysis.

Fluctuations in Output

When the solutions for n_1, n_2, and i_1 (shown in (11)) are substituted into (8), we can write equilibrium outputs of periods one and two (Y_1, Y_2) as functions of the state variables.[5] Differentiating these expressions leads to

$$\frac{\partial Y_1}{\partial z_1} = (2 + A) D_1 k_1$$

$$\frac{\partial Y_2}{\partial z_1} = D_1 k_1 z_2$$

and

$$\frac{\partial Y_1}{\partial z_2} = \frac{A}{(2+A)z_2^2}$$

$$\frac{\partial Y_2}{\partial z_2} = D_1 D_2$$

The equations show that output in the two periods reacts differently to each shock, that is to say, $\partial Y_1/\partial z_i \neq \partial Y_2/\partial z_i$, for $i = 1, 2$. So, output in our model economy will fluctuate over the two periods, where the particular shape is determined by the realizations of the exogenous technology shocks in both periods. Notice that the differential response of output over the two periods is perfectly compatible with the fully informed, optimizing behavior of agents in the economy. In the context of our model, attempts to offset this response (that is, attempts to "stabilize" output) will have adverse welfare consequences. That is because the fluctuations in output are the result of individuals' utility maximizing decisions about consumption and leisure over time, and attempts to alter these decisions will only force individuals to make choices that were initially rejected as being less desirable.

Consumption and Investment Volatility

Since no investment takes place in the second period, we will examine the consumption-investment (savings) decision of the first period to see what our model says about the relative volatility of consumption and investment. From (11) we obtain

$$\eta_1^c \equiv \frac{\partial c_1/\partial z_1}{c_1} = \frac{k_1}{1+k_1 z_1+1/z_2}$$

and

$$\eta_1^i \equiv \frac{\partial i_1/\partial z_1}{i_1} = \frac{k_1}{1+k_1 z_1-1/z_2}$$

so that

$$\frac{\eta_1^i}{\eta_1^c} = \frac{z_2(1 + k_1 z_1) + 1}{z_2(1 + k_1 z_1) - 1} > 1.$$

Carrying out the same exercise with respect to z_2 also leads to:

$$\frac{\eta_2^i}{\eta_2^c} = \frac{z_2(1 + k_1 z_1) + 1}{z_2(1 + k_1 z_1) - 1} > 1.$$

These semi-elasticities measure how much individuals modify their optimal consumption-saving allocations in response to a productivity shock either today or in the future. These results show that investment will be more responsive to external shocks than consumption in this economy, as long as z_2 is no smaller than 1. (This restriction implies that in the worst states of the world the decision to invest is equivalent to a decision to hold nonproductive inventories, since firms always get back what they invest.) The investment series will continue to be more volatile than the consumption series over time when the time horizon is extended in our economy.

The fundamental reason that consumption is less volatile than investment can be found in the basic properties of the utility function that describes preferences in our model economy. The specification of the utility function (1) implies that a typical person in the model economy does not regard consumption in different periods (periods one and two) as perfect substitutes. In other words, the individual wants to consume in both periods. If this were not the case, a small change in the relative advantage to consuming in any period would lead the individual to switch all consumption to that period.[6] One response to this desire to smooth consumption would be to smooth production as well. However, the returns to production, and to the ownership of capital, can vary widely over time, so investment will tend to be more volatile.

The mechanics of this argument are best understood in terms of the model discussed above. Consider, first, an increase in z_1. Recall that this implies an increase in wealth. The individual's response is to work less and consume more in both periods. However, the direct effect of working less in the second period would be to reduce second period output and, therefore, second period consumption. Consequently, in order to smooth consumption the individual must raise investment in period 1 by more than the change in consumption.

An increase in z_2 represents an increase in the rate of return on capital in the second period. As discussed above, individuals react to this increase by raising labor supply today and lowering consumption. So, period 1 output goes up while consumption declines, that is to say, investment rises by more than the fall in consumption.

Our finding that investment is more volatile than consumption is one of the widely recognized key stylized facts of the U.S. and other economies, and, as we discuss below, has been replicated by many different RBC models.

II. Matching the Model with the Data

The Methodology

As shown above, the pattern of output in our simple model depends upon the technology shocks in each of the two periods. In a more sophisticated multi-period model, typically used in such work, one can observe distinct cyclical fluctuations whose general characteristics will depend on the structure of the technology shock process, which is the primary source of exogenous impulses. A model builder can then obtain a set of descriptive statistics on artificial time series generated by simulating this model. These statistics can then be used to examine the explanatory power of a model, not only in terms of the qualitative implications, but also in terms of quantitative similarity to the actual time series data.

In practice, this methodology is implemented in the following way. First, one chooses explicit specifications for the preferences of consumers, the aggregate production technology, and an exogenous impulse generating mechanism. For example, the researcher may decide that the Cobb-Douglas function is a good representation of the production technology or that the stochastic process for technology shocks is well described as a first order autoregression. Second, the artificial economy is calibrated, that is to say, the researcher chooses specific parameter values for the functional forms she has selected. For instance, if the researcher were to employ the CRRA utility function described above, she would have to choose values for γ and A. Similarly, the values for the parameters of the production function (α_1 and α_2 in our example above) also have to be estimated. Typically, some of these values are drawn from various micro and macro studies; for example, the parameters measuring the degree of risk aversion, as well as the shares of labor and capital in the aggregate production function are obtained in this way. Values for other parameters are obtained by imposing the condition that the model's steady state implications are similar to long-run observations for the U.S. economy. This includes, for example, the average proportion of time devoted to leisure and to work, the inter-temporal discount factor (β in our model), etc.

Next, the model economy is solved for an equilibrium, and decision rules for the representative individual are obtained. These rules specify individual behavior as functions of state variables (such as the capital stock carried over from the last period) and the exogenous shocks. For our simple model, equation (11) presents the relevant decision rules. The capital stock does not show up in (11) because of our assumption of 100 percent depreciation. Before going further, it also is worth pointing out that only a certain limited class of specifications for preferences and technology allow one to obtain a closed form, or an analytical solution. Consequently, some type of approximation procedure is usually adopted in practice.[7]

Armed with these decision rules, we are now ready to face the critical test: how well does the model economy mimic the real one? Answering this question involves using the model economy to generate artificial data. Since the model is driven by random shocks, this involves repeated draws from the probability distribution specified for the technology shock process. This artificially generated data is then compared to data for the U.S. economy.

Prior to making such a comparison, the data need to be transformed to make them stationary. One way to do so is to use the method employed by Kydland and Prescott (1982), and to apply a filter proposed by Hodrick and Prescott (1980) to both the actual and artificial data. The usual practice then is to summarize the detrended data in terms of its second moments (such as the standard deviations and correlation coefficients), and to compare these statistics on the artificial economy with the corresponding statistics for the U.S. economy.

The Comparison

Table 1 presents one such example, reproduced from Kydland and Prescott (1982).[8] Notice that the standard deviation of output in the model economy is exactly the same as in the U.S. economy. This is by construction. Specifically, as part of the calibration process, the size of the technology shock in the model economy is chosen to obtain this result. This does not restrict the other variables in the model economy to behave in the same way as they do in the U.S. economy, and a comparison of these variances and covariances provides a way of judging the model's adequacy. This is because the relative behavior of different variables also is a function of the model's structure—its propagation mechanism—and does not depend only upon the kind of exogenous shock process that is employed. Later, we will discuss how altering the nature of the technology shock process alters the behavior of the model.

As Kydland and Prescott point out, the model captures the relative size of the fluctuations in output, consumption, and investment. Thus, investment is substantially more volatile than income in both the U.S. and the model economies, while consumption is less volatile. Recall that our simple model also leads to the result that investment is more volatile than consumption. In addition, the Kydland-Prescott model also captures the strong, positive correlation between these variables and output.

Table 1

Variable	Actual Data (Sample: 1950:1-1979:2)		Model Economy	
	Standard Deviation	Correlation with output	Standard Deviation	Correlation with output
Output	1.8	1.0	1.8 (.23)	1.0
Consumption	1.3	.74	.63 (.09)	.94 (.01)
Investment	5.1	.71	6.45 (.62)	.80 (.04)
Labor Hours	2.0	.85	1.05 (.13)	.93 (.01)

Source: Kydland and Prescott (1982).

Note: Standard errors are in parentheses.

Obviously, the model does not provide a "perfect fit." For example, both consumption and labor hours are only half as volatile in the model economy as they are in the U.S. economy. Of the two, attention has focused upon "fixing" the problem with labor hours. Kydland and Prescott attempted to raise the variability of labor hours in their model economy by increasing the substitutability of leisure in different periods. The results of this attempt are already incorporated in Table 1; obviously, their attempt was not completely successful.

A number of subsequent papers also have focused on this problem. Kydland (1984) assumes that there were two different kinds of workers—differentiated on the basis of work skills—and shows that this led to greater variability in labor hours than the homogeneous labor case. Using a suggestion by Rogerson, Hansen (1985) shows that indivisibility of labor could be the reason for the relatively high variability of labor hours. Allowing for indivisible labor, Hansen shows that in his model economy the standard deviation of labor hours was roughly 80 percent of that in the data for the U.S. economy (compared to the ratio of 50 percent shown in Table 1). Cho and Rogerson (1988) allow for heterogenous labor (or household production) and show that in their model economy total hours are roughly 10 percent more variable than in the U.S. economy (over the 1955-1984 period).

While these attempts have been focused on making the model economy match the "stylized facts," other economists have directed their efforts towards a closer examination of the stylized facts themselves. Singleton (1988) argues that since traditionally defined seasonal, cyclical, and secular components of time series have common determinants, prefiltering the data leads to a violation of the restrictions imposed by the theory. Consequently, the results are likely to be functions of the method used to prefilter the data. Using a bivariate Vector Autoregression of real wages and hours worked, he shows that Granger causality tests as well as variance decompositions are sensitive both to whether the data is seasonally adjusted and to the treatment of the secular component. He also points out that the filter used by Kydland and Prescott leads to results similar to those obtained after the data is first differenced.

King, Plosser, and Rebelo (1988, p. 225; hereafter KPR) also point out that the "stylized facts" about the U.S. economy are sensitive to how the data is detrended. Since ". . . the basic neoclassical model has implications for untransformed macroeconomic data and not some arbitrary or prespecified transformation or component that is defined outside the context of the model," they argue that the procedure employed to detrend the data should be consistent with the theoretical model. KPR work with a model in which deterministic labor-augmenting technological change is the engine of growth, and in which technological change itself takes place according to a log linear trend. Consequently, they study deviations of the log levels of output, consumption, and investment from a common linear trend. Labor hours are not detrended since they show no trend.

When post-war U.S. output (for the 1948-1986 sample period) is detrended this way the standard deviation of labor hours is only half as much as that of output, in contrast to the nearly equal standard deviations obtained after the Hodrick-Prescott filter is used (see Table 1). Thus, the evidence on the relative variability of labor hours seems sensitive to the detrending procedure employed.[9]

The Role of the Technology Shock Specification

The specification of the technology shock process is obviously a central issue. KPR examine how the behavior of the model economy changes in response to changes in the technology shock process. They find that if the technology shock is not serially correlated there is no serial correlation in output, investment, or labor hours, while consumption, wages, and the real interest rate continue to be serially correlated. Thus, fluctuations in output appear to reflect fluctuations in the technology shock process. In addition, the degree of persistence of the technology shock affects the relative volatility of different variables. For instance, more persistent technology shocks reduce the variability of labor hours. Highly persistent shocks imply that the return to working in adjacent (or nearby) periods is roughly the same, so the intertemporal substitution of labor becomes less desirable.

Do technology shocks in fact follow the kind of process required by RBC models to mimic key features of the U.S. economy? The problem here is that we do not directly observe the process governing the evolution of technology. To get around this problem, Prescott (1986, p. 25) suggests, "One method of measuring technological change is to follow Solow (1957) and define it as the changes in output less the sum of the changes in labor's input times labor share and the changes in capital input times capital share. Measuring variables in logs, this is the percentage change in the technology parameter of the Cobb-Douglas production function." After examining data on the U.S. economy for the 1955-1984 period he concludes that the process governing the change in technology is close to a random walk with drift, and so is consistent with the technology shock process assumed in RBC models.[10]

Accepting the Solow residuals as an appropriate measure of technological shocks to the U.S. economy gives us an additional dimension for judging the performance of the RBC model. Recall that Kydland and Prescott (1982) chose the size of the technology shock to match the standard deviation of output. If the measured Solow residuals are used as exogenous technological shocks instead, the model's prediction of the standard deviation of real output can be compared to that of the U.S. economy. Kydland and Prescott (1989) do exactly that, and conclude that about 70 percent of U.S. post-war cyclical fluctuations are induced by variations in the Solow technology parameter.[11] A similar strategy is followed by Plosser (1989), who inputs the measured Solow residual for the U.S. economy (over the 1954-1985 period) into a RBC model. In contrast to the Kydland and Prescott method of looking at the second moments of the data, this procedure leads to simulated time series for the major economic variables (such as output, consumption, etc.) that can be compared directly to data for the U.S. economy. Plosser finds that the simulated data are close to the actual data, with the correlations between the two ranging from .52 to .87 for different series. However, these papers do not provide a formal means of judging how close the predicted values are compared to the actual values. We will return to these issues in Section IV.

III. What Does Money Do?[12]

The RBC models that we have surveyed above have shown that it is possible to have economies display business cycle-like behavior *without* reference to money. This is in marked contrast to more traditional analyses, such as Friedman and Schwartz (1982), Lucas (1975) and Barro (1976), which assign an important role to monetary disturbances. Indeed, some have argued that this is the distinguishing feature of RBC models (as we point out in the introduction).

It is also possible to assert that some form of monetary neutrality is assumed implicitly in RBC analysis. However, to regard monetary neutrality as the only defining tenet of RBC theories would be similar to claiming that most papers in public finance are studies of monetary neutrality because they fail to include money in the models. It seems more likely that the omission of money or financial market variables reflects the fact that early contributors were more concerned with explaining the non-monetary characteristics of business cycles. For instance, KPR (1988, p. 196) stress that it is necessary first to understand the effects of real disturbances, and that, "Without an understanding of these real fluctuations it is difficult *a priori* to assign an important role to money."[13]

Indeed, more recent research in this field focuses on the issues related to monetary aspects of the aggregate economy. Since they are "fully articulated" economies, it is necessary to motivate the use of money in these models by explicitly specifying some kind of transactions technology. Below, we discuss the two alternative mechanisms that have commonly been used in these analyses: the cash-in-advance constraint and the shopping-time technology specification (or a household production technology). A series of related questions can be asked once money is introduced into an RBC model. How successful are these models in explaining the observed correlations among output, money, and other real and nominal variables? What is the nature of the causal link between fluctuations in money and output? Alternatively, does the inclusion of money improve our ability to explain business cycles?

One way of introducing money in an RBC economy is to model it as an input into the transactions technology. King and Plosser (1984) and Kydland (1989) adopt a shopping-time technology to model the transactions role of money. Specifically, they assume that the time required to carry out transactions varies inversely with the amount of money held. Huh (1990) adopts a household production technology which requires the use of both physical output and money to generate actual consumption for consumers.[14]

King and Plosser (1984) focused on explaining the procyclical correlation between output and the broad monetary aggregates (such as M1) that has been observed in the U.S. economy. They introduce separate competitive firms (banks) that produce transactions services. These services are demanded by both households (because of the shopping time technology) and firms (as an input to the production process). Thus, banks will increase the supply of transactions services in response to a favorable technology shock to the final-good-producing firms to meet the increased demand of both the firms and consumers. Consumer demand for transactions services goes up because the opportunity cost of leisure time, as well as the value of time taken up by shopping activities, has gone up due to an increase in the real wage rate. Thus, the King-Plosser model predicts the observed positive correlation between output and inside money. However, it is important to note that the causal relationship between the two is the reverse of what is traditionally assumed—an increase in output leads to an increase in the money stock, and not vice versa.

The price level is determined in the market for government issued currency, which is demanded by households as a substitute for transactions services supplied by financial intermediaries.

The King-Plosser paper emphasized establishing a plausible theoretical construct that gave rise to reverse causation, and the quantitative analysis characteristic of RBC analysis was not carried out. To carry out such an analysis one needs to calibrate the transactions technology explicitly based on empirical studies of individual or household behavior with respect to money holdings and purchasing patterns. This way of modeling provides a practical route that can potentially capture and measure the role of money as a medium of exchange in a real economy. This also will impose empirical discipline on studies of the monetary aspect of an economy, similar to that found in other RBC analyses.[15]

Kydland (1989) examines the implications of allowing the possibility of a tradeoff between leisure and money as envisioned in a shopping time technology. One interesting finding is that the price level of the model economy turns out to be half as variable as the CPI of the U.S. economy, even with a constant money stock assumption. These price level fluctuations in the model economy are due to shifts in the demand for real balances which, in turn, vary entirely due to the desire of agents in the economy to substitute leisure (or labor) over time. The price level also exhibits a negative contemporaneous correlation with output in this economy, a feature that both Cooley and Hansen (1989) and Kydland and Prescott (1990) also find in post-war U.S. data. However, Kydland finds that introducing money in this way does not change the behavior of either output or labor supply in the model economy.

Huh (1990) obtains a more comprehensive accounting of the pattern of comovements among output, money stock, and price level observed in the U.S. time series data. Huh adopts a household production specification of demand for money, which requires the use of both physical output and money as input factors in generating actual consumption. The money supply of the model economy each period is determined by an explicit monetary reaction function, which depends upon both lagged real shocks and past values of money growth. Given this specification, the model economy exhibits a spurious positive comovement between money and output that approximates the positive correlation observed in U.S. time series data on the two variables. Variations in the steady state rate of inflation turn out to have real effects in this economy.[16] However, changes in the money supply do not seem to be an important source of business cycle movements.

Huh partially exploits the added opportunity of imposing empirical discipline that was discussed earlier. For example, the paper uses information about the relative variability of a broader measure of monetary aggregates (M1) over a narrowly measured one (monetary base) in calibrating the money supply function. But no comparable procedure was implemented with regard to the transaction technology calibration.

The other specification that has been employed in these models is the cash-in-advance (or liquidity) constraint, which motivates the introduction of money by simply requiring the use of money in making transactions. Various economic implications of the cash-in-advance constraint have been extensively studied in monetary economics (for example, see Lucas (1980), Lucas and Stokey (1987), Stockman (1981)). Cooley and Hansen (1989) apply this liquidity constraint to the RBC economy of Hansen (1985).

In the Cooley-Hansen economy, goods can be divided into two groups: cash goods and noncash goods, depending on whether the purchase of a good requires the use of cash (e.g., consumption) or not (e.g., leisure). Money is nonneutral because anticipated changes in money affect the relative price of consumption (cash good) and leisure (noncash good). Cooley and Hansen found the steady state welfare cost of inflation to be nontrivial in their economy. However, variations in the money supply do not have much impact on the cyclical behavior of the real variables in their model either.[17] The authors speculate that money may have a larger role to play in a model with restrictions on available information similar to those in Lucas (1972).[18]

Kydland (1989) carries out such an exercise. To measure the informational impact in isolation, Kydland adopts a version of the model economy of Lucas (1972) which is populated by spatially separated agents. The information structure assumed by Kydland implies that agents must extract information about the real wage from observations on the nominal wage. Monetary shocks alter the price level, thereby complicating the agent's signal extraction problem. However, it turns out that variations in the growth rate of money do not lead to significant cyclical movements in this model either.[19]

Overall, these (ongoing) efforts to extend standard RBC research to allow a role for money have produced interesting results. These studies provide a positive answer to the question of whether there exist plausible specifications that can explain (in the sense of Lucas (1977)) a set of key observations on nominal quantities and prices. However, the answer to the question of whether these specifications of money are an exhaustive and sufficiently robust mapping of the role of money in the "real" economy seems less clear. Thus far, for example, no studies based on the RBC premises have shed light on the effects of open market operations involving different types of instruments of government indebtedness.[20] Another potential source of nonneutral money is some form of a nominal contractual arrangement.[21] Consequently, it seems inappropriate to interpret the results of these studies as demonstrating that money has no role to play in causing business cycles.

IV. What the Critics Say

The developments in RBC theory surveyed above represent innovations both in terms of technique and in ways of thinking about business cycles. However, that does not imply that RBC theory is free from shortcomings. In this section we review some of the criticisms leveled against this approach. We begin by reviewing what critics have to say in three broad areas. First, economists have expressed concern about a key propagation mechanism in these models, namely, the intertemporal substitution of leisure. Second, they have criticized the theory's reliance upon technology shocks. And third, they have also questioned the method by which parameter estimates have been obtained, that is to say, they have questioned the technique of "calibration." We conclude the section by summarizing some additional criticisms of the theory.

As discussed above, this approach relies upon intertemporal substitution of leisure to generate business cycles. This reliance has been criticized on several grounds. For instance, Walsh (1986) points out that while labor supply is procyclical, most of the cyclical variation in employment is accounted for by changes in the employment rate, rather than by changes in the labor force as the theory would predict. Since recessions are periods of low return, the theory also predicts that the quit rate should be countercyclical, whereas the data show that the quit rate is procyclical.

In addition to concerns about the mechanism generating business cycles, questions have also been raised about the nature and role of the technology shocks. For instance, Summers (1986) wonders where the technology shocks are, and whether recessions should be defined as periods of technological regress. A similar sentiment is expressed by Mankiw (1989, p. 85): "The existence of large fluctuations in the available technology is a crucial but unjustified assumption of real business cycle theory."

Over the postwar period, probably the most prominent aggregate shocks have been the changes in the relative price of oil. Since oil is a major input, variations in its relative price are likely to have a measurable impact on economy-wide output. However, in a recent study, Kim and Loungani (unpublished, p. 18) find that ". . . the inclusion of energy price shocks leads to only a modest reduction in the RBC model's reliance on unobserved technology shocks."

It is also possible that the economy-wide technology shocks represent the aggregation of a large number of shocks to different industries. However, this notion is questioned by McCallum (1989, p. 29), who states that if the term *technology shock* is ". . . . taken literally to refer to shifts in the state-of-knowledge technological relationship between inputs and outputs, then it would seem highly unlikely that there could exist any substantial *aggregate* variability." This is because the economy contains a large number of different sectors employing different technologies, and shocks to these technologies should be more or less independent. Since the economy-wide technology shock would be an average of these industry-specific shocks, it would evolve more smoothly than what RBC models seem to require.

Prescott's use of the Solow residual to measure the size of the technology shock has also been criticized. Recall that the Solow residual is obtained as a residual from a (Cobb-Douglas) production function using labor and capital as inputs. This procedure implies that errors in the measurement of labor and capital will show up as variations in the estimated Solow residual (since the errors in measuring output are likely to be uncorrelated with the errors in measuring labor and capital). Consider, for example, what happens when there are variations in the rate of capital utilization. Since the measured Solow residual is based upon an assumption of 100 percent capacity utilization, any change in the rate of capacity utilization will be measured as a technology shock.[22]

Variations in "the rate of utilization" for the labor input are likely to have similar effects. Eichenbaum (1990) points out that allowing for labor hoarding in an RBC model drastically reduces the role of technology shocks. Thus, naive Solow residual accounting overestimates the variance of the technology shocks.

McCallum (1989) also points out that the Solow residual will overestimate the variance of the technology shock in the presence of adjustment costs. (Adjustment costs can be one reason for labor hoarding.) As evidence, he points to a study by Jorgenson and Griliches in which the elimination of aggregation errors and a correction for variations in labor and capital utilization reduces the role played by the Solow residual (in explaining output growth) to only 7 percent of the initial estimate.

A number of others have also expressed similar reservations about the use of the Solow residual to measure technology shocks. According to Hall (1989), the Solow residual is correlated with oil prices, military spending, and even the political party of the president. Similarly, Evans (1990) shows that the Solow residual is correlated with alternative measures of the money supply. These correlations contradict the assumption that the Solow residual only measures shifts in the production function.

If the Solow residual is not a good measure of technology shocks, what are we left with? RBC proponents have not done a good job of coming up with alternatives, leaving critics to wonder how the theory can be verified.

The next major criticism of RBC models has to do with the issue of statistical inference. The basic problem is that the calibration techniques discussed above do not take account of the uncertainty that exists regarding the true value of the parameters. Thus, Manuelli and Sargent (1988, p. 531) express concern about the use of out-of-sample evidence to estimate parameters since it precludes the use of a formal probability model to make judgments about the results. They further ask "Does it matter *how* the extraneous (out of sample) parameter estimates have been made? Were these estimates obtained using a theoretical structure consistent with the general equilibrium structure Kydland-Prescott maintain? Were the extraneous estimates obtained in ways that would be statistically consistent in view of the cross-equation and cross-frequency restrictions imposed by the Kydland and Prescott model?"

In a similar vein, Eichenbaum (1990, p. 9) states ". . . calibration exercises do not provide any information on how loudly the data speak on any given question." He takes issue with Kydland and Prescott's contention that technology shocks account for 70 percent of the business cycle variation in post-war U.S. output. On the basis of his attempt to incorporate parameter uncertainty into measurements of the role of technology shocks, he concludes that ". . . we ought to be very comfortable believing that the model explains *anywhere* between 5% and 200% of the variance in per capita U.S. output." In other words, the role of technology shocks is very imprecisely estimated.

A number of other criticisms have also been made. For example, some economists (Summers (1986), among others) find a pervasive use of the "representative agent" construct in RBC theories objectionable. In addition, the model has only been tested on postwar U.S. data so far. Critics have pointed out the need to test the model using alternative samples. Rogoff (1986), for example, has suggested estimating the model for different countries.

Ingram and Leeper (1990) argue that the use of RBC models to examine policy issues may be subject to a version of the Lucas critique.[23] This criticism is applicable to models that use parameter values used in calibrating early RBC models which ignored the effects of policy (e.g., Kydland and Prescott 1982). Ingram and Leeper show that ignoring the effects of monetary policy in a world in which policy has real effects implies that some of the estimated parameters will be reduced form coefficients. Policy analyses based on the assumption that these are deep, policy invariant parameters will, therefore, lead to incorrect inferences.

V. An Appraisal

Clearly, RBC models are not without their critics. Nevertheless, this line of inquiry has made important contributions to economic analysis. RBC models represent a significant innovation in economic modeling, since they were the first operational models based upon microeconomic foundations. As such, they provide a coherent, logically consistent way of thinking about the macroeconomy. At one level, these models provide a useful counterpoint to the view that in the absence of fiscal and monetary policy shocks, real output would grow at a steady 3 percent annual rate (or whatever the sample average growth rate would happen to be).

One attraction of these models is that they provide a relatively straightforward way of testing theories against data. However, existing RBC models are highly stylized and do not have the same econometric detail as the large scale Keynesian models often used for policy purposes.

So what can these models tell us about how to conduct policy? Kydland and Prescott suggest that we need to learn more about business cycles before making policy recommendations. For instance, in Kydland and Prescott (1988, p. 358) they state, "Our analysis should not be interpreted to mean that fluctuations are optimal and that there is no role for stabilization policy. Our view is that public finance considerations are not the principal factor driving the business cycle and that abstracting from them at this stage is warranted. Only when we have considerable confidence in a theory of business fluctuations would the application of public finance theory to the question of stabilization be warranted."

Their conclusion is based on a model that does not explicitly incorporate either public spending or money. What can we say on the basis of models that do? As discussed above, changing either the growth rate of money or the size of the monetary shocks in these models does not have a significant effect on the cyclical behavior of the real variables. On the surface, this seems to suggest that monetary policy is not very important. However, existing models are not yet rich enough to support such a conclusion. For instance, these models allow only a limited role for money and do not allow for other nominal assets. Thus, the available evidence does not seem sufficient (or robust enough) to convince a risk-averse policymaker either to adopt or to abandon a specific course of action.

NOTES

1. Their first paper on this topic ("A Competitive Theory of Fluctuations . . . . ") was published in 1980, though Kydland and Prescott (1982) is more frequently cited.

2. This function belongs to the constant relative risk aversion (CRRA) class. See Blanchard and Fischer (1989) for a discussion.

3. A simpler production function does impose costs. For instance, our specification implies a constant marginal product of labor and consequently a constant wage rate.

4. For our purposes the important point is that the z_i's shift the marginal product of capital.

5. In our specification, Y_1 is not equal to Y_2 even in the absence of shocks. However, this difference is not central to our discussion, since our focus is on the *change* in output in response to the technology shocks.

6. The elasticity of intertemporal substitution is a fundamental determinant of the volatility of consumption. For example, if the utility function is linear in consumption, the elasticity of the intertemporal substitution of consumption becomes infinitely large. Since individuals do not care about the period they consume in, consumption becomes extremely volatile. To demonstrate this heuristically, suppose that the two-period utility function is as follows:

$$u(c_1, c_2) = [c_1^{-\rho} + c_2^{-\rho}]^{-\frac{1}{\rho}},$$

where c_i denotes consumption in period i for $i = 1, 2$. The elasticity of substitution between c_1 and c_2 is given by $1/(1 + \rho)$. The utility function becomes linear when ρ is -1. Note that the elasticity of substitution goes to infinity as ρ approaches -1.

7. See Kydland and Prescott(1982), and King, Plosser and Rebelo (1988) for two distinct solution procedures. A comparison of alternative solution procedures is contained in the *Journal of Business and Economic Statistics*, January 1990.

8. King and Plosser (1989) employ a different technique to carry out tests of RBC models.

9. KPR also cite other work by King and Rebelo that demonstrates that applying a low frequency filter (such as first differences) to the data from a theoretical economy raises the correlation between output and labor input.

10. Also see Kydland and Prescott (1988).

11. Their model is more general than the one discussed above, since it allows labor input to change both in terms of hours per worker and the number of employed workers.

12. As mentioned above, there are many extensions of the basic Kydland-Prescott model that we do not cover in our survey. For instance, Stockman (1988, 1990) deals with open economy issues. Christiano and Eichenbaum (1988) examine the effects of shocks to government spending in an RBC model. Christiano (1988) introduces inventories.

13. A somewhat different view is expressed by Eichenbaum and Singleton (1986, p. 92):

"In our view, proponents of real business cycle theories are not claiming that monetary policy cannot or has never had a significant impact on the fluctuation of real output, investment, or consumption. Rather we subscribe to the second interpretation of RBC analyses as investigations of real allocations under the assumption that, to a good approximation, monetary policy shocks have played an insignificant role in determining the behavior of real variables."

14. These techniques of introducing money are closely related to the money-in-utility-function (MIUF) approach. The MIUF approach is criticized by some monetary theorists as implicit theorizing because of its reliance on the underlying model and its assumptions with implications that might be contradictory to those of the final model (for a critical discussion, see Kareken and Wallace (1980)).

15. However, there is a justifiable concern about implementing this technique for a monetary economy. According to this methodology, one has to get estimates of the deep parameters governing preferences and technology that are invariant with respect to any type of monetary policy shifts and interventions. It might be especially difficult to obtain or isolate such information about the parameter values of the underlying transaction technology from data.

16. In both the Huh economy and the Cooley-Hansen economy (discussed below) changes in the steady state inflation rate have effects that are the opposite of the "Tobin effect." The Tobin effect implies a positive correlation between the steady state inflation rate and the capital stock. It arises as a result of portfolio substitution: an increase in the rate of inflation, for instance, lowers the rate of return on money and causes individuals to substitute into physical capital. By contrast, in a cash-in-advance model, an increase in inflation makes activities that require the use of money (purchases of consumption goods) less attractive relative to other activities (leisure), because of the decrease in the purchasing power of money holdings due to inflation. For more discussion see Stockman (1981) and Lucas (1987).

17. It is important to realize that a cash-in-advance constraint imposes some significant restrictions on the model structure. The first is the exogeneity of the length of the period defined in the economy, which was first pointed out by Harris (1980). Cash balance holding in a cash-in-advance economy is analogous to a hot potato, where the temperature of the potato measures the rate of inflation in the economy. The higher the inflation (i.e., the hotter the potato), the faster one wants to dispose of it. In this economy, the length of each period is defined as the time for which money is held, and, therefore, the velocity of money is defined to be one. Consequently, the length of the time period might change as the purchasing power of cash holdings varies due to changes in monetary policy, that is, as the economy moves between high and low inflation.

The next restriction is not unrelated to the first. The exogenous grouping of goods in terms of cash versus noncash goods is too restrictive. As the prevailing inflation rate changes, the scope of transactions involving cash versus noncash (credit or barter) is very likely to shift.

18. These restrictions lead to confusion about aggregate and relative price changes, and therefore cause money to have real effects.

19. Monetary misperception has been regarded as a potentially important source of monetary non-neutrality not only by the economists in the Lucas-Barro tradition, but also by some current practitioners of RBC theories (see the earlier discussion of the Cooley-Hansen paper). Thus, the test by Kydland has added significance. However, in an attempt to isolate the effect of money through informational confusion, a stringent neutrality is imposed on the model economy. In the model economy, individuals are paid in fiat currency (nominal wage), but it is unclear how transactions of goods are consummated or what happens to the individual money holdings in his "islands" economy. Consequently, interpreting the noise component of the observed nominal wage as a money or aggregate price shock seems arbitrary.

20. Imrohoroglu and Prescott (1990) is intended to examine some of these issues.

21. For example, Stadler (1990) obtains a strong non-neutrality result by incorporating a temporarily fixed nominal wage contract feature in an otherwise real model. We regard the assumed fixity too extreme and implausible, but it is one demonstration that such complications may alter the usual "effectively neutral money" results.

22. Greenwood, Hercowitz, and Huffman (1988) analyze an RBC model in which the rate of capital utilization is endogenous.

23. See Lucas (1976).

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