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Real Business Cycles

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I. *Introduction*

THE 1970s saw a distinctive shift in macroeconomic research. The traditional Keynesian research program was concerned with the determination of output and employment at a point in time and with how to alter and stabilize the time paths of major macroeconomic variables. In the 1970s this research program increasingly gave way to business cycle theory, that is, the theory of the nature and causes of economic fluctuations. This paper is a summary and assessment of Real Business Cycle (RBC) theory.[1]

The development of the New Classical macroeconomics brought about the revival of business cycle theory. The New Classical paradigm tried to account for the existence of cycles in perfectly competitive economies with rational expectations. It emphasized the role of imperfect information, and saw nominal shocks, in the form of monetary misperceptions, as the cause of cycles. The New Classical theory posed a challenge to Keynesian economics and stimulated the development of both the New Keynesian economics and RBC theory. The New Keynesian economics has generally accepted the idea of rational expectations, but emphasizes the importance of imperfect competition, costly price adjustment and externalities and considers nominal shocks as the predominant impulse mechanism.

RBC theory has developed alongside

[1] There have been a number of surveys of Real Business Cycle Theory, including Jean-Pierre Danthine and John Donaldson (1993), Chan Huh and Bharat Trehan (1991), Gregory Mankiw (1989), and Bennett McCallum (1989). These surveys do not always consider recent developments and extensions, which have gone some way towards mitigating some of the early criticisms of this theory. However, even where they do consider recent developments, they tend to focus on particular aspects of RBC research. For example, Danthine and Donaldson focus on developments concerning the labor market, while Huh and Trehan focus on the role of money in these models. Anyone interested in further reading on business cycles is referred to Thomas Cooley (forthcoming), which covers a number of areas of RBC research, that are dealt with only briefly in this survey, in greater depth, and provides an excellent introduction to the techniques required for building RBC models.

the New Keynesian economics, but, unlike it, RBC theory views cycles as arising in frictionless, perfectly competitive economies with generally complete markets subject to real shocks. RBC models demonstrate that, even in such environments, cycles can arise through the reactions of optimizing agents to real disturbances, such as random changes in technology or productivity.[2] Furthermore, such models are capable of mimicking the most important empirical regularities displayed by business cycles. Thus, RBC theory makes the notable contribution of showing that fluctuations in economic activity are consonant with competitive general equilibrium environments in which all agents are rational maximizers. Coordination failures, price stickiness, waves of optimism or pessimism, monetary policy, or government policy generally are not needed to account for business cycles.

The following section of the paper describes the background of RBC theory, the key features of RBC models and outlines a simple, prototype RBC model. Section III considers some of the many recent developments that have built on this basic RBC model. It finds that a number of cyclical phenomena cannot be explained by a model driven only by technology shocks. Increasingly, this has lead to the development of models where technology shocks are supplemented by additional disturbances that are analogous to taste shocks. It also assesses extensions of the basic model that incorporate money, government policy actions, and traded goods. Section IV examines the criticisms that have been leveled against RBCs. The strongest criticisms are first, there is no independent corroborating evidence for the large technology shocks that are assumed to drive business cycles and second, RBC models have difficulty in accounting for the dynamic properties of output because the propagation mechanisms they employ are generally weak. Thus, while RBC models can generate cycles, these are, as a general rule, not like the cycles observed. Section V surveys the empirical evidence, and finds little to mitigate these criticisms. The final section sums up, and considers the challenges that RBC theory still faces. The strong aggregation assumptions these models make by relying on representative agents cast doubt on their ability to assess policy questions, and also on their claim to have provided a more rigorous microfoundation for macroeconomics than competing paradigms.

II. *The Basic Real Business Cycle Model*

A. *Historical Background and Development*

Business cycles vary considerably in terms of amplitude and duration, and no two cycles appear to be exactly alike. Nevertheless, these cycles also contain qualitative features or regularities that persistently manifest themselves. Among the most prominent are that output movements in different sectors of the economy exhibit a high degree of coherence; that investment, or production of durables generally, is far more volatile than output; consumption is less variable than output; and the capital stock much less variable than output (Robert Lucas 1977). Velocity of money is countercyclical in most countries, and there is considerable variation in the correlation between monetary aggregates and output

[2] An alternative way of classifying these models is through the location of the dominant impulses driving the cycle: do they arise on the demand side or the supply side of the economy? New Classical and New Keynesian models are driven by demand-side shocks, while RBCs are driven by supply-side shocks. Some writers question the usefulness of this distinction, pointing out that any supply-side innovation causes a change in demand and vice versa.

(Danthine and Donaldson 1993). Long-term interest rates are less volatile than short-term interest rates, and the latter are nearly always positively correlated with output, but the correlation of longer-term rates with output is often negative or close to zero. Prices appear to be countercyclical, but I argue below that this evidence is tenuous. Employment is approximately as variable as output, while productivity is generally less variable than output, although certain countries show deviations from this pattern. RBC models demonstrate that at least some of these characteristics can be replicated in competitive general equilibrium models where all agents maximize and have rational expectations. Furthermore, this research program originated in the U.S.A. and usually American data have been used as the benchmark against which these models are judged.

Real Business Cycle theory regards stochastic fluctuations in factor productivity as the predominant source of fluctuations in economic activity. These theories follow the approach of Ragnar Frisch (1933) and Eugen Slutzky (1937), which clearly distinguishes between the impulse mechanism that initially causes a variable to deviate from its steady state value, and the propagation mechanism, which causes deviations from the steady state to persist for some time. Exogenous productivity shocks are the only impulse mechanism that these models originally incorporated. Other impulse mechanisms, such as changes in preferences,[3] or tax rates, or monetary policy, have been generally regarded by RBC theorists as having at best minor influence on the business cycle. It is this emphasis on productivity changes as the predominant source of cyclical activity that distinguishes these models from their predecessors and rivals. In particular, the absence of a role for demand-side innovations coupled with the assumption of competitive markets marks a clear break from the traditional Keynesian theory where changes in investment, consumption, or government spending are the main determinants of output in the short run.

The importance of exogenous productivity changes in economic theory can be traced to the seminal work of Robert Solow (1956, 1957) on the neoclassical growth model that appeared in the 1950s. Solow postulated a one-good economy, in which the capital stock is merely the accumulation of this composite commodity. The technical possibilities facing the economy are captured by a constant returns to scale aggregate production function. Technical progress proceeds at an exogenous rate in this theory, and augments the productivity of labor. (Technical change is Harrod neutral, so ensuring the constancy of relative shares and sustained steady-state growth.)

However, it is Solow's work on estimating the sources of economic growth that has proved most influential in the RBC literature. If markets are competitive and there exist constant returns to scale, then the growth of output from the aggregate production function is:

$$g_y = \alpha g_1 + (1 - \alpha) g_k + z,$$

where g_y, g_1 and g_k are the growth rates of output, labor, and capital respectively, α is the relative share of output of labor, and z measures the growth in output that cannot be accounted for by growth in la-

[3] Taste or preference shocks, by themselves, cannot explain cycles. Olivier Jean Blanchard and Stanley Fischer (1989b, p. 336) argue that, in an equilibrium framework, taste shocks lead to large fluctuations in consumption relative to output (in reality consumption is much less variable than output) and fail to generate the procyclical movement in inventories and investment that is observed in the data. Furthermore, it is difficult to believe that most agents suffer recurrent changes in their preferences that are large enough to drive cycles.

bor and capital. Thus z represents multifactor productivity growth and has been dubbed the "Solow residual." Rearranging the above equation one obtains:

$$(g_y - g_1) = \left(\frac{1-\alpha}{\alpha}\right)(g_k - g_y) + (1/\alpha)z.$$

This states that growth of output per capita depends on the growth of the capital-output ratio and on the Solow residual, z. The Solow residual has accounted for approximately half the growth in output in the U.S.A. since the 1870s (Blanchard and Fisher 1989b, pp. 3–5). This residual is not a constant, but fluctuates significantly over time. It is well described as a random walk with drift plus some serially uncorrelated measurement error (Edward Prescott 1986a).

The neoclassical model of capital accumulation, augmented by shocks to productivity, is the basic framework for RBC analysis. RBC theorists contend that the same theory that explains long-run growth should also explain business cycles. Once one incorporates stochastic fluctuations in the rate of technical progress into the neoclassical growth model, it is capable of displaying business cycle phenomena that match reasonably closely those historically observed in the U.S.A. Thus, RBC theory can be seen as a development of the neoclassical growth theory of the 1950s.

B. *The Basic Features of Real Business Cycle Models*

The evolution of RBC theory is notable for its emphasis on microfoundations: macroeconomic fluctuations are the outcome of maximizing decisions made by many individual agents. To obtain aggregates, one adds up the decision outcomes of the individual players, and imposes a solution that makes those decisions consistent.

Typically, RBC models contain the following features:

i) They adopt a representative agent framework, focusing on a representative firm and household, and in so doing the models circumvent aggregation problems.

ii) Firms and households optimize explicit objective functions, subject to the resource and technology constraints that they face.

iii) The cycle is driven by exogenous shocks to technology that shift production functions up or down. The impact of these shocks on output is amplified by intertemporal substitution of leisure—a rise in productivity raises the cost of leisure, causing employment to increase.

iv) All agents have rational expectations and there is continuous market clearing. There are complete markets and no informational asymmetries.

v) Actual cycles are generated by providing a propagation mechanism for the effects of shocks. This can take several forms. First, agents generally seek to smooth consumption over time, so that a rise in output will manifest itself partly as a rise in investment and in the capital stock. Second, lags in the investment process can result in a shock today affecting investment in the future, and thus future output. Third, individuals will tend to substitute leisure intertemporally in response to transitory changes in wages—they will work harder when wages are temporarily higher and compensate by taking more leisure once wages fall to their previous level. Fourth, firms may use inventories to meet unexpected changes in demand. If these are depleted, then, if firms face rising marginal costs, they would tend to be replenished only gradually, causing output to rise for several periods.

The first propagation mechanism is likely to be weak, while focusing on inventories yields negative serial correlation for output–output movements are strongly positively serially correlated in reality (Fischer 1988). Most RBC models focus on the second and third propagation mechanisms.

The intertemporal substitution mechanism is also likely to be weak. Most innovations in technology are regarded as highly persistent or even permanent, raising the real wage permanently. This is unlikely to elicit a large labor supply response, because the substitution effect of the higher wage is likely to be offset by the income effect. Only in response to temporary shocks is significant intertemporal substitution likely to occur. However, to fit the data, RBC models assume that most of the technology innovation is highly persistent. This points to the general difficulty of trying to reconcile observed labor market data with a technology driven equilibrium theory, and is examined in more detail in Section III.A below.

C. *A Simple Prototype RBC Model*

Consider an economy populated by identical, infinitely lived agents that produce a single good as output. There are no frictions or transactions costs, and, for simplicity we abstract from the existence of money and government. Each agent's preferences are

$$U_t = MaxE_t\left[\sum_{j=0}^{\infty} \beta^j u(c_{t+j}, 1_{t+j})\right], 0 < \beta < 1 \quad (1)$$

where β, c_t and l_t are a discount factor, consumption, and leisure and E is the expectations operator. The technology available to the economy is described by a conventional constant-returns-to-scale production function and an equation that gives the law of motion of the capital stock over time. The production function is:

$$y_t = z_t f(k_t, n_t) \quad (2)$$

where y_t is output, k_t is capital carried over from the previous period, and n_t is labor. z_t is a strictly positive stochastic parameter that shifts the production function, altering total factor productivity, and is assumed to follow a stationary Markov process (the distribution of z_t depends on z_{t-1} but is otherwise constant over time). The capital stock evolves according to:

$$k_{t+1} = (1 - \delta)k_t + i_t \quad (3)$$

where δ is the depreciation rate and i_t is gross investment. In a one-good model, that part of output not consumed becomes part of the capital stock the next period. The resource constraints that agents face restrict consumption and investment in any one period to output, and labor plus leisure time to the time endowment:

$$c_t + i_t = y_t$$
$$n_t + l_t = h_t \quad (4)$$

or $n_t = 1 - l_t$ if h_t is normalized to unity, where h_t is the total endowment of time.

Because all agents are identical, one can solve for the equilibrium quantities and prices by solving the agent's optimization problem. It is assumed that expectations are rational, so that the agent's expectations are based on the probability distributions implied by the economy's structure. All households are alike, agents know the probability distribution generating z_t as well as the current value of z_t, and all markets clear. Thus, maximizing (1) subject to constraints (2)–(4) provides a set of first-order conditions which characterize market equilibrium:

$$u_1(c_t, 1_t) - \lambda_t = 0 \quad (5)$$

$$u_2(c_t, 1_t) - \lambda_t z_t f_2(k_t, n_t) = 0 \quad (6)$$

$$-\lambda_t + E_t\beta\lambda_{t+1}[z_t f_1(k_t, n_t) - (1 - \delta)] = 0 \quad (7)$$

$$c_t + k_{t+1} = z_t f(k_t, n_t) + (1 - \delta)k_t \quad (8)$$

where u_i and f_i denote the partial derivatives of $u(\bullet)$ and $f(\bullet)$ with respect to their ith argument, and λ_t is the Lagrange multiplier. The first of the above equations equates the marginal utility of consumption to the shadow price of output, the second equates the marginal disutility of labor to labor's marginal product—the real wage—while the third equates the marginal product of capital to its opportunity cost in terms of foregone consumption. These equations determine the time paths of the economy's values of labor, capital, consumption, and λ.

Given explicit forms for the utility and production functions, it is possible to solve for the time paths of the three choice variables, c_t, k_t, and n_t. In order to obtain a specific solution, assume, for example (as in McCallum 1989) that capital depreciates fully within a single period ($\delta = 1$), utility is log-linear in form and the production function is Cobb-Douglas:

$$u(\bullet) = \theta \log c_t + (1 - \theta) \log (1 - n_t) \qquad (9)$$

$$z_t f(\bullet) = z_t n_t^{\alpha} k_t^{1-\alpha}. \qquad (10)$$

Under these assumptions the utility function ensures that the income and substitution effects of a wage change cancel each other, so that labor is constant in the solution. Using the method of undetermined coefficients, one can solve for the values of consumption and the capital stock:[4]

$$c_t = [1 - (1 - \alpha)\beta] z_t n_t^{\alpha} k_t^{1-\alpha} \qquad (11)$$

$$k_{t+1} = (1 - \alpha)\beta z_t n_t^{\alpha} k_t^{1-\alpha}. \qquad (12)$$

These time paths satisfy the first-order conditions and consequently represent optimal decision rules for the agents in this model economy. The intertemporal nature of the decision rules given by equations (11) and (12) is obvious. A temporary change in z_t around its long-run value produces not only a change in current consumption, but also translates into a change in the capital stock, which propagates the effects of the shock. A rise in productivity will raise the capital stock and consumption for several periods, causing the model to exhibit cycles. Consider the case where z_t follows a first order autoregressive (AR(1)) process. In this case, as illustrated by McCallum, consumption and the capital stock will follow AR(2) processes. This is significant because the detrended quarterly time series of various macroeconomic variables are well described by AR(2) processes for U.S. data.

However, normally the utility and production functions used are more complicated than (9) and (10), and do not admit of an analytical solution for the decision rules. The approach followed in such a case is to take linear approximations of the equivalent of equations (5) to (8) around a stationary point, which is usually assumed to be the steady state of the system, that is, those values of the variables when $z_t = 1$ for all t, given some initial value of the capital stock. This linear system can then be solved for time paths of the endogenous variables.

The next stage is to choose specific values for the parameters (α, β, etc.), usually by referring to previous econometric studies. One then generates a set of artificial data from the model. This involves specifying a stochastic process for the technology parameter (generally a random walk with drift or a highly persistent AR(1) process with positive trend) and generating many different series of values of the innovation in the technology parameter. One then feeds these series of shocks into the model to yield samples of artificial time series for c_t, k_t, etc. The model is judged by comparing the average properties of the samples of artificial, model-generated data

[4] See McCallum (1989, p. 22) for further details on this solution method.

TABLE 1
KYDLAND AND PRESCOTT'S (1982) MODEL,

	U.S. Economy[1]		Model's Results	
	(a)[2]	(b)3	(a)	(b)
Real Output	1.8	—	1.8	—
Consumption	1.3	0.74	0.63	0.94
Investment	3.1	0.71	6.45	0.80
Inventories	1.7	0.51	2.00	0.39
Capital Stock	0.7	–0.24	0.63	-0.07
Hours	2.0	0.85	1.05	0.93
Productivity	1.0	0.1	0.90	0.90

[1] Quarterly, data, 1950:1–1979:2, logged and detrended using the Hodrick-Prescott filter.
[2] Column (a) shows standard deviations, in percentages.
[3] Column (b) shows correlations with output.

with an actual data set. Normally the properties of interest are the second moments of output, consumption, investment, etc. as well as the comovements of these series with output.

As an example, Table 1 reproduces some results from Finn Kydland and Prescott (1982) (hereafter KP), one of the seminal papers on RBC theory. KP's model departs from the simple prototype model in two important ways. First, KP assume it takes four quarters to build capital (hence their model has become known as the time-to-build model). This imparts greater persistence to the effects of shocks. Second, KP assume that labor suffers from a fatigue effect. The harder one has worked in the past, the more one values leisure today. This increases the intertemporal substitution of leisure.[5] Table 1 shows that the model captures the fact that consumption is less volatile than output and investment much more volatile than output. However, like many RBC models, it greatly overpredicts the correlation between productivity and output. The standard deviation of output generated by the model and the data are identical, because the variance of the productivity shock has been chosen to ensure that the volatility of the model-generated output series matches that of the actual data set, which is fairly common practice among RBC theorists. Thus, the model is constructed so that all volatility in output is accounted for by stochastic productivity movements, and the model must consequently be judged by how well it mimics properties of the data other than the variance of output.

III. *Extensions of the Basic RBC Model*

This section is divided into five subsections. The first focuses on the labor market and deals with attempts to replicate labor market phenomena concerning hours worked, productivity, and unemployment. Subsequent subsections examine the introduction of new sectors, namely money, government, and interna-

[5] The KP model adds two further features to the prototype model: (i) Inventories are included as a factor of production. This improves the match of the model's serial correlation properties with the U.S. data. (ii) Agents observe a noisy signal of the productivity shock which contains a permanent and a transitory component. This noise is necessary to create a role for inventories to act as a buffer stock when expectations about productivity are not fulfilled.

tionally traded goods. A final subsection considers other extensions.

A. *The Labor Market*

There are a number of labor market regularities that are inconsistent not only with the simple prototype RBC model of Section II, but also with KP's model.

The first troublesome fact is the "employment variability puzzle." Employment (or total hours worked) is almost as variable as output, and strongly procyclical, while real wages are at best mildly procyclical. If most shocks hitting the economy shift the production function and alter the marginal product of labor then, ceteris paribus, the shifts in labor demand should trace out an upward-sloping labor supply function in real wage-employment space. Because micro studies suggest that the wage elasticity of labor supply is low, much of the adjustment to a productivity shock should be borne by wages, rather than employment. Consequently, RBC models like KP's predict that employment is less variable than in reality.

Second, in a world where cycles are caused by productivity shocks, the correlation between productivity and output should be high. In reality the correlation is moderate for most economies—for the U.S. estimates range from 0.4 to 0.6, depending on the sample period.[6] In KP's model the correlation is 0.90, and correlations of similar magnitude occur in many RBC models. As McCallum (1989) points out, the production function most RBC models (including KP) employ is essentially Cobb-Douglas. This implies that the marginal product of labor will move quite closely with the average product of labor, or productivity. Thus, although they generally do not generate artificial data series for real wages, these models imply that real wages (and productivity) are much more procyclical than in reality.[7]

Third, labor's share of income moves countercyclically over the cycle. However, if technology is Cobb-Douglas, labor's share is constant over the cycle.

A fourth labor market regularity that poses problems for RBC models is the so-called "productivity puzzle." If productivity shocks drive the cycle, employment and productivity would be highly correlated, and this is exactly what RBC models predict—usually the correlation between hours and productivity in these models is above 0.9. In reality, productivity and employment are negatively correlated for most economies. For the United States the correlation is roughly zero.[8]

Finally, there is no unemployment in KP's model. All variation in employment is due to variation in hours worked by the representative worker. Even where RBC models do succeed in accommodating unemployment, it is always voluntary, unless the Walrasian assumptions that underpin these models are dropped.

The remainder of this section deals with attempts to overcome these problems. The assumption that labor supply is indivisible goes a long way toward resolving the employment puzzle. How-

[6] The correlation between productivity and output given by Kydland and Prescott in Table 1 is only 0.1. In Prescott (1986a), using data from 1954 I to 1982 IV, the correlation is 0.34, and for studies using more recent data it is higher still. This suggests that the size of some of these correlations may be sensitive to the sample period employed, and is not a robust feature of the postwar U.S. economy.

[7] Kydland and Prescott (1993) argue that the implicit return to labor is much more procyclical than the aggregate data suggest. They define real wages as total labor compensation divided by aggregate, *quality adjusted* labor input derived from panel data, and find this is significantly procyclical.

[8] See Danthine and Donaldson (1993, table 6, p. 13). For the United States (and possibly for other countries as well) the magnitude of this correlation also seems to vary with the sample period and definition of employment.

ever, the productivity puzzle and the behavior of wages cannot be reconciled with a model driven solely by technology shocks. These facts can only be replicated by models that contain shocks to labor supply as well as labor demand.

A.1 *The Employment Variability Puzzle*. Under what conditions will RBC models display realistic real wage-employment correlations? Within an equilibrium framework, large movements in employment accompanied by only small wage changes suggest that the labor supply function is fairly flat, that is, there must be a high degree of intertemporal substitution over the business cycle. However, many critics (e.g., Lawrence Summers 1986; Mankiw 1989) regard the reliance on a high degree of intertemporal substitution as a weakness of these models, partly because there is no convincing empirical evidence for this.

Generally, quarterly data are used to assess the performance of RBCs, while micro studies of the elasticity of labor supply use annual data and are based on life cycle models. John Kennan (1988) argues that life cycle models, which estimate low elasticities, are not designed to measure responses to temporary wage changes within short periods of less than a year. He says that "these models assume that leisure in February 1989 is a perfect substitute for leisure in October 1989." He goes on to argue that

> a short-run elasticity of 0.1 is not credible: a 30 percent wage increase is not needed to call forth a 3 percent increase in hours worked (this would mean that in order to get someone to stay 15 minutes longer on the job today, he would have to be paid 30 percent more for the whole day).[9]

However, even if one accepts that the short-run labor elasticity is much higher than micro studies suggest, Kennan finds that, in an equilibrium framework, shocks to labor demand alone cannot generate the observed time series. Because innovations in real wages and employment both show great persistence, two separate impulse mechanisms are required to explain the data. Thus, Kennan's analysis also suggests that productivity shocks must be augmented by labor supply shocks, although the latter can have much smaller variance than the former.

In reality about two thirds of the variation in total hours worked appears to be due to movements into and out of employment, while the remainder is due to adjustments in hours worked by employees. This contrasts with the basic RBC models where all variation in hours is due to changes in intensity of work effort by the employed.

A different case occurs when a worker is constrained to work for a fixed amount of time or not at all, so that all changes in hours are brought about by changing employment (Gary Hansen 1985). Because the length of the working week is fixed, the marginal utility of leisure is constant. In this case the marginal benefit of working cannot be brought into equality each period by adjusting labor supply smoothly between periods. Under these circumstances, a representative agent will want to work as much as possible when the wage is high, so that the economy as a whole behaves like a hypothetical agent with infinite elasticity of substitution of leisure, even though individual agents have diminishing marginal utility of leisure. Thus, this type of nonconvexity in labor supply can reconcile

[9] Kennan (1988, pp. 196–97). Kennan also points out that hours worked at the individual level tend to be very variable, with a standard deviation of year-to-year changes of around 20 percent for the U.S. In a typical downturn, the decline in aggregate hours is less than 3 percent. The magnitude of individual variations is thus much larger than is necessary to explain cyclical variations, but the sources of these large variations are not pinned down in the microdata.

TABLE 2
HANSEN'S (1985) INDIVISIBLE LABOR MODEL

	U.S. Economy[1]		Model's Results	
	(a)[2]	(b)[3]	(a)	(b)
Real Output	1.76	—	1.76	—
Consumption	1.29	0.85	0.51	0.87
Investment	8.60	0.92	5.71	0.99
Capital Stock	0.63	0.04	0.47	0.05
Hours	1.66	0.76	1.35	0.98
Productivity	1.18	0.42	0.50	0.87

[1] Quarterly data, 1955:3–1984:1, logged, seasonally adjusted, and detrended using the Hodrick-Prescott filter.
[2,3] See Table 1 above.

the disparity in micro and macro findings with respect to the labor supply elasticity, as Prescott (1986b) emphasizes in his rebuttal of Summers' (1986) criticisms, and goes a long way towards resolving the employment puzzle. G. Hansen finds that in the presence of this nonconvexity the variability of hours rises considerably: indeed, in his model hours turn out to be far more variable relative to productivity than in the U.S. economy.[10] The results of Hansen's model are shown in Table 2.

A.2 *The Productivity Puzzle.* If all shocks impinging on the economy are productivity shocks that shift labor demand, hours and productivity will move together closely, for changes in employment result only from changes in productivity. Thus, an RBC model like KP's or G. Hansen's (1985) predicts that productivity is highly positively correlated with both hours and output. In reality, the first correlation is zero or negative, while the second is moderate (0.5 rather than 0.9). One way of reducing the correlation between employment and productivity is to introduce factors that will shift the labor supply function. Shifts in labor supply may arise through nominal wage stickiness, taste shocks, shocks to home or nonmarket production, or government spending shocks.

A traditional way of causing shifts in labor supply is through nominal wage stickiness and money supply shocks. If wages are preset, a nominal innovation shifts the effective supply of labor function. If both labor demand and labor supply are shifting, there is no a priori reason to expect a strong positive correlation between productivity (or wages) and hours or productivity and output.

Shifts in labor supply can also occur as a result of preference shocks that directly alter the willingness of agents to supply labor (Valerie Bencivenga 1992). However, there is no independent evidence that agents in aggregate suffer from large, recurrent fluctuations in

[10] G. Hansen's model suggests all changes in hours are due to changes in employment, which is clearly counterfactual. Jang-Ok Cho and Thomas Cooley (1988) address this problem by allowing agents to decide both on hours and whether to participate in the labor force at all. This extension improves the performance of the model in some areas. In particular, the ratio of the standard deviation of aggregate hours to the standard deviation of productivity produced by the model is virtually identical to that found in American data, around 1.4, whereas in Hansen's model the figure is around 2.7, because hours are so volatile in his framework. However, there is insufficient variability in all of Cho and Cooley's artificial time series.

preferences, and Bencivenga herself recognizes that such shocks might more plausibly be interpreted as shocks to the technology of home production.

Home production is potentially important because the household sector is large: home produced output relative to measured GNP is estimated to range between twenty and fifty percent, and includes such things as preparation of meals, cleaning and transportation services, and some residential maintenance activity. Assume that households have access to a home production function that uses time and capital to produce a nontradeable consumption good. A rise in market productivity leads not only to a rise in hours to accumulate more capital, but also to a substitution of market for home consumption, which also causes hours spent in the market consumption sector to rise. In a model with home production agents do not just substitute intertemporally, but also substitute labor between home and market commodities at a given date. Introducing this further margin of substitution improves the model's performance relative to models without home production. Moreover, if shocks to home productivity occur (possibly as the productivity of consumer durables changes) and these shocks are not perfectly correlated with shocks to market productivity, labor supply will fluctuate as relative changes in home productivity change the amount people are willing to work in the market at a given wage, and this reduces the correlation between market productivity and output and productivity and hours to values close to those observed in reality (Jess Benhabib, Richard Rogerson, and Randall Wright 1991).

Two criticisms can be leveled against household production models. In reality investment in market and nonmarket capital is positively correlated over the cycle (Greenwood and Zvi Hercowitz 1991), but negatively correlated in home production models unless the correlation between home and market disturbances is very high, in which case the productivity puzzle reappears. Second, these models suggests that business cycle episodes largely represent voluntary movements between home and market activities, which must be somewhat unsettling to the traditional macro theorist.

Two further factors that can help to resolve the productivity puzzle are labor hoarding behavior by firms and shocks to government spending. Government consumption and private consumption are not perfect substitutes in utility, so that a rise in government consumption financed by taxes results in a negative wealth effect that shifts labor supply.

Labor hoarding enables firms to change the effective labor supply without altering employment, so reducing the correlation between productivity and measured labor input, because reported hours worked are not an accurate measurement of true labor input under these circumstances. Labor hoarding can be introduced into an RBC model by assuming that the firm must hire workers before the current state of technology and demand are observed. Such a procedure attempts, rather crudely, to capture the fact that the firm cannot adjust the size of its workforce in response to every bit of new information it receives. Consequently, if productivity is higher than expected, labor input is initially adjusted only by varying labor effort, not by varying the number of employees—employment can only be adjusted with a one-period lag. Thus labor effort will be procyclical, rising during booms and falling during recessions, so that the Solow residual captures changes in labor effort that are not reflected in the labor input statistics. Both government expenditure shocks and labor hoarding cause fluctuations in the effective supply of labor which, acting in conjunction, significantly reduce the positive productivity-hours correlation that is implied by standard RBC models (Craig Burnside, Martin Eichenbaum, and Sergio Rebelo 1990). A model of this kind is also important because, as is discussed below, it can account for the dynamics of output, unlike most RBC models.

This section has examined several factors that can shift the effective supply of labor: the existence of a nonmarket production sector also subject to technology shocks, the existence of nominal wage contracts, taste shocks, government spending shocks, and labor hoarding behavior by firms. It is likely that in reality these factors have acted in conjunction in determining the pattern of employment, which makes it difficult to determine how significant each mechanism is empirically. For instance, it is questionable whether government spending shocks have a significant impact on labor supply, as opposed to labor demand (as is the case in traditional Keynesian models). I know of no empirical evidence to support this, and the low responsiveness of labor supply to tax changes that emerges from micro studies suggests that responses to changes in the government's provision of goods and services will also be low. (However, as discussed above, these micro studies are generally not informative about labor supply behavior over short horizons.) The fact that introducing government spending shocks into an RBC model in this way appears to have a significant effect on the model (as Lawrence Christiano and Eichenbaum 1992, find), does not prove that this mechanism has any relevance in reality. The same, unfortunately, applies equally to the other mechanisms considered and highlights the need for independent corroborating evidence, not only for shocks to labor demand, but also shocks to labor supply.

A.3 *Unemployment and Labor's Share*. RBC models can readily account for voluntary and frictional unemployment. This can be accomplished by the introduction of labor market search, where matching workers to jobs depends on aggregate search and recruiting effort. In search equilibrium, changes in employment tend to respond positively to permanent, rather than temporary, innovations in productivity. (By contrast, intertemporal substitution occurs in response to temporary shocks.) Further interesting features of this analysis are that searching increases the effect of a productivity shock on output and increases the persistence displayed by the cyclical component of macroeconomic time series (Dale Mortenson 1990; David Andolfatto 1994).[11]

In order to account for involuntary unemployment, one must assume that the wage no longer clears the labor market, but performs a different allocative role, for example, that it determines the level of labor effort, or is used to provide insurance against risk or must be set above a legal minimum level that is perceived to be "fair." Suppose that within an RBC framework risk averse older workers are covered by risk sharing wage contracts, but young workers must find employment in the casual labor market. If minimum wage legislation exists, it provides a floor to the wage in the casual labor market, allowing involuntary unemployment to occur in unfavorable states of the world. Results of simulations from a model similar to this due to Danthine and Donaldson (1991) are presented in Table 3.

RBC models with real wage rigidity

[11] Indivisibilities in labor supply (discussed above) also result in voluntary unemployment, with workers receiving the same income in both good and bad states of the world. (There is complete unemployment insurance in G. Hansen's model.)

TABLE 3
DANTHINE AND DONALDSON'S (1991) NON-WALRASIAN MODEL

	U.S. Economy[1]		Model's Results	
	(a)[2]	(b)3	(a)	(b)
Real Output	1.76	—	1.76	
Consumption	1.29	0.85	0.34	0.69
Investment	8.60	0.92	6.08	0.99
Capital Stock	0.63	0.04	0.54	0.03
Hours	1.66	0.76	1.26	0.98
Productivity	1.18	0.42	0.61	0.91
Unemployment rate			5%	

[1,2,3] See Table 2 above.

have the advantage that the correlation between wages and employment is lower than in standard models. A further advantage is that, like labor market search, real rigidities tend to amplify the impact of shocks on output, so that the variance of productivity shocks required to generate a certain standard deviation in output is much lower than in, say, KP's model.

The existence of risk-sharing contracts can also help to resolve the problem of the cyclical behavior of labor's share of income. Assume two types of agents inhabit an RBC model: entrepreneurs who provide optimal, risk-sharing contracts, and workers who thus obtain insurance against income losses due to cyclical fluctuations. In a bad state of the world the real wage rises relative to profits as the insurance element of the wage rises. This results in a countercyclical labor share and roughly acyclical wages, as observed in reality (Paul Gomme and Greenwood forthcoming).

B. *Extensions: Money*

The literature has explored several ways of introducing money into an RBC model, and RBC models can readily account for the procyclical movement of the money stock. Suppose that transactions (or financial) services can be produced more rapidly than goods, and these services are used by both firms and households to save time. A positive shock to productivity that increases output will also increase the demand for financial services: a model with these features predicts that these services will covary with output. Thus, the model explains the money-output correlation by means of a reverse causation argument: financial services change in response to output changes. Inside money is in fact much more closely correlated with output than outside money, which is exactly what this model predicts (Robert King and Charles Plosser 1984).

Other studies consider whether monetary shocks can have a significant effect on output variability in an RBC framework. These papers consider (1) a transactions technology, where changes in the money supply alter the time or resources needed to transact; (2) monetary shocks that affect output through price misperceptions in a Lucas (1972) informational "island" framework, along with real shocks (Kydland 1989); (3) a cash-in-advance constraint on the purchase of consumption goods, so inflation acts as a tax on consumption (Cooley and G. Hansen 1989). None of these approaches lead to

TABLE 4
CHO AND COOLEY'S (1990) MODEL WITH NOMINAL CONTRACTS

	U.S. Economy[1]		Model's Results[4]	
	(a)[2]	(b)3	(a)	(b)
Real Output	1.74	—	1.80	—
Consumption	0.81	0.65	0.37	0.53
Investment	8.49	0.91	6.54	0.95
Capital Stock	0.38	0.28	0.55	–0.09
Hours	1.80	0.87	1.31	0.84
Productivity	1.09	0.56	0.93	0.68
Prices (CPI)	1.60	–0.53	1.78	0.04

[1] Quarterly data, 1955:3–1984:1. Series are logged, seasonally adjusted, and detrended using the Hodrick-Prescott filter.
[2,3] See Table 1 above.
[4] Results for the model with 2-period staggered contracts and shocks to technology and the monetary base.

monetary innovations contributing significantly to output variability.

Thus, the introduction of a transactions technology or cash-in-advance constraint, by themselves, do little to alter the RBC model. For money to affect output significantly, it appears that one must depart from the Walrasian paradigm and allow for some nominal frictions in the economy. Consider a world in which agents face a cash-in-advance constraint for consumption goods, and money wages are set in advance for one or more periods to be equal to the expected market clearing wage, but that output prices are flexible. In such a world, any unanticipated movements in the money supply cause relative wage changes that have real effects over and above inflation tax effects. Incorporating nominal wage rigidity into an otherwise standard RBC model can amplify the effect of a monetary shock on output seventy-fold, and incorporating only a small amount of nominal wage rigidity (affecting one third of wage settlements) improves the performance of such an RBC model once both monetary and technology shocks are allowed for (Cho and Cooley 1990). In particular, as was noted above, this model can account for the "productivity puzzle." A summary of Cho and Cooley's results with respect to two-period staggered wage contracts is presented in Table 4.

RBC models that incorporate some nominal rigidity are important for two reasons. First, their properties suggest that nominal rigidity may well be an important missing element in standard RBC models. Second, such models introduce important Keynesian features into RBC analysis. They consequently bridge the dichotomy between two very different schools of thought in macroeconomics, and are likely to be regarded as a more acceptable development by some critics of RBCs. However, some aspects of the data generated by these models appear to be inconsistent with the U.S. data. For instance, in Table 4 nominal prices are very slightly procyclical, while in reality they appear to be countercyclical, at least if detrended by the Hodrick-Prescott filter.

This section has shown that it is quite possible to incorporate money into an RBC model, and to obtain the positive correlations between money and output that are observed in reality. However, in the absence of some nominal rigidity, changes in the inflation rate or in transactions costs caused by changes in the real money supply appear to have a negligible effect on real variables. Only the existence of significant nominal rigidity results in significant non-neutrality of money in an RBC model, and improves the fit of the model in some respects.

C. *Extensions: Government*

RBC models containing a government sector have been used to investigate the impact of government expenditure on the volatility of output. Generally, government spending is assumed to follow an exogenous stochastic process that approximates the real data on expenditure reasonably well. Innovations in government spending appear to contribute fairly little to output volatility (less than ten percent). Depending on the model structure, government spending shocks may even reduce the variability of output, because they are negatively correlated with Solow residuals (Mary Finn, forthcoming).[12]

An increasing number of papers have used RBC models to evaluate the benefits of alternative government policies. The long-run policy implications of these models are broadly consistent with the Neoclassical growth model, because RBC models are essentially extensions of the Neoclassical growth model. However, in RBC models the impact policies have over shorter horizons is very sensitive to the model structure. A change in the assumptions, such as requiring the government to balance the budget over the business cycle as opposed to leaving the level of government debt a free variable, can reverse the welfare rankings of alternative policies (V. V. Chari, Christiano, and Patrick Kehoe 1994). Interestingly, it has been found that the presence of distortionary taxes amplifies the persistence effects shocks have on aggregate time series and also increases the variability of these series (Greenwood and Gregory Huffman 1991).

One can conclude from this that RBC models can readily be used to evaluate the welfare costs of alternative policies. However, given the absence of agent heterogeneity in these models, and the consequent absence of any distributions of income and wealth, the absence of market power, of transactions costs, of externalities, and public goods, it is difficult to regard these models *as they currently stand* as providing plausible vehicles to assess policy issues. In particular, the reliance on a representative agent framework is regarded by some as especially damaging to the credibility of these models (see Section IV below).

D. *Extensions: The Open Economy*

One of the most active areas of business cycle research in recent years has been the development of open economy RBC models to explain patterns of trade and correlations across countries. Open economy RBC models have been successful in accounting for several stylized facts. First, the balance of trade moves countercyclically and second, the trade balance is positively correlated with the terms of trade—the relative price of ex-

[12] Solow residuals derived from a conventional production function like (2) above tend to be positively correlated with government spending (Burnside, Eichenbaum, and Rebelo 1991). Finn measures Solow residuals much more precisely, allowing for variable capital utilization and energy as a separate input. Her residuals are negatively correlated with government spending shocks, which is why they reduce output volatility under certain circumstances.

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ports to imports (David Backus, Kehoe, and Kydland 1994). Third, savings and investment are positively correlated in open economies (Finn 1990).

However, there are two stylized facts that these models cannot easily explain. RBC models with traded goods generally assume that each country experiences a different technology shock (though possibly positively correlated with the other country's shock). Agents can participate in international capital markets, so that consumption and investment are no longer constrained to equal domestic output. Given the opportunities of international risk sharing, one would expect consumption to be smoother than under autarky. Furthermore, it is a property of one-good economies with complete markets and additively separable preferences that consumptions of agents are positively correlated, even if their incomes are not. RBC models reflect this property and predict that correlations of consumption across countries are much higher than correlations of output, in contrast to what one observes in reality. This has been referred to as the quantity anomaly, because it is extremely robust to changes in parameter values and model structure. The second fact is that the terms of trade are much more variable and display greater persistence than RBC models suggest. This volatility in real exchange rates is called the price anomaly.

A large number of extensions to the theory have been proposed to deal with these two anomalies, including nontraded goods, taste shocks, energy price shocks, incomplete asset markets, and money. While some of these extensions have been able to account for the quantity anomaly, they are much less able to account for the quantity and price anomalies in conjunction (Backus, Kehoe, and Kydland forthcoming).

E. *Extensions: Other*

RBC models have been extended in a variety of other ways but, for reasons of space, only two further extensions are considered here—imperfect competition, and RBC's implications for asset prices.

Introducing imperfect competition into an RBC model has important consequences. Under imperfect competition, productivity shocks have very little effect on employment, so that the sizeable cyclical variation in employment one observes must be due to other shocks. For not implausible parameter values, a rise in productivity can even reduce employment slightly, because the wealth effect of a productivity shock on employment is greater than under perfect competition and offsets the substitution effect to a greater extent (Julio Rotemberg and Michael Woodford 1994). Furthermore, with increasing returns and imperfect competition, the economy may exhibit multiple equilibria, which suggests that such models are closer in spirit to the New Keynesian theory than the RBC paradigm.

The asset pricing implications of a standard RBC model are generally at variance with the stylized facts, because it is more difficult to account for significant risk premiums in a production economy than in an endowment economy. In an endowment economy, the representative agent simply consumes her endowment, but in a production economy the consumption decision is endogenous. As the degree of risk aversion rises, consumption becomes smoother and risk premiums less variable across assets. Thus, a standard RBC model cannot account for cross-sectional differences in returns on assets (such as the equity premium puzzle) nor for the time series behavior of returns (Geert Rouwenhorst 1994). It has been conjectured that other

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sources of shocks, or imperfect information, might be required to explain asset prices within an RBC framework.

IV. *Criticisms of RBC Theory*

Over the years a number of criticisms have been leveled against RBCs.[13] This section discusses five major criticisms. First, there is no independent evidence for the large, economy-wide disturbances that drive these models. Second, the models are not subjected to formal econometric tests: there is no *objective* yardstick to measure how well RBC models account for cycles. Third, they cannot account for the periodicity of cycles: the pattern of cycles generated by RBC models does not match reality at all well, because the models contain such weak mechanisms for propagating shocks through time. Fourth, RBCs cannot account for recessions, for this would require economy-wide reductions in productivity. Fifth, the utilization of a representative agent framework limits the ability of these models to address welfare or policy issues.

A. *The Nature of the Shocks*

Perhaps most frequently heard objection is that there is no independent evidence for the impulse mechanism that RBCs rely on. There is, says Summers (1986, p. 24) "no discussion of the source or nature of these shocks,. . . nor any microeconomic evidence of their importance." Furthermore, the way the shock is introduced into the models places strong implicit restrictions on the process of technological change. Technology shocks are assumed (a) to affect all sectors of the economy equally, and (b) to affect the productivity of all factors of production (or of all labor inputs in some formulations) equally, regardless of the vintages of capital or the ages and skill levels of labor. Not surprisingly, many people regard such pervasive, economy-wide changes in technology as implausible. Normally, a technological or scientific innovation affects only a few products. This section considers alternative characterizations of technical change, by examining a multisectoral RBC model and a model where technology shocks only affect new capital goods. It also assesses the importance of the role of energy price shocks in accounting for cycles.

If productivity innovations primarily affect only a particular sector, one must consider a multisectoral economy that produces many heterogeneous goods. Suppose these goods can be either consumed or used as inputs into next period's production process. If the different sectors are subject to independent shocks to productivity that follow a Markov process, aggregate output will display damped oscillations about its steady state that are similar to the business cycles observed in U.S. data (John Long and Plosser 1983). The problem with this approach is that much of the variation of individual sectors is averaged out: the variance of output aggregated across n sectors is much lower than the variance within each sector.[14] Using a disaggregated approach therefore has the drawback that the technology shocks hitting each sector have to be even larger than in a one-good model to result in the same variance of aggregate output.[15]

[13] Papers critical of RBC theory include Summers (1986), Mankiw (1989), McCallum (1989), and Eichenbaum (1991).

[14] In general, the variability of aggregate output tends to decrease as the number of sectors rises. For a discussion, see Per Bak et al. (1992). They argue that small, independent sectoral shocks can have significant aggregate effects only if costs are non-convex and there exist nonlinear, strongly localized interactions between different parts of the economy.

[15] Long and Plosser's model also appears to be at odds with several empirical facts. Horst Entorf

Furthermore, multisectoral models suffer from the same problems that afflict multicountry RBC models, because the basic structure of multisectoral and multicountry models is the same. Hence the theory will predict that consumption across sectors is more highly correlated than output across sectors, and productivity more highly correlated than output, while in reality the reverse is much more likely to be true (the absence of sectoral data on consumption makes this difficult to test). This suggests that disaggregating RBC models across sectors will prove challenging.

An alternative interpretation of technology shocks is that they are shocks to the marginal efficiency of investment. It is natural to think of such shocks as affecting the productivity of only new capital, not existing capital. This is a more plausible characterization of technology shocks, and provides a more Keynesian view of the causes of cycles, because shocks to the future marginal efficiency of capital can be interpreted as demand shocks.

How successful is such a characterization of technology shocks in accounting for cycles? Consider an RBC model with vintage capital subject to two shocks, a conventional RBC shock to total factor productivity and a shock that is specific to the productivity of new capital equipment, so the production of capital goods becomes increasingly efficient with the passage of time. In such a framework, about twenty percent of the cyclical volatility of output is due to investment-specific shocks, even though investment in new capital equipment is only about seven percent of GNP on average (Greenwood, Hercowitz, and Per Krussel 1992). This suggests that investment-specific technical change is important even at cyclical frequencies.

The interpretation of real shocks as impinging primarily on new capital goods is much more appealing than as a shock to total factor productivity, so it is regrettable that this formulation has not been adopted more widely. One reason may be that models with vintage capital are computationally more difficult to analyse than models with a single capital good. A second reason may be that, at least within this framework, most of the cyclical volatility of output is still due to the conventional RBC shock that impinges on total factor productivity. It would therefore be interesting to see the effects of introducing other shocks (government spending or nominal shocks, for example) into this model.

When asked for evidence of real shocks, RBC theorists often point to the large oil price shocks of the 1970s and the recessions that followed. Indeed, all but one of the postwar U.S. recessions have been preceded by a sharp rise in the price of crude petroleum (James Hamilton 1983). This raises the question whether the driving force behind RBCs is really energy price shocks. If so, these shocks are unlike those RBC theory assumes: the shocks RBCs contain shift the entire production function up or down, while a change in the relative price of an input would move one along the surface

(1991) argues that Long and Plosser's model leads to an inherent sectoral ordering, activity in some sectors leading that in others, with nonconsumer sectors as exogenous. He tests this using vector autoregressions and cross-spectral analysis, and finds that, contrary to the theory's predictions, consumer sectors tend to precede nonconsumer sectors. He concludes that this is consistent with a prominent role for demand disturbances. Kevin Murphy, Andrei Shleifer, and Robert Vishny (1989) argue that the variability of relative prices provides evidence against a multisectoral RBC. They find that raw materials prices are more procyclical than intermediate goods prices, which in turn are more procyclical than finished goods prices—the prices of outputs relative to inputs are countercyclical. If cycles result from shocks to common inputs (as in Long and Plosser) one would expect intermediate goods prices to decline relative to final goods over the cycle.

of an existing production function, without any change in the state of technology. Because RBCs consider only one shock to productivity, this has to absorb the role of both changes in productivity and any omitted factors, such as changes in availability of factor inputs, that may have played a role in reality but are not really productivity shocks. It is consequently of interest to introduce energy price shocks separately into an RBC.

A number of RBC models have explicitly incorporated energy price shocks (In-Moo Kim and Prakash Loungani 1992; Finn, forthcoming). Generally, the relative price of energy is modeled as an exogenous, stochastic ARMA process that fits the time series on energy price shocks quite well. These models lead to the conclusion that energy shocks seem to account for between eight and eighteen percent of output variation, which, while significant, suggests that, despite Hamilton's findings, these shocks have not been the dominant factor contributing to business cycles in the U.S.

Another omitted factor that the Solow residual might be capturing in closed-economy RBC models is changes in a country's terms of trade. It is possible to introduce the terms of trade as an exogenous process into an RBC model instead of endogenously determined by the model. Allowing the terms of trade process to approximate real data for industrialized countries, one finds that innovations in the terms of trade account for just over half of output variability—they are even more important than productivity shocks (Enrique Mendoza 1992). This suggests that changes in the terms of trade may be an important omitted source of output fluctuations in a closed-economy model. But, as noted above, models driven by productivity shocks alone cannot explain the volatility in terms of trade when these are endogenously determined in a multicountry framework. This again suggests that additional shocks are essential to replicate cycles adequately.

B. *Testing RBC Models and the Problem of Filtering*

Tests of RBC models are very informal. Generally authors just present two sets of statistics: second moments derived from the model-generated data and moments from a real data set. Casual inspection determines how closely the two sets of moments correspond to each other, and this decides whether the model is a good approximation of reality. No formal test statistics are presented.

Furthermore, RBC models are not tested against alternative hypotheses. It is not clear what the value of testing a highly abstract, but fully articulated, model against a much less restrictive, less comprehensively articulated alternative would be. In terms of predictive power, one would expect a time series model that places few restrictions on the data to reject an RBC model. The real issue here is how one should judge the relative performance of alternative, fully articulated business cycle models. The current informal method of testing RBC models cannot resolve this issue and is anyway subject to two pitfalls: first, the data filtering procedure can result in spurious inferences being made, and second, the method is purely subjective.

RBC models almost universally use the Hodrick-Prescott (HP) filter to decompose time series into long-run and business cycle components.[16] This filter has two problems. First, it "removes important time series components that have traditionally been regarded as representing business cycle phenomena" (King and Rebelo 1993, p. 208). Thus

[16] Kydland and Prescott (1990) provide a description of this filter. Essentially, the filter amplifies growth cycles at business cycle frequencies and dampens short- and long-run fluctuations.

this filter removes potentially valuable information from time series. Second, the HP filter can impart spurious cyclical patterns to the data. If one passes a random walk through the HP filter, the filtered data will display cycles, even though none was present in the raw data. Similarly, HP filtering can induce spurious correlation patterns among two data series that were not present in the prefiltered data (Timothy Cogley and James Nason, forthcoming). Application of the HP filter to real and model-generated data sets causes them to display similar cyclical properties that were not necessarily present in prefiltered data. This is illustrated by the fact that the raw data generated by a typical RBC are almost white noise, but display cycles once passed through the HP filter (Cogley and Nason, forthcoming). Consequently, correspondence between real and artificial data may simply reflect common properties induced by the HP filter.

This suggests that the properties of real and artificial data sets should be examined to see how sensitive they are to the filter employed. Second, goodness of fit statistics invariant to the HP filter, as used by Cogley and Nason (forthcoming), should begin to be more widely employed. Such formal test statistics would also facilitate objective comparison between different RBC models.

C. *Output Dynamics and the Problem of Propagation Mechanisms*

Can RBC models generally account for the output dynamics displayed by U.S. GNP? The answer is no, because the propagation mechanisms they incorporate are so weak.

In RBC models, cycles in output are driven by cycles in the exogenous technology disturbance. A purely temporary shock to productivity does not result in cyclical activity in output or employment: a temporary shock only causes temporary deviations in output and employment from their long-run paths, i.e., detrended output and employment display no serial correlation (King, Plosser, and Rebelo 1988a). In order to generate cycles, it is necessary to incorporate substantial first-order autocorrelation in productivity shocks, causing the shocks themselves to exhibit cycles, and this is what all RBC models do.

The ability of KP's widely used time-to-build construct to propagate shocks has been studied by Rouwenhorst (1991), who finds that in the KP model

> the main determinant of these model dynamics is the stochastic process for the shocks that hit the economy. Time-to-build, by itself contains only relatively weak material propagation mechanisms for transferring real shocks in terms of effects on output, labor input and consumption. For persistent deviations in output and investment to occur in the neoclassical model *it is required that the time series of shocks that hit the economy behave very much like the fluctuations which the model seeks to explain*. This conclusion is robust to allowing for nonseparabilities in preferences . . . time to build does not seem to be central to the explanation of business cycles. (1991, p. 242, my emphasis)

The ability of KP's fatigue effect to propagate shocks is also barely significant: "Labor input responds slightly more elastic[ally] than in the model with time separability, but the differences appear quantitatively small" (Rouwenhorst 1991, p. 252). Thus, despite being widely used, neither time-to-build nor fatigue effects contain strong propagation mechanisms for translating uncorrelated shocks into serial correlation in output and investment. Instead, the artificial time series generated by the model largely reflect the properties of the exogenous shocks that are meant to initiate the cycle.

This is a serious problem, for it is not confined to the KP model. Even if one accepts that exogenous technological innovations are highly autocorrelated, RBC models generally cannot replicate the dynamics of the U.S. GNP growth.

The extensive literature on the time series properties of U.S. output documents two sylized facts. First, output growth displays significant positive autocorrelations at short horizons, and weak negative autocorrelations at longer horizons (Charles Nelson and Plosser 1982). Second, if one decomposes output into permanent and transitory components, output displays a hump-shaped response to a transitory innovation, and thus appears to have an important trend-reverting component (Blanchard and Danny Quah 1989).

In order to account for these features, RBC models must propagate shocks over time in a particular way. Cogley and Nason (1993) examine the properties of eight different models: (i) A "baseline" RBC model (King, Plosser, and Rebelo 1988b); (ii) A time-to-build model; (iii) Christiano and Eichenbaum's (1992) model with government expenditure shocks; (iv) A variant of Christiano and Eichenbaum's model that also incorporates quadratic costs of adjusting the capital stock; (v) A further variant of Christiano and Eichenbaum's model that incorporates distortionary taxes on labor and capital; (vi) Greenwood, Hercowitz, and Huffman's (1988) model with variable capacity utilization and shocks only affecting the productivity of new capital goods; (vii) Benhabib, Rogerson, and Wright's (1991) model with home production; and (viii) Burnside, Eichenbaum, and Rebelo's (1993) model with labor hoarding.

They find that only the labor hoarding and home production models generate serial correlation in output endogenously, but that in the latter case it is negative, instead of positive, at short horizons. Furthermore, the labor hoarding model is also partially successful in accounting for the impulse response function of transitory shocks. In all the other models, output dynamics are nearly the same as impulse dynamics (just as Rouwenhorst found for the KP model).

Why, then, do RBC models appear to conform fairly well to real data? The answer is contained in the aforegoing subsection: both the real and model-generated data are HP filtered, and may contain some common cyclical properties induced by this filter. One is led to conclude that the great majority of RBC models studied in this survey cannot replicate the periodicity of output: they do generate cycles, but these are quite unlike the business cycles experienced by the postwar United States. This inability to account for the dynamics of output growth remains a major challenge to RBC theory.

D. *Recessions in RBC Models*

Many critics also express skepticism about the ability of RBCs to account for recessions. Why should there be aggregate declines in productivity that cause output to fall? Most people do not find the interpretation of recessions as periods of technological regress convincing.

RBC theorists tend to interpret technology shocks fairly broadly as "changes in the production functions, or, more generally, the production possibility sets of the profit centers" (G. Hansen and Prescott 1993, p. 280). However, changes in the stock of public technical and scientific knowledge alone cannot account for business cycles, because even though the rate of inventions may vary, the stock of knowledge should not decrease. Instead, RBC theorists have drawn attention to the legal and institutional framework which, in part, determines the incentives to adopt particular technologies. Changes in this framework, for instance tighter pollution laws, can, it is argued, be interpreted as a negative technology shock.[17]

The improvements in health, safety, and environmental standards that many Western economies have experienced in recent decades may well be one explanation why these economies have grown slowly over the past twenty years. However, some RBC theorists claim that the *cyclical* component of output can also be explained by such changes: taken literally, they suggest that recessions are induced by rashes of bureaucratic intervention in the market process, and are likely to occur when the stock of knowledge is growing only slowly. Thus, they see recessions as periods when there are no large technological innovations to offset regulatory changes that depress profits.[18]

An alternative explanation of recessions is due to Louis Corriveau (1994), who has examined the conditions under which an economy driven solely by technological advances will exhibit recessions. He assumes technical change is endogenous and occurs through innovation races. Each period resources are allocated between production and innovation. A potential innovator cannot know in advance whether he will succeed, but chances of success increase with factors devoted to innovation. He shows that downturns in output do not require negative technology shocks. Downturns are caused by increased allocation of resources to innovation in the face of increased opportunity ex ante that fails to materialize ex post, leaving fewer resources for production with last period's (unchanged) technology.

E. *The Representative Agent and the Problem of Aggregation*

All macroeconomic models face aggregation problems. RBC models overcome these by using "representative agents." The entire economy is collapsed into a single utility specification and a single production specification. This solution is radical, and consequently leaves even some economists working within the mainstream neoclassical tradition uneasy.

Alan Kirman (1992) has launched a strong attack on the representative agent construct. His case rests on a number of well known results. The Debreu-Mantel-Sonnenschein result demonstrates that individual maximization imposes only the weakest restrictions on the properties of aggregate functions.[19]

Even introducing a small amount of agent heterogeneity can have destructive consequences. If agents have identical preferences, and differ only in terms of the income they receive, the "representative agent" for such an economy need not be well behaved and the economy can manifest a large number of unstable equilibria. Optimization at the

[17] This is stated quite explicitly by G. Hansen and Prescott: "It would not be surprising then, that changes in the legal and regulatory system within a country often induce negative as well as positive changes in technology" (1993, p. 281).

[18] This hypothesis has some testable implications. Economies with relatively static institutional and regulatory frameworks should, in principle, experience less cyclical activity than those economies where these frameworks are more subject to change. Furthermore, because different countries have very different regulatory frameworks, and legislation to change them is seldom introduced at the same time, and because G. Hansen and Prescott argue the stock of technical knowledge is broadly similar across countries, a priori one would not expect the incidence of recessions to be significantly correlated across countries.

[19] More specifically, consider a pure exchange economy where each individual has a well-behaved textbook excess demand function. Summing over the finite number of individuals provides the aggregate excess demand function. Generally only three properties carry over from the individuals' to the aggregate excess demand function: it must be continuous, it must satisfy Walras Law (aggregate excess demand must equal zero at positive prices) and it is homogeneous of degree zero in absolute prices. This is not sufficient to obtain uniqueness and stability of equilibrium.

level of (very similar) individuals cannot ensure that the economy as a whole will behave like an optimizing individual. There is not necessarily a clear correspondence between the preferences and reactions to policy changes of the individual agents and the preferences and reactions of the hypothetical "average" or representative agent. This can lead to paradoxical situations where every individual in the economy may prefer situation *a* to situation *b*, but the representative agent prefers situation *b* to *a*. Consequently, changes in the welfare of the representative agent need not correspond to changes in society's welfare.

Secondly, many writers (e.g., Lucas 1987) regard one of the strengths of the RBC paradigm as being that it provides a rigorous microfoundation for macroeconomic behavior. Aggregate outcomes are explained as resulting from optimizing actions at the individual level. But the aforementioned arguments imply that the reliance on a representative agent deprives these models of much of their explanatory power: aggregate fluctuations result from the responses of the average agent to stochastic change in productivity; one cannot say that they result from the responses of maximizing individuals to productivity shocks.[20]

To take the argument further, it is well known that constrained maximization by all individuals is not sufficient to generate a well-behaved representative. Indeed, it is not even a necessary condition: one can obtain a well-behaved aggregate excess demand function provided agents have no money illusion and comply with their budget constraints (Jean-Michel Grandmont 1992). Well-behaved aggregate relationships do not require individual optimization: even economies whose agents have bounded rationality or follow simple rules of thumb can display well-behaved aggregate functions, a result that appears destructive of the claim of RBC theorists to have provided a more rigorous microeconomic foundation for macroeconomics than competing paradigms.[21]

V. *The Empirical Evidence*

The previous section showed that RBC models as a rule are not subjected to formal statistical tests against competing alternatives, and that there is no microeconomic evidence for the large real shocks that drive these models. However, a number of studies and empirical facts, to which we now turn, act as indirect tests of these models.

A. *The Empirics of Business Cycles*

Philip Cagan (1991) argues that the traditional view of the sources of business cycles has tended to focus on nominal demand. In this view, sluggish price adjustment causes output to react to changes in nominal demand brought about by changes in private sector confidence, government spending, or monetary policy. This view has several implications for the behavior of certain time series over the business cycle. First, it implies prices and output will covary positively over the cycle. Second, one would expect real wages to be countercyclical since the rise in output depresses the marginal product of labor. Third, under perfect competition the more intensive use of capital and labor during booms suggests, ceteris paribus, that

[20] An illustration of this lack of correspondence within the RBC paradigm is provided by G. Hansen (1985) who shows that a small change, like fixing the hours an agent may work at some number "*x*" or zero, causes the representative to exhibit infinite intertemporal substitution of leisure, even though the individual agents are assumed to have conventional labor supply functions.

[21] RBC models are also subject to the criticisms that can be leveled against the use of aggregate production functions. For an overview of this issue, see Geoffrey Harcourt (1969).

productivity should be countercyclical. Fourth, the traditional view is that the classical dichotomy holds in the long run: one would not expect nominal changes to alter the long-run time profile of output—nominal shocks should only cause transitory deviations from this long-run path.

RBCs predict different patterns for prices, wages, productivity, and output. If cycles are driven by real shocks, then in the absence of a consistently procyclical monetary policy, prices will be countercyclical—for a given money stock, prices should fall as productivity and output rise. Furthermore, because expansions are induced by positive innovations in productivity, real wages and productivity will be procyclical. Finally, some real shocks are permanent and will alter the long-run path of output.

The models' different time series predictions have led a number of writers to conclude that the "stylized facts" about these series can be used to discriminate between RBCs and competing theories. I examine the evidence for the pattern of output, wages, prices, and productivity below, and consider the implications this has for RBCs.

A.1 *Nonstationarity*. Before the influential work of Nelson and Plosser (1982), it had been common practice to treat macro time series as stationary movements around a deterministic linear trend. Nelson and Plosser found the trends of most series to be nonstationary stochastic processes, often well described as a random walk with trend. Their findings also led them to conclude that most output movements appear to result from changes in the secular, or permanent component of output, rather than the transitory cyclical component.

Many writers (including Nelson and Plosser) argued that these time series properties are most easily explained by a predominance of real shocks in the economy. RBC theorists typically regard the technology parameter as having a unit or near unit root. Because output inherits the trend properties of technology, RBC models can readily account for nonstationarity, with transitory (though possibly long lasting) deviations from this trend determining the cycle. Nominal shocks, by contrast, seem unable to account for the nonstationary trend.

This argument is weakened by three points. First, in finite samples it is not possible to discriminate between the hypothesis that a series is nonstationary (or difference stationary) and has a unit root, and the hypothesis that it is stationary but has a root that is less than, but close to unity.[22] Second, David DeJong and Charles Whiteman (1991) have argued from a Bayesian perspective that most economic time series are in fact more likely to be trend stationary than difference stationary—given reasonable priors, the relative support the data give to a trend stationary representation is stronger than that given to a nonstationary representation. Third, if technology is endogenous to the economic system, a monetary theory of the business cycle can account for nonstationarity just as well as an RBC model can (Stadler 1990). Despite the original claims of Nelson and Plosser, their work does not provide unequivocal support for RBCs.[23]

[22] The widely used Augmented Dickey-Fuller test of nonstationarity will actually reject the hypothesis of stationarity in series that are stationary but have an autoregressive component close to unity (John Campbell and Pierre Perron 1991).

[23] A further factor that creates problems for RBCs is that macroeconomic time series may contain non-linearities. For instance, Hamilton (1989) finds that the growth rate of output is better described by a regime-switching model than a linear model. Hamilton's findings can be replicated within an RBC model if the productivity shocks follow a Markov process with asymmetric transition probabilities. However, this implies that the Solow residuals should exhibit heteroscedasticity, for which there is no evidence in the data (Rouwenhorst 1994, fn. 5).

A.2 *Real Wages*. Are real wages procyclical? Until the mid-1980s, empirical work on this issue was inconclusive, and sometimes contradictory. For instance, Patrick Geary and Kennan (1982) found wages and employment to be statistically independent. Subsequent papers, using micro data on individuals, found a significant but mild procyclical movement (Michael Keane, Robert Moffit, and David Runkle 1988). However, discrepancies between the findings of these and other studies actually result from changes in the sample period, rather than the data set, employed. Periods dominated by demand disturbances exhibit countercyclical real wages, while periods dominated by supply disturbances manifest procyclical movements in real wages, which accounts for the low correlation between wages and employment (Scott Sumner and Stephen Silver 1989). This finding is hardly unexpected, but does not lend strong support to RBC theory.

A.3 *Prices*. Are prices procyclical? The actual pattern prices follow is difficult to determine. When variables have been detrended using the HP filter, regression analysis invariably yields a negative correlation between prices and output, as stressed by Kydland and Prescott (1990). However, there is some evidence that the sign of this correlation is sensitive to the filter employed to detrend the data (Keith Blackburn and Morten Ravn 1991). Cagan (1991) eschews detrending and visually inspects the time profile of the logarithm of prices over postwar business cycles. He concludes that most of the movement is procyclical.

However, the price-output correlation is not necessarily informative about the cyclical behavior of prices. Even models driven solely by demand shocks can exhibit a negative correlation. A change in aggregate demand initially causes prices and output to move in the same direction, but in opposite directions subsequently. The correlation coefficient depends both on the initial and later movements, and may consequently be negative (John Judd and Trehan, forthcoming). Thus, there need be no systematic relationship between the price-output correlation and the cyclical pattern prices actually follow. Because similar reasoning applies to other variables as well, it suggests that correlation coefficients may not be very informative about cyclical comovements.

A.4 *Productivity*. A further feature of the cycle that has arguably lent support to RBC theory is that productivity is procyclical. The conventional neoclassical theory of the firm suggests that as output rises and firms move down their demand for labor functions, productivity and wages should fall, ceteris paribus (there are short-run decreasing returns to labor). However, Robert Hall (1988) argues that productivity is procyclical because firms in imperfectly competitive markets operate on the downward-sloping portion of their average cost curves. In an interesting paper, Ben Bernanke and Martin Parkinson (1991) find that procyclical productivity was as marked during the Great Depression and its aftermath (1929–1939) as in the postwar period. Because the Great Depression hardly can have been caused by technical regress, they argue that these results show that procyclical productivity cannot always be due to procyclical technology shocks as RBC theorists claim.

The empirical "regularities" concerning nonstationarity, prices, and real wages are clearly not robust. Furthermore, the fact that the correlation between output and productivity is positive, and output and prices negative, is not really informative about the underlying causes of cycles. While there is no

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persuasive evidence against RBCs here, there is no clear evidence in their favor either.

B. *Testing First-Order-Condition Restrictions*

One way of testing RBCs indirectly is to test the restrictions that the first-order conditions which characterize market equilibrium in a competitive economy impose on the data—i.e., equations like (5) to (7) in the simple prototype RBC model outlined above. Studies using a time separable utility function (Mankiw, Rotemberg, and Summers 1985) and a non-time separable utility function (Eichenbaum, Lars Hansen, and Kenneth Singleton 1988) find that the restrictions imposed by first-order conditions are strongly rejected by the data.

In the light of the above discussion of the representative agent, this is hardly surprising, for these studies are testing a joint hypothesis: first, that the economy is well captured by a competitive general equilibrium model of optimizing agents, and second, that the preferences of all these agents are reasonably accurately captured by the particular preference specification ascribed to a single, fictional representative agent. The rejection of this joint hypothesis suggests that the preferences of agents in real economies are not accurately captured by a single, reasonably tractable utility function of the kind RBC models employ.

C. *Tests Using Solow Residuals*

To test RBCs, one needs to uncover what degree of fluctuation in output is really due to innovations in productivity. Prescott first suggested that the Solow residual, which is highly procyclical, captures such innovations, and a natural test of RBCs is to investigate what amount of output volatility is due to changes in the Solow residual. This is exactly what Kydland and Prescott (1991) undertake. They obtain measured Solow residuals from estimates of an aggregate production function and use these residuals as productivity shocks in the model.[24] They then compare the resulting standard deviation of output to that of the actual U.S. economy. They find that about 70 percent of the variance of postwar U.S. output can be accounted for by fluctuations in the Solow residual.

This type of test is subject to two criticisms. First, Solow residuals will reflect shifts in the production function accurately only under conditions of perfect competition and constant returns to scale. Second, even with perfect competition, Solow residuals will capture changes in total factor productivity only if there are no measurement errors in the indices of the capital and labor inputs that are used in estimating the aggregate production function: measurement errors in factor inputs will show up as variations in the estimated Solow residual. If firms hoard labor, measurement errors in labor input may be important. With labor hoarding, changes in real labor input are not captured by the employment data, because labor effort is procyclical, rising during booms when productivity is higher than expected, and falling during recessions, so that the procyclical Solow residual also captures changes in labor effort not reflected in the labor input statistics. This causes the

[24] The aggregate production function is assumed to be Cobb-Douglas and labor's share parameter constant over the sample period, whereas Solow originally treated the labor share parameter as variable, and it does vary over the cycle. Clearly, a variable share parameter would fit the observations more closely and reduce the residuals. It is not clear which procedure is the more appropriate, although the latter would almost certainly reduce the variance of output due to Solow residuals.

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measured Solow residuals to overstate the importance of technology shocks. In a model that incorporates labor hoarding, Burnside, Eichenbaum, and Rebelo (1993) find that technology shocks can account for between 30 percent and 60 percent of aggregate fluctuations, depending on the estimation procedure employed. This is significantly less than the figure of 70 percent claimed by Kydland and Prescott.

A further problem with Solow residuals is that they do not behave like an exogenous impulse, but are Granger-caused by money, interest rates, and government spending, and this finding does not appear to be due to reverse-causation (Charles Evans 1992). Between one quarter and one half of the variation in the measured Solow residual is attributable to variations in aggregate demand. This suggests that Solow residuals are not simply measures of productivity shocks, but capture a variety of other factors at work in the economy as well and reflect both supply-side and demand-side impulses. Another reason for procyclical Solow residuals is that they may result from short-run increasing returns. These could arise through cross-sectoral complementarities in demand and supply, whereby a rise in output in one sector has favorable spillover effects on other sectors.

D. *Tests Using Aggregate Decompositions*

A number of studies (Donna Costello 1993; Stefan Norrbin and Don Schlagenhauf 1988; Alan Stockman 1988) have decomposed the sources of output fluctuations into national (or aggregate), industry specific, and (in some cases) regional shocks. These studies are motivated by the fact that industry-specific shocks that are common across regions or countries are most readily interpretable as technology shocks. A predominant role for industry-specific shocks would provide evidence in favor of RBCs.

Generally, productivity growth is more strongly correlated across industries within one country than across countries within one industry. As a result, these studies find that shocks at the national level are at least as important as shocks at the industry-specific level. Estimates of the amount of output volatility attributable to industry-specific shocks differ, but they cannot account for much more than about a third of output volatility. These results suggest that cycles are not caused by worldwide technology shocks within a particular industry, for nation-specific shocks are as important. Some of the latter could be interpreted as technology shocks if they capture changes in the infrastructure or human capital accumulation that impinge primarily on productivity within one country. Skeptics, however, may well view the importance of nation-specific shocks as evidence in favor of traditional sources of business cycles, such as changes in nominal demand.

Econometric tests indicate that output, consumption, and investment are cointegrated—they share a common stochastic trend. King et al. (1991) identify permanent productivity shocks as shocks to the common stochastic trend of output, consumption, and investment. They find that productivity shocks typically explain less than half of the volatility in output, and considerably less of the variability of investment. They also find that innovations in inflation could account for up to 20 percent of variability of investment, but only for four percent of output variability. Furthermore, a shock corresponding to permanent movements in real interest rates could account for more of the short-run variation in output than the productivity shocks, and for much more of the variation in investment than the productivity shock. This suggests that impulse mechanisms omitted from conventional RBCs may be important.

E. *Scientific Evidence*

In considering the scientific evidence, it is natural to ask whether there is evidence for large shocks to technology (which can be most easily thought of as unexpected scientific discoveries) which are generally exogenous to the economic system, as RBC models assume.[25] The pioneering work of Jacob Schmookler (1966) is of particular interest here. Schmookler regards an innovation or invention as essentially a response to profit opportunities. He finds the rate of technological opportunity—given by the underlying scientific base—to be of little significance, because chronologies of hundreds of inventions typically reveal the stimulus to be a technical problem or opportunity conceived largely in economic terms. There is little evidence of scientific discovery initiating an invention.

Schmookler argues that invention is largely an economic activity, pursued for profit. Using data from the railroad, building, and petroleum refining industries, he finds a strong positive correlation between investment and capital goods invention in each industry, investment acting as a proxy for expected future sales and thus expected future profits. Schmookler concludes that, "Invention is governed by the extent of the market," and that, "The belief that invention, or the production of technology generally, is in most instances a noneconomic activity, is false" (1966, p. 208).[26]

One shortcoming of the RBC paradigm is that, in assuming productivity changes are purely exogenous, it ignores the economic factors underlying technical change. But even if most scientific progress were due to random and exogenous discoveries, it does not follow that the growth of productivity will be. The decision to adopt a new, low cost technology is determined by economic criteria. Shleifer (1986) has argued that firms will innovate when they expect booms and aggregate demand and profits are high (so helping to fulfill the expectation of a boom). Thus, productivity shocks may manifest themselves as the optimizing response to innovations in the money supply or government spending, and hence may explain why Solow residuals appear to be Granger-caused by money, interest rates, and government spending (Evans 1992). This suggests that the way technology is modeled in RBCs may be a poor approximation of how technology evolves in reality. Ignoring the endogeneity of technology may well limit the usefulness and applicability to policy issues of RBC models, because the estimation of welfare costs is sensitive to the endogeneity of technology (Gomme 1993).

[25] If technology is exogenous, then the cycle can be considered independently of growth considerations, because growth is determined by the (exogenous) trend in technology, while the cycle is determined by deviations from this trend. But if growth is endogenous, it raises the possibility that trend and cycle will be correlated, because they are driven by the same forces. If this is the case, one needs an underlying structural model to derive a theoretical identifying restriction that will separate cycle from trend. It is consequently not clear that the filters RBC theorists employ succeed in accurately separating out the cyclical component.

[26] Further evidence is provided by James Utterback in his survey of innovation and the diffusion of technology. He finds that "Market factors appear to be the primary influence on innovation. From sixty to eighty percent of important innovations in a large number of fields have been in response to market demands and needs. The remainder have originated in response to new scientific advances. . . ." Furthermore, "Firms tend to innovate primarily in areas where there is a fairly clear, *short-term* potential for profit" (1974, p. 621, my emphasis).

F. *An Empirical Assessment*

As is often the case, the empirical evidence considered here is not sufficiently conclusive to tilt the balance either in favor of or away from RBC theory. Real shocks are important, and may be the cause of as much as one third of cyclical fluctuations, but there is no persuasive evidence that they account for much more than this. There is certainly no cogent evidence that they account for 70 percent, as Kydland and Prescott claim, let alone for 100 percent as some RBC models assume when they suppress all other sources of economic fluctuations.

VI. *A Summing Up*

Real Business Cycle Theory has brought about a significant improvement in our understanding of the causes and mechanisms that underlie business cycles. RBC theory has shown that fairly simple general equilibrium models, in which technical change is stochastic, are capable of capturing many of the cyclical features of economic time series. These models provide the important insight that the existence of fluctuations in output does not imply any failure of markets to clear. Even economies with complete and efficient markets will display business cycles if technical change is stochastic. Although government intervention may be welfare-improving if equilibrium is not Pareto-optimal to begin with (say through the presence of distortionary taxes or money), the existence of cycles per se is not sufficient to justify stabilization policies. It is not necessarily sensible to try to increase output when factor productivity is low and decrease output when productivity is high, any more than it is sensible to try to iron out seasonal fluctuations (to use an analogy due to McCallum) by stimulating economic activity in January and February and trying to decrease production during the harvest season. Thus, RBC theory has changed our view of cycles in a fundamental way.

RBC theory has made considerable progress since the early 1980s. Nevertheless, it still faces a number of challenges: it has difficulty in accommodating a number of empirical facts, it cannot adequately account for the dynamics of output, and it cannot account for a significant degree of agent heterogeneity.

Many empirical regularities that manifest themselves in labor markets, in asset markets, and in international trade cannot be explained by RBC models that rely solely on productivity shocks to induce cycles. To explain numerous facts, other shocks must be added to these models, such as shocks to tastes, government spending, or the money supply. However, even such multi-shock RBC models cannot account for a number of important phenomena. Even if shocks impinge on both labor demand and supply, RBC models cannot simultaneously account for the productivity puzzle and the cyclical pattern of household investment. Nor can they readily account for the volatility and persistence of the terms of trade together with the fact that output is more highly correlated than consumption across countries. Furthermore, RBC models have even more difficulty than endowment economy models in explaining the cross-sectional and time series behavior of asset returns. Resolving these problems is the subject of ongoing research.

A further problem is that the great majority of RBC models are unable to account for output dynamics (and thus, by implication, for the cyclical pattern of most major macroeconomic time series). They cannot propagate shocks through time in a manner that generates cycles similar to those observed in reality. Furthermore, the emphasis on matching model-generated with real correlation coefficients may be misplaced, because these coefficients are not necessarily informative about the true cyclical comovements of variables. Accounting for the dynamics of GNP and other major macroeconomic time series will, I suspect, prove a major challenge to business cycle theorists.

If RBC models must be supplemented by additional shocks, this raises the fundamental question of whether productivity shocks are really the dominant cause of cycles. The models surveyed above demonstrate that, provided sufficiently large, autocorrelated, economy-wide productivity shocks exist, most fluctuations could be due to such shocks. Introducing additional sources of shocks does not alter this result—most of the models' output volatility is still due to productivity shocks. However, there is no corroborating evidence for large shocks that impinge on most sectors of the economy. In this regard it is important to note that the incorporation of certain features, such as distortionary taxes, real wage rigidity, or traded goods amplifies the impact of shocks on output and causes their effects to persist longer. For example, KP's model requires the economy-wide real shock to have a standard deviation of 0.0093. In Danthine and Donaldson's (1991) model with wage rigidity, the required standard deviation is only 0.0027. It would be interesting to combine several features that reduce the required volatility of the productivity shock. With several factors acting in concert, the required standard deviation may be very small indeed. But this argument is countered by noting that generalizing RBC models by introducing imperfect competition or multiple sectors is likely to reduce the importance of productivity shocks sharply.

The empirical evidence of what causes business cycles does not give strong support to the proposition that real shocks are responsible for more than a third of output fluctuations. What determines the remaining two-thirds? There is no clear answer to this at the present time. Since the work of Milton Friedman in the 1960s, the main alternative impulse mechanism has been nominal shocks, particularly monetary shocks. As evidence of their importance, economists often point to the recession of 1982–83 in the United States that followed closely on the deflation induced by the Federal Reserve in 1981. This, and similar episodes (see Christina Romer and David Romer 1989) must cast some doubt on the proposition that real shocks are the predominant cause of cycles.

Finally, we must consider whether we can use RBC models, containing representative agents, to guide policy. In surveying the problems of aggregation over individuals, Thomas Stoker says that

> to the author's knowledge, there are no studies of disaggregated micro level data that fail to find strong systematic evidence of individual differences in economic behaviour, whether one is concerned with demographic differences of families or industry effects in production . . . it matters how many households are large or small, how many elderly or young and how many companies are capital intensive or labor intensive. Such heterogeneity of concerns is an essential feature of the overall impacts of . . . changes in interest rates on saving, or the impact of an investment tax credit. (1993, pp. 1827–28)

This suggests that representative agent models, by their very nature, are not well suited to address policy issues, and that a further major challenge to RBC theory is to develop more disaggregated models. Models with heterogeneous agents are being developed (Jose-Victor Rios-Rull, 1994, provides a survey), but the degree of heterogeneity introduced is very limited—for example, in some formulations workers differ only in the probability of being employed, or some are older, skilled workers, others young, unskilled workers. Generalizing such models further poses formidable technical problems, but is essential to give this research program greater practical relevance.[27]

It is difficult to predict the ultimate outcome of a research program. However, even if the consensus at the end of the day is that RBC models cannot account for most of the movements in macroeconomic time series, RBC theory will probably change the way macroeconomies are modeled. For not only has RBC theory significantly altered our view of business cycles, but the development of this research program also offers us a fundamental change in the way we can model the macroeconomy. It has introduced into macroeconomics computable general equilibrium models that can replicate certain characteristics of real data sets. As the technical frontier moves outwards, these models will be able to incorporate more and more features of reality. Such models may one day be used, with reasonable confidence, to address a whole host of issues. Thus, the long-run contribution of Real Business Cycle theory may well prove to be a revolution in the methods of macroeconomic research and policy appraisal.

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