Real Business Cycle Theory-A Systematic Review

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—A Systematic Review

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Abstract

In the past few decades, real business cycle theory has developed rapidly after the initiation of Kydland and Prescott in 1982. It has grown substantially as an independent literature and served as a widely recognized framework for studies of the economy at business cycle frequencies. It has enjoyed great success for its ability to replicate most of the observed characteristics of U.S. aggregate economic activity after WWII. Over the years, different extensions to and modifications of the real business cycle model have been proposed by many researchers. In the mean time, various criticisms and challenges have been exposed to the theory from different perspectives. Recently, new developments have been undergoing a constructive process and emerging questions are being considered to improve the empirical performance of the theory. To celebrate the theory, several works have been devoted to a comprehensive survey of the literature, represented by King and Rebelo (1999). Efforts have been also made to discuss open questions in the literature in an attempt to suggest future studies, such as Rebelo (2005). However, a systematic review of the real business cycle theory involving different perspectives to compact the literature into a narrative representation seems currently unavailable. This paper tries to fill the gap.

Content

1. Introduction

In the past few decades, real business cycle (RBC) theory has developed rapidly after the initiation of Kydland and Prescott in 1982. It has grown substantially as an independent literature and served as a widely recognized framework for studies of the economy at business cycle frequencies. It has enjoyed great success for its ability to replicate most of the observed features of the aggregate U.S. economy after WWII. Over the years, different extensions to and modifications of the RBC model have been proposed by many researchers. Meanwhile, various criticisms and challenges have been posed against the theory from different perspectives. Recently, new developments have been undergoing a constructive process and emerging questions are being considered to improve the empirical performance of the theory. This paper serves as a systematic review of the RBC theory, in an attempt to compact the literature into a narrative representation involving different perspectives, with a rough historical time line. In the next section, I give a brief description of the business cycles commonly defined. Then in Section 3, I briefly present some alternative explanations of business cycle fluctuations before the rise of the RBC theory. I devote Section 4 to a brief description of the theory itself. Several extensions to the basic RBC model are introduced in Section 5 while some criticisms and challenges to the theory will be presented in Section 6. In Section 7, I identify some current research topics in the literature and discuss some remaining questions. Section 8 concludes.

2. Business Cycles

If we were to take a snapshot of an economy at different points in time, no two photos would look alike. An economy is ever evolving, at the same time with ups and downs in its performance. Many advanced economies exhibit sustained growth over time, which is to say, the snapshot taken years apart would simply depict different levels of economic activities in the two periods. However, were we to predict the total output in the next period using the data we have this period, chances are that it might not be consistent with the number predicted by the growth trend. To observe and understand the aggregate behavior of an economy, a common way is to look at a time series of its output.

Figure 1

Figure 2

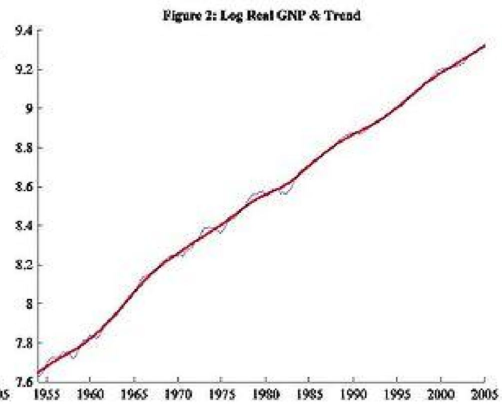

Figure 1 shows the time series of real GNP for the United States[2] from 1954 to 2005. In order to extract a clearer picture of growth, we take logarithm of the real GNP, which helps construct a smoother growth trend of the economy. With the H-P filter, we can detrend the output series and distinguish between the longer term fluctuations as part of a growth trend and the more short-lived fluctuations as part of cyclical movements. Here, we refer to these cyclical movements about the trend as business cyclesみeconomy-wide fluctuations in production or economic activity over several periods. These fluctuations occur around a long-term growth trend, and typically involve shifts over time between periods of relatively rapid economic growth (booms), and periods of relative stagnation or decline (recessions). Since the output fluctuations and long-term growth trend sketch an overall picture of an economy, understanding the mechanisms of the business cycles has significant policy implications. Over the years, various competing theories and constructions have tried to explain and model the fluctuations in aggregate economic activity, which has brought about vibrant development of the business cycles literature, and made this field of research one of the primary concerns of modern macroeconomics.

[2] This paper makes use of the U.S. economy as the subject for observed features of aggregate economic activities.

3. Alternative Explanations

In the post-war era[3], among the explanations for business cycles, the most commonly used framework is from the Keynesian school. In the Keynesian view, business cycles reflect the possibility that the economy may reach short-run equilibrium at levels below or above the full-employment levelみthe market has failed to clear. If the economy is operating with less than full employment, i.e., with high unemployment, then in theory monetary and fiscal policies can have a positive role to play in the economy rather than simply causing inflation or economic inefficiency.

Keynesian models do not necessarily imply periodic business cycles. However, simple Keynesian models involving the interaction of the Keynesian むmultiplierめand むacceleratorめgive rise to cyclical responses to initial shocks. Paul Samuelsonゃ むoscillator modelめ was supposed to account for business cycles by the multiplier and the accelerator. The magnitude of the variations in aggregate economic activities depends on the level of investment, for investment determines the level of aggregate output (multiplier effect), and is determined by aggregate demand (accelerator effect).

In the Keynesian tradition, Richard Goodwin[5] accounted for business cycles by the distribution of income between firm profits and worker wages. The fluctuations in wages are the same as in the level of employment, since when the economy is at the full-employment level, workers are able to demand rises in nominal wages, whereas in periods of high unemployment, nominal wages tend to fall. According to Goodwin, when unemployment and firm profits rise, the aggregate output rises.

Hyman Minsky[6], another Keynesian economist, had proposed another explanation

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[3] Historically, business cycle theory was a well-established part of the 20th century economics. Before Keynes, economists such as Wesley Mitchell, Simon Kuznets, and Frederick Mills had carefully documented the characteristics of business cycle fluctuations for the U.S. and other countries. In the 1930s, different theories explaining business cycles were proposed by economists such as Rangar Frisch and Eugen Slutsky and many others. After WWII, the question of output determination associated with the Keynesian revolution had gradually dominated the macroeconomic research agenda. Business cycle research had not attracted much interest until the path-breaking revisit of Robert Lucas Jr. in the 1970s.

[4] Paul A. Samuelson, [1939a]1966, “Interactions between the Multiplier Analysis and the Principle of Acceleration”, Chap. 82, and, [1939b]1966, “A Synthesis of the Principle of Acceleration and the Principle of the Multiplier”, Chap. 83, *The Collected Scientific Papers of Paul A. Samuelson, Vol. 2*, Cambridge: MIT Press

[5] Richard M. Goodwin, 1949, "The Business Cycle as a Self-Sustaining Oscillation", Econometrica

[6] Hyman, P. Minsky, 1992, “The Financial Instability Hypothesis”, *Economics Working Paper Archive*, Levy Economics Institute

for business cycles, which was founded on the fluctuations on credit, interest rates and financial frailty. According to Minsky, in an expansionary period, interest rates are low and firms can easily borrow money from banks to invest, which increases production and thus output. Given this, banks are not reluctant to grant those loans because the expanding economy allows firms to increase cash flows and therefore be able to easily pay back the loans. However, this process induces firms to become excessively indebted, discouraging them to further invest, which eventually leads to an economic downturn caused by lack of investment and production.

However, beginning in the early 1970s, the methods used to study business cycles changed in a fundamental way. In what is referred to as the new classical revolution, led by the path-breaking work of Robert E. Lucas, Jr., macroeconomists began to study business cycles using the tools of competitive equilibrium theory.[7] Under the widespread influences of むrational expectationsめfrom Lucas, the Keynesian views began to be challenged by a rising school of business cycle research, especially a theory initiated in the early 1980sみthe real business cycle theory, in which fluctuations are mainly accounted for by technology shocks. This theory is most associated with Finn E. Kydland and Edward C. Prescott. They considered that economic crisis and fluctuations cannot stem from a monetary shock, only from an external shock, such as from the technological progress. This new approach to the aggregate output fluctuations have injected fresh momentum to this field of research and brought new debates among the macroeconomics profession.

4. Real Business Cycle Theory

Real business cycle theory attributes aggregate output fluctuations to a large extent to the real shocks rather than nominal shocks to the economy. The theory sees recessions and economic booms as efficient responses to exogenous changes in the real economic environment. The proponents of the theory base the construction of their model on rational expectations and expected utility maximization. They holds the view that the level of output in the economy necessarily maximizes the expected utility of the economy-wide agents, and government should thus concentrate on the long-term structural changes of the economy rather than intervene through

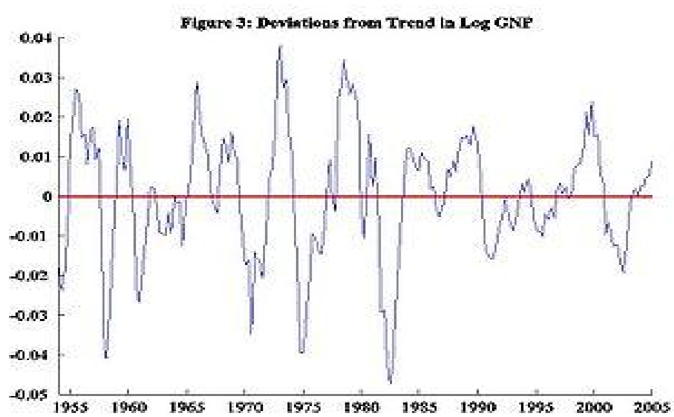
[7] This transformation was significant in the logic of studying business cycles because it established a rigorous process of understanding business cycles by using standard tools of economic analysis, but not ad hoc models that are inconsistent with the rational behavior of a representative agent and the general equilibrium of the economy.

discretionary fiscal or monetary policies to actively smooth the aggregate economic fluctuations. The central idea of the theory is that business cycles are むealめ in that they do not represent a failure of markets to clear but rather reflect the possibly most efficient operations of the economy, given the structure of the economy and the rationality of the economic agents. In this framework, business cycles are recurrent fluctuations in an economyや output, incomes, and factor inputs, especially labor, that are due to nonmonetary sources[8].

4.1 Stylized Facts about Business Cycles

Before we look into the theory, an initial statistical breakdown of an economy is helpful to bring our attention to what the RBC theory tries to explain and model. We first look at the historical data of the U.S. national output during 1954 to 2005. Figure 3 captures the deviations from trend of real GNP at that point in time. A point on the horizontal axis at 0 indicates no deviation from trend, while any points above or below the 0-line indicate above-trend or below-trend behavior of the national output.

Figure 3



At first glance, the deviations seem so irregular that hardly a cause can be found to consistently account for the output fluctuations. But if we introduce the time series of some other macroeconomic variables, i.e., consumption, investment, labor hours, productivity, and capital stock, and put them together with the output series, we will observe some patterns.

8 These sources include changes in technology, tax rates, government spending, taste and preferences, government regulations, terms of trade, energy prices, etc.

Figure 4

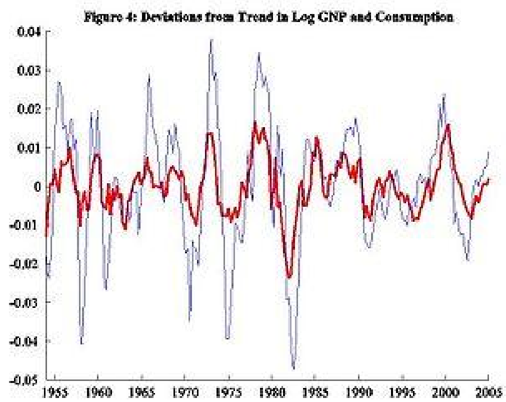


Figure 5

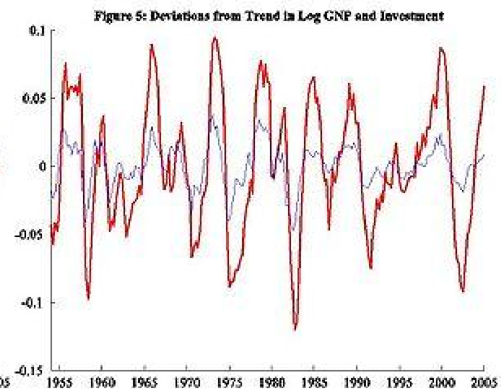


Figure 4 and 5 show that the series of output deviations and consumption deviations are highly correlated and the same applies to investment deviations, with a greater variance in investment deviations than in consumption deviations. Yet, figure 6 tells a different story since there exists no apparent relation between output deviations and capital stock deviations. From the statistics in table 1, we learn three stylized facts about the relations between fluctuations in aggregate output and deviations in other key macroeconomic variables:

A. Cyclical variability. All variables show certain volatility over time with repetitive patterns, though magnitudes of the fluctuations are different.
B. Correlation. The co-movements of output and other variables are quite evident except for the capital stock. Although with different levels, all variables are pro-cyclical, while capital stock seems acyclical.
C. Persistence. If we take any point in the series above the trend, the probability that the next period is still above-trend is very high. However, this persistence appears to wear out over time.

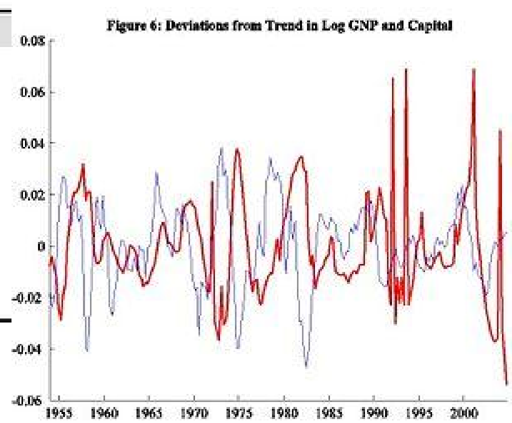
Table 1

Table 1: Summary Statistics

Series	(A)	(B)
Output	1.76	1.00
Consumption	1.29	0.85
Investment	8.60	0.92
Capital Stock	0.63	0.04
Labor	1.66	0.76
Productivity	1.18	0.42

Source: Hansen (1985)
(A) Standard deviation in %
(B) Correlation with output

Figure 6



Given these seemingly accountable yet non-deterministic fluctuations about trend, we come to the fascinating question of why these facts occur and how to explain them in a consistent manner, preferably using a well-constructed equilibrium model.

4.2 The RBC Model

If we believe that people prefer economic booms over recessions, it follows that given all economic actors in an economy make optimal choices to pursue prosperity, those fluctuations are necessarily caused by some factors outside the decision-making process. So the key question is that what main exogenous factors influence the decisions made by the actors in the economy?

The 1982 paper ひTime to Build and Aggregate Fluctuationsめby Finn E. Kydland and Edward C. Prescott on *Econometrica* pioneered the whole macroeconomics profession by building a new theoretical system to account for the observed aggregate fluctuationsみReal Business Cycles[9]. In their paper, they envisioned the crucial factor to be technology shocks, i.e. random fluctuations in the productivity level that shifted the constant growth trend of output up and down. The general idea is that fluctuations in aggregate output are real in that they are direct changes in the effectiveness of capital/labor, which affects the decisions made by workers and firms, who in turn change their consumption and investment and thus affect total output eventually.

Proposed by Kydland and Prescott, the RBC theory rests on the neoclassical concept of rational expectations and constructs on the basis of expected utility maximization. Therefore, it is important to understand the central assumption in the RBC theory: individuals and firms respond to economic events optimally all the time. This translates into that business cycles exhibit in an economy are chosen in preference to no business cycles at all. We are not saying that people like to be in recessions but recessions are preceded by an undesirable productivity shock that brought constraints to the economy and given these constraints, people will make choices that maximize their expected utility and achieve the best possible outcomes. Therefore when a recession comes, people are choosing to be in it because given the situation, it is the optimal choice which enables the market to react efficiently. This is to say, recessions and economic booms are actually efficient responses to exogenous changes in the real economic environment.

[9] The term was coined by Long and Plosser later in their 1983 paper “Real Business Cycles”.

i. Puzzles:

Referring back to the stylized facts about business cycles, we have a few major puzzles here:

1. Why do labor hours vary?
   The RBC theory explains employment fluctuations by the notion of inter-temporal substitution between work and leisure. During some periods, labor is less productive than in others. Lower marginal productivity results in lower real wages and thus the optimal action for workers is to work more in productive periods and less in unproductive periods, which eventually leads to market-clearing employment fluctuations.

2. Why productivity is pro-cyclical?
   The RBC theory explains pro-cyclical labor productivity in a very straightforward way: economic booms are good draws of technological progress and recessions are bad draws.

3. Why are recessions so persistent?
   The RBC theory explains the persistence of economic activities by the むinternal propagation mechanismめみthe capital accumulation process that naturally converts shocks without persistence into highly persistent shocks to output even after the initial shocks disappear.

4. Why investment is more volatile than consumption?
   The RBC theory explains with the むLife cycle hypothesisめ[10] that an agent with the preference to smooth consumption over time will invest in productive periods and eat capital in unproductive periods.

[10] The "Life cycle hypothesis" is a concept that analyzes individual consumption patterns, which was developed by the economists Irving Fisher, Roy Harrod, Alberto Ando, and Franco Modigliani. The concept assumes that individual consumes a constant percentage of the present value of their lifetime income and saves while working to finance consumption after retirement. This concept is adopted by many economists from the neoclassical school.

ii. Principles:[11]

The RBC theory has two underlying principles:

- Money is of little importance in business cycles. Monetary shocks have insignificant power in explaining aggregate output fluctuations.
- Business cycles are the results of rational economic agents responding to real shocks optimallyみmostly fluctuations in productivity growth (technological progress), but also fluctuations in government spending, import prices, or preferences, etc.

The RBC theory methodology also has two underlying principles:

- The economy should preferably always be modeled using dynamic general equilibrium models, with rational expectations and expected utility maximization in mind.
- The quantitative policy implications of a proposed model which fits the actual data should be taken seriously. The quantitative technique known as むalibrationめshould be applied to evaluating the suitability of the model for describing reality.

The RBC methodology has far more theoretical implications than in the construction of the baseline RBC model. Many researchers[12] have analyzed RBC models with money and many other market imperfections[13]. This modeling technique has now been coined the term むDynamic Stochastic General Equilibriumめto reflect its technical features.

iii. A Baseline Model:

To construct a baseline general equilibrium model for an economy, we first characterize the environment for the aggregate economic activity, where the optimization problems of the two groups of representative agentsみconsumers (households) and firmsみare cast, and then define as well as derive a competitive equilibrium for the economy.

[11] David Romer, *Advanced Macroeconomics*, 2e

[12] E.g. Cooley and Hansen (1989), Kim and Loungani (1992), Braun (1994), Mendoza (1995), Andolfatto (1996), and Rogerson (1988)

[13] E.g. money, energy prices, taxes, terms of trade, labor market search friction, and indivisible labor

Consumers

For consumers, they face two basic trade-offs. One is the consumption-investment trade-off. Assume a productivity increase in the economy, people have more output to consume. Given a two period dynamic consumption decision an individual faces, he might not consume all that extra output today but choose to reallocate his consumption capacity in a way that he consumes some today but invests the rest in capital stock to enhance production in the next period and thus increase future consumption. The むLife cycle hypothesisめargues that households base their consumption decisions on expected lifetime incomes and so they prefer to smooth consumption over time. They will thus save more and invest in periods of high income and defer consumption of this to periods of low income, which nicely explains for the strong volatility of investment compared to consumption over time. The other trade-off is the labor-leisure choice. In the tradition of neoclassical economics, individuals are assumed to value not only consumption but also leisure. Given a positive technology shock, higher productivity encourages substitution of current work for future work since workers will earn more today in terms of real wages. In turn, more labor and less leisure results in more output, consumption and investment today. Although there is an opposite むincome effectめthat workers may not want to work as much today because of increased income, the pro-cyclical nature of labor makes sure that the むsubstitution effectめdominates the むincome effectめ These two trade-off mechanisms indicate seemingly an internal persistence momentum that keeps the output above-trend or below-trend after an initial shock, which makes the business cycles more むrealめin effect.

In a dynamic economic environment, we assume infinitely many identical consumers (households) that will exist forever, with identical preferences defined in each period, who choose sequences of consumption and leisure to maximize their lifetime utility, and as each consumer has uncertainty over future prices, he maximizes expected utility. Here we first identify a single representative agent, and define his preferences as to maximize the value of

$$U[c(\cdot), h(\cdot)] = E\sum_{t=0}^{\infty}\beta^t u(c_t, 1-h_t) \tag{1}$$

where $c(\cdot), h(\cdot)$ represent the sequences of Arrow-Debreu event-contingent consumptions and labor efforts, u is the utility function of the representative consumer, c_t is the consumption in period t, h_t is the hours worked while $1-h_t$ is the amount of leisure in period t, and β is the discount factor of the lifetime utility with $0<\beta<1$. Consumers are endowed with time in each period, normalized to unity without loss of generality, which they choose to allocate between work and leisure. The consumer owns an initial capital stock k_0, which they rent to firms and may augment through investment. Here, each consumer only has control over his own capital stock. In each period, each consumer invests x_t in new capital goods to help enhance the production capacity in the next period for more consumption. Doing this yields an aggregate evolution equation of household capital stock in the economy, transforming the capital this period into the next:

$$N_{t+1}k_{t+1}=(1-\delta)N_t k_t+N_t x_t \quad \text{or} \quad (1+\eta)k_{t+1}=(1-\delta)k_t+x_t \tag{2}$$

where δ is the rate of depreciation of capital stock in period t; k_t is the capital per capita at the beginning of period t and k_{t+1} is the capital per capita at the end of the period, with the upper case letters representing their aggregate counterparts. There is population growth and N_t represents the population in period t which grows at the rate η.

In reality, consumers face taxes on their consumption and investment and also on their incomes from capital and labor. With taxation, a representative consumer will face a budget constraint in each period as

$$(1+\tau_{c_t})c_t+(1+\tau_{x_t})x_t=r_t k_t-\tau_{k_t}(r_t-\delta)k_t+(1-\tau_{h_t})w_t h_t+\psi_t \tag{3}$$

where w_t and r_t are pre-tax unit payments to capital and labor, respectively, $\tau_{ct},\tau_{xt},\tau_{kt},\tau_{ht}$ are the tax rates on consumption, investment, capital and labor income, respectively, which are all assumed to be stochastic and follow a Markov process. ψ_t is the per capita transfer payment in period t made by government to each consumer. Total transfer payments are equal to tax revenues less total government spending. In terms of per capita measurement, we have

$$\tau_{c_t}c_t+\tau_{x_t}x_t+\tau_{k_t}(r_t-\delta)k_t+\tau_{h_t}w_t h_t-g_t=\psi_t \tag{4}$$

where g_t is the per capita government spending in period t and let G_t be the aggregate, with $G_t=g_t N_t$. Here we assume the consumer is making all period-t choices (c_t,x_t,k_{t+1},h_t) conditional on period-t information. To describe the representative consumer's behavior, we can combine equations (2), (3) and (4) and we have

$$c_t + (1+\eta)k_{t+1} = r_t k_t + w_t h_t + (1-\delta)k_t - g_t \quad (5)$$

Thus, a representative consumer in this economy will choose consumption, investment and labor effort at each period to maximize his expected lifetime utility. Given the expectations over future prices subject to budget constraints and the rule of household capital evolution, the representative consumer's behavior can be modeled as

$$\max_{(c_t, h_t, k_{t+1})_{t=0}^{\infty}} E\sum_{t=0}^{\infty} \beta^t (1+\eta)^t U(c_t, 1-h_t), 0 < \beta < 1 \quad (6)$$

$$\text{s.t. } c_t + (1+\eta)k_{t+1} = r_t k_t + w_t h_t + (1-\delta)k_t - g_t$$

Firms

We've talked about a representative consumer maximizing expected lifetime utility by varying his consumption and labor effort inter-temporally, given uncertain future prices and productivity. Now we discuss the source of the uncertainty—firms, who have the access to technology. Here we adopt a neoclassical aggregate production function and incorporate a stochastic technology shock to it. As the firms in this economy are assumed to be identical, we can treat them as a single representative firm and solve a period-by-period profit maximization problem:

$$\max_{(K_t, H_t)} e^{z_t} F_t(K_t, H_t) - w_t H_t - r_t K_t, \forall t \quad (7)$$

where F_t is the output[14] produced in period t with K_t units of capital and H_t units of labor hours, z_t is the stochastic technology shock given in period t which follows a Markov process and is the source of uncertainty in the economy. The variation of z modeled here is the variation in the effectiveness of factor inputs—capital and labor—to produce final goods and services, or more generally, total factor productivity (TFP). Variations in TFP can arise from many different possible sources, e.g. new inventions or innovations in the existing production process can result in an increase in TFP while stricter government regulations on firm productions can have negative effects on TFP. Solving the above maximization problem for 1st order conditions, we have

$$w_t = e^{z_t} F_H(K_t, H_t) \quad (8)$$

$$r_t = e^{z_t} F_K(K_t, H_t) \quad (9)$$

[14] Here we assume homogeneous goods in the economy.

Equilibrium

To derive explicit predictions about the behavior of households and thus the behaviors of those key macroeconomic variables (consumption, investment, labor hours, and capital stock), it is necessary to first define and then derive a general equilibrium for the economy.

Under the concept of recursive competitive equilibrium[15], the household decisions are separated from aggregate decisions, which are influenced by the state variables (k_t, K_t, s) and (K_t, s) respectively. In a closed economy without market distortions, a competitive equilibrium[16] is defined as deriving the follows

1. *Household policy functions:* $c(k,K,s)$, $x(k,K,s)$, $h(k,K,s)$, and the corresponding *per capita Aggregate policy functions*: $C(K,s)$, $X(K,s)$, $H(K,s)$[17]
2. *Pricing functions:* $w(K,s)$ and $r(K,s)$[18]
3. *Evolution equation of aggregate capital stock:* $K' = \phi(K,s)$, where K' is the aggregate capital stock in the next period
4. *Transition equation of stochastic shocks:* $\frac{\partial s}{\partial t} = \varphi(s', s)$, with s' being the stochastic shocks in the next period

such that,

1. The representative consumer maximizes his expected lifetime utility:

$$\max_{(c_t, h_t, k_{t+1})_{t=0}^{\infty}} E\sum_{t=0}^{\infty} \beta^t (1+\eta)^t U(c_t, 1-h_t), 0<\beta<1$$

s.t. $c_t + k_{t+1} = r_t(K_t, s)k_t + w_t(K_t, s)h_t + (1-\delta)k_t - g_t$

with initial capital stock $k_0 > 0$ and $c_t \geq 0, 0 \leq h_t \leq 1$; also given the rule of household capital stock evolution and the transition process of

15 The technical tools for solving dynamic equilibrium problems are well discussed and presented in the book *Recursive Methods in Economic Dynamics* by Stokey and Lucas, with Prescott.

16 If the consumers are behaving competitively, they will be likely to assume that their own choice of capital next period does not affect the economy-wide level of capital. Therefore when deriving the optimal decision functions for a representative consumer, it is important to distinguish between the consumer's individual capital stock on hold and the aggregate level of capital stock.

17 $s = (z, \tau_c, \tau_x, \tau_k, \tau_h, g)$, here s represents the stochastic shocks from exogenous factors. Here we assume taxes and government spending to be constants and focus mainly on the technology shock.

18 Here the prices are in terms of real goods. For simplicity, we do not introduce a monetary pricing system in the baseline model.

stochastic shocks.

2. The representative firm maximizes profits in each period:

$$\max_{(K_t,H_t)} e^{z_t}F_t(K_t,H_t)-w_tH_t-r_tK_t,\forall t$$

and satisfies equations (8) and (9) that productive factors are paid their marginal products
that is, $w=w(K,s)$, $r=r(K,s)$

3. Expectations are rational so that individual and aggregate decisions in each period are consistent

$$c(k,K,s)=C(K,s)$$
$$x(k,K,s)=X(K,s)$$
$$h(k,K,s)=H(K,s)$$
$$\phi(Nk,s)=(1+\eta)Nk' \qquad (10)$$

4. Market clears (the aggregate resource constraint)

$$C(K,s)+X(K,s)+G(s)=z(s)F[K,H(K,s)],\forall(K,s) \qquad (11)$$

iv. Calibration:

With a well-specified environment and a well-defined equilibrium concept, the baseline RBC model described above has established a framework for qualitative study of business cycles. In order to go from this general framework to a more quantitative analysis of the equilibrium processes in the economy, we adopt the following approach. First, we restrict the equilibrium processes to a parametric class, using parameterized models that are consistent with growth observations to study aggregate fluctuations. Second, we have to construct a set of measurements that are consistent with the parametric class of models, establishing the correspondence between the models and the observed data for the actual economy. Finally, we assign values to the parameters of the above models, allowing the behavior of the modeled economy to match the features of the observed data in as many dimensions as there are unknown parameters. These parameters are chosen with the purpose to mimic the actual economy from the long-term growth perspective. The above three-step process that converts a qualitative framework into a restricted quantitative representation of the modeled economy is termed むalibrationめa technique that puts us in a position where we can study the quantitative behavior of aggregate fluctuations. This technique for finding numerical values for model parameters greatly applies economic theories as the basis for restricting the general framework to reproduce observed features of the actual economy.

Applying the calibration technique, Kydland and Prescott (1982), through quantitative statements of the dynamic stochastic model under technology shocks, found that the simulated data showed the same patterns of volatility, persistence, and co-movement as were present in the actual U.S. statistics. This finding was particularly surprising, because the model abstracted from monetary policy, which economists such as Friedman (1968) considered an important element of aggregate fluctuations. It has greatly challenged the idea that monetary shocks drive the business cycles and also implied that the stabilizing fiscal and monetary policies are inefficient in that they would alter the optimal reactions from households and firms to economic events.

v. Internal Propagation Mechanism:

Dynamic optimizing behavior on the part of agents in the economy implies that both consumption and investment react positively to the direct shocks to output. Since the marginal productivity of labor is directly affected, employment is also pro-cyclical. The resulting capital accumulation provides a channel of persistence, even if the technology shocks are serially uncorrelated. This is to say, the baseline RBC model predicts that given a temporary productivity shock, output, consumption, investment, and labor hours all rise above their long-term trends and hence formulate into a positive deviation. Now since investment has increased, capital stock increases in turn. From this channel, a short-lived shock may impact the future performance of the economy, which is, the above-trend behavior may persist for some time even after the initial shock disappears. This capital accumulation process serves as an internal combustion engine that converts the initial technology shocks without persistence into highly persistent impacts to the output of the economy. This internal propagation mechanism has become one of the best selling points of the RBC theory in explaining persistent fluctuations in the aggregate economic activity.

4.3 Evaluation

Actually, Kydland and Prescott in their 1982 paper introduced not only one, but three, revolutionary ideas. The first idea, which built on the prior work by Lucas and Prescott (1971), was that business cycles can be studied using dynamic general equilibrium models. These models feature utility-maximizing agents who operate in competitive markets and form rational expectations about the future. The second idea was that it is possible to unify business cycles and growth theory by insisting that business cycle models must be consistent with the empirical regularities of long-term growth. The third idea was that we can go way beyond the qualitative comparison of model properties with stylized facts to predictive quantitative analysis. This early work of RBC theory has established a prototype of modeling and a set of tools for carrying out the equilibrium approach. The RBC methodology has combined the general equilibrium theory with computable equilibria of artificial economies, enabling the study of empirical properties of the modelみwe can calibrate models with parameters drawn, to the extent possible, from microeconomic studies and long-term properties of the economy, from which we can generate artificial data to compare with actual statistics. After the introduction of the RBC approach, it has been generally accepted the notion that business cycle theories should be consistent with long-term observations about economic growth and the principles of competitive equilibrium theory.

The RBC literature has grown substantially since the initial paper by Kydland and Prescott. Part of the reason is that the methodology it advocates is comparatively more accurate like a science in that the adherents take the model seriously, and expect it to actually match real life data quantitatively, in which they adjust the model when it does not. Another reason is that the motivation of this literature has been to assess the relative importance of real versus nominal shocks, and of aggregate supply versus aggregate demand disturbances in the generation and propagation of business cycles. This implies that the RBC model is self-generating in that anything you find that could impact the cycles can be added to the baseline model to construct a new model, which literally means another paper in the literature.

One of the most important contributions of the RBC theory is the methodology it applies to analyzing an economyみdynamic stochastic general equilibrium approach. This methodology, which Kydland and Prescott first used in their baseline model, has become more influential than the original RBC findings, in a way that the DSGE model has been used in many different sources of business cycles, including monetary shocks. This quality of the RBC theory has naturally brought with it numerous extensions and variations, which we will focus on in the next section.

5. Extensions of the Baseline Model

Since the revolutionary work by Kydland and Prescott, business cycle research had come to an age in which it was exploratory but methodologically rooted[19]. Their 1982 paper with so many revolutionary ideas has shaped the macroeconomics research agenda of the last few decades. The wave of models that first followed Kydland and Prescott (1982) were referred to as むeal business cycleめmodels because of their emphasis on the role of real shocks, particularly technology shocks, in driving business fluctuations. But RBC models later became a point of departure for many theories in which technology shocks do not play a central role. During the 1980s and 1990s, different shocks other than technology shocks were considered and incorporated into the baseline model to be understood the effects they had on aggregate fluctuations, the mechanisms that propagated them and their policy implications. This was done in a consistent manner with the calibration technique to ensue an accurate description and possibly prediction over the actual economy.

5.1 Investment-specific Productivity Shocks

In the tradition of Kydland and Prescott, also following Long and Plosser, Greenwood et al. (1988) also emphasized the importance of technology shocks as an essential source of fluctuations, but different from the former, they focused their attention on the specific technology shocks to the productivity level of new capital goods and allow for accelerated depreciation of capital stock. Their paper adopted the Keynesian view that shocks to the marginal efficiency of investment are important for aggregate fluctuations, but incorporated it into a neoclassical framework with

[19] After the establishment of the RBC theory, business cycles have been excessively studied in the tradition of Kydland and Prescott, though with variations in practices. And the methodological approach of Dynamic Stochastic General Equilibrium modeling has become a powerful tool that many modern macroeconomists use to further business cycle research, including the New Keynesian economists who basically add price and wage stickiness to the DSGE model to achieve their multiple equilibria with recognized market imperfections.

endogenous capital utilization. In their paper, they consider a perfectly competitive closed economy populated by infinitely many identical households and identical firms. Aggregate output is given by an adapted neoclassical production function with a variable rate of capital utilization incorporated, as follows

$$y_t = F(k_t, h_t, \theta_t) \tag{12}$$

where y_t is the aggregate output, k_t is the capital stock at the beginning of the period, θ_t is an index of the period-t utilization rate of k_t, and h_t is the labor hours.[20] The variable θ_t represents the intensity of capital useみthe speed of operation or the number of hours per period the capital is used.[21] The production function F is quasi-concave, satisfying $F_1, F_2 > 0$, $F_{11}, F_{22} < 0$, and $F_{11}F_{22} - F_{12}^2 = 0$. The constant-returns-to-scale assumption implies that $F_{12} > 0$, which implies capital and labor are complements under the Edgeworth-Pareto principle. This feature provides a positive link between capital utilization and labor productivity.

When we consider the capital utilization decision, Keynes' notion of "user cost" is introducedみa higher utilization rate causes a faster depreciation of the capital stock, because wear and tear increase with use or less time can be devoted to maintenance. This effect can be modeled in the capital evolution equation as

$$k_{t+1} = k_t[1 - \delta(\theta_t)] + x_t(1 + \varepsilon_t) \tag{13}$$

where the depreciation function δ satisfies $0 < \delta \leq 1, \delta' > 0, \delta'' > 0$. The contribution of new investment x_t to the production capacity in t+1 depends on the technological factor ε_t, affecting the productivity of the new capital goods. The productivity of the already installed capital stock is not affected by the technology. Note that this technology factor is very different from the usual technology shock in the baseline model: it works as a shift in the marginal efficiency of capital produced in period t, which comes on line into t+1.[22] Increases in the efficiency of newly produced investment goods will stimulate the formation of new capital and more intensive utilization and accelerated depreciation of old capital.

In the Keynesian view, changes in the marginal efficiency of investment affect investment, aggregate demand and therefore, given the disequilibrium in the labor

[20] In this model, the population is assumed to be stationary, thus we make no effort to distinguish between aggregate production factors and factors at the individual level.

[21] An alternative interpretation is that while h_t represents the total labor employed, θ_t reflects the portion of it used directly in production, with the remainder being involved in maintenance activities.

[22] The length of the basic period, which corresponds to the time-to-build, is thought of as nontrivial, say one year.

market, employment and output. When a shock of this type occurs in a standard neoclassical model, employment and output also tend to rise, but with a very different mechanism. The increase in the investment rate of return stimulates current employment and output through an inter-temporal substitution effect on leisure. A potential problem with this mechanism is that when the inter-temporal substitution induces individuals to postpone leisure, it also works to cut consumption, which tends to make consumption counter-cyclical, contradicting the reality. [23]

Contrary to the inter-temporal substitution effect mentioned above, the transmission mechanism of the investment shocks in the present model works through the optimal utilization of capital and its positive effect on the marginal productivity of labor. To see this, we look at a representative consumer maximizing expected lifetime utility as given by

$$E\sum_{t=0}^{\infty}\beta^t u(c_t,h_t), 0<\beta<1 \tag{14}$$

Here we adopt a specific form of the utility function $u(c_t,h_t)=u[c_t-G(h_t)]$, with $u'>0, u''<0, G'>0, G''>0$, and also satisfies the quasi-concave conditions, which implies that the marginal rate of substitution of labor for consumption depends on labor only:

$$-\frac{U_h(c_t,h_t)}{U_c(c_t,h_t)}=G'(h_t) \tag{15}$$

That is, labor effort is determined independently from the inter-temporal consumption-investment decision. When analyzing fluctuations in labor effort, this framework emphasizes changes in the productivity of labor brought about by changes in the optimal rate of capital utilization, given an investment shock, as opposed to by the inter-temporal substitution effect on leisure.

An important aspect of such a change in labor productivity is that it creates intra-temporal substitution, away from leisure and towards consumption, generating pro-cyclical effects on consumption and labor. Given the quantities of capital and labor input, current productivity shifts are endogenous in this framework. This type of technology shocks appears more realistic than the direct shock to productivity since important technical improvements of new productive capital seem to occur quite often.

The theoretical and quantitative analysis of Greenwood et al. (1988) suggested that shocks to the productivity of new capital goods through increased marginal efficiency

[23] The problem is discussed in detail by Barro and King (1984).

of new investments might be important elements of business cycles. The results in the paper suggest that a variable capital utilization rate may be important for the understanding of aggregate fluctuations. It provides a channel through which investment shocks via their impact on capital utilization can affect labor productivity and hence equilibrium employment and output. Such a mechanism may allow for a smaller burden on inter-temporal substitution in generating observed patterns of aggregate fluctuations.[24]

5.2 Monetary Shocks

Begun by Lucas (1972)[25], much of the modern general equilibrium approach to business cycles then had viewed aggregate fluctuations as a monetary phenomenon, which was heavily influenced by the post-war evidence of strong relations between nominal and real variables. To achieve the equilibrium approach, Lucas, or any other macroeconomists who view macroeconomic outcomes as results of a general equilibrium, face two challenges: 1. to provide a theory in which money is valued in equilibrium; 2. to show how changes in money supply could significantly affect the real economy in a world of rational agents, without simply asserting some ad hoc models. The first challenge [26] was addressed by Lucas using the overlapping-generations model of Samuelson, where money facilitates existing trades as well as permits new ones. The second challenge was addressed by what have become the two predominant modern theories about the role of money in business cycles. The first one was formulated by Lucas, which treats monetary shocks as a source of confusion that makes it difficult for rational agents to extract signals from changes in observed prices. The second theory, represented by the works of Fischer (1977), Taylor (1979), Mankiw (1985), and Parkin (1986), argues that monetary shocks have important real effects because of rigid wages and prices caused by contracting behavior. But real business cycle models, like the one constructed above in Section 3.2, have been a significant research departure from the traditional approach since money is assigned to a very small role.

[24] Greenwood, Hercowitz, and Krusell in their 1997 paper argued that 60% of postwar growth in output per man-hour is due to investment-specific productivity shocks. In a 2003 paper, Fisher found that investment-specific productivity shock accounted for 50% of the variation in labor hours and 40% in the variation in output. Starting with Greenwood, Hercowitz, and Krusell (2000), this type of shock has become a standard shock in RBC models.

[25] To provide an equilibrium theory based on rational expectations that accounts for the strong relationship between money and real activity was the motivation behind his work.

[26] There are other approaches, which will be discussed later in the section.

In an attempt to study monetary shocks in the context of RBC models, Cooley and Hansen (1989) have modified the basic neoclassical growth model, with a cash-in-advance constraint, to capture how monetary forces could influence real output in a world of rational agents. In the later work of Cooley and Hansen (1995) in *Frontiers of Business Cycle Research*, they did a more comprehensive treatment of the above two predominant theories using the baseline model as a vehicle to reexamine the quantitative importance of money in aggregate fluctuations. As to the problem of valuing money in equilibrium, they simply assume that currency must be used for certain transactions by imposing the cash-in-advance constraint. Cooley and Hansen evaluate the models with quantitative assessments of the monetary shocks propagated by the mechanisms in question and also compare features in observed data to those displayed by the models.

The information problem envisioned by Lucas is known as the ゐLucas island modelめ which was designed to capture the money non-neutrality. In his subsequent works, Lucas has constructed an equilibrium business cycle model where monetary shocks, rather than technology shocks, are the source of aggregate fluctuations. In this model, changes in the rate of money growth have real effects since agents in the economy have incomplete information. Being separated from each other spatially makes them unable to clearly distinguish relative price changes from aggregate price changes. Therefore, an unanticipated change in the growth rate of money, resulting in an unanticipated change in the inflation rate, may well cause the imperfectly informed agents to confuse a purely nominal movement with changes in relative prices. Thus, as long as the monetary shocks are unanticipated, they will create real effects, which is how money creates cycles suggested by Lucas. However, Cooley and Hansen (1995) pointed out that there is nothing inherently monetary in Lucasゅtheory. To capture the essentials of the theory, thereゅno need for an explicit motive for holding money. Instead, the features can be reproduced in a real economy characterized by technology shocks that is observed with noise, where the noise can be informally interpreted as from monetary policies. Thus, the agents will face the same kind of informational problems as in the Lucas model that they are uncertain about future productivity. By setting up and solving such an economy with noisy technology shocks for an equilibrium path, it is shown that the noisy shocks, resembling incomplete information, have very small effects on the fluctuations in the model. This implies that an explanation of business cycles by informational problems caused by money non-neutrality is not practical and the effects of monetary shocks to business cycles are negligible.

In the previous model, although money can create informational problems for agents through misconception, it is in itself neutral in the economy since only the real variables appear in the equilibrium path. In order to study the features of an economy where money is valued in equilibrium, we introduce money explicitly. To do this, we first define the reason for holding money, which in turn decides how money affects output. In the work of Cooley and Hansen (1995), they suggest three general approaches to introduce money into the neoclassical growth framework: 1. money is treated symmetrically with other goods by placing real money balances directly as an argument in the utility function; 2. money can be assumed to save on the transaction costs associated with purchasing goods; 3. money can be required to purchase consumption goods or some subset of themみcash-in-advance constraint. In their analysis, Cooley and Hansen introduce the cash-in-advance[27] motive for holding money into the baseline RBC modelみagents simply hold money because cash is required to purchase some consumption goods. In an economy with no money illusion, non-neutrality will only arise due to anticipated inflation acting as a distorting tax on the holding of money. In this economy, the competitive equilibrium is not Pareto optimal because of distortion resulting from forcing agents to hold money. After setting up an adapted version of the baseline model and calibrating it to match the observed data, Cooley and Hansen find that monetary growth shocks do not contribute much to the fluctuations in real variables displayed by a basic neoclassical growth model when money is introduced by requiring cash-in-advance constraint. Monetary shocks do distort allocations in the economy because of the inflation tax, but they are quantitatively unimportant for the real business cycles.

Alternative to the Lucas model, the possibility that nominal rigidities may play an important role in propagating monetary shocks to generate real impacts at business cycle frequencies has been studied extensively by many researchers. In a competitive economic environment, prices are set by firms that commit to supplying goods at the posted prices, and wages are set by workers who commit to supplying labor at the posted wages. Prices and wages can only be changed periodically or at a cost. Firms and workers are forward looking, so in setting prices and wages, they take into account that it can be too costly, or simply impossible, to change prices and wages in the near future. Nominal rigidities have been considered seriously because of the prevalence of such nominal contracts observed in the market. Several papers in the RBC literature have explored the implications of nominal wage and price contracts for

[27] The theoretical foundations of the basic cash-in-advance model of money are carefully constructed in Lucas and Stokey (1983, 1987) and Svensson (1985). The model has been empirically tested in Cooley and Hansen (1989, 1991, and 1992).

the transmission of monetary shocks. Cho (1990, 1993) has examined the quantitative implications of one-period nominal wage and price contracts whereas Cho and Cooley (1991, 1995) have examined the multi-period case as well as staggered contracts. Besides, Haubrich and King (1991) have also examined the multi-period case but in an economy with no explicit motive for holding money. To illustrate the problem clearly without loss of generality, we adopt the simple model of a contracting economy described in Cooley and Hansen (1995), with one-period nominal wage contracts. This model is identical to the cash-in-advance model used in the introduction of money, but with a variation on the standard recursive competitive equilibrium concept. In this adapted model, households and firms agree to specify the nominal wage in advance and households cede to firms the right to determine aggregate hours, leaving firms free to maximize profits. Under this arrangement, a typical economic environment can be described and a competitive equilibrium can be defined and computed after calibration. The extensive exploration of economies with nominal contracting by many researchers[28] has concluded that the RBC-based monetary models can generate impulse responses to a monetary shock that are similar to the responses estimated using VAR techniques. In many of these models, technology shocks continue to be important, but monetary forces play a significant role in shaping the economy的 response to technology shocks. In fact, Altig, Christiano, Eichenbaum, and Lindé (2004) and Galí, López-Salido, and Vallés (2004) find that in their models, a large short-run expansionary impact of a technology shock requires accommodative monetary policy. However, monetary shocks are unlikely to be the sole or even the most important source of fluctuations because they by themselves produce correlations in the generated data that are inconsistent with the observed U.S. statistics.[29]

5.3 Fiscal Shocks

RBC models in the tradition of Kydland and Prescott (1982) assume technology shocks to be the driving force of business cycle fluctuations observed in the post-war

[28] Cho (1990), Cho and Cooley (1991), Cho and Phaneuf (1993), and Cho, Cooley, and Phaneuf (1994)

[29] Besides the above research in a monetary economy, there are a great many further studies which explore the role of monetary shocks in RBC models that are extended to include additional real elements as well as other nominal frictions. Bernanke, Gertler, and Gilchrist (1999) emphasize the role of credit frictions in influencing the response of the economy to both technology and monetary shocks. Dixit and Stiglitz (1977) consider another important real element—monopolistic competition. In this environment, it is not meaningful to think of firms as choosing prices or workers as choosing wages. Introducing monopolistic competition in product and labor markets gives firms and workers nontrivial pricing decisions.

U.S. data. While these models are successful in explaining a large fraction of the variability and co-movements of the aggregate time-series, they are insufficient in accounting for some other prominent features of the economy. The variability of consumption, labor hours, and output are too low compared to the observed data, while the variability of investment and the correlation between labor hours and the return to working are too high. Researchers have long noticed the problem and many papers have been devoted to examining other possible sources of fluctuations in aggregate variablesみmonetary or fiscalみto reconcile these contradictions. In the last section, we have examined the impact of monetary shocks to the real economy and concluded with non-negligible effects of money on business cycles. In this section, we extend the basic framework of Kydland and Prescott (1982) to include a public sectorみtaking government spending and taxation explicitly into account.

1) Government spending

In an attempt to study the effects of government spending shocks on aggregate variables, Christiano and Eichenbaum (1992)[30] have constructed a model where aggregate demand shocks, besides aggregate supply shocks, affect the equilibrium path of the economy. In their paper, they assessed the quantitative implications of RBC models for the time-series properties of labor hours and the return to working, and found the overestimated correlation between the two variables to be the single most salient short-coming of all RBC models. In empirical work, they measure the return to working by the average productivity of labor rather than real wages for both empirical and theoretical reasons.[31] The RBC models at the time predicted that the correlation was well in excess of 0.9, whereas the actual correlation was much closer to zero. The only shocks generating fluctuations in aggregate employment in those RBC models are stochastic shifts in the marginal product of labor. Loosely speaking, the time series on labor hours and the return to working are modeled as the intersection of a stochastic labor demand curve with a fixed labor supply curve. Therefore, these theories predict a strong positive correlation between labor hours and the return to working. Christiano and

[30] In further studies of the role of government spending in business cycles, Ramey and Shapiro (1998) have considered the effects of changes in the composition of government spending, while Burnside, Eichenbaum, and Fisher (2004) have studied the effects of large temporary increases in government spending in the presence of distortionary taxation.

[31] From an empirical point of view, the results are not very sensitive to whether the return to working is measured by real wages or average productivity: Neither displays a strong positive correlation with labor hours. From a theoretical point of view, by using average productivity as our measure of the return to working, we avoid imposing the assumption that the market structure is one in which real wages are equated to the marginal product of labor on a period-by-period basis. For the calculations performed, the two are interchangeable.

Eichenbaum then argued that this implication is grossly counterfactual, at least for the post-war United States.

To model the observed weak correlation between labor hours and the return to working, several strategies[32] emerged. The strategy pursued by Christiano and Eichenbaum (1992) was to simply abandon the one-shock model of aggregate fluctuations. With observed data, they concluded that there must be other quantitatively important shocks driving fluctuations in aggregate output. Under this assumption, the Dunlop-Tarshis observation[33] imposes no restriction per se on the response of real wages to any particular type of shocks. Given a specific structural model, however, it does impose restrictions on the relative frequency of different types of shocks. This suggests that to reconcile existing RBC models with the Dunlop-Tarshis observation one has to find measurable economic shocks that shift the labor supply curve. With different shocks shifting the labor supply and labor demand curves, there is no priori reason anymore for labor hours to be correlated with the return to working in any particular ways. Candidates for such shocks include tax rate changes, innovations to the money supply, demographic changes in the labor force, and shocks to government spending. Christiano and Eichenbaum (1992) focus on the last one. They use the argument by Barro (1981) that if $1 of additional public consumption drives down the marginal utility of private consumption by less than does $1 of additional private consumption, then positive shocks to government spending in effect shift the labor supply curve outward. With diminishing labor productivity, and also given technology shocks, such government spending shocks will generate a much smaller but positive correlation between labor hours and the return to working in RBC models. According to the empirical results of Christiano and Eichenbaum (1992), this change substantially improves the empirical performance of RBC models. But two important caveats about the empirical results should be emphasized. One is the implicit assumption that public capital and private capital are perfect substitutes in the aggregate production function[34], which makes it easier for the model to account for the Dunlop-Tarshis observation. The other is the implicit assumption that all taxes are lump-sum, which works to isolate the role of government spending shocks per se without the introduction of distortionary taxation.

[32] One is to consider models in which the return to working is unaffected by shocks to agents' environments, regardless of whether the shocks are to aggregate demand or to aggregate supply. See Blanchard and Fischer (1989).

[33] Dunlop-Tarshis observation is the observation by John T. Dunlop (1938) and Lorie Tarshis (1939) that in a real economy, real wages tend not to move counter-cyclically.

[34] Some researchers, especially Aschauer (1989), have argued that this assumption is empirically implausible.

While variability of government spending is generally small, temporarily large increases in government spending are usually observed in periods of war. Ohanian (1997)[35] show that RBC models can explain the main aggregate features of many war episodes: a moderate decline in consumption, a large decline in investment, and an increase in labor hours. According to his analysis, these features emerge naturally from an economy where government spending is financed by lump-sum taxes. Besides current taxes, additional government spending will be financed by future taxation. Thus, the wealth of households declines due to the increase in the present value of their tax liabilities. In response, households reduce their consumption and work more. This increase in labor hours produces a moderate increase in output. Since the marginal utility of consumption is decreasing, households prefer to pay for the war-related taxes by reducing both current and future consumption. Given that the reduction in consumption today plus the output increase are generally smaller than the rise in government spending, there will be a decline in investment.

2) Distortionary taxation

In Christiano and Eichenbaum (1992), government spending acts as aggregate demand shocks to the labor supply, causing a fraction of the aggregate fluctuations. In their model, taxes have been considered but they assume lump-sum taxes rather than allowing for distortionary taxes to finance the government expenditure. Although their model generates a correlation between labor hours and average productivity much closer to that observed, it is still significantly positive. McGrattan (1994) and Braun (1994), among others, have gone one step further to study the effects of distortionary taxes on aggregate fluctuations in RBC models. In these adapted models, it is assumed that the government not only purchases consumption goods but also levies distortionary taxes on factors of productionみcapital and laborみto finance its expenditure. In the baseline model constructed in Section 3.2, we have shown an economy in which government spending and taxes are taken into account as part of the budget constraint of households, but they are assumed to be constant in the problem. Here, to study the dynamic effects of distortionary taxes on the equilibrium path of the

[35] In another 1997 paper, Ohanian cooperates with Cooley to use an RBC model to compare the welfare implications of different strategies of war financing.

economy, we allow for the state-contingent feature and use a stochastic process to capture the law of motion of the tax rate changes.

Actually, like government spending, changes in tax rates will also affect the labor supply, which provides another mechanism for explaining the observed low correlation between labor hours and the return to working. Moreover, if we assume the tax rates to be state-contingent, then it is possible for the model to improve the predictions of variability of consumption, investment, labor hours, average productivity and real output, while the dynamics depend on the specific form of tax rules. To quantitatively study the effects of distortionary tax policies on business cycles, McGrattan (1994) has constructed a modified version of the model of a distortion-free economy in Kydland and Prescott (1982) to include stochastic tax processes. The economy in this model is comprised of infinitely many identical households and firms, and a government. The householdゃproblem is still to maximize expected utility, but with a budget constraint containing stochastic distortionary taxes that influence the maximization process. Thus, the preferences of households are distorted by the taxes and a unique competitive equilibrium may not exist. For the firmゃproblem, taxes are levied on the factors of production and are taken into account in the profit maximization process. As a form of fiscal policy, the tax rate process is governed by a specific evolution equation together with the government spending.[36] The presence of distortions in the model makes it impractical to use the method of computing an equilibrium by exploiting the equivalence between the competitive equilibrium concept and the なsocial planerゃ problemめTo study such a distorted economy and compute its equilibria, McGrattan (1994) has introduced a technique to approximate the true preferences of households with a quadratic function, which was used by Kydland and Prescott (1982).[37] Therefore, the competitive equilibrium is computed directly, and the pricing functions and laws of motion for aggregate variables are determined endogenously and must be computed along with the decision rules of households and firms.

By setting up a parametric class of models and calibrate them to the observed U.S. data, McGrattan (1994) shows explicitly the fractions of variances in aggregate time series due to technology shocks and to government spending and tax rate shocks. The results of the analysis show that tax rate shocks have a

[36] Specification of the process is studied in Seater (1982).
[37] Such method is called linear-quadratic approximation and is discussed in Diaz-Gimenez (1996) and reexamined in detail in Benigno and Woodford (2006).

significant effect on the variance of most of the aggregate variables of interest. And under distortionary tax shocks, the correlation between labor hours and average productivity falls significantly close to zero, matching the observed U.S. data. In McGrattan (1994), technology shocks are estimated to account for at most 70% of the fluctuations in such an economy with fiscal distortions. In further works, researchers have computed equilibrium directly from non-linear models and have also relaxed the assumption of a representative agent so as to explore the distributional effects of taxation across agents with different preferences and investment opportunities.

These fiscal shocks have improved the ability of RBC models to replicate both the variability of consumption, labor hours, and labor productivity, and the low correlation between labor hours and average labor productivity. Fiscal shocks also increase the volatility of output generated by RBC models. It is shown that fiscal factors can be important determinants of cyclical movements in aggregate variables. Sims (1980) used what is referred to as むinnovation accountingめto decompose the variances in aggregate variables with fractions attributed to innovations in technology, government spending, factor tax rates, and found that the government spending and taxes can explain a significant portion of variances of consumption, investment, labor hours, capital stock and real output. However, there is not enough cyclical variation in tax rates and government spending for fiscal shocks to be a major source of business cycle fluctuations. Nevertheless, empirical results do suggest that incorporating a public sector into the analysis substantially improves the performance of RBC models.[38]

5.4 Energy Price Shocks

A common criticism[39] to the Kydland-Prescott model is that Solow residuals, which are used to measure technological progress, reflect labor hoarding and other むoff the production functionめbehavior rather than solely the state of technology.

[38] The impact of this perturbation is about as large as allowing for non-convexities in labor supply of the type stressed by Hansen (1985) and Rogerson (1988). Once government is incorporated into the analysis, we cannot reject the hypothesis that a version of the Hansen-Rogerson indivisible-labor model is consistent with both the observed correlation between labor hours and average productivity and the observed volatility of labor hours relative to average productivity. This is not true if government is excluded from the analysis.

[39] This criticism was most prominently put forward by Summers (1986) and Mankiw (1989).

McCallum (1989)[40] has pointed out that measurements of technology following the Solow tradition would strongly overstate the technological change unless certain neglected effects were taken into account, such as, adjustment costs and aggregate errors. He has also argued that in the nature of technological change, the variability of the economy-wide technology shocks is fairly small, which implies that technology shock itself may not be sufficient a force to generate all the observed aggregate fluctuations. In the last two sections, monetary and fiscal shocks have been incorporated into the economy to be seen the improvements they bring to the performance of RBC models. In this section, we consider another prominent factor which may help better explain the observed properties of the U.S. aggregate time seriesみenergy price shocks.

The role of energy price shocks has been first advocated persuasively by McCallum (1989), when he wrote:

> *There is one prominent type of "supply-side" disturbance that has effects across a wide range of industries, namely, a change in the real price that must be paid for imported raw materials—especially, energy. The oil price shocks in the 1970's and 1980's clearly have had a significant impact on the U.S. economy at the aggregate level. And since the Kydland-Prescott model does not have a foreign sector, such effects are treated by their analysis as 'residuals'—shifts in the production function. Such a treatment is, however, avoidable since these price changes are observed and are documented in basic aggregate data sources. It is also analytically undesirable: to lump input price changes together with production function shifts is to blur an important distinction.*

In 1992, Kim and Loungani in their influential paper, extend the model of Hansenゃ (1985) indivisible-labor economy to incorporate energy price shocks to the RBC model. In the analysis, they add some energy variables to the aggregate time series to observe the related properties. They find that with regard to energy variables, energy use is slightly more volatile than output, and energy prices are highly volatile while energy prices and output are negatively correlated with a point estimate of -0.44. In their model, energy is considered explicitly in the simplest way possible as an input to the aggregate production functionみthe use of energy is required to produce goods and services. The production technology of firms is described by a nested CES function with constant return to scale:

[40] Bennett McCallum, 1989, "Real Business Cycles", *Modern Business Cycle Theory*, ed. Robert Barro

$$y = \tau h^{\theta}[(1-\alpha)k^{-v} + \alpha e^{-v}]^{-(1-\theta)/v} \tag{16}$$

where y is the aggregate output, h is labor hours, k is capital stock, e is the energy input, while α is the share of capital stock relative to the energy input, v is equal to $(1-s)/s$, with s being the elasticity of substitution between capital and energy, and θ represents the labor's distributive share. The relative price of all energy used in the economy is given exogenously by a stochastic process. The role of energy price shocks is displayed in the aggregate resource constraint given by

$$c + x + pe \le y \tag{17}$$

where c is consumption, x is investment, p is the relative price of energy.

By calibrating the model to observed U.S. data and simulate a time series of aggregate variables, Kim and Loungani (1992) find that incorporating an exogenous shock to energy prices, which leads to shifts in both labor demand and labor supply, reduces the predicted correlation between labor hours and the return to working measured by average productivity, with a magnitude of reduction comparable to that achieved by introducing government spending shocks in Christiano and Eichenbaum (1992). The addition of energy price shocks also raises the percentage of output volatility explained by the basic RBC models. But if we modify the model to consider only the role of energy price shocks, it will account for only 16% of output volatility in the CES case, and the model will not be able to mimic many other features of the observed data, such as the smoother consumption compared to output. These facts suggest that although the energy price shocks do have a non-negligible effect on aggregate fluctuations, the inclusion of such shocks leads to only a modest reduction in the RBC model's reliance on unobserved technology shocks. After Kim and Loungani (1992), Rotemberg and Woodford (1996), and Finn (2000) have also studied the effects of energy price shocks in the context of RBC models. Their results suggest that although energy prices are highly volatile, energy costs are too small a fraction of GNP for changes in energy prices to have a major impact on economic activity. Besides, movements in energy prices are actually loosely associated with U.S. recessions even in the presence of the energy crises in the 1970's and 1980's, which is discussed in Barsky and Killian (2004). To sum up, though the introduction of energy price shocks has improved the performance of RBC models, energy price shock is not a major cause of aggregate fluctuations per se.[41]

[41] However, the model of Kim and Loungani (1992) has abstracted from many of the channels through which energy prices may affect the aggregate activity. For example, some models derive strong impact of energy prices on real variables by assuming some rigidity in the response of wages and non-energy prices to energy price shocks [e.g., Phelps (1978) and Black (1985)]. Besides, Bernanke (1983) has emphasized the impact of future long-term energy price uncertainty on the economy when investment projects are irreversible. Also, researchers like Hamilton (1988) and Mork (1989) have

5.5 International Business Cycles

In the early works of the RBC literature, studies have been carried out almost exclusively within the context of a closed economy. Quantitative studies of closed economies suggest that a neoclassical growth model with a stochastic technology shock can account for, among other things, the variability of consumption and investment relative to output and the correlations of these fluctuations, in the post-war U.S. economy. But in reality, modern economies are strongly characterized by openness. In a world economy, countries experience imperfectly correlated shocks to their technologies. The interaction between these shocks and the ability to borrow and lend internationally can in principle have a substantial influence on the variability and co-movements of aggregate variables in different countries. In open economies, a country's consumption and investment decisions are no longer constrained by its own production. The opportunity to share risk across countries may lead to equilibrium consumption paths that are both less volatile and less correlated with domestic outputs than in a close economy. Also, capital tend to be allocated to countries with more favorable technology shocks and thus generate greater variability in domestic investments.

Apart from the variability of domestic aggregate time series, the open-economy perspective also leads us to consider co-movements at an international level. In an open economy, countries can borrow and lend in international markets by running trade surpluses and deficits. The trade balance can vary substantially over cycles. Its cyclical properties are determined by two balancing forces: the desire and ability of agents to smooth consumption using international markets and the additional cyclical variability of investment brought by international capital flows. These phenomena are reflected in the correlation between saving and investment rates, which are perfectly correlated in closed economies but may be imperfectly correlated in open economies if countries use international markets for debit and credit. The open-economy perspective also leads us to consider correlations across different countries, in which the most obvious is the correlation between output fluctuations. Another such correlation is predicted by theory: given complete markets, we expect the international risk-sharing ability to produce a large correlation between consumption fluctuations across countries.

emphasized the “reallocative” effects of energy price shocks—they may require costly reallocations of capital and labor across sectors in a multi-sector economy with specialized inputs. Many more papers have been devoted to examining the role of energy prices in different directions.

Given the above considerations with the introduction of an international economic environment, we ask the question: whether an international version of RBC models can account simultaneously for the domestic variability and co-movements, and the international co-movements, including correlations across countries of aggregate variables and movements in the trade balance.[42]

In an attempt to study international business cycles from the perspective of stochastic dynamic general equilibrium, Dellas (1986), Stockman and Svensson (1987), and Cantor and Mark (1988) have taken the first steps to extend the basic RBC models to incorporate an international market. In an influential paper, Backus, Kehoe and Kydland (1992) have given the previous works quantitative support by assigning a parametric class of models to the theory and comparing its properties with those of observed international aggregate time-series.

In Backus et al. (1992), they have extended the RBC theory to a competitive model of a world economy with a single homogeneous good[43] and internationally immobile labor. Their theoretical model economy consists of two countries, each represented by a large number of identical households and firms, and the preferences of households and the production technologies have the same structure and parameter values. Although the technologies have the same form, they are different in that the labor input in each country comes only from domestic labor, and production is subject to country-specific technology shocks. The model represents the main properties of introducing an international market in two ways: countries experience different technology shocks each period; agents participate in international capital markets. As also a feature of the model, transmissions of shocks are correlated across countries, and the diffusion of these shocks between countries is also allowed as technological change is transmitted across borders.

In their analysis, Backus et al. (1992) find that openness substantially changes the nature of some of the closed-economy co-movements. For example, consumption is smoother in the model than in the data. In contrast, investment is much more volatile in the model. The contemporaneous cross correlation between investment and output

[42] In empirical work, researchers have paid particular attention to statistics that relate directly to the allocative role of international markets: the cross-country correlations of consumption and output, the correlation of net exports with output, and the correlation between saving and investment rates.

[43] To focus attention on the role of financial markets in allocating risk and determining inter-temporal production decisions, Backus et al. (1992) retain from the basic model the assumptions of a single homogeneous good and of complete markets for state-contingent claims. A more complicated model of a two-good economy is studied in Ahmed, Ickes, Wang, and Yoo (1993).

is substantially smaller in the model than in the U.S. data. For each of these properties, the closed-economy model matches the data more, which suggests an important influence on the economic behaviors brought by opening the economy. Besides domestic properties, similar differences between the model and data appear in the behavior of international co-movements. The trade balance is much more volatile in the model than it is in any of the major developed economies.[44] Although output is positively correlated across most major countries, it is the opposite in the model. In contrast, consumption is much more strongly correlated in the model than in the data.

In an attempt to address the discrepancies, Backus et al. (1992) attribute them to the ability of agents to trade costlessly between countries, when they wrote:

> *The ability of free-trade is reflected in the large cross-country consumption correlation, the small or even negative cross-country output correlation, the large variability of investment and net exports, and the cyclical movements of investment and net exports—all of which differ from the data.*

To reconcile this problem, Backus et al. (1992) have come to the idea that whether a world economy with small trading frictions would produce co-movements more like those observed in the data. To test this hypothesis, they introduce into the model a small transportation cost on net trades between countries. After some econometric treatments, they find that the introduction of such a cost has substantially lowered the variability of investment and net exports and produced strongly pro-cyclical investment. It has also reduced the difference between cross-country correlations of consumption and output. But in contrast to the data, consumption correlation in the model remains substantially larger than that of output. To test this particular discrepancy, Backus et al. (1992) have considered a more extreme case in which international loans do not exist at all. This adjustment prohibits not only physical trade in goods but also the trade in state-contingent claims that underlies international risk sharing. However, the quantitative properties of this case are very close to those with small trading frictions, which suggest that the consumption-output discrepancy is not simply the result of international risk sharing with complete markets. Actually, in all of the experiments carried out by Backus et al. (1992), including those with several alternative parameter settings, the cross-country correlation of consumption remains substantially larger than the output correlation, which is completely contrary to the data. Since this feature is robust to a number of reasonable adjustments in the economy, Backus et al. (1992) have labeled it an anomaly.

[44] The standard deviation of the ratio of net exports to output is 2.90 for the model versus 0.79 for Canada, 0.85 for Germany, 0.89 for Japan, and 0.42 for the United States.

After Backus et al. (1992), in another paper, Ahmed, Ickes, Wang, and Yoo (1993) develop and estimate a multivariate, structural, two-country, two-good model of the world economy to measure the relative contributions of supply shocks, fiscal and monetary shocks, and preference shocks in explaining aggregate fluctuations in the U.S. and a five-nation[45] OECD aggregate. Their empirical study assess whether the correlation of output movements across countries is primarily due to a common world disturbance, or due to the spillover effects of shocks originating in one country to the other. Besides, their paper also deals with the role of exchange-rate regimes in an open economic environment. In further studies of the empirical properties of international business cycles and world disturbances to aggregate activity, Mendoza (1995) include shocks to the terms of trade in an international business cycle and constructed an extended model to show, both qualitatively and quantitatively, the difference in the responses of real exchange rates to productivity shocks and term-of-trade shocks.

Since the 1990s, more and more macroeconomic questions have been calling for an international version of the RBC framework. One of the most important questions is whether the possibility of international trade alters our assessment of the importance of technology shocks for aggregate fluctuations. It is hold the view that in open economies, additional sources of shocks may be more important than they have been in closed economies. Other questions for international business cycle theory concern the behavior of relative prices of international goods, co-movements between relative prices and the trade balance, and the international co-movements of consumption and output. To address these questions, extensions and modifications of the theoretical structure laid out by Backus et al. (1992) have been performed by an increasing number of researchers.[46] The papers from these researchers focus on the behavior of a world economy at business cycle frequencies, while a complementary issue is the ability of these models to account for co-movements at lower frequencies. For example, mentioned in Backus et al. (1992), poor but quickly growing countries

[45] The five nations are the U.K., Germany, Canada, Japan and Australia.

[46] Bergman, Bordo, and Jonung (1998) analyze a large set of countries from a historical perspective to test the international business cycle theory against statistical evidence; Perez, Osborn, and Artis (2003) study in detail the volatility and the propagation of shocks at an international level; Jansen and Stokman (2004) study the international business cycle co-movements with particular focus on foreign direct investments; Ghironi and Melitz (2005) focus on international trade and study the macroeconomic dynamics of an economy with heterogeneous firms; Andrews and Kohler (2005) study international time series co-movements extensively; Chauvet and Yu (2006) use statistics from the G7 and OECD countries to reexamine the stylized facts about international business cycles; Olivero (2006) emphasize on the counter-cyclical margins in banking as an important transmission mechanism in international business cycles; Khan (2008) examine investment-specific productivity shocks in the context of a two-sector international real business cycle model, etc.

generally borrow less from richer, more slowly growing countries than theory suggests. This and other low-frequency discrepancies between theory and data provide additional topics for further research. In the stream of international business cycle research, the consumption-output anomaly, labeled by Backus et al. (1992), remains to be the single most salient problem in need of explanation. Backus, Kehoe and Kydland (1993) first attempt to address the issue by modifying the structure of their 1992 model to specify time-to-build capital and restrict agentsやrisk sharing ability. In a later paper, Guo and Sturzenegger (1998) examine an increasing return-to-scale model in which the economy is subject to むbelief shocksめthat affect the consumption Euler equations rather than productivity. They show in their model that under certain assumptions, the belief-driven model can account for the consumption-output anomaly.

5.6 Implications

In the development of the real business cycle theory in the past few decades, many more different stochastic shocks and propagation channels[47] have been considered and incorporated into the neoclassical growth model in the tradition of Kydland and Prescott (1982) to examine many different aspects of the business cycles fluctuations and explain an increasing number of macroeconomic questions. The ability of absorbing different factors into the consideration of a general equilibrium approach to the aggregate economic activity has enabled RBC-based models to become widely used as laboratories for macroeconomic analysis: policy analysis in general and the study of optimal fiscal and monetary policies in particular. These policy implications reflect the fact that RBC models represent an important step in meeting the challenge laid out by Robert Lucas Jr. in 1980, when he wrote:

> *One of the functions of theoretical economics is to provide fully articulated, artificial economic systems that can serve as laboratories in which policies that would be prohibitively expensive to experiment with in actual economies can be tested out at much lower cost. [...] Our task as I see it [...] is to write a FORTRAN program that will accept specific economic policy rules as 'input' and will generate as 'output' statistics describing the operating characteristics of time series we care about, which are predicted to result from these policies.*

[47] One of these stochastic shocks is the preference shock considered by Benvicenga (1992).

6. Criticisms and Challenges

In the past few decades, real business cycle models have become a notable success for its ability to mimic the real world economy and serve as a laboratory for economic research. However, in the development of the theory, considerable criticisms and challenges have been posed to the models and its adherents, which has brought vibrant debates among the economics profession. In the following sections, we briefly examine some of the most prominent arguments and show how the RBC theorists respond to these criticisms and challenges in the attempt to improve the RBC approach.

6.1 Criticism of Technology Shocks in Explaining Business Cycles:

In the baseline RBC model, aggregate fluctuations were explained mainly through direct shocks to productivity. Prescott in his 1986 paper argued that technology shocks accounted for more than half of the aggregate fluctuations in the post-war era. However, the hypothesis that technology shocks are the central source of business cycles has become controversial. Prescott (1986) computed changes in total factor productivity (TFP)[48] and treated it as a measure of exogenous technology shocks. But this measure was doubted the ability to truly describe shocks to technology. It was argued that TFP can be forecast by using military spending, suggested by Hall (1988), or monetary policy indicators, suggested by Evans (1992), both of which are variables that hardly affect the rate of technological progress. This suggests that TFP may not be purely exogenous, but has some endogenous components. Variations in labor effort, variations in capital utilization, and changes in firm markups, considered by Burnside et al. (1996), Burnside et al. (1993), and Jaimovich (2004), respectively, drove further away TFP from serving the measurement of true technology shocks. These considerations imply that the magnitude of true technology shocks is likely to be much smaller than that measured by changes in TFP originally considered by Prescott (1986).

However, King and Rebelo (1999) argue that although true technology shocks are smaller than TFP shocks, it does not mean that technology shocks are unimportant. The previous mechanisms introduced, such as labor effort variation, capital utilization and markup changes in RBC models has on the one hand, made true technology shocks less volatile than TFP, but also on the other, significantly amplified the effects

[48] The rate of change of TFP is measured by Solow residuals, as the method was first proposed by Robert Solow.

of technology shocks. This amplification allows models with these mechanisms to generate output volatility similar to actual data with much smaller technology shocks.

Apart from the measurement problem, another criticism of technology shocks in RBC models is its role in generating recessions[49]. Most RBC models require declines in TFP in order to replicate the declines in output observed in actual data. If we are to agree that expansions in output, at least in the medium to long run, are driven by TFP increases from technological progress, then in contrast, we are literally interpreting many deep recessions as in effect exhibiting technological regress, which faces substantial skepticism, represented by Gali (1999). In his paper, Gali uses a structural VAR that he identifies by assuming that technology shocks are the only source of long-term changes in labor productivity. He finds that in the short run, labor hours decrease in response to a positive shock to technology, which directly contradicts the implications of basic RBC models.[50] Later, ongoing debates followed Galiや findings.[51]

In response, one approach that some proponents of the RBC theory have suggested to account for the role of technology shocks in generating recessions is to argue that the TFP was poorly measured. They argue that, capital and labor utilization rates tend to vary significantly and pro-cyclically. If the capital stock is used to measure the flow of capital services, the extent of fluctuations in technological progress will be overstated. Typically, King and Rebelo (1999) has added variable utilization of labor and capital to an RBC model and used the strong amplification properties, which results from a highly elastic labor supply and capital utilization, to obtain plausible output fluctuations, without the need for TFP declines or negative TFP in generating recessions.

6.2 Criticism of the Internal Propagation Mechanism:

Apart from the above criticism to the root of the RBC theory, one of the most difficult problems exposed to the RBC theorists comes from Cogley and Nason (1995), among others. In their paper, they investigate whether RBC models are

[49] The NBER business cycle dating committee defines a recession as "a significant decline in economic activity spread across the economy, lasting more than a few months, normally visible in real GDP, real income, employment, industrial production, and wholesale-retail sales.
[50] King, Plosser, and Rebelo (1988) and King (1991) have discussed in detail the property that positive technology shocks raise labor hours in RBC models.
[51] Typical papers: Christiano, Eichenbaum, and Vigfusson (2003); Chari, Kehoe, and McGrattan (2004); Basu, Fernald, and Kimball (1999); Francis and Ramey (2001).

consistent with the stylized facts[52] about output dynamics in the U.S. and find that many RBC models have weak internal propagation mechanisms. They argue that although one of the best selling points of the RBC theory is that fluctuations in the model are persistent, the persistence comes from little more than the Solow residual, which is in essence an exogenous source of shocks. In RBC models, the internal propagation mechanism says that the source of persistence is that investment is higher in economic booms, which enables higher capital accumulated in the near future even when the original shocks disappear. But the problem shown by Cogley and Nason is that in reality the amount of new investment is too small relative to the capital stock that the capital stock itself varies little. This argument casts doubt on the ability of the after-shock capital stock to produce sufficient a variation to drive output fluctuations as observed in the data.

In response to the criticism, many researchers after Cogley and Nason (1995) have tried to find a better internal propagating channel to account for the observed persistence in the aggregate movements.

1. Labor market search frictions

To find a channel through which the persistent aggregate fluctuations can be explained endogenously, Mortensen and Pissarides (1994), Merz (1995), and Andolfatto (1996) turn to the fact that it usually takes time for workers to find new jobs that match well with their ability and for firms to find new workers that match well with their requirements in the labor market. Before these search and matching models, Burnside, Eichenbaum, and Rebelo (1993) have considered a model with labor-hoarding, which serves as an exception in RBC models that can better replicate the persistent output dynamics. Since costly search gives employers a motive for hoarding labor, it is possible that an RBC model that incorporates search in the labor market will enjoy greater success.

Here we use the example from Andolfatto (1996)[53] to illustrate the idea.

[52] The stylized facts are GNP growth is positively autocorrelated, and GNP appears to have an important trend-reverting component. Cogley and Nason in their paper incorporate certain labor adjustment costs to successfully generate positive autocorrelation in output growth endogenously but fail to account for the trend-reverting feature.

[53] His work is motivated by the appearance of a theoretical literature focusing on aggregate labor market dynamics and business cycle activity around models based on search-theoretic principles. Some of it is concerned with explaining important business cycle facts that RBC models are not designed to address: e.g., Phelps et al. (1970) and Pissarides (1985). Other demonstrate how labor-market-search considerations may help resolve some of the well-known problems that RBC

Andolfatto evaluates the quantitative properties of an RBC model in which the level of employment is determined within a labor-market-search framework instead of the standard Walrasian mechanism. In this model, hiring and firing are determined by the search and recruiting decisions of workers and firms. These decisions serve as complementary inputs into an aggregate matching function, through whose process the aggregate employment is determined. Changes in the expected returns to search due to changes in labor productivity or other structural variations induce equilibrium responses in search and recruiting activities. These effects are then propagated via changes in employment through time.

After parameterization, calibration, simulation and comparison between model and actual data, it is found that incorporating labor-market-search into the RBC model greatly improves its empirical performance along several dimensions[54], where a number of business cycle facts are accounted for with difficulty in the standard theory.

The core question addressed by Andolfatto is the empirical importance of the propagation mechanism embedded in the search environment. He has quantified the degree of internal propagation induced by labor market search frictions compared to a standard model. The empirical results show that by incorporating labor-market-search into a standard model, the RBC theory can be improved considerably along three key dimensions. First, the search model accounts for the observed patterns of aggregate economic activity reasonably well. In particular, the model generates persistent unemployment. Second, the model is consistent with the observation that most of the variability in aggregate labor is from cyclical adjustments in employment rather than hours worked per person. The model is also consistent with the observation that hours fluctuate much more than wages and the contemporaneous correlation between hours and productivity is fairly low. Finally, the model derive equilibrium output dynamics substantially different from the assumed impulse dynamics: the model is able to replicate the observed dynamic patterns of output growth, which displays a positive autocorrelation. Overall, the empirical results suggest that the labor-market-search model embodies a quantitatively important propagation mechanism for aggregate fluctuations.

models have in explaining key features of the labor market: e.g., Wright (1986) and Howitt (1988).

[54] (i) the persistence and variability of unemployment; (ii) the large cyclical movements in job availability; (iii) the negative correlation between vacancies and unemployment; (iv) the large cyclical movements in the aggregate labor input compared to relatively small movements in the real wage; and (v) the asymmetric dynamic correlation between labor hours and average productivity.

2. Learning-by-doing

Different from the approach to account for the persistent aggregate movements from the perspective of adjustment costs in labor allocations, Chang, Gomes and Schorfheide (2002) have considered another important issue in the aggregate economic environment to be a plausible candidate for alternative propagation mechanisms.

In their important paper, Chang et al. suggest that skill accumulation through past work experience, or "learning-by-doing" (LBD), which has direct effects on current productivity by being incorporated into workers' wages, can provide an important propagation mechanism in a dynamic stochastic general equilibrium model, as the current labor supply affects future productivity. Their point of departure from the standard RBC model is motivated by a strong tradition in labor economics.[55] In their view, the aggregate economy experiences systematic changes in labor productivity, given observed strongly pro-cyclical hiring and counter-cyclical layoffs in business cycles. Their econometric analysis uses a Bayesian approach to combine micro-level panel data with aggregate time series.

The main findings can be summarized as follows. First, introducing the LBD propagating channel improves the overall performance of the model relative to the standard RBC model. Second, the LBD model is able to generate a positive autocorrelation in output growth, albeit a smaller one than in the data. Finally, the aggregate output in the model follows a path that better matches the observed reverting trend in response to a serially correlated transitory shock, as propagated through the LBD channel that converts the current increase in labor hours to a subsequent increase in labor productivity. However, according to the model, the response of hours is immediate, whereas it is delayed by 2-3 quarters in the data, suggesting important frictions in the labor market. Moreover, the model requires serially correlated external shocks to be able to generate trend-reverting responses in output. Nevertheless, we view learning-by-doing as an important propagation mechanism that can easily be built into more complicated RBC models to improve their empirical performance. Also, formal model evaluation does show that the introduction of the LBD mechanism improves the model's ability to fit the dynamics of aggregate output better.

[55] Altug and Miller (1998), Cossa, Heckman, and Lochner (2000), Jacobson, LaLonde, and Sullivan (1993), and Topel (1991)

Apart from Chang et al. (2002), a number of papers have studied the role of learning in generating persistent effects from short-lived shocks on aggregate dynamics endogenously. Cooper and Johri (2002) include organizational capital in the production function and assume that the current stock of organizational capital depends on past production rates. Perli and Sakellaris (1998) and DeJong and Ingram (2001) emphasize schooling as another important source of learning.

In addition to the above two influential works, alternative propagation mechanisms have also been explored in various forms of adjustment costs in the allocation of labor: Burnside and Eichenbaum (1996), Hall (1999), and den Haan, Ramey, and Watson (2000). Besides the labor market and production perspective, attention has also been paid to other markets for the possibility of an embedded propagation channel. For example, financial markets have been proposed to be such a new focus. Suppose that an unexpected negative shock causes solvent but illiquid firms to become cash-flow-constrained or even go bankrupt. They could then become less efficient and aggregate production could thus be affected as a result. However, no matter how these studies propose new approaches to address the propagation issue, the solutions all tend to move the RBC model away from a world of perfectly functioning markets and no motivation for government intervention, which to a large extent contradicts with the basic idea of the RBC theoryみmarkets always clear.

6.3 Labor Market Issues:

Observed from statistics, we see much of the aggregate fluctuations at business cycle frequencies are characterized by changes in the labor input. Of prime importance to business cycle theory, movements in labor input account for about 2/3 of the business cycle fluctuations. Therefore, most business cycle theorists agree that an understanding of how the aggregate labor market functions is a prerequisite for understanding how business cycles propagate through time. However, in extensive studies of the aggregate labor market in the context of RBC models, researchers find two prominent problems exist in virtually all technology-driven RBC models: when compared to actual data, there is under-prediction of the fluctuations in observed labor hours and over-prediction of the correlation between labor hours and average labor productivity. These two problems, for their consistent appearance in different versions of adapted RBC models, have drawn substantial attention from RBC theorists, who have tried hard to investigate labor market models, in an attempt to search for better mechanisms that propagate productivity shocks in accordance to the behavior of the aggregate labor market.

1. Indivisible labor

Most business cycle models require high elasticities of labor supply to generate fluctuations in aggregate variables of the observed magnitude. In RBC models, these high elasticities are necessary to match the high variability of labor hours, together with the low variability of labor productivity. Since microeconomic studies indicate a low elasticity of labor supply, this requirement has motivated several researchers to explore mechanisms that can make a high aggregate elasticity of labor supply compatible with low labor supply elasticities for individual workers in a standard RBC model. To achieve this goal, Rogerson (1988) propose an infinite aggregate elasticity of labor supply in a world with variations in the proportion of people working: individuals work a standard workweek or not at allみlabor is indivisible. This idea has been incorporated into the RBC model by Hansen (1985), with results generated by the new model having a significant increase in labor hours fluctuations compared to Kydland and Prescott (1982).

In the Rogerson-Hansen indivisible-labor model, households in the economy are defined in the same way as in the standard model, but different in their specifications of the leisure choiceみthe choice of labor effort. In the standard modelみthe divisible-labor economyみall variations in aggregate hours come from changes in the hours worked per household. In this case, the period t expected utility is given by

$$u(c_t, h_t) = \alpha \log c_t + (1-\alpha)\log(1-h_t) \quad (18)$$ [56]

In the new economyみthe indivisible-labor economyみlabor is indivisible in that individuals are assumed to choose either working full time h_0, or not at all. Hence all variations in labor hours come from changes in the number of people employed. In this economy, the representative householdや period t expected utility is given by

$$u(c_t, \pi_t) = \alpha \log c_t + (1-\alpha)\pi_t \log(1-h_0) \quad (19)$$

where π_t is the probability of working in period t. After calibration and simulation,

[56] This is a specification of the parametric form of the utility function by using a CES utility function, assuming the elasticity of substitution to be 0, which yields a log form.

Hansen shows that the model displays a very high aggregate elasticity of labor supply that is independent of the labor supply elasticities of individual workers. In Rebelo (2005), he notes that the above property results from the fact that in this model, variation in labor hours comes from the extensive margin, i.e., from workers moving in and out of the labor force. The elasticity of labor supply of an individual workerみthe intensive margin, i.e., the increase in hours worked by the individual given a 1% wage increase, is irrelevant, because the number of hours worked is not a choice variable.

In fact, the divisible and indivisible labor economies represent polar cases, representing distinct sources of variation in aggregate labor hours. Cho and Cooley (1988) have pointed out that, in the real U.S. economy, about 75% of the aggregate labor hours fluctuations is due to changes in employment and the remainder is due to changes in hours worked per person employed.

2. Household production

While the under-prediction of fluctuations in observed labor hours is resolved by the indivisible-labor model, it cannot explain satisfactorily the over-prediction of the correlation between labor hours and average labor productivity. To reconcile this discrepancy, Benhabib, Rogerson, and Wright (1991) introduce an important new element to the RBC modelみhousehold production.

As a matter of fact, the household sector is sizable, both in terms of the labor and capital inputs used in home production and in terms of home-produced output, which suggests that household production is an empirically significant entity at the aggregate level. Evidence suggests that employed individuals spend much less time working at home than unemployed individuals and also that employed individuals with higher wages are more likely to substitute market work for household production. This suggests not only a large household sector, but also a noticeable substitutability between it and the market. Thus, Benhabib et al. argue that business cycle predictions may depend heavily on the willingness as well as opportunities of households to substitute home production for market work.

In their paper, they explore the aggregate implications of introducing household, or non-market, production into an otherwise standard RBC model. They add in a home production sector by assuming that households have access to household production functions that use time and capital to produce a non-tradable consumption good. They show that when individuals are able to substitute between market and non-market productions over time, volatility in market activity will arise because of relative productivity differentials between the two sectors, but not just absolute productivity shocks, as is the case in one-sector models. Moreover, the size of the fluctuations induced by productivity shocks will depend on the degree to which individuals are willing to substitute between household production and market work at a given date.

By calibrating the model to microeconomic evidence and long-term properties of the economy, Benhabib et al. find that by introducing household production, we can improve the performance of RBC models in comparison to data in all these dimensions simultaneously: (i) output fluctuates too little; (ii) relative to output, labor hours fluctuate too little; (iii) relative to output, consumption fluctuates too little; (iv) relative to output, investment fluctuates too much; and (v) the correlation between labor productivity and output is too high. Out of these results, most importantly, they find that under plausible parameterizations, the models do in fact generate lower correlations between labor hours and average productivity, which better replicates the data.

After Benhabib et al. (1991), McGrattan, Rogerson, and Wright (1992) and Fisher (1992) extend the household production models to more general economic environments and estimate their structural parameters econometrically. Fung (1992) introduces money into a home production model. Greenwood, Rogerson, Wright (1993) communicate and extend some of the previous findings. McGrattan, Rogerson, and Wright (1997) evaluate the effects of fiscal policy in household production models. Canova and Ubide (1998) put household production in the context of international business cycles and study the impact of it on financial markets. Baxter and Jermann (1999) perform a sensitivity test on the household production models of consumption to current income.

In the RBC literature, labor market issues are more than the above two topics. In monetary RBC models, wage stickiness is emphasized its role in generating a high elasticity of aggregate labor supply. Hall (2005) notes that in sticky wage models, nominal wages change only sporadically and workers commit to supplying labor at the posted wages. Thus, firms can employ more labor hours without paying higher wages in the short run. But when firms do so, workers can work more hours off-schedule that they would like, given the wages they are being paid. Therefore, both workers and firms can benefit by renegotiating towards an efficient level of labor supply. Mentioned by Rebelo (2005), sticky wage models raise the question of whether wage rates are allocational over business cycles. Using Hallや(2005) remark: can firms really employ workers for as many hours as they see fit at the going nominal wage rate? This has been discussed by Hall (2005) in great detail where he proposes a matching model in which sticky wages can be an equilibrium outcome. Last but not least, we have to mention that in most RBC models, firms hire workers in competitive spot labor markets where there is no unemployment, which is simply unrealistic. To consider a more realistic labor environment and understand the unemployment dynamics, macroeconomists have made concerted efforts. Search and matching models proposed by Mortensen and Pissarides (1994) and implemented by Merz (1995) and Andolfatto (1996) have become not only an important internal propagation channel but also a framework for understanding the dynamics of unemployment, the properties of vacancies, and the flows in and out of the labor force. In subsequent studies, den Haan, Ramey, and Watson (2000) and Gomes, Greenwood, and Rebelo (2001), among others, have extended the idea to broader economic environments. However, as indicated by Shimer (2005), more work need to be done to construct a better model that can replicate the entire aggregate labor market with patterns of volatility, co-movements of employment, vacancies, wages, and labor productivity observed in the U.S. data.

6.4 The Behavior of Asset Prices

Despite the above criticisms and controversies, real business cycle models are to a large extent successful at replicating most of the cyclical behavior of the aggregate economy. However, in a notable paper, Mehra and Prescott (1985) have shown that the utility specifications common in RBC models actually have counterfactual implications for asset prices. Their main argument is that these utility specifications are not consistent with the difference between the average return on equity and debt. Historically, the average return on equity has far exceeded the average return on short-term risk-free debt in the U.S.[57] But in the model constructed by Mehra and Prescott, the equity premium is extremely small relative to that observed.[58] In order to reconcile this discrepancy, individuals must have implausibly high risk aversion according to a standard RBC model. Thus, they argue that the existing RBC models, which abstract from transaction costs, liquidity constraints and other frictions absent

[57] From 1889-1978, the average real annual yield on the S&P 500 Index was 7%, while the average yield on short-term debt was less than 1%.

[58] Similar situations prevail in many other industrialized countries.

in the Arrow-Debreu setting, are unable to account for the existing large equity premium. To address the problem, they suggest that non-Arrow-Debreu competitive equilibrium models with factors such as heterogeneous agents, non-time-additive separable preferences, and other features that prohibit inter-temporal trade among agents, may help rationalize the large equity premium, which characterizes the U.S. economy.

Coined the term ゐequity premium puzzleめby Mehra and Prescott (1985), this problem has led to an extensive research effort in both macroeconomics and finance. So far, a range of useful theoretical tools and several plausible explanations have been proposed, but a solution generally accepted by the economics profession remains elusive. The literature has been reviewed by Mehra and Prescott (2003), who conclude that the puzzle is real and remains. Subsequent reviews, e.g., Grant and Quiggin (2006), have similarly found no agreed resolution. Here we distinguish several classes of explanations of the puzzle and summarize as follows.

1. **Denial of equity premium**

In the first attempts to account for the puzzle, the most radical explanation is that there is no puzzle at all: the equity premium puzzle is a statistical illusion. Proponents of this ゐexplanationめargue from a number of ways: (i) Following the stock market crashes of the 2008-2009 recession, there has been hardly any global equity premium over the 40 years from 1969 to 2009, as observed by Bloomberg; (ii) Previous studies of the puzzle have extensively focused on the US market, which was the most successful stock market in the 20th century. While other countries' markets displayed substantially lower long-term returns, picking the best observationみthe U.S.みfrom a sample leads to an upwardly biased estimate of the premium; (iii) Exchanges may go bust (just as governments may default), and this risk needs to be includedみusing only exchanges that have survived for the long term overstates returns; (iv) Returns to equities vary greatly depending on which data points are included. Using data starting from the top of the market in 1929 or the bottom of the market in 1932, or ending at the top in 2007 or the bottom in 2009 completely changes the overall conclusion.

2. **Individual characteristics**

Different from the ゐdenialistめ perspective, some explanations rely on assumptions about individual behavior and preferences different from those made by Mehra and Prescott (1985). In Rebelo (2005), he notes that many researchers have viewed the introduction of habit formation as an important step in addressing some of the first-order dimensions of the puzzle. The endowment models by Lucas (1978), in which preferences feature simple forms of habit formation, are consistent with the difference in average returns between equities and debts. However, these models generate bond yields that are too volatile relative to the data. Boldrin, Christiano, and Fisher (2001) show the simple incorporation of habit formation into a standard RBC model cannot reasonably resolve the problem. Fluctuations in the returns to equity are very small given the infinitely elastic capital supply. Habit formation introduces a strong desire for smooth consumption paths, but these smooth paths can be achieved without generating fluctuations in equity returns. Thus, Boldrin et al. modify the basic RBC model to reduce the elasticity of capital supply. In their model, investment and consumption goods are produced in different sectors across which there are frictions to the reallocation of capital and labor. As a result, the desire for smooth consumption introduced by habit formation generates volatile equity returns and a large equity premium.

A second aspect of the explanation is based on the relaxation of optimization assumptions in the standard model. The standard model represents consumers as むcontinuously-optimizing dynamically-consistent expected-utility maximizersめ mentioned by Mehra (2003). These assumptions provide a strong link between risk attitudes and attitudes to variations in inter-temporal consumption which is crucial in deriving the puzzle. Solutions of this kind work by weakening the assumption of continuous optimization, such as assuming that consumers satisfice rather than optimize. A typical example is the むinfo-gap decision theoryめinitiated by Ben-Haim in 2006, which applies a non-probabilistic treatment of uncertainty to achieve a robust satisficing approach to asset allocation.

A third aspect of the explanation is about the attitudes towards uncertainty of economic agents. For example, Benartzi and Thaler (1995) focus extensively on the particular risk aversion of losses of individuals and find that the size of the equity premium in their model is consistent with the previously estimated parameters of prospect theory if investors evaluate their portfolios annually. Besides, Erbas and Mirakhor (2007) consider ambiguity aversion rather than risk aversion and find that a large part of equity premium may reflect investor aversion to ambiguities resulting from institutional weaknesses.

3. **Market imperfections**

Different from the examination of economic agents, some researchers have turned to the economy-wide structural characteristics for possible explanations. Some of them study the equity characteristics that have not been captured by standard capital market models, but nonetheless consistent with rational optimization by investors in smoothly functioning markets. Such works are represented by Bansal and Coleman (1996) and Holmstrom and Tirole (1998). Focusing on another aspect of market imperfections, McGrattan and Prescott (2001) argue that the observed equity premium in the U.S. since 1945 may be explained by changes in the tax treatments of interest and dividend incomes. But as Mehra (2003) points out, there are some difficulties in the calibration method used in this analysis and the existence of a substantial equity premium before 1945 is left unexplained. In addition, another broad class of market imperfections is the problems caused by adverse selection and moral hazard. These problems of asymmetric information may result in the absence of markets in which individuals can insure themselves against systematic risk in labor income and non-corporate profits, which induce high risk aversion that cannot be captured by the standard model, leading to a discrepancy between observed and modeled data.

7. Current Research and Remaining Questions

Since Kydland and Prescott (1982), the RBC literature has grown substantially and the RBC theory has evolved beyond the study of business cycles. The core methodology of RBC modelsみthe DSGE modelingみhas now been applied to many other fields of study, including labor economics, industrial organization, finance, public finance, international finance and trade, etc. Interacting with emerging ideas in macroeconomics, the RBC theory itself has been greatly influenced and shaped by different economic arguments to initiate many new areas of research and generate many new questions in the interest of macroeconomic researchers. In the following sections, I briefly identify several of these topics of current concern in the RBC theory and try to map an overall picture of the latest development of this thriving literature.

7.1 Endogenous Business Cycles

In the tradition of Kydland and Prescott (1982), most RBC models rest on the framework of neoclassical growth theory, represented by the works of Robert Solow. In these models, the long-term growth rate of output per capita is exogenously determined by technological progress. However, modern economic research has found evidence that contradicts with these models of economic growth. Calculations made by Solow claimed that the majority of economic growth was due to technological progress rather than inputs of capital and labor. But studies since the 1970s have found such calculations to be invalid since they did not take into account changes in the quality of investment and that of capital and labor inputs.[59]

In the 1980s, as a response to criticisms of the neoclassical growth theory, endogenous growth theory emerged, represented by the works of Paul Romer, and also Robert Lucas Jr. and Robert Barro. Unsatisfied with Solow's explanation, these economists worked to endogenize technology. Romer et al. first developed a mathematical explanation of technological advancement and built it into the aggregate production function. Crucial importance is usually given to the production of new technologies and human capital. In their view, the engine for economic growth can be as simple as a constant-returns-to-scale production function (the AK model) or more complicated ones with spillover effects, increasing numbers of goods, increasing qualities, etc. Such models incorporate a new concept of human capital, the skills and knowledge that make workers productive. Unlike physical capital, human capital has increasing returns to scale, which leads to constant returns to capital overall, suggesting nothing like a むsteady stateめin the economy. In such models, although growth does not slow as capital accumulates, the rate of growth depends on the types of capital invested in. Related research has focused on education and innovation for increases in human capital and technological advancement.

In response to the endogenous growth theory, business cycle theorists have applied the idea to the study of short-term fluctuations and initiated a new direction in the RBC research programみendogenous business cycles. This literature studies models that

[59] Dale Jorgenson, President of the American Economic Association in 2000, concluded that changes in the quality of capital and labor inputs and the quality of investment goods explained most of the Solow residual. Jorgenson and Vu (2000) estimated that capital and labor inputs accounted for 85% of growth during the period 1945–1965, while only 15% could be attributed to productivity growth. Taking the G7 economies and the largest non-G7 economies, Jorgenson and Vu concluded that productivity growth accounted for only 1/5 of the total growth during 1989-1995, while input growth accounted for almost 4/5. Similarly, input growth accounted for more than 70% of growth after 1995, while productivity growth accounted for less than 30%.

generate aggregate fluctuations without relying on exogenous shocks. In these models, fluctuations resultみat least in partみfrom complicated deterministic dynamics rather than stochastic processes. Many of these models are adapted from the neoclassical growth framework and thus have the same basic structure as RBC models. Therefore, they can be evaluated the empirical validity in similar ways using the general equilibrium approach. But since they attribute fluctuations to factors endogenously embedded in the production process, they do differ from the DSGE modeling.

In the standard class of endogenous-business-cycle models, the possibility of aggregate fluctuations typically arises as a consequence of increasing returns to production, as noted by Cazzavillan, Lloyd-Braga, and Pintus (1996), or variable markups of prices over marginal costs, as noted by Gali (1994). However, Basu and Femald (1997) criticize those models as empirically implausible because endogenous fluctuations can only arise for increasing returns or markups that are significantly larger than empirical estimates. This criticism leads to the development of multi-sector models with sector-specific returns to scale that display indeterminacy of the rational expectations equilibrium for substantially smaller degrees of returns to scale, which is empirically more realistic. However, Schmitt-Grohe (2000) studies fluctuations predicted by a two-sector endogenous-business-cycle model with sector-specific external increasing returns to scale, and find through empirically realistic calibrations that endogenous fluctuations do not provide the observed dynamics missing[60] in existing RBC models. In subsequent studies, theorists of endogenous-business-cycle models try to use the theory to account for aspects of actual fluctuations that have been identified as defining features of business cycles but cannot be explained by standard RBC models.

Wälde (2003) shifts the focus from increasing returns to production to the more fundamental source of endogenous growthみR&D investment. He analyzes the empirically controversial prediction of RBC models that a growing economy displays counter-cyclical R&D investment. He uses a stochastic Poisson model of endogenous business cycles to study the determinants of the cyclical behavior of R&D investment. He shows that by providing an explicit expression for the expected length of a cycle, high frequency fluctuations can indeed be understood by this approach. He also shows how small technological changes translate into large aggregate fluctuations.

[60] Some of these missing dynamics are: positive serial correlation of output and a strong internal propagation mechanism to innovations in the temporary component [Cogley and Nason (1995)], and, time series of output, labor hours, and consumption are strongly positively correlated [Rotemberg and Woodford (1996)].

To replicate the observed features of aggregate dynamics, Maliar and Maliar (2004) have constructed a computable general equilibrium model of endogenous growth that can account for both long-term balanced growth and short-term business cycles. Their model assumes that economic growth is the consequence of periodic arrivals of innovations. Growth sustains because each subsequent innovation leads to a permanent improvement in the production technology and cycles arise because innovations trigger reallocations of resources between production and R&D. Under certain parameterizations, their model can improve two shortcomings of standard RBC models: It can account for the persistence in output growth and the asymmetry of growth within business cycles.

Dosi, Fagiolo, and Roventini (2006) present an evolutionary model of industry dynamics yielding endogenous business cycles. The model describes an economy in which firms belong to two industries, one performs R&D and produces heterogeneous machine tools and the other invests in new machines and produce a homogenous consumption good. In line with the empirics of investment patterns, they assume the investment decisions of firms are lumpy and constrained by their financial structures. Also, based on behavioral theories of firms, they assume bounded rational expectation formation. Simulation results show that the model is able to produce self-sustaining growth characterized by endogenous fluctuations. The model can also replicate the most important stylized facts about aggregate dynamics: investment is more volatile than output; consumption is less volatile than output; investment, consumption and employment are pro-cyclical; output is positively serially correlated.

7.2 Multiple Equilibria and the New Keynesian RBC Models

Since the massive adoption of the general equilibrium approach to study macroeconomic problems, an increasing number of papers have been devoted to examining models that display multiple rational expectations equilibria. Early works in this area relied heavily on overlapping-generations models, which can often be studied without resorting to numerical methods. However, in order to understand the quantitative implications of multiple equilibria, later works, as discussed in Farmer (2000) and also reexamined in Morris and Hyun (2000), take the standard RBC model as a point of departure and apply the DSGE methodology to search for plausible modifications that generate multiple equilibria.

In standard RBC models, we can compute the competitive equilibrium as a solution to the むsocial plannerゃ problemめas did Kydland and Prescott (1982). This concave planning problem has a unique solution, which leads to a unique equilibrium. However, when we introduce features like increasing returns to scale or monopolistic competition considered by the endogenous growth theory, we can no longer compute a single competitive equilibrium by solving the above problem, which suggests the possibility of multiple equilibria. Yet, early versions of RBC-based multiple equilibria models required large increasing returns to scale or implausibly high markups, which is empirically unrealistic.

In the late 1980s and early 1990s, New Keynesian economists, represented by John Taylor, N. Gregory Mankiw, David Romer, Olivier Blanchard, and Michael Woodford, have studied multiple equilibria in the context of RBC models with Keynesian features extensively. The New Keynesian economics first developed as a response to criticisms of Keynesianism by New classical economists, represented by Robert Lucas Jr., using the idea of むrational expectationsめ Like the New classical approach, New Keynesian analysis assumes rational expectations, but differently, it recognizes a variety of market failures, which may alter the original expectations formed by the agents. In particular, New Keynesians assume prices and wages are sticky that they cannot adjust instantaneously to changes in economic conditions. Nominal rigidities, among other market failures recognized in New Keynesian models, imply that the economy may fail to attain full employment with a unique market-clearing equilibrium and thus falls into a multiple equilibria situation.

Early contributions to the theory were compiled in 1991 by N. Gregory Mankiw and David Romer in *New Keynesian Economics, vol.1&2*, which focused mostly on providing micro-foundations for Keynesian macro-effects, with no attempt to construct a systematic macroeconomic model. Later, researchers have begun to build dynamic stochastic general equilibrium models with Keynesian features. The New Keynesian DSGE modeling methodology is explained in Michael Woodford's textbook *Interest and Prices: Foundations of a Theory of Monetary Policy*. New Keynesians construct their models out of the RBC framework with recognized market imperfections. Nominal rigidities[61], externalities[62], monopolistic competitions[63], coordination failures[64], real rigidities[65], among other possible market failures, are

[61] Gail (2004), Malley, Muscatelli, and Woitek (2005), and Mulligan (2006)
[62] Boldrin (1992), Bover, de Lucio, and Rodriguez (1998), and Randon (2004)
[63] Manning (1990) and Gali (1996)
[64] Bohn and Gorton (1993)
[65] Laurence and Romer (1990) and Kryvtsov and Midrigan (2009)

incorporated into otherwise standard RBC models to be seen their effects on the formation of rational expectations, through which the model may yield multiple equilibria results.

At the policy level, multiple equilibria models may have potentially great implications. While New classical economists assume that price and wage adjustments would automatically attain full employment in the short run given aggregate fluctuations, New Keynesians argue that full employment can only be automatically achieved in the long run, given short-term nominal rigidities. Therefore, they argue that macroeconomic stabilization policies by the government or the central bank are needed for a more efficient outcome, since the むlong runめmay be very long. By using the RBC approach, New Keynesian economists, among others, are now actively estimating quantitative models of this type, and using them to analyze optimal monetary and fiscal policies.[66]

In the study of multiple equilibria, beliefs of economic agents are essential since they lead agents in different sectors to form specific expectations about future economic environments and thus react differently towards given changes in economic conditions. This process then leads the economy towards multiple equilibria in models with market imperfections. Since beliefs are self-fulfilling, belief shocks can generate business cycles per se. If agents become pessimistic about the future and think that the economy is going into a recession, the economy does indeed slowdown. Also, given volatile belief shocks in an imperfect economic environment, multiple equilibria models tend to have strong internal persistence, for they do not need serially correlated shocks to generate persistent macroeconomic time series.[67] This potentially strong internal persistence mechanism of multiple equilibrium models are quite an advantage over standard RBC models. However, an important difficulty with the current generation of multiple equilibria models existみthey require that beliefs be volatile, but coordinated across agents. Agents must often change their views about the future, but doing so in a coordinated manner. This むbelief coordinationめhas led to new studies that explore the process by which agents learn about the economic environments and form their expectations about the future.

[66] E.g., Benhabib, Schmitt-Grohe, and Uribe (2001) have discussed monetary policy in multiple equilibria models; King (2006) uses multiple equilibria models to study the effects of discretionary government policies in general; Kobayashi and Nutahara (2008) examine a news-driven business cycle model with nominal rigidities to study the impact of monetary policy.

[67] See Chari, Kehoe, and McGrattan (1998) for a discussion on whether a sticky price multiple equilibria model of business cycles can account for the persistence in aggregate time series.

7.3 Expectation Shocks

Playing an important role in multiple equilibria models, individual beliefs, or expectations, have been increasingly considered the role in generating persistent business cycle fluctuations.

In a review paper of business cycle shocks, Cochrane (1994) first attempt to explore the possibility that individual expectations upon given information may be important drivers of aggregate fluctuations. To describe the key idea of Cochrane, Rebelo (2005) uses a simple example: suppose that agents learn that there is a new technology, such as the internet, that will be available in the future, and expect it to have a significant impact on future productivity. Does this news generate an expansion today? Suppose that later on, the impact of this technology is found to be smaller than previously expected. Does this cause a recession? Such questions have triggered the interest of many macroeconomic researchers to develop theories and construct models that can incorporate this potentially significant source of persistent aggregate fluctuations into standard RBC models.

In an influential paper, Beaudry and Portier (2004) show that standard RBC models cannot generate the co-movement between consumption and investment in response to expectations about future productivity as empirical estimates. They argue that if agents believe that there will be an increase in future productivity, this expectation will raise the current real rate of return on investing, and at the same time, generate a positive wealth effect. If the wealth effect dominates, agents will increase consumption and leisure, while labor hours and output will fall. Since consumption rises and output falls, investment has to fall. However, if the real rate of return effect dominates, which happens for a high elasticity of inter-temporal substitution, then investment and labor hours will rise. In this case, output does not increase sufficiently to accommodate the rise in investment so consumption will fall. To model this empirical observation, Beaudry and Portier (2004) take an important first step in proposing a model that generates the right co-movement in response to expectations about future productivity. In a standard RBC model, changes in expectations cannot generate positive co-movements between consumption, investment and labor hours. Beaudry and Portier show that if a sufficiently rich description of the production technology is performed, which is rare in macro-models, expectation-driven business cycle fluctuations can arise in an RBC model.[68]

[68] In particular, they identify a multi-sector setting and a setting with a costly distribution system in which expectation-driven business cycles can arise. These models require that durables and

The work of Beaudry and Portier (2004) has served as an interesting challenge for following research to produce alternatives that can better model expectation shocks in generating business cycles. Lorenzoni (2005) studies consumersゃexpectation shocks with imperfect information, or imperfect foresight; Veldkamp and Wolfers (2007) focus on the question of consistency between business cycle co-movements and expectation shocks with costly information; Eusepi and Preston (2008) develop a theory of expectation-driven business cycles based on learning in an environment with incomplete information where agents learn to acquire knowledge; Huang, Liu, and Zha (2009) explore macroeconomic implications of the self-confirming equilibrium in a standard RBC model where rational expectations are replaced by adaptive expectations, which are found to have substantially altered the propagation mechanism, allowing technology shocks to exert much more impact on aggregate variables than do rational expectations; Li and Mehkari (2009) present a model incorporating endogenous firm entry that translates positive news about the future into current expansions, and accounts for the positive co-movements in output, consumption, investment and employment; Jaimovich and Rebelo (2006) explore the business cycle implications of expectation shocks from the aspects of two well-known psychological biases, optimism and overconfidenceみthe expectations of optimistic agents are biased towards good outcomes, while overconfident agents overestimate the precision of the signals they receiveみand find that overconfidence can increase business cycle volatility, while preserving the empirical properties of co-movements and relative volatilities.

7.4 Sources of Movements in Total Factor Productivity

Standard RBC models assume that aggregate fluctuations are mainly caused by exogenous technology shocksみthe direct changes in total factor productivity (TFP), as measured by the Solow residual. However, increasing studies over the years have cast doubt on the ability of changes in TFP to truly measure the technological progress, as referred to in Section 6.1. In response to this controversy, more recent studies have focused on the details of TFPみits technological component and the source of its movements, in an attempt to explore the empirical content and sources of technological advancement.[69] Questions in need of explanation in this area are

nondurables consumption to be strongly complementary, and abstract from capital as an input into the production of investment goods.

[69] A systematic discussion of TFP is provided in Hulten (2000).

mainly those that ask: are movements in TFP primarily due to new inventions and process stochastically discovered by the nature of R&D? Or are they primarily due to changes in government regulations that alter the efficiency of firm production? Or are they due to unmeasured investments that vary over time?

In early stages, Kalirajan, Obwona, and Zhao (1996) present a method to decompose the sources of TFP growth into technological progress and changes in technical efficiency within the framework of a neoclassical production function. Later, Comin and Gertler (2006) extend a standard RBC model to incorporate endogenous changes in TFP that result from R&D activities. Although they focus on medium-run cycles, their analysis also has some implications at higher frequencies, especially the co-movement of output and technological progress measured by TFP growth rate. In their 2004 paper, Carlaw and Kosempel have constructed a dynamic general equilibrium model to further identify sources of TFP growth using data from Canada and to quantify their importance. The model provides procedures for constructing quantitative measures of technological progress. Interestingly, they result shows that periods of low productivity growth correspond to periods of high growth in investment-specific technology (IST) or high rates of technology embodiment. In a later study, Jeong and Townsend (2007) develop a method of growth accounting based on the integrated use of transitional growth models and micro data. They decompose TFP growth into the occupational-shift effect, financial-deepening effect, capital-heterogeneity effect, and sectoral-Solow-residuals. Applying this method to Thailand, which experienced rapid growth with enormous structural changes between 1976 and 1996, they find that 73% of TFP growth is explained by occupational shifts and financial deepening, without presuming exogenous technological progress. More generally, subsequent research on the adoption and diffusion of new technologies has gradually shown their importance in understanding the component and changes in TFP and thus the source of business cycle fluctuations. So far, this area of research on TFP growth decomposition and measurement has shown its potential in generating a large literature and sustaining a promising future prospect.

7.5 Understanding the Great Depression

In the 20th century, one of the most important macroeconomic eventみthe Great Depression, has drawn substantial works and efforts from macroeconomists in an attempt to provide a theoretically-established and empirically-plausible explanation.

In the tradition of Keynes, many economists interpret the large output decline, stock market crash, and financial crisis that occurred between 1929 and 1933 as a massive failure of markets that could have been prevented had the government played a larger role in the economy. The event seemed to confirm, in the eyes of most contemporary macroeconomists, the correctness of the Keynesian intuition that, in the short run at least, a capitalistic economy does not naturally reach a full employment position. Although the Keynesian model lost its predominance to the rise of new classical macroeconomics, the Great Depression still stand as an example of market failure, which the New classicals themselves considered a phenomenon somehow beyond the reach of equilibrium theory, particularly noted by Lucas (1980). However, since the 1990s, a new interpretation of the Great Depression, based on the RBC framework, began to gain ground. Such an interpretation served as a first step in overcoming the once accepted limit to equilibrium theory. The proponents of the RBC explanation of the Great Depression view it as a むnormalめbusiness cycle, which, despite its exceptional scope and magnitude, can be understood by using the general equilibrium theory.

The literature of RBC-based explanation for the Great Depression has been surveyed by Pensieroso (2005). In this survey, Pensieroso notes that, instead of viewing the Great Depression as a phenomenon beyond the grasp of equilibrium theory, researchers in the literature believe that the RBC methodology can be applied to tackle it. They argue that it is plausible that the Great Depression were resulted from an unusual combination of bad shocks compounded by bad policy. Large drops in the world price of agricultural goods, instability in the financial system, and the worst drought ever recorded served as sufficiently bad shocks to the economy. Besides, failure of the central bank to serve as lender of last resort when bank runs forced many U.S. banks to close, contractionary monetary policy, the bitter tariff war that crippled international trade after the introduction of the Smoot-Hawley tariff introduced in 1930 to protect farmers from declines in world agricultural prices, the massive tax increase through the Revenue Act of 1932, government policies that permitted industry to collude and increased the bargaining power of unions, which undermined competition in both product and labor markets, etc., all served as sufficiently bad policies. Together with bad shocks at the time, long-lasting deep recessions were to be expected. In addition to Pensieroso (2005), De Vroey and Pensieroso (2006) also review the literature but suggest that although the RBC-based explanation is plausible, its contribution now is still slim and given the available rudimentary data sources, sorting out the effects of different shocks and policies is a demanding task, which requires substantial works in the future.[70]

8. Conclusion

The real business cycle theory has gone through decades of extensions, modifications, criticisms and challenges and has developed now as one of the main research literatures in the study of macroeconomic activity. It has been interacting with many other disciplines and branches of economic study to produce a fruitful combination of macroeconomic research direction as well as methodology. The RBC theory has contributed greatly to the development of modern macroeconomics. Would there not be a paradigm shift in the theoretical ideology of the study of aggregate economic activity, future works are expected to improve the theory and related methods to achieve a better empirical performance.

[70] However, there are also some voices of disagreement. For example, in response to the book *Great Depression of the Twentieth Century* by Timothy J. Kehoe and Edward C. Prescott, Temin (2008) criticizes the RBC approach to explain the Great Depression. He finds that the use of closed economy models without frictions is not useful for the analysis of short-run variations in the rate of economic growth. In his view, almost all essays in the book end by claiming that variations in the rate of output growth were due to changes in the rate of TFP growth and they do not provide any explanation for fluctuations in the rate of TFP growth, leaving the reader no closer understanding of those periods of depression and slow growth.

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