Monopolistic Competition and Nonclearing Labor Market in Business Cycles*

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Abstract

This paper presents a dynamic optimization model of RBC type augmented by monopolistic competition in product market and disequilibrium in labor market. Calibration for the U. S. economy shows that the model will produce higher volatility in employment and less correlation between employment and consumption. Moreover, the mechanism through which the technology shock impact the economy is more reasonably explained.

Keywords: sticky price, disequilibrium, monopolistic competition and RBC

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1 Introduction

The real business cycle (RBC) model has become one of the major approaches in macroeconomics to explain observed economic fluctuations. Despite its rather simple structure, it is successful, at least partially, in explaining the volatility of some key economic variables such as output, consumption and capital stock. However, there are still two types of problems for the model to explain business cycles effectively. The first problem regards the labor market. The model generally predicts an excessive smoothness of labor effort in contrast to the empirical data. It also produces a high correlation between consumption and employment while the empirical data do not observe such correlation.

The excessive smoothness of labor effort and thus the low variation in the employment series is the well-known puzzle in the RBC literature. A recent evaluation of this failure of the RBC model is given in Schmidt-Grohe (2001), where the RBC model is compared to an indeterminacy model. The excessive correlation between consumption and labor has, to our knowledge, not sufficiently been studied in the literature. We will explore this puzzle in Section 3 when we calibrate the model.

A more fundamental issue in RBC literature is on technology shock, which is assumed to be measured by the Solow residual. As King and Rebelo (1999) pointted out, "it is the final criticism that the Solow residual is a problematic measure of technology shock that has been remained the Achilles heel of the RBC literature." The Solow residual is computed on the basis of observed output, capital and employment, it is therefore presumed that all factors are fully utilized. There are several reasons to distrust the standard Solow residual as a measure of technology shock. First, Mankiw (1989) and Summers (1986) have argued that such a measure often leads to excessive volatility in productivity and even the possibility of technological regress, both of which seems to be empirically implausible. Second, It has been shown that the Solow residual can be expressed by some exogenous variables, for example demand shocks arising from military spending (Hall 1988) and changed monetary aggregates (Evan 1992), which are unlikely to be related to factor productivity. Third, the standard Solow residual can be contaminated if the cyclical variation in factor utilization are significant.

Considering that Solow residual cannot be trusted as a measure of technology shock, researchers have now developed different methods to measures technology correctly. One possible approach is to use an observed indicator to proxy for unobserved utilization. A typical example is to employ electricity use as a proxy for capacity utilization (see Burnside, Eichenbaum and Rebelo 1996). Another strategy is to construct an economic model so that one could compute the factor utilization from the observed variables (see Basu and Kimball 1997 and Basu, Fernald and Kimball 1999). In Gali (1999), the labor productivity computed as observed GDP over actual employment is simply employed as an indicator of technology.

It is well known that one of the major celebrated argument from real business cycles theory is that technology is pro-cyclical. A positive technology shock will increase output, consumption and employment. Yet this celebrated result is obtained from the "empirical evidence", in which the technology is measured by the standard Solow residual. Recently, Gali (1999) and Francis and Ramey (2001) have found that if one does not rely on Solow residual to measure technology, the shock moves counter-cyclically with employment and therefore the celebrated argument must be rejected.[1]

It seems that the aforementioned puzzles in labor market and technology mechanism cannot be resolved within the RBC general equilibrium framework. Improvement must be made in its model structure that may go beyong the competitive general equilibrium. Attempts have now been made that introduce variants of Keynesian features into the RBC model. There are models of wage constract and efficiency wage where nonclearing labor market could occur.[2] In all these papers with labor market nonclearing, an explicit labor demand function is introduced, which is derived from the marginal product of labor. However, the decision rule with regard to labor supply in these models is often dropped because the labor effort no longer appears in the utility function. Consequently, the moments of labor effort become purely demand-determined.[3] On the other hand, Rotemberg and Woodford (1995, 1999), King and Wollman (1999), Gali (1999), Erceg, Henderson and Levin (2000), Christiano, Eichenbaum and Evan (2001) and Woodford (2003) present models with imperfect competition and sluggish price adjustment.

In this paper, we shall present a benchmark RBC model augmented by monopolistic competition in product market and disequilibrium in labor market. The objective to construct this model is to approach the two aforementioned puzzles coherently within a single model of dynamic optimization. Unlike the current model with nonclearing labor market, we however do not

[1]Their finding has in turn been contested by e.g. Fisher (2002) and Christiano, Eichenbaum and Vigfusson (2003) among others. A more recent study on this issue is found in Uhlig (2003).

[2]See, for instance, Benassy (1995), Danthine and Donaldson (1990, 1995) and Uhlig and Xu (1996). Another line of recent research on modelling unemployment in dynamic optimization framework can be found in the work by Merz (1999) who employs search and matching theory to model the labor market.

[3]The labor supply in these models is implicitly assumed to be given exogenously, such as set to 1. Hence disequilibrium occurs if the demand is not equal to 1.

drop the labor effort from the decisions of the households. We view the decision concerning the labor effort derived from dynamic optimization as a natural reflection of the agent's willingness to supply labor. With the introduction of labor demand, the two basic forces in the labor market can be formalized.

The remainder of this paper is organized as follows. Section 2 presents the theoretical structure of our model. Section 3 calibrates the model in contrast to the benchmark RBC model. Section 4 concludes the paper.

2 The Model

We shall still follow the benchmark assumptions on identical households and identical firms. Therefore we are considering an economy that has two agents: the representative household and the representative firm. There are three markets in which the agents exchange their product, labor and capital stock. The household owns all the factors of production (including technology) and therefore sells factor services to the firm. The revenue from selling factor service can only be used to buy the goods produced by the firm either for consuming or for accumulating capital. The representative firm owns nothing. It simply hires capital and labor to produce output, sells the output and transfers any profit back to the household.

Unlike the typical RBC model, in which one could assume once-for-all market, we, however, in this model shall allow that the market to be reopened at the beginning of each period t. This is necessary for our model in which adjustments should take place in response to the market nonclearing. Let us first describe how price and wages are set.

2.1 Price and Wage Setting

As usual, we presume that both the household and the firm express their desired demand and supply on the basis of given prices, including the output price p_t, the wage rate w_t and the rental rate of capital stock r_t. We shall first discuss how these period t prices are determined at the beginning of period t. Note that here there are three commodities in our model. One of them thus should serve as a numeraire, which we assume to be the output. Therefore, the output price p_t always equals 1. This indicates that the wage w_t and the rental rate of capital stock r_t are all measured in terms of the physical units of output. As to the rental rate of capital r_t, it is assumed to be adjustable and clear the capital market. We can then ignore its settling. Indeed, as will become clear, one can image any initial value of the rental rate of capital when the firm and the household make the quantity decisions and express their desired demand and supply. This leaves us to focus the discussion only on the wage setting. Let us first discuss who set up the wage rate.

Most recent literature in discussion of wage setting have assumed that it is the supplier of labor, the household, that sets the wage rate whereas the firm is simply a wage taker.[4] On the other hand, there are also the models that discuss how firms set the wage rate. In reality, it is also quite possible, as Taylor (1999) pointed out, that wage setting is an interaction process between firms and households. Despite this variety, let us consider the case that the wage is set by the household.

Suppose that at the beginning of period t the representative household can set up a new wage rate by his monopoly power in supply of labor. The first problem that he might need to decide is whether he actually should change the existing wage or simply keep the wage as before. According to the New Keynesian literature, any price change (including the price of labor) might be costly. There are so-called menu cost for changing price. There are also reputation cost for changing price and wage.[5] In addition, changing price (or wage) needs information, computation and communication, which may also be costly.[6] All these costs may be summarized as adjustment cost in changing price or wage. The adjustment cost in chagning the wage may provide some reason for the presentative household to stick to the wage rate even if it is known that current wage may not be the optimal. [7] This indicates that in aggregation there is only a certain probability, as suggested by Calvo (1983) that the household may exercise his monopoly power to change the wage.

Suppose now that the household decide to change the wage so that in period t the new wage rate will be w_t^*. Due to the adjustment cost to change w_t^* in the future, the household may also expect that w_t^* will stick for some periods, and therefore the effect of such stickness should be formulated into the optimization problem for the household to choose w_t^*.

One thus can image that the dynamics of wage rate follows the updating scheme as in Calvo's staggered price model (1983) or in Taylor's wage contract model (1980). In each period, there exists a certain probability that a

[4]See, for instance, Erceg, Henderson and Levin (2000), Christiano, Eichenbaum and Evans (2001) and Woodford (2003) among others.

[5]This is more emphasized by Rotermberg (1982)

[6]See the discussion in Christiano, Eichenbaum and Even (2001) and Zbaracki, Ritson, Levy, Dutta and Bergen (2000).

[7]One may also derive this stickiness of wage from wage contract as in Taylor (1980) with the contract period to be longer than one period.

new wage rate will be decided. This new decided wage rate should respond to the expected market condition not only in period t but also through t to $t+j$, where $t+j$ can be regarded as the future period at which reoptimization will occur to decide the next new wage rate.

Explicit formulation of this type of wage dynamics is cumbersome and not the task of this paper.[8] Indeed, as will become clear in section 3, the empirical study of our model does not rely on how we formulate the wage dynamics since we treat the wage as an exogenuous variable and therefore introduce the observed wage sequence directly into the model for our empirical analsys.

2.2 The Willingness of the Household

When the prices (including wage) have been settled, the household is now going to choose his (or her) willingness in demand and supply. We define the household's willingness as those demand and supply that can allow the household to obtain the maximum utility on the condition that these demand and supply can be realized at the given set of prices. We can express this willingness as a sequence of output demand and factor supply $\left\{c_{t+i}^d, i_{t+i}^d, n_{t+i}^s, k_{t+i+1}^s\right\}_{i=0}^{\infty}$, where c, i, n and k are respectively consumption, investment, labor and capital. Note that here we have used the superscripts d and s to refer to the agent's willingness in demand and supply. The decision problem for the household to derive his (or her) willingness can be formulated as

$$\max_{\left\{c_{t+i}^d, n_{t+i}^s\right\}_{i=0}^{\infty}} E_t\left[\sum_{i=0}^{\infty} \beta^i U(c_{t+i}^d, n_{t+i}^s)\right] \tag{1}$$

subject to

$$\begin{aligned} c_{t+i}^d + i_{t+i}^d &= r_{t+i}k_{t+i}^s + w_{t+i}n_{t+i}^s + \pi_{t+i} && (2) \\ k_{t+i+1}^s &= (1-\delta)k_{t+i}^s + i_{t+i}^d && (3) \end{aligned}$$

Above δ is the depreciation rate; β is the discounted factor and π_{t+i} is the expected dividend. Note that (2) can be regarded as a budget constraint. The equality holds due to the assumption $U_c > 0$. Next, we shall consider how the representative household compute π_{t+i}. Assuming that the household know the production function while expect that the market will be cleared

[8] For the wage setting model of the heterogenuous households as differentiated type of labor supply, we want to refer to Erceg, Henderson and Levin (2000), Christiano, Eichenbaum and Evan (2001) and Woodford (2003).

at the given price sequence $\{p_{t+i}, w_{t+i}, r_{t+i}\}_{i=0}^{\infty}$,[9] we thus obtain

$$\pi_{t+i} = f(k_{t+i}^s, n_{t+i}^s, A_{t+i}) - w_{t+i} n_{t+i}^s - r_{t+i} k_{t+i}^s \tag{4}$$

Above, $f(\cdot)$ is the production function. Explaining π_{t+i} in (2) in terms of (4) and then substituting from (3) to eliminate i_t^d, we obtain

$$k_{t+i+1}^s = (1-\delta)k_{t+i}^s + f(k_{t+i}^s, n_{t+i}^s, A_{t+i}) - c_{t+i}^d \tag{5}$$

For the given technology sequence $\{A_{t+i}\}_{i=0}^{\infty}$,[10] equations (1) and (5) form a standard benchmark RBC model. The solution of this model can be written as:

$$\begin{aligned} c_{t+i}^d &= G_c(k_{t+i}^s, A_{t+i}) \quad (6) \\ n_{t+i}^s &= G_n(k_{t+i}^s, A_{t+i}) \quad (7) \end{aligned}$$

We shall remark that although the solution appears to be a sequence $\left\{c_{t+i}^d, n_{t+i}^s\right\}_{i=0}^{\infty}$ only (c_t^d, n_t^s) along with $\left(i_t^d, k_t^d\right)$, where $i_t^d = f(k_t^s, n_t^s, A_t) - c_t^d$ and $k_t^s = k_t$, are actually carried into the market by the household for exchange. This is certainly due to our assumption of re-opening market.

2.3 The Willingness of the Firm

Since the firm simply rents capital and hires labor on a period-by-period basis, the problem faced by the representative firm at period t is to choose the current input demands and output supplies (n_t^d, k_t^d, y_t^s) that maximizes the current profit. Since we have assumed that our representative firm behaves as a monopolistic competitor, the firm has a perceived demand curve for its product. Thus given the output price, which is set at 1 as a numeraire, the firm have an expected constraint on the market demand for its product. We shall denote this expected demand as $\widehat{y}_t$.

On the other hand, given the prices of output, labor and capital stock $(1, w_t, r_t)$, the firm should also have its own willingness to supply y_t^*. This willingness to supply is the amount that allows the firm to own the maximum profit on the assumption that all its output can be sold out. Apparently, if the expected demand $\widehat{y}_t$ is less than the firm's willingness to supply y_t^*, the firm will choose $\widehat{y}_t$. Otherwise, it will choose y_t^* as in disequilibrium analysis.

Thus, for our representative firm, the optimization problem can be expressed as

$$\max \ \min(\widehat{y}_t, y_t^*) - r_t k_t^d - w_t n_t^d \tag{8}$$

[9] Note that for those prices beyond period t, we can assume that they are simply expected.

[10] Again for those technologies beyond period t, we can assume that they are expected.

subject to

$$\min(\widehat{y}_t, y_t^*) = f(A_t, k_t, n_t) \tag{9}$$

For the regular condition on production function, the solutions should satisfy

$$\begin{aligned} k_t^d &= f_k(r_t, w_t, A_t, \widehat{y}_t) && (10) \\ n_t^d &= f_n(r_t, w_t, A_t, \widehat{y}_t) && (11) \end{aligned}$$

We are now considering the transactions in our three markets. Let us first consider the two factor markets.

2.4 Transaction in Factor Market

We have assumed the rental rate of capital r_t to be adjustable in each period when the market is re-opened and thus the capital market is cleared so that we have

$$k_t = k_t^s = k_t^d$$

In the labor market, there is no reason to believe that the firm's demand for labor as expressed in (11) should be equal to the willingness of household to supply as determined in (7). Therefore, we cannot regard the labor market to be cleared.[11]

If the labor market is not cleared, we shall have to specify what rule applies regarding the realization of actual employment. In the literature on disequilibrium analysis (see, for instance, Benassy 1975, 1984, among others), the most famous rule that has been used is the short side rule, that is,

$$n_t = \min(n_t^d, n_t^s)$$

Thus, when disequilibrium occur, only the short side of the demand and supply will be realized.

The second might be called the compromising rule. This rule indicates that when disequilibrium occurs in the labor market both firms and workers have to compromise. In particular, we can formulate this rule as

$$n_t = \omega n_t^d + (1 - \omega) n_t^s \tag{12}$$

[11] Strictly speaking, the so-called labor market clearing should be defined as the condition that the firm's willingness to demand for labor is equal to the household's willingness to supply the labor. Such concept is somehow disappeared in the new Keynesian literature in which the household supplies the labor effort according to the market demand and therefore there does not seem to face the problem of excess demand or supply. Yet, even in this case, the household's willingness to supply labor effort is not necessarily equal to his actual supply, i.e., the market demand. This further indicates that even if there is no adjustment cost so that the household can adjust the wage rate in every t, the disequilibrium in the labor market may still exist.

where $\omega \in (0,1)$. Therefore, if there is excess supply, firms will employ more labor than what they wish to employ.[12] On the other hand, when there is excess demand, workers will have to offer more effort than they wish to offer.[13] Such mutual compromises may be due to institutional structures and moral standards of the society.[14] Such a rule that seems to hold for many countries was already discussed early in the economic literature, see Meyers (1964) and also Solow (1979).

In this paper, we shall consider the compromising rule only.[15]

2.5 The Transaction in the Product Market

After the transactions in these two factor markets have been carried, the firm will engage in its production activity. The result is the output supply, which is now given by

$$y_t^s = f(k_t, n_t, A_t) \tag{13}$$

Then the transaction needs to be carried out with respect to y_t^s. It is important to note that when disequilibrium occurs in the labor market the previous consumption plan as expressed by (6) becomes invalid due to the improper budget constraint (2), which further lead to (5) for deriving the plan. Therefore, the household will construct a new plan as expressed below:

$$\max_{(c_t^d)} U(c_t^d, n_t) + E_t \left[\sum_{i=1}^{\infty} \beta^i U(c_{t+i}^d, n_{t+i}^s) \right] \tag{14}$$

[12]This could also be realized by firms by demanding the same (or less) hours per worker but employing more workers than being optimal. This case corresponds to what is discussed in the literature as labor hoarding where firms hesitate to fire workers during a recession because it may be hard to find new workers in the next upswing, see Burnside, Eichenbaum and Rebelo (1993).

[13]This could be achieved by employing the same number workers but each worker supplying more hours (varying shift length and overtime work); for a more formal treatment of this point, see Burnside, Eichenbaum and Rebelo (1993).

[14]Note that if firms are off their supply schedule and workers off their demand schedule, a proper study would have to compute the firms cost increase and profit loss and the workers' welfare loss. If, however, the marginal cost for firms is rather flat (as empirical literature has argued, see Blanchard and Fischer, 1989) and the marginal disutility is also rather flat the overall loss may not be high.

[15]Empirically, the short side rule seems to be less satisfying than the compromising rule, the rule that we shall immediately discuss. See the comparison of these two realization rules in Gong and Semmler (2003).

subject to

$$k_{t+1}^s = \frac{1}{1+\gamma}\left[(1-\delta)k_t + f(k_t, n_t, A_t) - c_t^d\right] \tag{15}$$

$$k_{t+i+1}^s = \frac{1}{1+\gamma}\left[(1-\delta)k_{t+i}^s + f(k_{t+i}^s, n_{t+i}^s, A_{t+i}) - c_{t+i}^d\right] \tag{16}$$

$$i = 1, 2, ...$$

Note that in this optimization program the only decision variable is about c_t^d and the data includes not only A_t and k_t but also n_t, which is given by (12) with n_t^s and n_t^d are implied by (7) and (**??**) respectively. We can write this solution in terms of the following equation (see the appendix for the detail):

$$c_t^d = G_{c2}(k_t, A_t, n_t) \tag{17}$$

Given this adjusted consumption plan, the product market should be cleared if the household demand $f(k_t, n_t, A_t) - c_t^d$ for investment. Therefore, c_t^d in (17) should also be the realized consumption.

3 Estimation and Calibration

This section provides an empirical study of our model as presented in the last section. However, the model in the last section is only for illustrative purpose. It is not the model that can be tested with empirical data, not only because we do not specify the forms of production function, utility function, the expectation function of $\hat{y}_t$ and the stochastic process of A_t, but also we do not introduce the growth factor into the model. For an empirically testable model, we employ here the model as formulated by King, Plosser and Rebelo (1988).

3.1 The Empirically Testable Model

Let K_t denote for capital stock, N_t for per capita working hours, Y_t for output and C_t for consumption. Assume the capital stock in the economy follow the transition law:

$$K_{t+1} = (1-\delta)K_t + A_t K_t^{1-\alpha}(N_t X_t)^\alpha - C_t, \tag{18}$$

where δ is the depreciation rate; α is the share of labor in the production function $F(\cdot) = A_t K_t^{1-\alpha}(N_t X_t)^\alpha$; A_t is the temporary shock in technology and X_t the permanent shock that follows a growth rate γ.[16] The model is

[16] Note that X_t includes both population and productivity growth.

nonstationary due to X_t. To transform the model into a stationary formulation, we divide both sides of equation (18) by X_t:

$$k_{t+1} = \frac{1}{1+\gamma}\left[(1-\delta)k_t + A_t k_t^{1-\alpha}(n_t \bar{N}/0.3)^\alpha - c_t\right], \tag{19}$$

where $k_t \equiv K_t/X_t, c_t \equiv C_t/X_t$ and $n_t \equiv 0.3N_t/\bar{N}$ with $\bar{N}$ to be the sample mean of N_t. Note that n_t is often regarded to be the normalized hours. The sample mean of n_t is equal to 30 %, which, as pointed out by Hansen (1985), is the average percentage of hours attributed to work. Note that the above formulation also indicates that the form of $f(\cdot)$ may follow

$$f(\cdot) = A_t k_t^{1-\alpha}(n_t \bar{N}/0.3)^\alpha$$

while $y_t \equiv Y_t/X_t$ with Y_t to be the empirical output.

With regard to the household preference, we shall assume that the utility function take the form

$$\log c_t + \theta \log(1-n_t)$$

The temporary shock A_t may follow an AR(1) process:

$$A_{t+1} = a_0 + a_1 A_t + \epsilon_t, \tag{20}$$

where $\epsilon_t \sim N(0, \sigma_\epsilon^2)$ is an independently and identically distributed (*i.i.d.*) innovation.

Finally, we assume that the output expectation $\widehat{y}_t$ be simply equal to y_{t-1} so that the expectation is fully adaptive to the actual output in the last period.[17]

3.2 The Data Generation Process

For our empirical test, we consider two model variants: the benchmark RBC model, as the standard for comparison, and our model with monopolistic competition and nonclearing labor market. Specifically, we shall call the benchmark model as Model I and the model with monopolistic competition and nonclearing market as Model II.

For the benchmark model, the Model I, the data generating process include (19), (20) as well as

$$c_t = G_{11}A_t + G_{12}k_t + g_1 \tag{21}$$

$$n_t = G_{21}A_t + G_{22}k_t + g_2 \tag{22}$$

[17] Of course, one can also consider other forms of expectation. One possibility is to assume expectation to be rational so that it is equal to the steady state of y_t. Indeed, we also have done the same empirical study, yet the result is less satisfying.

Note that here (21) and (22) are the linear approximations to (6) and (7). The coefficients G_{ij} and $g_i (i = 1, 2$ and $j = 1, 2)$ are the complicated functions of the model's structural parameters, α, β, among others. They are computed by a numerical algorithm using the linear-quadratic approximation method.[18] Given these coefficients and the parameters in equation (20), including σ_ε, we can simulate the model to generate stochastically simulated data. These data can then be compared to the sample moments of the observed economy.

To define the data generating process for our model with monopolistic competition and nonclearing labor market, the Model II, we shall first modify (22) as

$$n_t^s = G_{21}A_t + G_{22}k_t + g_2 \tag{23}$$

On the other hand, the equilibrium in product market indicates that c_t^d in (17) should be equal to c_t. Therefore, this equation can also be approximated as

$$c_t = G_{31}A_t + G_{32}k_t + G_{33}n_t + g_3 \tag{24}$$

In the appendix, we provide the details how to compute the coefficients G_{3j}, $j = 1, 2, 3$, and g_3.

Next we consider the demand for labor n_t^d derived from the firm's optimization problem (8) - (9), which shall now be augmented by the growth factor for our empirical test. The following proposition regards the derivation of n_t^d.

Proposition 1 *When the capital market is cleared, the demand for labor can be expressed as*

$$n_t^d = \begin{cases} (0.3/\bar{N})\,(\hat{y}_t/A_t)^{1/\alpha}\,k_t^{(\alpha-1)/\alpha} & \text{if } \hat{y}_t < (\alpha A_t Z_t/w_t)^{\alpha/(1-\alpha)} k_t A_t \\ (\alpha A_t Z_t/w_t)^{1/(1-\alpha)} k_t (0.3/\bar{N}) & \text{if } \hat{y}_t \geq (\alpha A_t Z_t/w_t)^{\alpha/(1-\alpha)} k_t A_t \end{cases} \tag{25}$$

The proof of this proposition is provided in Appendix.

Thus, for Model II, the data generating process includes (19), (20), (12), (23), (24) and (25) with the wage w_t given by the observed wage rate. We thereby do not attempt to give the actually observed sequence of wages a further theoretical foundation. For our purpose it suffices to take the empirically observed series of wages.

3.3 The Data and the Parameters

Before we calibrate the models we shall first specify the parameters. There are altogether 10 parameters in our three variants: a_0, a_1, σ_ε, γ, α, β, δ,

[18]The algorithm that we used here is from Gong and Semmler (2002). It is developed from Gong (1998).

θ and ω. We first specify α and γ respectively at 0.58 and 0.0045, which are standard. This allows us to compute the data series of technology A_t. With this data series, we estimate the parameters a_0, a_1 and σ_ε. The next three parameters β, δ and θ are estimated with the GMM method by matching the moments of the benchmark model generated by (19), (20), (21) and (22). The estimation is conducted by a global optimization algorithm called simulated annealing.[19] These parameters have been estimated in Gong and Semmler (2005). We therefore shall employ them here. For the new parameters ω in Model II, we specify it at 0.4446. It is estimated by minimizing the residual sum of square between actual employment and the model generated employment. The estimation is executed by a conventional algorithm, the grid search. Table 1 illustrates these parameters:

Table 1: Parameters Used for Calibration

a_0	0.0333	σ_ε	0.0185	ω	0.4446	β	0.9930	θ	2.0189
a_1	0.9811	γ	0.0045	α	0.5800	δ	0.2080		

The data set used in this paper is taken from Christiano (1987). The wage series are obtained from Citibase. It is re-scaled to match the model's implication.[20]

3.4 Calibration

Table 2 provides our calibration results from 5000 stochastic simulations. The results in this table are confirmed by Figure 1, where a one time simulation with the observed innovation A_t are presented. All time series are detrended by the HP-filter.

[19]For details of simulated annealing and the estimation strategy, see Semmler and Gong (1996, 1997).

[20]Note that this re-scaling is necessary because we do not know exactly the initial condition of Z_t, which we set to 1. We re-scaled the wage series in such a way that the sample average of the Keynesian demand for labor as expressed by the first equation of (25) is equal to the sample average of the neoclassical demand for labor as expressed by the second equation of (25). Also note that we introduced the data of capacity utilization (from Citibase) to compute the technology A_t more appropriately.

Table 2: Calibration of the Model Variants
(numbers in parentheses are the corresponding standard deviations)

	Consumption	Capital	Employment	Output
Standard Deviations				
Sample Economy	0.0081	0.0035	0.0165	0.0156
Model I Economy	0.0091	0.0036	0.0051	0.0158
	(0.0012)	(0.0007)	(0.0006)	(0.0021)
Model II Economy	0.0061	0.0048	0.0119	0.0166
	(0.0011)	(0.0012)	(0.0046)	(0.0038)
Correlation Coefficients				
Sample Economy				
Consumption	1.0000			
Capital Stock	0.1741	1.0000		
Employment	0.4604	0.2861	1.0000	
Output	0.7550	0.0954	0.7263	1.0000
Model I Economy				
Consumption	1.0000			
	(0.0000)			
Capital Stock	0.2043	1.0000		
	(0.1190)	(0.0000)		
Employment	0.9288	-0.1593	1.0000	
	(0.0203)	(0.0906)	(0.0000)	
Output	0.9866	0.0566	0.9754	1.0000
	(0.0033)	(0.1044)	(0.0076)	(0.0000)
Model II Economy				
Consumption	1.0000			
	(0.0000)			
Capital Stock	0.3659	1.0000		
	(0.1449)	(0.0000)		
Employment	0.4221	0.2430	1.0000	
	(0.1406)	(0.1099)	(0.0000)	
Output	0.9089	0.1081	0.6508	1.0000
	(0.0358)	(0.1055)	(0.1304)	(0.0000)

3.4.1 The Labor Market Puzzle

First we want to remark that the structural parameters that we used here for calibration are estimated by matching the Model I Economy to the Sample Economy. The result, reflected in Table 2, is therefore somewhat biased in favor of the Model I Economy. It is not surprising that for most variables the moments generated from the Model I Economy are closer to the moments of the Sample Economy. Yet even in this case, there is an excessive smoothness of the labor effort and the employment series of the data cannot be matched. For our time period, 1959.1 to 1984.1, we find 0.32 in the Model I Economy as the ratio of the standard deviation of labor effort to the standard deviation of output. This ratio is roughly 1 in the Sample Economy. The problem is somewhat resolved in our Model II Economy representing monopolistic competition and non-clearing labor market. There the ratio is equal to 0.71.

Further evidence on the better fit of our Model II Economy — as concerns the volatility of the macroeconomic variables — is also demonstrated in Figure 1 where the horizontal figures show, from top to bottom, actual (solid line) and simulated data (dotted line) for consumption, capital stock, employment and output, and the two columns, from the left to the right, represent the figures for Model I and Model II Economies respectively. As observable, the volatility of employment has been greatly increased in the Model II Economy and the series fits the data better than the Model I Economy.

Next, we look at the cross-correlations of the macroeconomic variables. In the Sample Economy, there are two significant correlations we can observe: the correlation between consumption and output, roughly 0.75, and the correlation between employment and output, about 0.72. These two correlations can also be found in all of our simulated economies. However, in our Model I Economy — and this only holds for the Model Economy I (the benchmark RBC model) — in addition to the above two correlations, consumption and employment are, with 0.93, also strongly correlated.

This result of the benchmark model is not surprising given that movements of employment as well as consumption reflect the movement in the same state variables, capital stock k_t and the temporary shock A_t. They, therefore, should be somewhat correlated. We remark here that such an excessive correlation has, to our knowledge, not explicitly been discussed in the RBC literature, including the recent study by Schmidt-Grohe (2001). Discussions have often been focused on the correlation with output.

One success of our Model II Economy is that employment is no longer significantly correlated with consumption. This is because we have made a distinction between the demand and supply of labor, whereas only the latter, labor supply, reflects the moments of capital and technology as consumption does. Since the realized employment is not necessarily the same as the labor supply, the correlation with consumption is therefore weakened.

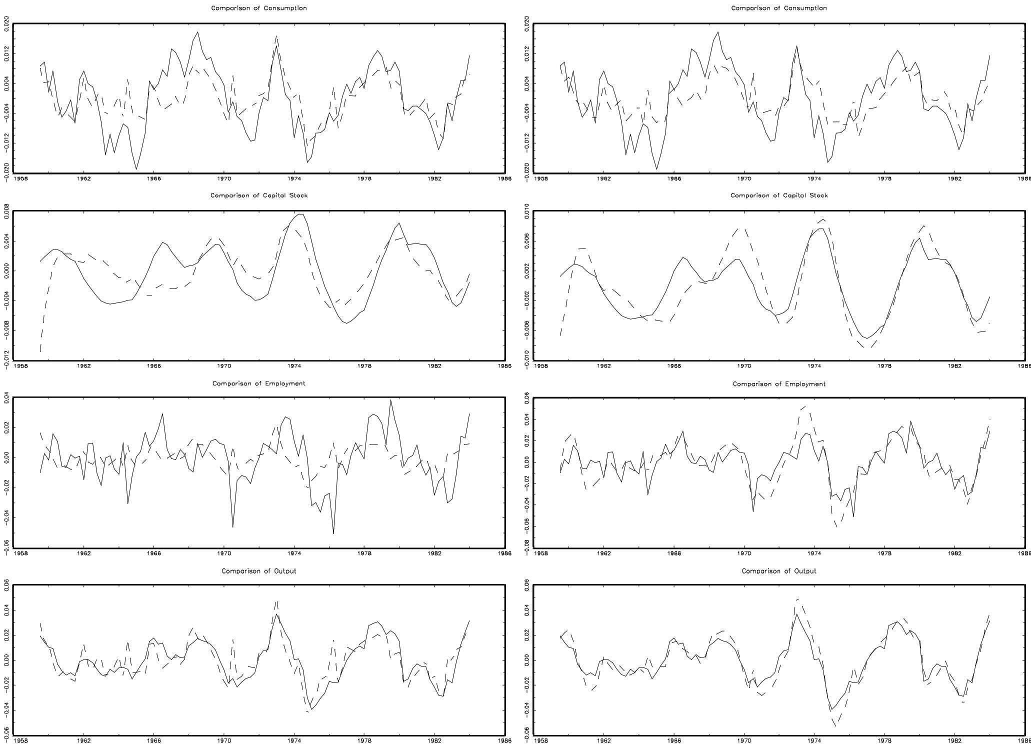

Figure 1: Simulated Economy versus Sample Economy: U.S. Case (solid line for sample economy, dotted line for simulated economy)

3.4.2 Technology Puzzle

Next, we shall investigate the temporary effect of technology shock. Table 3 records the cross correlation of temporary shock A_t from our 5000 thousand stochastic simulation. As one can find there, the two models predicts rather different correlations. In the Model I (RBC) Economy, technology A_t has temporary effect not only on consumption and output, but also on employment, which are all significantly positive. Yet in our Model II Economy with monopolistic competition and nonclearing labor market, we find that the correlation with employment is no longer significant. This is consistent with the widely discussed recent finding that technology has near-zero (or even negative) effect on employment.

Table 3: The Correlation Coefficients of Temporary Shock in Technology.

	output	consumption	employment	capital stock
Model I Economy	0.9903	0.9722	0.9966	-0.0255
	(0.0031)	(0.0084)	(0.0013)	(0.1077)
Model II Economy	0.8943	0.8582	0.2801	-0.1451
	(0.0304)	(0.0426)	(0.1708)	(0.1163)

4 Conclusions

The benchmark RBC model has difficulties to explain the labor market variation and the impact of technology shock on the economy. These difficulties are likely to be caused by its structural settling of competitive general equilibrium. This modeling structure may restrict its usefulness to the real world, which perhaps is featured by sticky price, disequilibrium and monopolistic competition. In this paper, we present a dynamic optimization model of RBC type augmented by wage and price stickiness, the monopolistic competition and nonclearing in labor market. Calibration for the U. S. economy shows that such model variant will produce a higher volatility in employment, and thus fit the data better than the benchmark model. Moreover, the mechanism through which the technology shock impact the economy is also more reasonably explained. The result is consistent with a class of model along the line of New Keynesian tradition. We however approach both the labor market and technology puzzles coherently within a single model of dynamic optimization.

5 Appendix

5.1 Temporary Consumption Decision

For the problem (14) - (16), we define the Lagrange:

$$\begin{aligned} L &= E_t \left\{ \left[\log c_t^d + \theta \log(1-n_t)\right] + \right. \\ & \left. \lambda_t \left[k_{t+1}^s - \frac{1}{1+\gamma} \left[(1-\delta)k_t^s + f(k_t^s, n_t, A_t) - c_t^d\right]\right]\right\} + \\ & E_t \left\{ \sum_{i=1}^{\infty} \beta^i \left[\log(c_{t+i}^d) + \theta \log(1-n_{t+i}^s)\right] + \right. \\ & \left. \beta^i \lambda_{t+i} \left[k_{t+1+i}^s - \frac{1}{1+\gamma} \left[(1-\delta)k_{t+i}^s + f(k_{t+i}^s, n_{t+i}^s, A_{t+i}) - c_{t+i}^d\right]\right]\right\} \end{aligned}$$

Since the decision is only about c_t^d, we thus take the partial derivatives of L with respect to c_t^d, k_{t+1}^s and λ_t. This gives us the following first-order condition:

$$\frac{1}{c_t^d} - \frac{\lambda_t}{1+\gamma} = 0; \tag{26}$$

$$\frac{\beta}{1+\gamma} E_t \left\{ \lambda_{t+1} \left[(1-\delta) + (1-\alpha) A_{t+1} \left(k_{t+1}^s\right)^{-\alpha} \left(n_{t+1}^s \bar{N}/0.3\right)^{\alpha} \right] \right\} = \lambda_t \tag{27}$$

$$k_{t+1}^s = \frac{1}{1+\gamma} \left[(1-\delta)k_t^s + A_t (k_t^s)^{1-\alpha} \left(n_t \bar{N}/0.3\right)^{\alpha} - c_t^d \right], \tag{28}$$

Recall that in deriving the decision rule as expressed in (21) and (22) we have postulated

$$\begin{aligned} \lambda_{t+1} &= H k_{t+1}^s + Q A_{t+1} + h \\ n_{t+1}^s &= G_{21} k_{t+1}^s + G_{22} A_{t+1} + g_2 \end{aligned}$$

where H, Q, h, G_{21}, G_{22} and g_2 have all been resolved preliminarily in the household optimization program. We therefore obtain

$$E_t \lambda_{t+1} = H k_{t+1}^s + Q(a_0 + a_1 A_t) + h \tag{29}$$

$$E_t n_{t+1}^s = G_2 k_{t+1}^s + D_2(a_0 + a_1 A_t) + g_2 \tag{30}$$

Our next step is to linearize (26), (27) and (28) around the steady states. Suppose they can be written as

$$F_{c1} c_t + F_{c2} \lambda_t + f_c = 0 \tag{31}$$

$$F_{k1} E_t \lambda_{t+1} + F_{k2} E_t A_{t+1} + F_{k3} k_{t+1}^s + F_{k4} E_t n_{t+1}^s + f_k = \lambda_t \tag{32}$$

$$k_{t+1}^s = A k_t + W A_t + C_1 c_t^d + C_2 n_t + b \tag{33}$$

Expressing $E_t\lambda_{t+1}, E_t n_{t+1}^s$ and $E_t A_{t+1}$ in (32) in terms of (29), (30) and $a_0 + a_1 A_t$ respectively, we obtain

$$\kappa_1 k_{t+1}^s + \kappa_2 A_t + \kappa_0 = \lambda_t \tag{34}$$

where, in particular,

$$\kappa_0 = F_{k1}(Qa_0 + h) + F_{k2}a_0 + F_{k4}(G_{22}a_0 + g_2) + f_k$$
$$\kappa_1 = F_{k1}H + F_{k3} + F_{k4}G_{21}$$
$$\kappa_2 = F_{k1}Qa_1 + F_{k2}a_1 + F_{k4}G_{22}a_1$$

Using (31) to express λ_t in (34), we further obtain

$$\kappa_1 k_{t+1}^s + \kappa_2 A_t + \kappa_0 = -\frac{F_{c1}}{F_{c2}} c_t^d - \frac{f_c}{F_{c2}}$$

which is equivalent to

$$k_{t+1}^s = -\frac{\kappa_2}{\kappa_1} A_t - \frac{F_{c1}}{F_{c2}\kappa_1} c_t^d - \frac{\kappa_0}{\kappa_1} - \frac{f_c}{F_{c2}\kappa_1}$$

This can be substituted into the right side of (33), which will allow us to resolve c_t^d as

$$c_t^d = -\left(\frac{F_{c1}}{F_{c2}\kappa_1} + C_1\right)^{-1} \left[Ak_t + \left(\frac{\kappa_2}{\kappa_1} + W\right) A_t + C_2 n_t + \left(b + \frac{\kappa_0}{\kappa_1} + \frac{f_c}{F_{c2}\kappa_1}\right)\right]$$

5.2 The Firm's Demand for Labor (Proposition 1)

Let $X_t = Z_t L_t$, with Z_t to be the permanent shock resulting purely from productivity growth, and L_t from population growth. We shall assume that L_t has a constant growth rate μ and hence Z_t follows the growth rate $(\gamma - \mu)$. The production function can be written as $Y_t = A_t Z_t^\alpha K_t^{1-\alpha} H_t^\alpha$, where H_t equals $N_t L_t$ and can be regarded as total labor hours.

Let us first consider the firm's willingness to supply Y_t^*, $Y_t^* = X_t y_t^*$, under the condition that the rental rate of capital r_t clears the capital market while the wage rate w_t is given. In this case, the firm's optimization problem can be expressed as

$$\max \; Y_t^* - r_t K_t^d - w_t H_t^d$$

subject to

$$Y_t^* = A_t \left(Z_t\right)^\alpha \left(K_t^d\right)^{1-\alpha} \left(H_t^d\right)^\alpha$$

The first-order condition tells us that

$$(1-\alpha)A_t\left(Z_t\right)^{\alpha}\left(K_t^d\right)^{-\alpha}\left(H_t^d\right)^{\alpha} = r_t \tag{35}$$

$$\alpha A_t\left(Z_t\right)^{\alpha}\left(K_t^d\right)^{1-\alpha}\left(H_t^d\right)^{\alpha-1} = w_t \tag{36}$$

from which we can further obtain

$$\frac{r_t}{w_t} = \left(\frac{1-\alpha}{\alpha}\right)\frac{H_t^d}{K_t^d} \tag{37}$$

Since the rental rate of capital r_t is assumed to clear the capital market, we can thus replace K_t^d in the above equations by K_t. Since w_t is given, and therefore the demand for labor can be derived from (36):

$$H_t^d = \left(\frac{\alpha A_t}{w_t}\right)^{\frac{1}{1-\alpha}}\left(Z_t\right)^{\frac{\alpha}{1-\alpha}} K_t$$

Dividing both sides of the above equation by X_t, and then making re-organization, we obtain

$$n_t^d = \frac{0.3}{\bar{N}}\left(\frac{\alpha A_t Z_t}{w_t}\right)^{\frac{1}{1-\alpha}} k_t$$

We shall regard this labor demand as the demand when the firm fulfill its willingess, which is indeed the second equation in (25). Given this n_t^d, the firm's willingness to supply y_t^* can be expressed as

$$\begin{aligned} y_t^* &= A_t k_t^{1-\alpha}(n_t^d \bar{N}/0.3)^{\alpha} \\ &= A_t k_t \left(\frac{\alpha A_t Z_t}{w_t}\right)^{\frac{\alpha}{1-\alpha}} \end{aligned} \tag{38}$$

Next, we consider the case that the firm's supply is constrained by the expected demand $\hat{Y}_t$, $\hat{Y}_t = X_t\hat{y}_t$. In other words, $\hat{y}_t < y_t^*$ where y_t^* is given by (38). In this case, the firm's profit maximization problem is equivalent to the following minimization problem:

$$\min \; r_t K_t^d + w_t H_t^d$$

subject to

$$\hat{Y}_t = A_t\left(Z_t\right)^{\alpha}\left(K_t^d\right)^{1-\alpha}\left(H_t^d\right)^{\alpha} \tag{39}$$

The first-order condition will still allows us to obtain (37). Using equation (39) and (37), we obtain the demand for capital K_t^d and labor H_t^d as

$$
\begin{aligned}
K_t^d &= \left(\frac{\hat{Y}_t}{A_t Z_t^\alpha}\right)\left[\left(\frac{w_t}{r_t}\right)\left(\frac{1-\alpha}{\alpha}\right)\right]^\alpha \\
H_t^d &= \left(\frac{\hat{Y}_t}{A_t Z_t^\alpha}\right)\left[\left(\frac{w_t}{r_t}\right)\left(\frac{\alpha}{1-\alpha}\right)\right]^{1-\alpha}
\end{aligned}
$$

Dividing both sides of the above two equations by X_t, we obtain

$$
k_t^d = \left(\frac{\widehat{y}_t}{A_t}\right)\left[\left(\frac{w_t}{r_t Z_t}\right)\left(\frac{1-\alpha}{\alpha}\right)\right]^\alpha \tag{40}
$$

$$
n_t^d = \left(\frac{0.3\widehat{y}_t}{A_t \overline{N}}\right)\left[\left(\frac{r_t Z_t}{w_t}\right)\left(\frac{\alpha}{1-\alpha}\right)\right]^{1-\alpha} \tag{41}
$$

Since the real rental of capital r_t will clear the capital market, we can replace k_t^d in (40) by k_t. Substituting it into (41) for explaining r_t, we obtain

$$
n_t^d = \left(\frac{0.3}{\overline{N}}\right)\left(\frac{\widehat{y}_t}{A_t}\right)^{1/\alpha}\left(\frac{1}{k_t}\right)^{(1-\alpha)/\alpha}
$$

This is the second equation in (25).

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