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Capacity Constraints, Asymmetries, and the Business Cycle

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1. Introduction

Although standard equilibrium business cycle models have the property that the entire stock of capital is used for production in each period, casual observation indicates that this is not the case in actual economies. We often observe idle plants, vacant office buildings, and other forms of unused capacity. Cooley, Hansen and Prescott (1995) study a real business cycle model where, in equilibrium, there is idle capital every period and utilization rates vary over the business cycle. They find that the cyclical properties of aggregate variables are not any different in this environment than in a standard real business cycle model. Evidence from micro data, however, indicates that cyclical capacity utilization may affect the properties of business cycles when capacity constraints are occasionally binding. For example, Bils and Klenow (1998) find that relative prices and TFP movements in highly procyclical consumption good sectors are evidence in favor of models that feature varying capacity utilization with capacity constraints that are binding in some periods.

In this paper, we study how aggregate fluctuations in a one-sector growth model with occasionally binding capacity constraints differ from fluctuations if the capacity constraints never bind. In the economy we study, if capacity constraints bind, they bind during expansions but not during downturns. Hence, the equilibrium stochastic process implied by this model is nonlinear. In this case, our model exhibits fluctuations above trend that are smaller on average than fluctuations below trend and, in addition, the model exhibits fluctuations in factor shares. Indeed, as we will show, U.S. aggregate time series also display these features. On the other hand, our theoretical results indicate that if capacity constraints are never binding, business cycles do not display these properties and are identical to those of a standard real business cycle model.

The equilibrium of a standard real business cycle models, such as those studied in Kydland and Prescott (1982), Hansen (1985) or Christiano and Eichenbaum (1992), are closely approximated by a linear stochastic dynamical system. Hence, the business cycles exhibited by these models are symmetric fluctuations around trend. The response of the economy to a positive shock (an expansion) is the mirror image of the response to an equal sized negative shock (a contraction). Still, as these papers demonstrate, these models display fluctuations that have many important statistical properties in common with fluctuations observed in actual economies.

One feature of actual time series fluctuations not displayed by these standard models is documented in section 2 of this paper: U.S. real gross national product exhibits deviations above trend that are smaller on average than deviations below trend. This property is even more pronounced for measures of hours worked. We find that, with an appropriate choice of parameter values, our model with capacity constraints displays quantitatively the same asymmetry in output as observed in U.S. GNP. This result is an implication of the endogenous propagation mechanism in the model; the exogenous shock process is symmetric. As a test of the model, we check whether, with the same parameter values, the model accounts for the more severe asymmetry in hours worked. We find that it does.

In addition, the model we study displays counter-cyclical fluctuations in labor's share of total income similar to what is observed in actual data.[1] Labor's share in most real business cycle models, and in our model if parameterized so that capacity constraints never bind, is constant. Other cyclical properties—standard deviations of aggregate variables relative to the standard deviation of output and correlations of variables with output—are not affected much by introducing binding capacity constraints. Including this feature does, however, lower our estimate of the percentage of fluctuations accounted for by technology shocks.[2]

Production in our economy requires labor and two types of capital, a type that is location specific and a type that can be freely moved across locations. Output is produced at individual plants consisting of one unit of location specific capital. In order to operate a plant, labor and

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[1] We find, as do Cooley, Hansen and Prescott (1995) for a version of their model where capacity constraints always bind, that capacity constraints lead to counter-cyclical movements in labor's share in a model with a Cobb-Douglas technology. This is desirable because technological growth is consistent with balanced growth without requiring that it be exclusively labor augmenting. Gomme and Greenwood (1995) provide an alternative explanation for varying factor shares based on insurance contracts between workers and firms.

[2] This finding is the opposite of the role played by variable capacity utilization in Burnside and Eichenbaum (1996) where occasionally binding capacity constraints are absent.

mobile capital must be assigned to the location. In particular, a minimum labor requirement must be satisfied if the plant is to be operated. Given a fixed quantity of location specific capital, and depending on the technology shock and the amount of mobile capital available, all plants may be operated (the capacity constraint is binding) or some plants may be left idle.

How often, if ever, the capacity constraint binds depends on how cheaply plants can be established. If plants are sufficiently inexpensive to build, the capacity constraint will never bind and the model behaves exactly the same as a standard real business cycle model. On the other hand, if location setup costs are sufficiently high, capacity constraints will occasionally bind and the model displays business cycle asymmetries and counter-cyclical labor's share. When the setup costs are calibrated so that the model matches the asymmetry in U.S. GNP, we find that output fluctuations are somewhat smaller than if capacity constraints never bind. In addition, as compared with the "never binding" case, hours worked fluctuates somewhat less relative to output, and productivity somewhat more. In general, however, the properties of aggregate fluctuation most commonly focused on in real business cycle studies are not affected very much by the addition of occasionally binding capacity constraints.

The existing literature studying the effects of capacity constraints and idle capital in equilibrium business cycle models include Cooley, Hansen and Prescott (1995) and Gilchrist and Williams (2000).[3] Cooley, Hansen and Prescott study an economy in which there is idle capital in all states. Unlike the current paper, capacity constraints are never binding in the sense that the fraction of plants that are left idle is always greater than zero. The fraction of idle plants does, however, fluctuate in response to technology shocks. Gilchrist and Williams study an economy with a "putty-clay" technology. There are various types of capital that differ according to the level of technology embodied in it. A given amount of labor is required to operate any particular

[3] There is a related literature where varying capital utilization is modeled as changes in the intensity with which the capital stock is used. See, for example, Burnside and Eichenbaum (1996) and Greenwood, Hercowitz and Huffman (1988). Another set of papers models variation in the workweek of capital. Examples include Bills and Cho (1994) and Kydland and Prescott (1991). Fluctuations in capital utilization do not involve letting capital remain idle for an entire period in these papers.

vintage. In any given period, some types of capital will be employed and others will not, which gives rise to varying capacity utilization.

The remainder of this paper is organized as follows. Section 2 describes the statistical properties of US data. The model economy is described in section 3, and the procedure used to solve for an equilibrium is explained in section 4. The results of our quantitative experiments are discussed in section 5.

2. Aggregate Fluctuations in U.S. Time Series

We consider here cyclical fluctuations in U.S. data on output (GNP) and hours worked from 1954:1 to 1999:3. In Figure 1, we report percent deviations from trend for GNP, where the trend is constructed using the Hodrick-Prescott filter. What we find is that deviations *below* trend are larger in absolute value than deviations above trend. For example, there are four dates at which GNP falls 4 percent below trend or more. On the other hand, output never fluctuates as much as 4 percent above trend. The average percent deviation below trend is 1.35 percent, while the average deviation above trend is 1.28 percent.

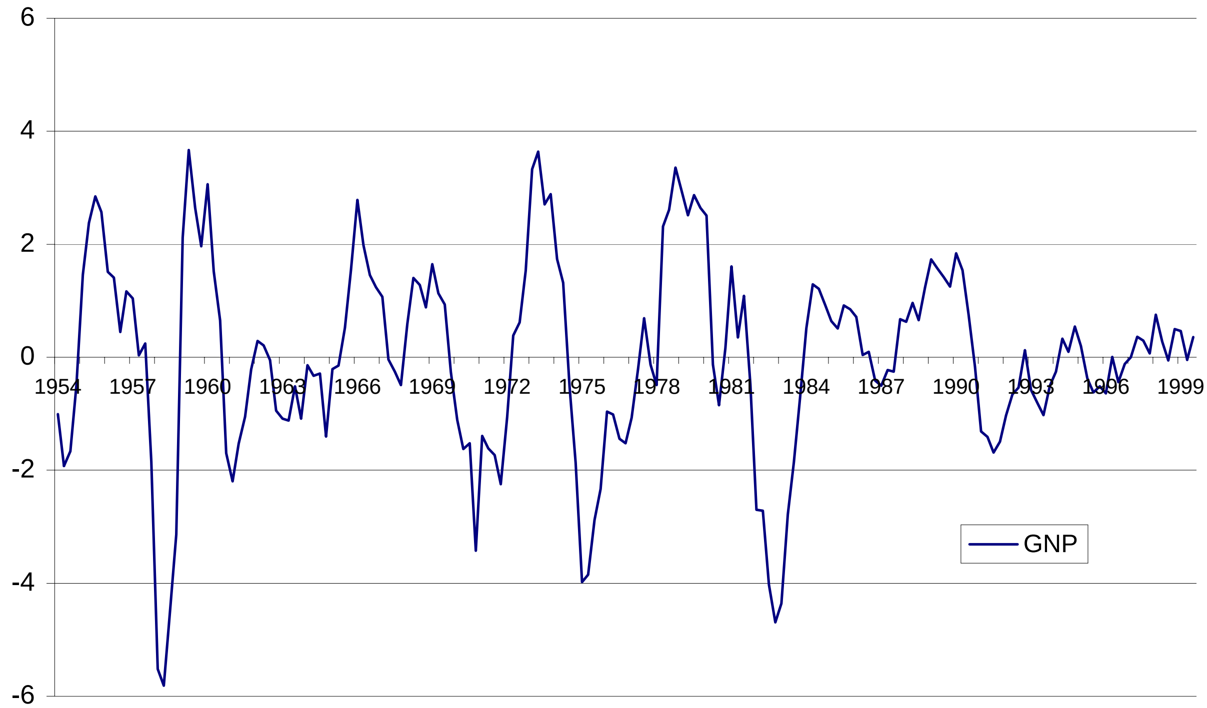

Figure 1: Percent Deviation from Trend for GNP (1954:1 – 1999:3)

The asymmetry observed in Figure 1 is more pronounced for the labor input. In Figure 2 we report deviations from trend for hours worked, based on establishment data, for the same time period. In this case, there are two dates at which hours worked falls below trend by more than 4 percent. There are no deviations above trend of this magnitude. In fact, hours worked barely reaches 3 percent above trend at one point. The average percent deviation below trend is 1.41 percent, and the average deviation above trend is only 1.12 percent.

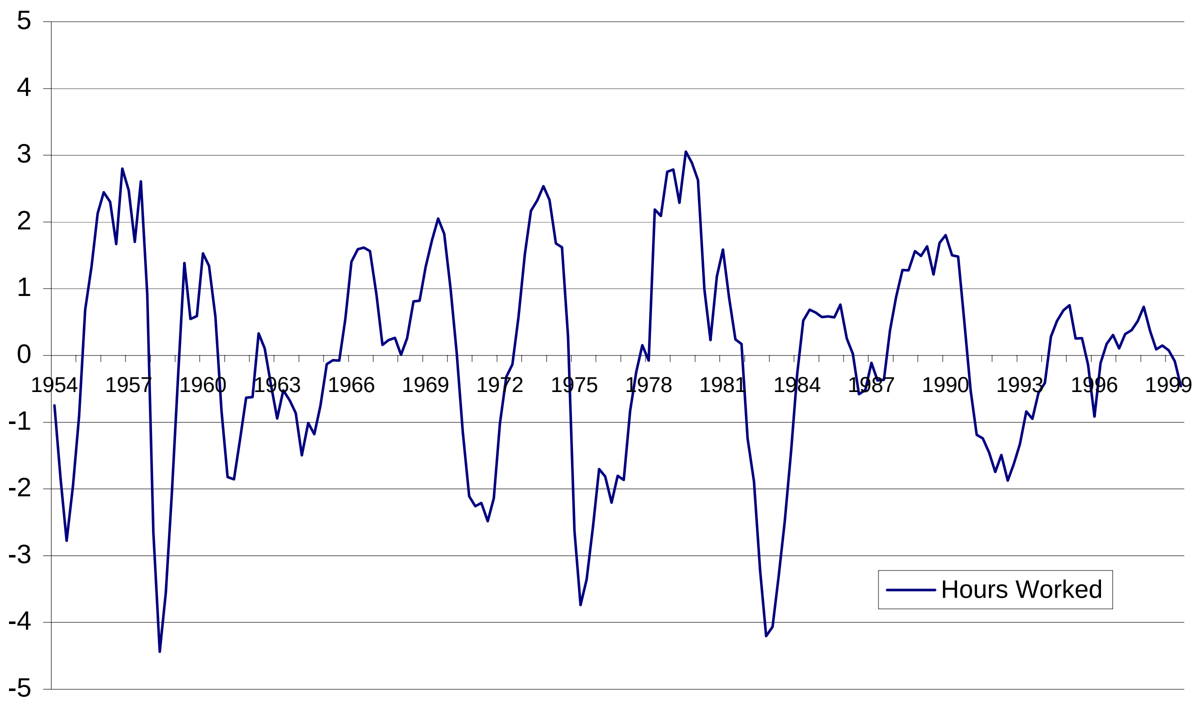

Figure 2: Percent Deviation from Trend for Hours Worked (1954:1 – 1999:3)

As discussed in the introduction, a standard real business cycle model does not display this asymmetry. In the next section, we develop a model that has the potential to exhibit this feature of U.S. time series.

3. Model Economy

Technology

The economy we study is a one-sector stochastic growth model in which output is produced from three factors of production, labor and two types of capital. One type of capital is fixed to a particular location (land and structures are examples) while the other is mobile and is assigned, along with labor, to a location each period. Assigning labor and mobile capital to a location forms an operating plant. The production function of a particular plant is given by,

$$y = \begin{cases} zk^{\theta}n^{\phi} & \text{if } n \geq \bar{n} \\ 0 & \text{otherwise} \end{cases} \tag{1}$$

In this expression, *k* is the quantity of mobile capital and *n* is the quantity of labor employed at the plant in a given period. The variable *z*, where $z \in \{z_1, ..., z_{n_z}\}$, is the realization of an aggregate technology shock that follows a n_z state Markov chain with transition matrix *P*. We assume eventual decreasing returns to scale at the plant level, so $\theta + \phi < 1$. This assumption guarantees that it is profitable to operate many small plants rather than one large one and that all operating plants will employ the same amount of capital and labor. In addition, the requirement $n \geq \bar{n}$, along with a limited population of potential workers, implies an upper bound on the total number of plants that can be operated.

In any given period there is a fixed number, *M*, of available locations that can be potentially operated. Mobile capital and labor (*k* and *n*) can be costlessly moved across locations, so these factor inputs will only be placed at operating plants. This assumption, along with the minimum labor requirement ($n \geq \bar{n}$), implies that, although mobile capital will never be idle, there may be idle location capital in some states.

Suppose that in a given period, there are *K* units of mobile capital and *M* locations. In addition, suppose that *N* units of labor are employed. The aggregate production function for this economy is given by the following expression, where x_{kn} is the number of plants operated with *k* units of capital and *n* units of labor:

$$\begin{aligned} F(K,N,M) \equiv \max_{x_{kn}} & \sum_{k,n} z k^{\theta} n^{\phi} x_{kn} \\ \text{subject to } & \sum_{k,n} k x_{kn} \leq K \\ & \sum_{k,n} n x_{kn} \leq N \\ & \sum_{k,n} x_{kn} \leq M \\ & x_{kn} = 0 \text{ for } n < \bar{n} \end{aligned} \tag{2}$$

A solution to this problem will equate marginal products across operating plants. This implies that there will be just one type of plant operated in any given period, $x_{\hat{k}\hat{n}}$. That is, all operating plants employ the same quantity of capital and labor. If $m \leq M$ is the number of locations operated, then $\hat{k} = K/m$, $\hat{n} = N/m$, and $m = x_{\hat{k}\hat{n}}$. With this change of variables, equation (2) can be rewritten as,

$$F(K,N,M) = \max_{m \le \min\left\{M, \frac{N}{\bar{n}}\right\}} z\left(\frac{K}{m}\right)^{\theta}\left(\frac{N}{m}\right)^{\phi} m. \tag{3}$$

The constraint $m \le N/\bar{n}$ in this problem follows from the requirement that the amount of labor employed at each plant, N/m, must be greater than $\bar{n}$.

The assumption that $\theta + \phi < 1$ implies that the constraint, $m \le \min\{M, N/\bar{n}\}$ will always bind in problem (3). Hence, two possibilities can arise: $M < N/\bar{n}$, in which case $m = M$ in equation (3), or $M > N/\bar{n}$, in which case $m = N/\bar{n}$. Hence, solving problem (3), we obtain,

$$F(K,N,M) = \begin{cases} zK^{\theta}N^{\phi}M^{1-\theta-\phi} & \text{if } N > M\bar{n} \\ zK^{\theta}N^{1-\theta}\bar{n}^{\theta+\phi-1} & \text{if } N < M\bar{n} \end{cases} \tag{4}$$

The aggregate production function in equation (4) can be understood in the following way. In the first case, all *M* plants are assigned physical capital and at least $\bar{n}$ units of labor. Hence, the economy is operating at "full capacity" in that all locations are operated and the shadow value of additional locations is positive. As a result, in a decentralized version of this economy with competitive markets, locations earn a share of total income equal to $1-\theta-\phi$. In the second case, an insufficient amount of labor is employed to operate all *M* locations, so the economy is operating at less than full capacity. Location capital, since it is not a scarce input, earns no rent. Instead, in this "excess capacity" case, labor earns a larger share, $1-\theta$, of income. Notice that labor's share under full capacity is ϕ, which is smaller than $1-\theta$ given our assumption that $\theta + \phi < 1$.

Resource Constraint and the Evolution of Capital

Output in our one-sector economy can be used to provide a perishable consumption good C_t, an investment good X_t, and to establish new locations $M_{t+1} - M_t$.

The evolution of the mobile component of the capital stock is standard. One unit of investment today produces one unit of capital, K_{t+1}, available for use in production the following period. The depreciation rate is denoted by δ, where $0 < \delta < 1$, so the law of motion of the mobile capital stock is given by,

$$K_{t+1} = (1-\delta)K_t + X_t\,. \tag{5}$$

In comparison, each additional unit of location capital $M_{t+1} - M_t$, which is available for production in the following period, requires that ω units of output be invested today. Location capital does not depreciate and location investments are irreversible. Hence, the resource constraint for this economy can be written,

$$C_t + X_t + \omega(M_{t+1} - M_t) \leq z_t F(K_t, N_t, M_t)\,, \tag{6}$$

where $M_{t+1} \geq M_t$.

Preferences

The economy consists of an infinitely lived stand-in household with a continuum of identical members. Each individual in the household has a utility function of the form, $E\Sigma_{t=0}^{\infty}\beta^t[\log c_t + v(l_t)]$, where *v* is an increasing function of leisure. Individuals in the household are endowed with one unit of time each period that can be allocated to work or leisure. Labor is assumed to be indivisible, meaning that individuals work some parametrically given shift-length or not at all. In addition, the household has access to a lottery mechanism for allocating time use among its members. Under these assumptions, the aggregate preferences of the household are summarized by the following utility function,

$$E\sum_{t=0}^{\infty}\beta^t(\log C_t - \gamma N_t)\,, \quad 0 < \beta < 1,\ \gamma > 0\,, \tag{7}$$

where N_t is the fraction of household members employed in period *t*.[4]

4. Computing Equilibrium Allocations

Given that there are no distortions in this economy, equilibrium allocations are equivalent to those that would be chosen by a social planner who maximizes (7) subject to (4) - (6). This problem has the property that, once a sufficient amount of location capital has been accumulated,

[4] See Rogerson (1988) or Hansen (1985) for details.

no further investments will be made in *M*. This follows from the fact that *M* does not depreciate, that the technology shock *z* has bounded support, and the fact that we have abstracted from population growth. We suppose that this economy has been operating for a long time, so restrict ourselves to computing equilibrium allocations that are relevant once this sufficient quantity of *M* has been accumulated.[5]

This can be done in two steps. First, optimal decision rules for the social planner's problem given an arbitrary fixed value of *M* are computed. Second, given these decision rules, one can compute the constant value of *M* that would hold in a stationary solution to the planner's problem.[6]

The following is the dynamic program solved by a social planner given a fixed value of *M*:

$$
\begin{aligned}
&v(z,K;M) = \max_{N,K'}\left\{\log C - \gamma N + \beta \sum_{z'} P(z,z')v(z',K';M)\right\} \\
&\text{subject to} \\
&\qquad C + K' = (1-\delta)K + \begin{cases} zK^{\theta}N^{\phi}M^{1-\theta-\phi} & \text{if } N > M\bar{n} \\ zK^{\theta}N^{1-\theta}\bar{n}^{\theta+\phi-1} & \text{if } N < M\bar{n} \end{cases} \\
&\qquad 0 \le N \le 1
\end{aligned}
\tag{8}
$$

The solution to this problem is a set of decision rules of the form, $N = \mathrm{N}(z,K;M)$, $K' = \mathrm{G}(z,K;M)$, and $C = \mathrm{C}(z,K;M)$.

The value of *M* in a stationary solution to the planner's problem is determined by setting the maximal marginal value of an additional location across all possible states equal to the cost of establishing the location, ω. The marginal value of an additional location given the current

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[5] The result that, in the limit, investment in location capital is zero in all states generalizes to a balanced growth version of this economy with exogenous technological progress. In particular, if we were to replace equation (1) with the same technology premultiplied by $\rho^{(1-\theta)t}$, where $\rho > 1$, the balanced growth path would involve output, C_t, X_t, and K_t all growing at the rate $\rho - 1$. The variables M_t and N_t are constant along this balanced growth path. Intuitively, N_t is constant because the population is fixed and *M* only earns rents if $N_t > M_t\bar{n}$, where $\bar{n}$ is a constant. Hence, *M* cannot, in the limit, grow at a rate higher than the *N*. Of course, if there is population growth, *M* does grow and ongoing investment in location capital would be undertaken.

[6] Alternatively, we can back out the fixed cost ω that would induce the value of *M* used when computing the decision rules.

state, $v_M(z,K,M)$, is the present discounted marginal product of the location over its infinite lifetime. This can be found by solving the following functional equation:

$$v_M(z,K,M)=\sum_{z'}Q(z,z')\{z'F_3(K',N(z',K';M),M)+v_M(z',K',M)\}$$

In this expression, $K'=G(z,K;M)$ and F_3 is the partial derivative with respect to *M* of the function *F* in equation (4). The stochastic discount factor employed by the social planner, *Q*, is given by,

$$Q(z,z')=\beta P(z,z')\frac{\mathrm{C}(z,K;M)}{\mathrm{C}(z',\mathrm{G}(z,K;M);M)}.$$

The value of *M* in a stationary solution to the planner's problem is determined as follows, where E_M is the ergodic subset of the state space implied by the solution to problem (8):

$$\omega=\sup_{\{z,K\}\in E_M} v_M(z,K,M) \tag{9}$$

Solution Method

To solve the planner's problem (8), we use a version of value iteration to compute piecewise linear approximations to the optimal decision rules.[7] In particular, a set of values for the capital stock with n_K elements is chosen and we let Ω be the set $\{z_1,...,z_{n_z}\}\times\{K_1,...,K_{n_K}\}$.[8] We then chose initial guesses for the values of the decision rules at each point in Ω, $N_0(z,K)$ and $G_0(z,K)$, that satisfy the constraints in problem (8). We also chose a function $v_0(z,K)$ that assigns a real number to each element of Ω. We then iterate on the following mapping *N* times (we set *N* to be 100), setting $\tilde{v}_0(z,K)=v_0(z,K)$:

$$\tilde{v}_{i+1}(z,K)=\log C-\gamma N+\beta\sum_{z'}P_{zz'}\tilde{v}_i(z',K'),\ \text{for all}\ (z,K)\in\Omega, \tag{10}$$

where $K'=G_0(z,K)$, $N=N_0(z,K)$, $C=zF(K,N,M)+(1-\delta)K-K'$, and *M* is taken as a parameter.

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[7] Our solution procedure is similar to the Howard improvement algorithm described in Ljungqvist and Sargent (2000).

[8] We experiment to insure that the upper and lower bounds of the capital stock grid are chosen so that the interval $[K_1,K_{n_K}]$ includes all points that have positive probability in the invariant distribution implied by the solution to the dynamic program.

The next step is to compute functions $N_1(z,K)$ and $G_1(z,K)$, for each $(z,K)\in\Omega$, as follows:

$$\{N_1(z,K),G_1(z,K)\} = \arg\max_{N,K'}\{\log(zF(K,N,M) + (1-\delta)K - K') - \gamma N + \beta\sum_{z'} P_{zz'}\tilde{v}_N(z',K')\} \tag{11}$$

We use linear interpolation to evaluate $\tilde{v}_N$ at values of K' not in Ω. In addition, we define $v_1(z,K)$ to be the maximized value of the function on the right side of (11).

Using the functions N_1, G_1 and v_1 in place of N_0, G_0 and v_0, these steps are repeated to obtain N_2, G_2 and v_2. We continue in this manner until successive iterations converge. For each $z\in\{z_1,...,z_{n_z}\}$, we form piecewise linear decision rules by linearly interpolating between points on the grid $\{K_1,...,K_{n_K}\}$.

5. Findings

Calibration

Values must be assigned the parameters of the model, β, γ δ, θ, ϕ, ω, and $\bar{n}$. The first two are preference parameters and the rest technology parameters. In addition, values must be chosen for the parameters of the technology shock process. These include values for $\{z_1,...,z_{n_z}\}$, and the elements of the transition matrix, *P*.

Following Cooley and Prescott (1995), β and δ are chosen so that the model economy exhibits the same average capital to output and investment to output ratios as observed in the postwar U.S. economy. Similarly, γ is chosen so that the employment rates in the actual and artificial economies are the same.

The technology shock process was calibrated so that it approximates the technology shock process employed in Cooley and Prescott (1995). In that paper, an autoregressive process is employed, where $\log z_{t+1} = \rho\log z_t + \varepsilon_{t+1}$, and $\varepsilon_{t+1} \sim N(0,\sigma_\varepsilon^2)$. In this paper, the technology shock process is an n_z-state Markov chain. We use Tauchen's (1986) method, with $n_z = 15$ and

$\{z_1, ..., z_{n_z}\}$ evenly spaced between ± 2 standard deviations from the mean, to compute the transition matrix, *P*.[9]

In the model studied, there is a one to one relationship between the value of ω and the value of the constant endogenous variable, *M*. implied by equation (9). Hence, we can simplify solving for an equilibrium by treating *M* as a parameter and the value of ω becomes irrelevant. It turns out, however, that only the value of the product, $M\bar{n}$, matters for the quantitative properties of the model, not the values of the parameters individually. This makes intuitive sense since it is this product that the plays the key role in the aggregate technology described in equation (4). In our experiments we consider two alternative values for this product, which determines how often in equilibrium (for a given shock process) the capacity constraint binds.

The final two parameters, θ and ϕ, determine the share of income earned by each of the three factors of production. We choose these parameters so that labor's share is between .61 and .62, and fluctuates between these values depending on whether the economy is at full or excess capacity.

Given these considerations, we have employed the following values for the parameters of the model:

[9] For computational reasons, the number of states, n_z, was kept to a minimum. It was set large enough, however, so that, given a common set of random shocks, simulated time series from the Markov chain and from the autoregressive process being approximated appear similar when plotted together. The two series are simulated by choosing a common initial value from the set $\{z_1, ..., z_{n_z}\}$ and by drawing a sequence of random numbers using a uniform random number generator. The inverse probability distribution function for the normal distribution was used to compute a sequence of ε's, which were then used to obtain a sequence of *z*'s from the autoregressive process. Using the transition matrix *P*, the same random numbers were used to generate a sequence of *z*'s from the Markov chain.

Parameter Values						
β	γ	δ	θ	ϕ	σ	ρ
.99	2.667	.019	.38	.61	.007	.95

Quantitative Experiments	
Experiment	$M\bar{n}$
1. Capacity constraint never binds.	.5
2. Calibrated to asymmetry in output fluctuations.	.315

Results

Two experiments are conducted which differ from each other according to the value of $M\bar{n}$, or equivalently, the value of ω. The first, which corresponds to a standard real business cycle model, is one in which the economy is unconstrained in all states ($M\bar{n} = .5$). In the second experiment, the economy is calibrated so that the asymmetry in output fluctuations observed in the U.S. data is exhibited by the model economy ($M\bar{n} = .315$).

In each experiment, 100 simulations of 183 periods each are computed.[10] For each simulation, we compute the cyclical properties of actual and artificial data by logging the series (except labor's share, which is already expressed as a rate) and applying the Hodrick-Prescott filter. The means of various summary statistics over the 100 simulations are reported in Table 1, along with the same statistics computed from the U.S. data.

In the first experiment, since the capacity constraint is never binding, fluctuations above trend are the same size (in absolute value) on average as fluctuations below trend. In particular, output deviations above and below trend are equal to 1.48 percent and -1.48 percent, respectively. As discussed in section2, in U.S. postwar data, average deviations of output above trend are equal to 1.28 percent and -1.35 percent below trend. In our second experiment, by

[10] We compute simulations of 183 periods since this is the number of quarters in the U.S. data sample we use in section 2 and in Table 1.

choosing $M\bar{n} = .315$, average output deviations above and below trend are equal to 1.25 and –1.37, which is close to what is observed in the U.S. economy.

As a test of our model, we check whether, with the same parameter values, the model accounts for the more severe asymmetry observed in hours worked. As reported in section 2, the average percent deviation of hours worked above trend in U.S. data is 1.12 and the average percent deviation below trend is –1.41. The corresponding numbers obtained from the second experiment are 1.15 and -1.41. Hence, the asymmetry displayed by cyclical fluctuations in hours worked is quite similar in the actual and artificial economies.

Table 1 Business Cycle Properties of U.S. Data and Model Economies

Series	**Percent Standard Deviation**			**Std. Dev. Relative to Output**			**Correlation with Output**		
	Data	Exp. 1	Exp 2	Data	Exp 1	Exp. 2	Data	Exp. 1	Exp. 2
Output	1.73	1.83	1.63	1.00	1.00	1.00	1.00	1.00	1.00
Consumption	0.82	0.41	0.38	0.47	0.23	0.23	0.69	0.85	0.85
Investment	5.01	6.41	5.76	2.89	3.50	3.53	0.88	0.99	0.99
Capital Stock		0.40	0.35		0.22	0.22		0.01	0.01
Total Hours	1.57	1.50	1.23	0.91	0.82	0.75	0.86	0.99	0.96
Labor per Plant		0.00	0.13		0.00	0.08		0.00	0.20
Productivity	0.90	0.41	0.55	0.52	0.23	0.34	0.43	0.85	0.81
Labor's Share	0.46	0.00	0.32	0.27	0.00	0.19	-0.33	0.00	-0.52

Note: Data is from 1954:1 to 1999:3
In Experiment 1, capacity constraint is never binding (M*nbar = .5).
In Experiment 2, capacity constraint is sometimes binding (M*nbar = .315).

Additional summary statistics showing the cyclical properties of the actual and artificial economies are reported in Table 1. In Experiment 1 there is no variation in labor per plant or in labor's share. When $M\bar{n}$ is reduced in the second experiment, the size of the fluctuations in labor per plant and labor's share increase. Fluctuations in labor's share are counter-cyclical as in the data. The standard deviation of productivity also increases. The size of the fluctuations in output, hours, consumption and capital all decrease, however, when the capacity constraint binds occasionally. In addition, the variability of hours worked and productivity relative to output differ across the two experiments. In particular, the standard deviation of hours worked divided by the standard deviation of output falls from .82 to .75 and the standard deviation of productivity divided by the standard deviation of output increases from .23 to .34.

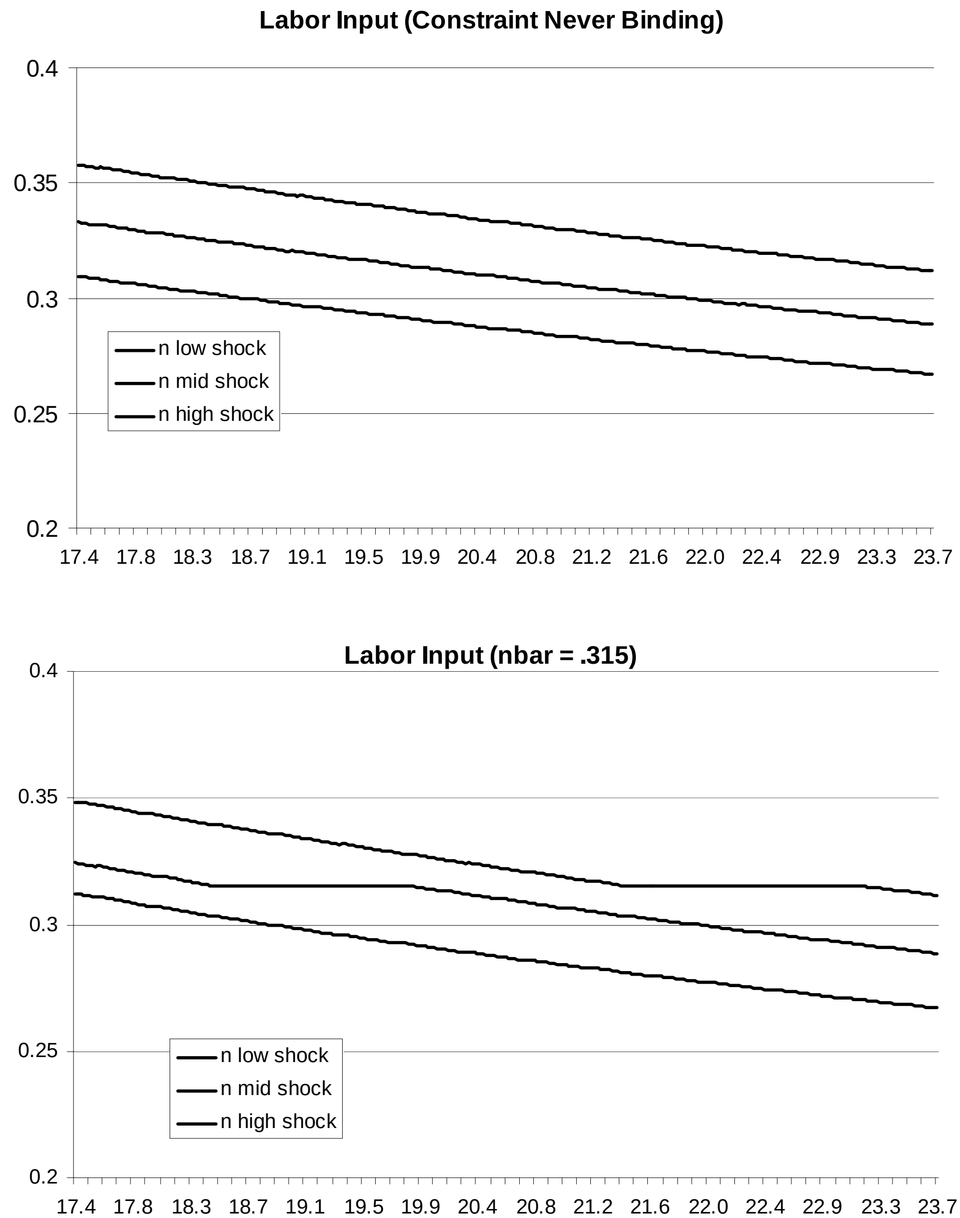

Figure 3

To illustrate why the results differ across the two experiments, the decision rule for N is plotted as a function of the capital stock for three different values for the technology shock in Figure 3. The top and bottom panels show decision rules from the first and second experiments, respectively. The decision rules for Experiment 1 are essentially linear and are parallel to each other. This means that a given change in z will lead to the same size change in N independent of the size of the capital stock. This is a feature shared by most standard real business cycle models.

This is not true for the second experiment. In this case the response of hours worked to a given change in *z* will be different depending on the size of the capital stock. Impulse-response functions are not linear and expansions and contractions are not necessarily mirror images of each other. In particular, the shape of these decision rules is the reason that the labor input does not exceed the kink point ($M\bar{n}$ -- this is the flat part observed in the decision rules of the bottom panel) as often in Experiment 2 as it does in Experiment 1. This is why expansion get "cut off" and are smaller in terms of absolute deviations from trend than are contractions.

5. Conclusion

To be added.

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