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Capital Utilization, Maintenance Costs and the Business Cycle

Omar LICANDRO, Luis A. PUCH *

ABSTRACT. – In this paper, we analyze the role played by capacity utilization and maintenance costs in the propagation of aggregate fluctuations. To this purpose we use an extension of the general equilibrium stochastic growth model that incorporates a depreciation technology depending upon both capital utilization and maintenance costs. In addition, we argue that maintenance activity must be countercyclical, because it is cheaper for the firm to repair and maintain machines when they are stopped than when they are being used. We show that the propagation mechanism associated with our technology assumption is quantitatively important: the countercyclicality of maintenance costs contributes significantly to the magnification and persistence of technology shocks.

Utilisation du capital, coûts de maintenance et cycle économique

RÉSUMÉ. – Dans ce papier, nous analysons le rôle du taux d'utilisation du capital et des coûts de maintenance dans la propagation des fluctuations agrégées. Dans ce but, nous proposons une extension du modèle de croissance stochastique d'équilibre général, qui incorpore une technologie de dépréciation qui dépend du taux d'utilisation et des coûts de maintenance. En plus, nous supposons que les activités de maintenance doivent être contra-cycliques, parce qu'il est moins cher pour les entreprises de réparer et entretenir les machines quand elles sont arrêtées que quand elles sont utilisées. Nous montrons que le mécanisme de propagation associé à nos hypothèses technologiques est quantitativement important : le comportement contra-cycliques des coûts de maintenance contribue de manière significative à l'amplification et à la persistance des chocs technologiques.

* O. LICANDRO: FEDEA ; L.A. PUCH: Universidad Complutense de Madrid.
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1 Introduction

One of the main contributions of KYDLAND and PRESCOTT [1982] is that productivity shocks can account for a great part of the variability of output, where the Solow residual is normally used as a measure of the shocks to technology. Since then, the scope of this claim and the related measure of productivity shocks have been extensively discussed. In a recent paper investigating the sensitivity of the Solow residual to labor hoarding behavior, BURNSIDE *et al*. [1993] argue that "*…the variance of innovations to technology is roughly 50 percent less than the one implied by standard real business cycle models*". Moreover, BURNSIDE *et al.* also show that labor hoarding substantially reduces the variability of output the model can account for, because the propagation mechanism implicit in the labor hoarding assumption is quantitatively very low. A main question must then be addressed: if the variability of technology shocks is significantly smaller than the Solow residual, artificial economies should incorporate quantitatively important propagation mechanisms to restate the role of technology shocks in the propagation of aggregate fluctuations in actual economies. In this sense, a promising research project is to investigate the economic mechanisms through which technology shocks propagate and magnify aggregate fluctuations, and to quantify the extent to which these propagation mechanisms replicate certain features of the data. In addition, if it turns out that the strength of the propagation mechanisms investigated is quantitatively important, this will provide support for the view that fluctuations in technical progress can account for a large fraction of observed volatility in aggregate output.

In this paper, we analyze the role played by capital utilization and maintenance costs in propagating technology shocks over the business cycle.[1] As KYDLAND and PRESCOTT [1988] pointed out, capital may be underutilized over the business cycle insofar as hours of labor services are proportionate to the workweek of capital. A next step in this direction is in BILS and CHO [1994], where the capital utilization rate is assumed to depend on effective hours per worker. An alternative argument is the one in GREENWOOD *et al.* [1988]: In an economy where production depends on the effectively utilized capital, they impose the *depreciation-in-use* assumption (the depreciation rate is an increasing function of the capital utilization rate) to obtain a procyclical utilization rate. BURNSIDE and EICHENBAUM [1996] and FINN [1995] have developed this idea. Both papers are mainly concerned with the propagation mechanisms behind capital utilization: a procyclical capital utilization rate magnifies and propagates the impact of environmental shocks, allowing the observed volatility of output to be reproduced with a smaller volatility of the technology shock.[2] As a direct consequence of this assumption, the depreciation rate is also procyclical.[3]

1. LICANDRO *et al.* [1998] study the role on growth of utilization and maintenance.

2. Alternative approaches to analyze the role of capital utilization rates on the business cycle are in COOLEY *et al.* [1995] and FAGNART *et al.* [1999].

3. Survey data suggest that both depreciation and utilization are procyclical. However, this evidence is not conclusive. As stated by SHAPIRO [1989], utilization rates are partially built on production indicators. Moreover, information on depreciation is mainly obtained from accounting data so that it is contaminated by tax considerations.

The key assumption in this paper is that depreciation depends not only on the utilization rate but also on *maintenance costs*, since machines are better preserved when firms engage in repair and maintenance activity. Moreover, we argue that maintenance should be countercyclical because it is cheaper for the firm to repair and maintain machines when they are stopped than when machines are being used. Implicitly, we assume that the opportunity cost to maintain is procyclical: the cost of renouncing to profits is lower in recessions, and thus more resources can be reallocated to maintenance activities. This claim is consistent with the findings in FAY and MEDOFF [1985], who estimate that during recessions firms devote around a 2 percent of total hours to maintenance activities. We formalize this by assuming that the depreciation function has a positive cross derivative with respect to maintenance and utilization.

This paper shows that the propagation mechanism associated with the maintenance costs assumption is quantitatively more important than under the depreciation-in-use assumption: the volatility of output is almost 1.85 times greater than the volatility of the innovation to technology, whereas in BURNSIDE and EICHENBAUM [1996] it is nearly 1.47. It is worthwhile noting that in standard real business cycle models the volatility of output and the volatility of technology shocks are approximately of the same order of magnitude. This seems to be a strong evidence in favor of countercyclicality of maintenance costs as a quantitatively convincing propagation mechanism of technology shocks.

One important feature of this family of models is that only *effectively utilized* units of capital and labor matter for production. Consequently, technological shocks cannot be measured by the Solow residual, which by definition does not take into account the variability of factor utilization. For this reason, the conventional Solow residual must be distinguished from the model-based measure of the technology shock. However, there are no reliable data on the intensity of factor utilization. As in BURNSIDE *et al*. [1993] and BURNSIDE and EICHENBAUM [1996], to have a measure of technology shocks consistent with the varying utilization assumption we use the model to generate the series for the unobserved variables.

The model is presented in Section 2. Section 3 is devoted to an intuitive explanation of the propagation mechanism behind utilization and maintenance. Calibration is in Section 4 and the main findings are in Section 5. Section 6 concludes.

2 The Model

We consider an enhanced version of BURNSIDE and EICHENBAUM [1996] with the added feature of maintenance costs. More precisely, capital utilization, endogenous depreciation and maintenance costs are analyzed in a modified version of HANSEN's [1985] indivisible labor model augmented to incorporate government consumption as in CHRISTIANO and EICHENBAUM [1992] and labor hoarding as in BURNSIDE *et al*. [1993]. It is assumed that using capital increases the rate at which capital depreciates. However, depreciation can be reduced by maintenance. The depreciation rate δ_t is a function of the maintenance cost rate m_t (*i.e.*, total maintenance costs divided by the capital stock) and the utilization rate u_t: $\delta_t = \delta(m_t, u_t)$, decreasing in m_t, increasing in u_t and convex.

The economy is populated by a large number of everlasting individuals that we normalize to one. The social planner orders individuals' stochastic sequences of consumption and leisure in order to maximize the expected utility function of the representative individual:

$$E_0 \sum_{t=0}^{\infty} \beta^t [\ln(C_t) + \theta\, n_t \ln(T - \psi - e_t\, l) + \theta(1 - n_t)\ln(T)] \tag{1}$$

where β is the time-discount factor; C_t is private consumption; θ is a positive scalar; n_t is the fraction of individuals at work at time t; T is an individual's endowment of productive time; ψ is a fixed cost that each individual must incur to go to work; and $e_t\, l$ is the total effective work an individual cares about, where e_t denotes the level of effort and l denotes the shift length of hours an individual stays at work. The linear specification of labor disutility builds upon ROGERSON's [1988] lotteries.

We assume that aggregate output at time t, Y_t, depends on the total amount of effective capital, $K_t u_t$, and on total effective hours of work, $n_t l e_t$, through a COBB-DOUGLAS production function. Additionally, maintenance costs must be deduced from production :[4]

$$Y_t = (K_t\, u_t)^{(1-\alpha)}\, (n_t\, l\, e_t\, X_t)^{\alpha} - m_t\, K_t \tag{2}$$

where X_t is the aggregate state of technology which evolves according to:

$$X_t = X_{t-1} \exp\{\gamma + \upsilon_t\}. \tag{3}$$

Here υ_t is an *i.i.d.* process with zero mean and standard deviation σ_υ.

The aggregate resource constraint is given by

$$C_t + K_{t+1} - (1 - \delta(m_t, u_t))\, K_t + G_t \leqslant Y_t \tag{4}$$

G_t denotes the time t government consumption. For simplicity and consistent with our balanced growth assumption, we assume that G_t is an exogenous stochastic process that evolves according both to a component which grows at the same rate as the labor augmenting technical progress X_t and to a stochastic component, *i.e.*,

$$G_t = X_t g_t \tag{5}$$

where g_t follows the law of motion

$$\ln(g_t) = (1 - \rho)\ln(\bar{g}) + \rho \ln(g_{t-1}) + \mu_t \tag{6}$$

4. Maintenance activity, like any other adjustment cost activity, could be internal or external. In any case, the central planner must deduct it from total production before assigning output to consumption, investment or government expenditures.

Here $\ln(\bar{g})$ is the mean of the stationary component of government consumption, $\ln(g_t)$, $|\rho| < 1$ and μ_t is the innovation to $\ln(g_t)$ which is assumed to follow an *i.i.d.* process with zero mean and standard deviation σ_μ.

The social planning problem of this economy is to maximize (1) subject to (2)-(6) and given K_0, X_{-1} and g_{-1}, by choice of contingency plans for $\{Y_t, C_t, K_{t+1}, u_t, n_t, e_t, m_t : t \geqslant 0\}$. This problem is not completely specified until we specify the planner's information set at time t. Following BURNSIDE *et al*. [1993] we assume that n_t is chosen before X_t and g_t are seen. This formulation allows for a simple form of factor hoarding in the sense that once capital and employment decisions are made, firms adjust to observed shocks by varying labor and capital effort.

To achieve a stationary representation we normalize all variables by the state of technology, X_t,

$$c_t = \ln(C_t/X_t), k_{t+1} = \ln(K_{t+1}/X_t), \text{ and } y_t = \ln(Y_t/X_t)$$

Note that g_t, m_t, u_t, e_t and n_t are stationary variables. Here we use KING *et al.* [1988] log-linear modification of the solution procedure proposed by KYDLAND and PRESCOTT [1982] to obtain an approximate solution to the planning problem.

3 The Propagation Mechanism

It is worth noting that the term *Propagation Mechanism* embodies two distinct but related phenomena: *amplification and persistence*. We will say that a propagation mechanism amplifies when the standard deviation of output is larger than the standard deviation of the shock. We will refer to a persistent propagation mechanism as one in which the serial correlation of output growth is higher than the serial correlation of shocks.[5] In this section we point out why this model displays amplification. The analysis of persistence is somewhat immediate and it is postponed to section 5.3.

The amplification component of the propagation mechanism associated with utilization and depreciation can be understood by analyzing the following subset of the optimal conditions of the planner's problem:

$$-\delta_m(m_t, u_t) = 1 \tag{7}$$

$$(1-\alpha)\left(\frac{Y_t}{K_t} + m_t\right) = \delta_u(m_t, u_t)\, u_t \tag{8}$$

$$Y_t = (u_t K_t)^{1-\alpha}(n_t l e_t)^{\alpha} X_t^{\alpha} - m_t K_t \tag{9}$$

5. For instance, if the shock processes are white noise, then the propagation mechanism is persistent if some of the autocorrelation coefficients of the first differences of output are significantly distant from zero.

In equation (7), at the optimum, the marginal cost of increasing the maintenance rate, which is equal to one, must be equal to the reduction on the depreciation rate that it generates. The optimal condition for the utilization rate, equation (8), states that the marginal productivity of utilization must be equal to the increase in the depreciation rate that it produces. Equation (9) comes from the previous section and represents technology.

The Cyclical Behavior of Maintenance Costs

The sign of the depreciation function's cross derivative determines the comovement of the utilization rate and the maintenance rate over the cycle. We can see it by differentiating (7):

$$\frac{\mathrm{d}m_t}{\mathrm{d}u_t} = -\frac{\delta_{mu}}{\delta_{mm}}.$$

In the following it is assumed that $\delta_{mu} > 0$, which implies that maintenance costs move in the opposite direction to the utilization rate. As has been stated in the Introduction, we argue that the maintenance activity must be countercyclical because it is cheaper for the firm to repair and maintain machines when they are stopped than when machines are being utilized.

The Cyclical Behavior of the Utilization Rate

We derive the procyclical behavior of the utilization rate from the optimal rule for utilization (8). The main argument is straightforward, an increase in output should be compensated by an increase in the utilization rate, given that the right hand side is increasing in u. In the general case, since (8) depends on the maintenance rate, maintenance activity could in very extreme situations more than compensate for this direct effect. However, all the calibrations we analysed exclude this extreme situations. In particular, we will refer to the depreciation-in-use assumption as the case in which the depreciation function depends only on the utilization rate. In this case, the utilization rate is always procyclical. Even though capital utilization rates are poorly measured, there is empirical evidence that the utilization of capital is procyclical.[6]

The Amplification Mechanism

Equation (9) suggests that procyclical utilization rates and countercyclical maintenance costs magnify the effect of productivity shocks. The argument can be stated intuitively as follows: a positive productivity shock will increase output, since utilization is procyclical and maintenance is countercyclical, they will generate an additional increase in output amplifying the initial effect of the technology shock.

Even though employment is predetermined, effort is an endogenous variable. For this reason, it is not possible to have a precise characterization of the parameter conditions under which the amplification mechanism operates

6. Shapiro [1989] indicates that the utilization rates from the surveys are procyclical even though they are less cyclical than production. Bresnahan and Ramey [1993] provide evidence of the underutilization of capital in the automobile industry following the oil shocks.

through utilization and maintenance. Consequently, only the simulations of the model can allow us quantitatively to evaluate the amplification mechanism associated with capital utilization and maintenance costs. However, as in BURNSIDE *et al.* [1993], we expect that the variability of effort has no significant effect on the amplification of technology shocks.

4 Calibration

We calibrate our model economy following the methods described in COOLEY and PRESCOTT [1995], and we use the set of measurements constructed by CHRISTIANO [1988] as our basic data source. In addition, we make use of the US National Income and Product Accounts (NIPA) data to calibrate the capital income share in output. The official measurements are rearranged and augmented to correspond both to the structure of our model economy, and to the definitions and sample period of the variables in our basic data source.[7]

Next, we give some details on the data set we use, then, we discuss our selection of parameter values and we restrict the depreciation function to a parametric specification. Finally, we describe our strategy to empirically implement our model economy.

4.1 Data

The data set from CHRISTIANO [1988] covers the period 1955:3-1984:1 for the US economy, and includes private consumption, C_t, gross investment, I_t, government consumption, G_t, gross output, Y_t, hours worked, h_t, and the official capital stock, $\bar{K}_t$.[8] In addition, to construct our measure of the capital share in output we use annual data for the period 1955-1984 and we follow the definition of variables discussed in COOLEY and PRESCOTT [1995] while maintaining consistency with the definition of variables in CHRISTIANO [1988]. Essentially this implies considering consumer durables as capital goods and then adding the imputed flow of services of consumer durables to measured output. This is equivalent to the output measure in our basic data source.

4.2 Model Parameters

Table 1 reports the calibrated economy's parameter values. The number in parentheses accompanying each entry of Table 1 indicates the calibration

7. The definition of variables reported in CHRISTIANO [1988] is close to that discussed in COOLEY and PRESCOTT [1995]. The only difference is that CHRISTIANO's definition of output does not include the imputed flow of services from government capital.

8. All series were converted to per-capita terms using an efficiency-weighted measure of the population to abstract from demographic changes in the work force. For further details on this data set, see CHRISTIANO [1987]. The time series for hours worked, h_t, is that constructed by HANSEN [1985]. Note, finally, that to be consistent with our model assumptions we construct a model-based measure of the capital stock since the official capital stock series were obtained from the Survey of Current Business (SCB) data which are mainly based on straight-line depreciation assumptions.

TABLE 1

Calibrated Economy Parameters. Criteria: (1) external information, (2) sample averages on data, (3) relations at the steady state, (4) second-moment properties, (5) stochastic properties of the processes

Preferences			
Individual's time endowment	(1)	T	1 369 hours per quarter
Annual real interest rate	(1)	r	3%; $\beta = 1.03^{-1/4}$
Fixed cost of going to work	(1)	ψ	60 hours
Steady state employment	(2)	$\bar{n}$	0.9863
Shift length	(3)	l	324.7775 hours
Preference for leisure	(3)	θ	3.5195
Steady state effort	(3)	$\bar{w}$	1
Technology			
Average labor share	(1)	$\tilde{\alpha}$	0.6351
Average utilization rate	(1)	u	0.82
Capital-output ratio	(2)	k/y	10.6096
Employment elasticity	(3)	α	0.6236
Steady state maintenance	(3)	$\bar{m}$	0.0017
Shares of output			
Consumption share	(2)	c/y	0.5545
Investment share	(2)	i/y	0.2678
Government share	(2)	g/y	0.1778
Depreciation function			
Average depreciation rate	(2)	$\bar{\delta}$	0.0213
Elasticity with respect to *u*	(3)	ϕ	0.6251
Elasticity with respect to *m*	(3)	μ	0.0822
Cross derivative	(4)	ν	0.0051
Shock proccesses			
Average rate of growth	(2)	γ	0.0040
Std. dev. of Tech. shock	(5)	σ_v	0.0075
Correlation of Gov. exp.	(5)	ρ	0.9398
Std. dev. of Gov. shock	(5)	σ_μ	0.0151

criterium amongst: (1) external information, (2) sample averages on data, (3) relations at the steady state, (4) second moment properties, and (5) stochastic properties of the processes. We discuss below most of the parameter values corresponding to (1), (2) and (3). We discuss the calibration of the depreciation function in section 4.3 and the calibration of the stochastic processes in section 4.4.

External Information

We select our model period as a quarter of a year. We fixed the individual's time endowment, T, at 1369 hours per quarter and a real interest rate of 3 percent (annually). Following BURNSIDE *et al.* [1993] we assume a fixed cost to go to work, ψ, of 60 hours per quarter. Following COOLEY *et al.* [1995] we calibrate the steady state utilization rate to the average rate implied by the US official series.

As has been stated above, we first calibrate the labor income share in output. Note that our model specification implies that $\tilde{\alpha} = \alpha/(1-\tilde{m})$, where $\tilde{m}$ is the ratio of maintenance costs to ouptut and $\tilde{\alpha} = 0.6351$is the value that we obtained from the US NIPA data (and some additional sources). Thus, incorporating maintenance costs into the analysis drives a wedge between the employment elasticity α and the labor share $\tilde{\alpha}$.

Sample Averages on Data

Next we turn to our reference data set to calibrate the shares of the components of output, the capital-output ratio, the average rate of growth and the average depreciation rate to those average values implied by the data. In addition, the shift length of l hours was chosen so that the non-stochastic steady state value of work effort equals one, and the average employment rate $\bar{n}$ was chosen so that steady state average hours, $\bar{h} = \bar{n}l$, match the average of HANSEN's hours series.

Relations at the Steady State

With this selection of parameters we can solve the non-stochastic steady state of our model for the rate of maintenance costs, $\bar{m}$, the elasticity of marginal depreciation, $\delta_u \bar{u}$, the preference for leisure, θ, and the shift length, l. The selection for $\bar{u}$ and the optimal condition for maintenance costs imply the δ_u and δ_m parameter values.

Observation

In a standard RBC model, the steady state marginal productivity of capital must equal $r + \bar{\delta}$. Then, it is not possible to select values for α, β and k/y independently. COOLEY and PRESCOTT [1995] calibrate α and k/y to actual data and then use the Euler equation for capital to compute β, *i.e.*: r. CHRISTIANO and EICHENBAUM [1992], choose a value for β and then estimate α so that the model capital-output ratio matches the corresponding sample first moment of the data. The existence of maintenance costs drives a wedge between the interest rate and the marginal productivity of capital, this equating to $r + \delta + \bar{m}$. Because we do not have reliable information on maintenance costs, our calibration strategy is as follows: we calibrate $\alpha$and k/y, as in COOLEY and PRESCOTT [1995], we fix β as in CHRISTIANO and EICHENBAUM [1992], and then we compute $\bar{m}$ from the first order optimal condition from capital. Equivalently, we could have fixed $\bar{m}$ and solved for β. In the Appendix below we evaluate the sensitivity of our results to changes in $\bar{m}$.

4.3 The Depreciation Function

To go from our general framework to quantitative statements about the joint behavior of the rates of depreciation, utilization and maintenance costs we need to calibrate the elasticities of functions $\delta(m,u)$, $\delta_m(m,u)$and $\delta_u(m,u)$. We propose the following notation for the non-stochastic steady state elasticities: $-\dfrac{\delta_m m}{\delta} \equiv \mu$, $\dfrac{\delta_u u}{\delta} \equiv 1 + \phi$ and $\delta_{mu}(\bar{m},\bar{u}) \equiv \dfrac{\nu}{\bar{m}\bar{u}}$, where $\bar{m}$ and $\bar{u}$ are the steady state values of m and u respectively and $0 < \mu \leqslant 1$, $\phi > 0$ and $\nu > 0$. Concerning the non-stochastic steady state value of $\frac{\delta_{mm} m}{\delta_m}$ and $\frac{\delta_{uu} u}{\delta_u}$ we assume that they are equal to $\mu - 1$ and ϕ respectively. For ν small enough the function $\delta(m,u)$ is convex in a neighbourhood of $(\bar{m},\bar{u})$. BURNSIDE and EICHENBAUM [1996] assume that $\delta(m,u) = \bar{\delta}(u/\bar{u})^{1+\phi}$, corresponding to the particular case when $\mu = \nu = 0$.

As discussed above we can calibrate μ and ϕ in the non-stochastic steady state of the economy by using the optimal conditions for utilization and maintenance costs. In particular, it can be shown that $\mu = \bar{m}/\bar{\delta}$. However, the ν parameter can not be calibrated on the basis of the non-stochastic steady state conditions of the model.[9] It is for this reason that we calibrate the parameter ν so that some selected second moment properties of the model economy's aggregates are close to the corresponding statistics for the US economy. More precisely, ν was chosen to match the volatility of logged, detrended investment relative to output.[10]

4.4 Empirical Implementation

In addition to the parameters already discussed, in order for the program in (1)-(6) to be fully calibrated we must choose the parameter values for the stochastic processes describing the state of technology and government expenditures. This is done given the rate of labor augmenting technical progress, γ, obtained in subsection 4.2 above.

As pointed out by COOLEY and PRESCOTT [1995], the standard procedure to calibrate the stochastic technological process relies on the calculation of the Solow residual. Since the volatility of the Solow residual is a consistent measure of the volatility of the technology shock, it allows us to evaluate the ability of the model to reproduce the observed volatility of output. However, in our model, technology shocks cannot be measured by the Solow residual since these shocks can cause capital utilization, maintenance costs and labor effort to vary over the business cycle. For this reason, we follow BURNSIDE and EICHENBAUM [1996] to deduce a time-series on technology shocks. To do this we need data on effort and maintenance costs. In addition, to be consistent with our time-varying depreciation function hypothesis, we have to construct series on depreciation, utilization and the capital stock. In dealing with these problems we proceed as follows:

i) Given a vector of parameters $\Psi = \{\alpha, \bar{m}, \bar{u}, \bar{\delta}, \gamma, \phi, \mu, \nu\}$ and an initial value for K_t we recursively obtain series on u_t, m_t, δ_t, and K_t. Then, for each period t we solve the log-linearized first-order conditions for maintenance costs (7) and utilization (8) of the planner's problem jointly with the law of

9. Note that we can not generate series for the unobserved variables and deduce the process for the technology shock until this set of parameters has been chosen. We consider this issue in detail in section 4.4.

10. This procedure is consistent with the methodology of COOLEY and PRESCOTT [1995] and it is justified because our selection does not affect the question that we want to address, which is restricted to the propagation mechanism implied by the model.

motion for the capital stock given series on observed Y_t and I_t. We search for an initial value of capital stock such that the average capital-output ratio implied by our resulting capital series is approximately the same as the one obtained from the official capital stock series. Figures 1 and 2 depict observed and model-based time series for K_t and u_t respectively.

Figures 4 and 5 show our model-based series for δ_t and m_t respectively, and their cyclical behavior with respect to observed and detrended output (Y_t/X_t).

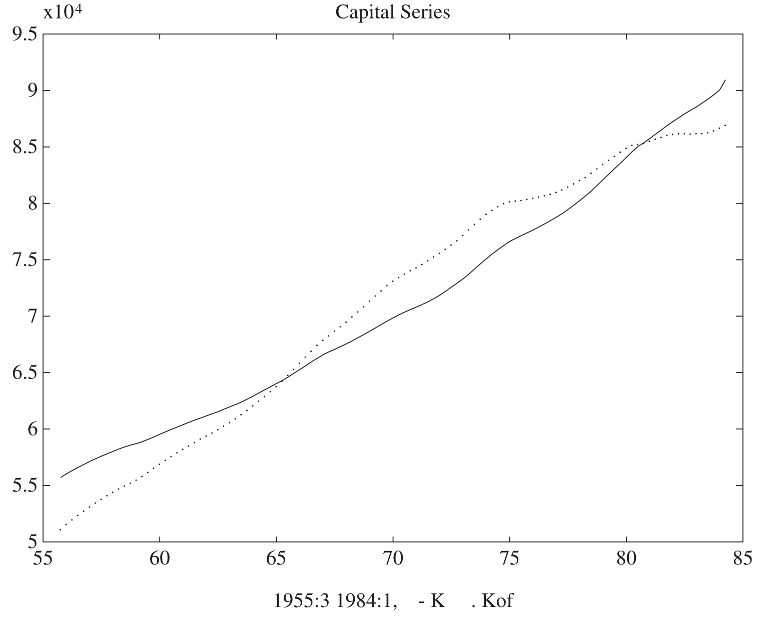
ii) With the observed C_t, Y_t and h_t series, and given our measures of K_t and m_t, we deduce a time-series on effort by solving the log-linearized version of the optimal condition for effort:

$$\frac{\theta}{(T-\psi-e_t\,l)} = \frac{\alpha(Y_t+m_tK_t)}{C_te_th_t}. \tag{10}$$

iii) Once unobserved variables as well as those poorly measured variables have been computed, we linearly approximate the technology process for each point in our sample according to [11]

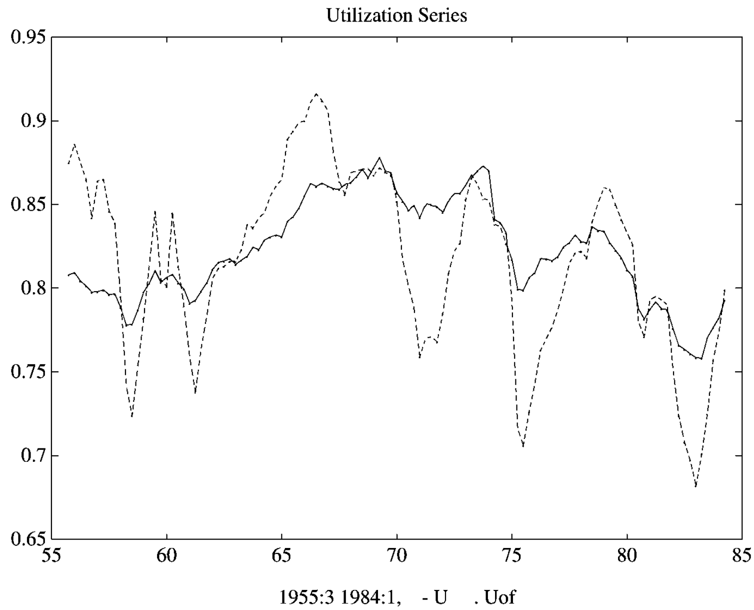
$$\ln(X_t) = [\ln(Y_t+m_tK_t)-(1-\alpha)(\ln(K_t)+\ln(u_t))-\alpha(\ln(h_t)+\ln(e_t))]/\alpha \tag{11}$$

FIGURE 1
Measures of Capital. Official and Model-Based (solid line) Series



11. It is worth noting that in our calculations we abstract from classical measurement error in hours worked. We briefly discuss this issue and its implications below.

FIGURE 2
Measures of Utilization. Official and Model-Based (solid line) Series Capacity Utilization in Manufacturing



Source: Board of Governors of the Federal Reserve System.

FIGURE 3
Measures of Technology Shocks. Solow Residual and Model-Based (solid line) Series

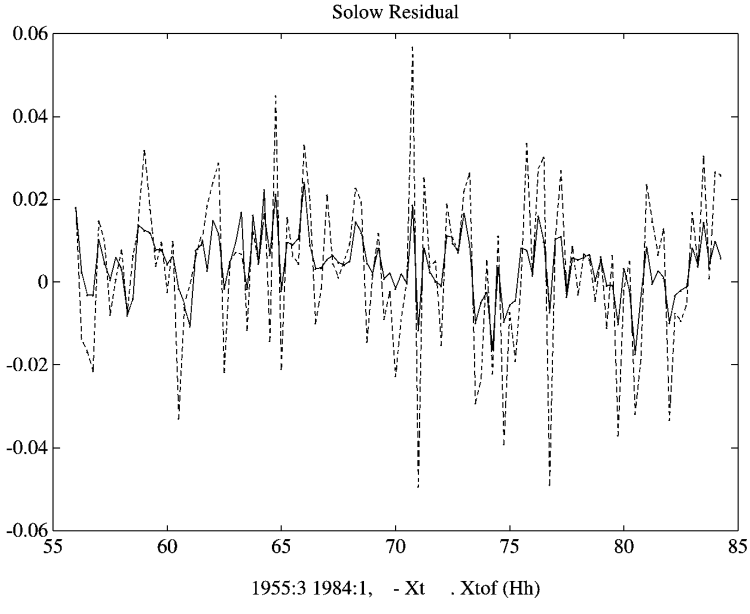


FIGURE 4
Cyclical Behavior of Depreciation. Model-Based Depreciation and Observed Output Series

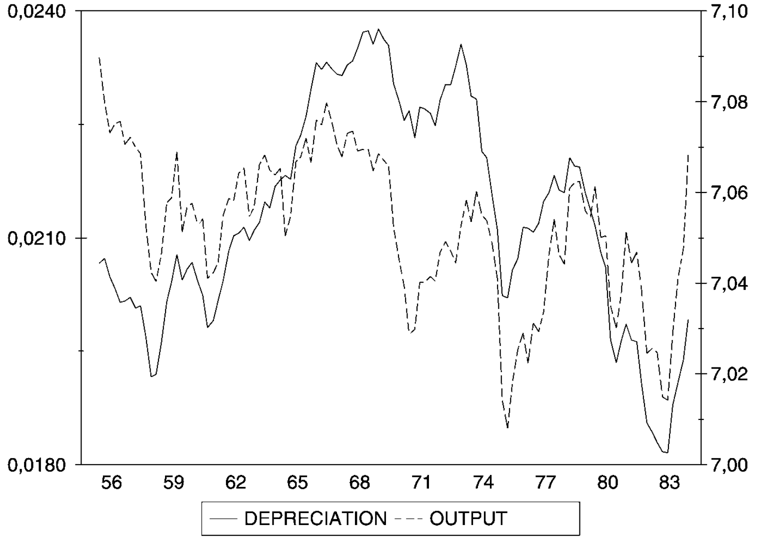
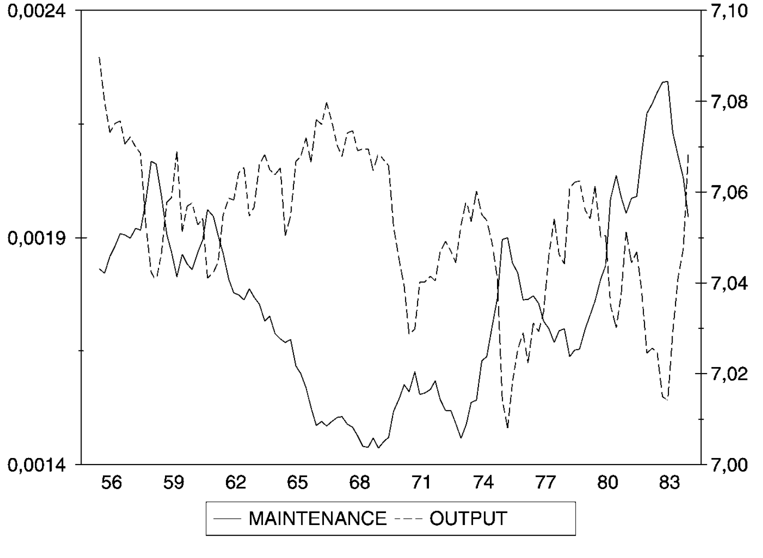


FIGURE 5
Cyclical Behavior of Maintenance Costs. Model-Based Maintenance Costs and Observed Output Series



We find that the process $\ln(X_t)$ is difference-stationary and according to equation (3) we interpret the innovation to this process as the true technology shock and we estimate σ_v from this measure. Time-series for the Solow residual and our measure of technology shocks are depicted in Figure 3. Clearly, our approximate measure of technology shocks is less volatile than the one obtained from the conventional Solow approach. Finally, given our measure for the technology process X_t, we estimate the law of motion of government expenditures (6) to obtain the parameters ρ and σ_μ.

5 Findings

5.1 Stylized Facts

Table 2 reports some selected properties of the second moments of HODRICK and PRESCOTT (HP) filtered data for the US economy and for the model economy: column 2 summarizes the results under the depreciation-in-use assumption, and column 3 reports the results under the maintenance costs assumption. This allows us to evaluate separately the role played by capital utilization against the role played when utilization and maintenance costs are jointly considered.

First, it can be said that our results for the model with depreciation-in-use do not differ substantially from those reported in BURNSIDE and EICHENBAUM [1996], but in the labor market variables dimension. This is basically explained by the fact that we are not considering the effect of measurement error in hours worked. CHRISTIANO and EICHENBAUM [1992] show that measu-

TABLE 2

Second Moment Properties for HP Detrended Data. Statistics for the Models are Averages over 1000 Simulations, each of 115 Observations Length

Moment	US data	Depreciation-in-use ($\bar{m} = 0$)	Maintenance costs ($\bar{m} = 0.0017$)
σ_c/σ_y	0.437	0.474	0.465
		(.032)	(.027)
σ_i/σ_y	2.224	2.282	2.220
		(.082)	(.068)
σ_g/σ_y	1.147	1.547	1.254
		(.221)	(.181)
σ_h/σ_y	0.859	0.633	0.566
		(.033)	(.029)
$\sigma_h/\sigma_{y/n}$	1.221	1.060	0.984
		(.021)	(.019)
σ_y	0.0193	0.0141	0.0172
		(.020)	(.024)
corr$(y/n, n)$	– 0.192	0.330	0.510
		(.122)	(.106)

rement error in hours worked can explain by itself an important part of the observed cyclical behavior of hours and productivity in the US economy. We consider this issue beyond the scope of this paper. We choose this strategy even though incorporating this feature into the analysis improves the model's empirical performance with respect to the variables of the labor market.

Second, the results for the maintenance costs model suggest that the selected parameter values of the depreciation function fit well our targeted second moments properties. In the Appendix we discuss to what extent these results are sensitive to different specifications.

Third, the standard deviation of HP filtered output of the model economy approximates to the corresponding one generated by US data, which stresses the contribution of productivity shocks to the propagation of aggregate fluctuations. Below, we examine the implications of this result in terms of our measure of technology shocks.

5.2 Amplification

To quantify the strength of amplification in the model we compute, for simulated data, the ratio of the standard deviation of HP filtered output to the standard deviation of HP filtered X_t, the aggregate state of technology. We denote σ_z at the standard deviation of detrended X_t.[12] Table 3 reports our measure of the amplification component of the propagation mechanism associated with the two models under consideration. As we expected from our results in section 3, with countercyclical maintenance costs we find that the standard deviation of output is 1.835 times the standard deviation of the technology shock. This statistic is larger than the corresponding one reported by BURNSIDE and EICHENBAUM [1996], which is in line with our result when just the depreciation-in-use assumption is under consideration.

However, σ_z is just 6 % less than the one obtained under the depreciation-in-use assumption. Thus, incorporating maintenance costs into the analysis does not affect substantially our measure of technology shocks[13] but our measure of the volatility of output. Consequently, we do not need to identify

TABLE 3
Propagation Mechanism for HP Detrended Data

Moment	Depreciation-in-use ($\bar{m} = 0$)	Maintenance costs ($\bar{m} = 0.0017$)
σ_z	0.0099	0.0093
σ_y/σ_z	1.4250	1.8350

12. It is important to note that in our model output fluctuates due to government shocks too. BURNSIDE and EICHENBAUM [1996] propose an alternative measure of amplification, denoted $\tilde{\sigma}_y/\sigma_z$, by simulating the model economy without government shocks. They found that: "*As is well known, shocks to government purchases do not contribute substantially to the volatility of output, so that the value of $\tilde{\sigma}_y/\sigma_z$ is quite close to σ_y/σ_z, regardless of which model we consider.*"

13. We find that the standard deviation of our measure of the innovation to technology is nearly 60 % less than that of the computed Solow residual. Note, here, that a direct comparison with previous results in the literature on this issue requires both the same assumptions on the process governing the state of technology and, in particular, to take into account whether or not measurement error in hours worked is incorporated into the analysis when computing technology shocks.

large technology shocks to account for the volatility of output. Thus, we conclude that incorporating the existence of a procyclical utilization rate jointly with countercyclical maintenance costs gives rise to a quantitavely important source of amplification to aggregate technology shocks.

An alternative way to evaluate the amplification mechanism is to consider the impulse response function of output to a technological shock. Figures 7 and 8 depict the response of the log level of output to 1 percent shocks in X_t and g_t for the depreciation-in-use model and the maintenance cost model respectively. Concerning technological shocks, in the impact period, output rises 1.07 percent in the depreciation in use model and 1.20 percent in the maintenance cost model. The one-period-ahead impact is much larger in both models, 1.46 percent and 1.89 percent respectively. Notice that this two last measures are very closed to the amplification measures presented in Table 3.

5.3 Persistence

Next we evaluate persistence in the propagation mechanism for shocks. In doing so, we concentrate on the autocorrelation function of output growth. In general, persistence will be driven by a serial correlation in output growth higher than that of the innovations to technology and government purchases. In our case, we have assumed that both innovations follow *i.i.d.* processes. From the results in BURNSIDE and EICHENBAUM [1996] we know that a model incorporating labor hoarding generates persistence. Furthermore, they show that depreciation-in-use alone can account for the observed autocorrelation in

FIGURE 6

Autocorrelations of Output Growth. Top: correlations for $\bar{m} = 0$ ***(left) and*** $\bar{m} = 0.0017$ ***(right); the dashed lines correspoind to US data. Bottom: differences; the dashed lines represent a 2-standard error band around the difference, over 1 000 simulations.***

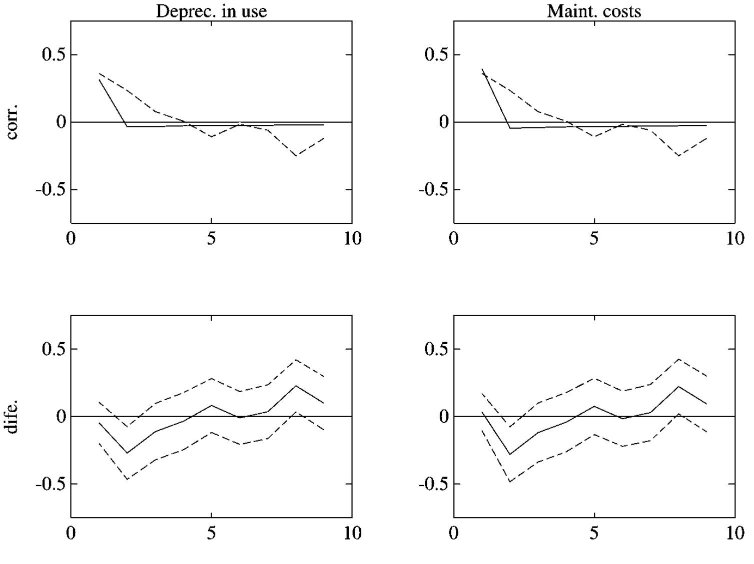


FIGURE 7
Depreciation in Use Model. Impulse Response Functions: Output and Hours

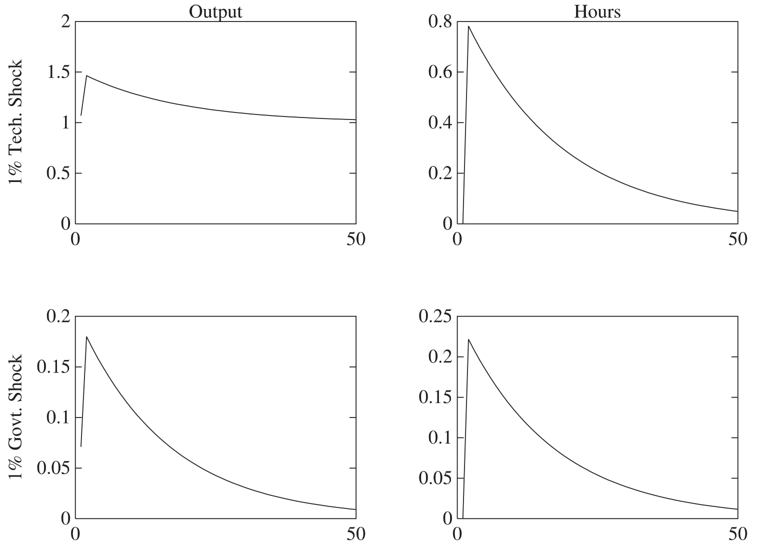


FIGURE 8
Maintenance Cost Model. Impulse Response Functions: Output and Hours

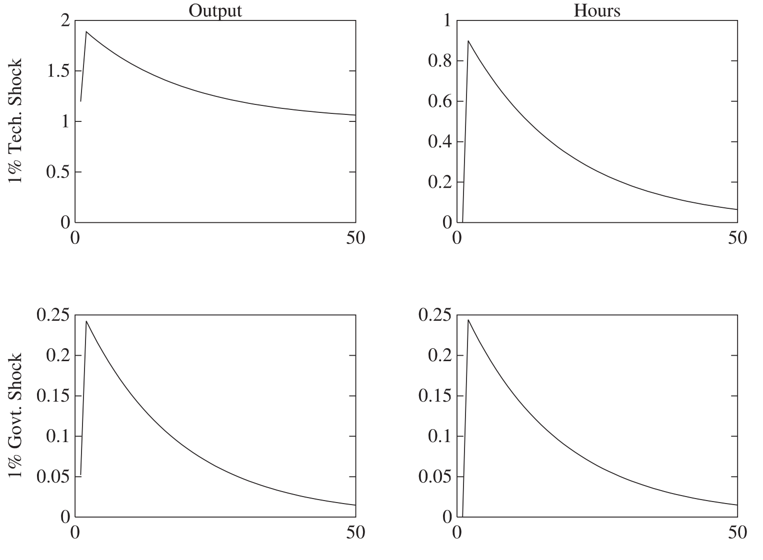


FIGURE 9
Depreciation in Use Model. Impulse Response Functions: Effort and Utilization

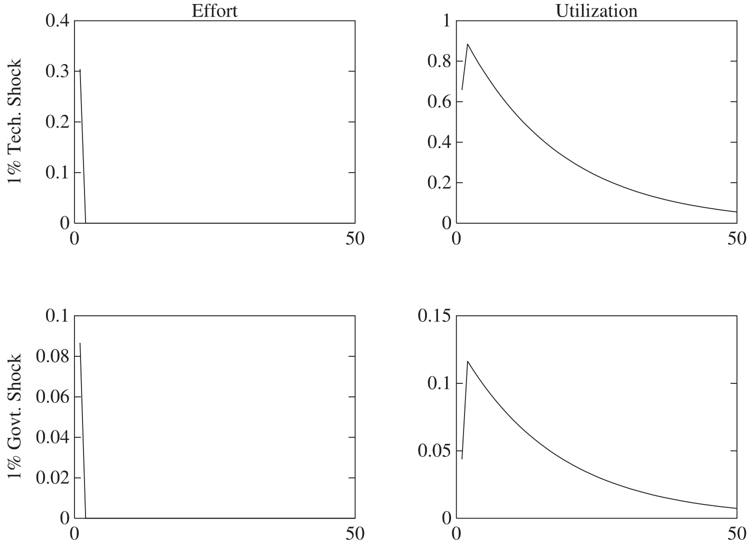


FIGURE 10
Maintenance Cost Model. Impulse Response Functions: Effort and Utilization

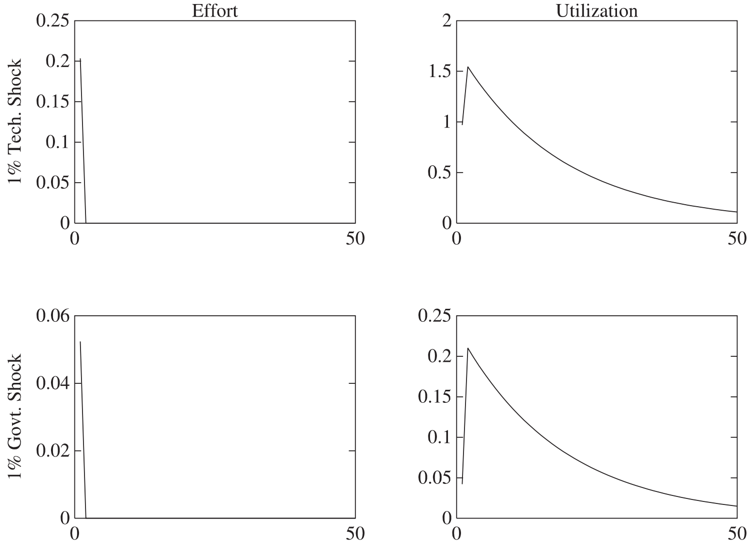


FIGURE 11

Depreciation in Use Model. Impulse Response Functions: Investment and Consumption

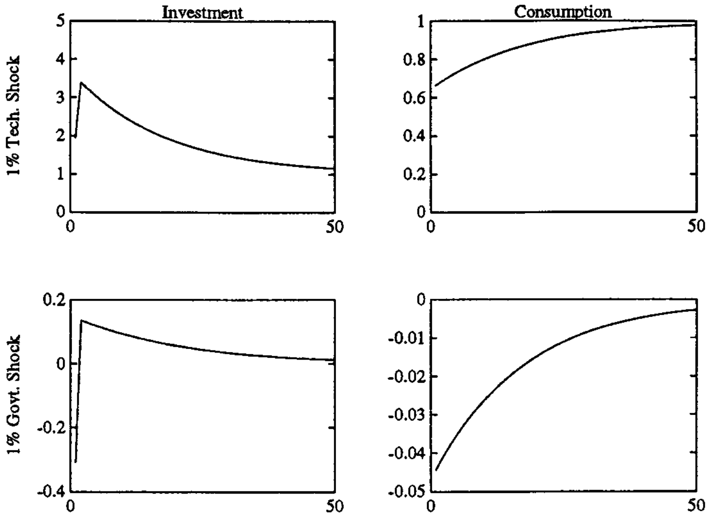
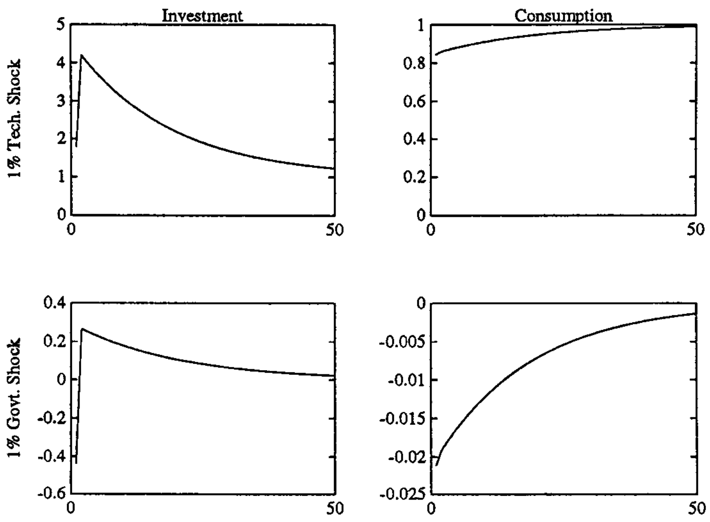


FIGURE 12

Maintenance Cost Model. Impulse Response Functions: Investment and Consumption



output growth. The question here is whether maintenance costs add any additional source of persistence.

Figure 6 depicts the autocorrelation function of output growth jointly with those corresponding to the models of depreciation-in-use and maintenance costs, respectively. As we expected both models produce a first-order autocorrelation coefficient which is positive and significant (of 0.31 (0.08) and 0.40 (0.07), respectively). The lower panels show that the difference between autocorrelations implied by the models and those in actual data is just significantly away from zero for the second-order autocorrelation coefficient. However, the maintenance cost model generates a higher first-order autocorrelation in output growth. The reason is the stronger amplification mechanism behind this model. Figures 7-12 depict the impulse-response functions of model variables to shocks in X_t and g_t. As can be seen in Figure 8 in the maintenance cost model the dynamic response of output is just slightly higher in the impact period of technology shock (1.20 % against a 1.07 %), but significantly higher in the second period after the shock (1.89 % against 1.46 %, that is an additional 0.69 % against a 0.39 %). This is due to the larger response of utilization in both periods, and of employment in the second period after the shock.

6 Concluding Remarks

In this paper, we quantify the role played by variable capital utilization rates and maintenance costs in propagating technology shocks over the business cycle. To this end we model a depreciation technology depending upon both the utilization rate and the maintenance rate. Following part of the literature we assume that using capital increases the rate at which capital depreciates. In addition, we argue that the maintenance activity must be countercyclical, because it is cheaper for the firm to repair and maintain machines when they are stopped than when machines are being used. We find that small innovations to technology induce large fluctuations in output through the procyclicality of effective capital services and the countercyclicality of maintenance activity. Specifically, we find that the volatility of output is more than 1.8 times larger than the volatility of our measure of technology shocks. Furthermore, our estimate for the volatility of output is close to the one implied by US data.

These findings support the traditional argument of the real business cycle literature that fluctuations in technical progress can account for a large fraction of observed fluctuations in aggregate economic time-series. Further explorations are necessary to evaluate the behavior of the model in accounting for additional features of observed business cycles and to build evidence either confirming or rejecting our hypothesis. We view the model considered in this paper as a first approximation to richer environments incorporating a completely specified depreciation technology jointly with the role played by utilization rates in determining the effective capital services. We conclude that there is much to be learned from the explicit modeling of the underemployment of production factors and maintenance activity.

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APPENDIX

Sensitivity Analysis

It is important to note that the convexity of the depreciation function depends upon the value chosen for ν. Convexity around $(\bar{m}, \bar{u})$ is guaranteed when $\delta_{mm}\delta_{uu} - \delta_{mu}^2 > 0$, or equivalently $\nu < \nu^*$, where $(\nu^*)^2 = \bar{\delta}^2\,(1-\mu)\,\mu\,\phi\,(1+\phi)$. Under our baseline calibration $\nu^*/\nu = 1.15$.

TABLE 4
Sensitivity to Changes in $\bar{m}$***.*** $\nu^*/\nu = 1.15$***. Measure of the Amplification of Shocks for 1000 Simulations (HP filtered data). * % Annual***

r^*	$\bar{m}$	$\frac{\sigma_i}{\sigma_y}$	$\frac{\sigma_y}{\sigma_z}$	σ_z
3.35	0.0009	2.29	1.824	0.0095
3.00	0.0017	2.22	1.834	0.0093
2.65	0.0026	2.16	1.841	0.0092

TABLE 5
Sensitivity to Changes in ν^*/ν***.*** $r = 3.00\,\%$ ***Annual. Measure of the Amplification of Shocks for 1000 Simulations (HP filtered data)***

ν^*/ν	$\frac{\sigma_i}{\sigma_y}$	$\frac{\sigma_y}{\sigma_z}$	σ_z
1	2.268	2.089	0.0093
1.15	2.220	1.834	0.0093
1.3	2.207	1.710	0.0094

Table 4 shows the effects of varying the interest rate r, that is the steady state maintenance cost rate, on the amplification mechanism of the model. Table 5 describes the effects of changing the parameter ν of our baseline calibration. We can conclude from Tables 4 and 5:

1) Given ν^*/ν, an increase in $\bar{m}$ implies a slight decrease both in the volatility of investment relative to output and the technology shock, whereas it gives rise to a slight increase in the amplification mechanism of shocks.

2) Given $\bar{m}$, an increase in ν^*/ν generates a slight decrease both in the relative volatility of investment and in the amplification mechanism, whereas it increases very slightly the volatility of the technology shock.

3) For sensible choices of $\bar{m}$ and ν, amplification ranges between 1.43 (corresponding to the depreciation-in-use model, *i.e.*, $\bar{m} = 0$) and 2.09. The latter must be taken as an extreme upper bound, since $\nu = \nu^*$ corresponds to a non-convex depreciation function in any neighbourhood of $(\bar{m}, \bar{u})$.