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ENDOGENOUS GROWTH AND ECONOMIC FLUCTUATIONS

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The specific contribution of endogenous growth models to RBC literature remains unclear since, although the implication of assuming endogenous growth for explaining aggregate fluctuations has already been considered for instance by Gomme (1993) and Ozlu (1996), these papers introduce additional shocks in order to reproduce some labor market fluctuations. In this paper we attempt to identify the success of some endogenous growth models in mimicking some key aspects of labor market behaviour while retaining a single shock. This paper shows that the introduction of an activity competing with the final output production activity may help to explain some labor market features, there being no need to introduce any additional source of uncertainty as is usually done in standard growth models.

Key words: Real business cycles, aggregate fluctuations, endogenous growth, propagation mechanism.

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1. Introduction

Real business cycle models have made a major contribution in explaining some regularities that characterize the fluctuations of some relevant aggregate variables. However, this literature has given rise to some criticisms concerning two important aspects. On the one hand, the assumption of strict exogeneity of the engine of growth has been questioned due to the weakness of the propagation mechanism of innovative progress, which attributes a disproportionate weight to technology shocks in order to replicate the intensity of cyclical behaviour (see Summers, 1986). On the other hand, standard real business cycle models predict a high correlation between output and productivity and

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also between hours worked and productivity, whereas actual data seem in general to indicate a lack of correlation. Standard exogenous growth models have concentrated on answering this second criticism while retaining the assumption of strict exogeneity of technological progress. For instance, Hansen (1985) and Rogerson (1988) consider that labor is indivisible; Kydland and Prescott (1982) incorporate the idea of nonseparable leisure; Christiano and Eichenbaum (1992) introduce the idea of government spending being stochastic; Benhabib, Rogerson and Wright (1991) and Greenwood and Hercowitz (1991) consider an activity parallel to the market such as household production, which is stochastic in both papers. Although they obtain advances in this direction, some of these extensions do need a second source of uncertainty in order to replicate the fluctuations observed in U.S. data for the labor market[1], which in turn is not very helpful as far as the weakness of the propagation mechanism of these models is concerned.

The implication of assuming non-strict exogenous growth for the explanation of aggregate fluctuations has already been considered, for instance by Ozlu (1996) and Gomme (1993), and their models also show advances in accounting for labor market fluctuations. However, these papers consider additional sources of uncertainty too (a shock in the process of human capital accumulation and training, and a monetary shock, respectively)[2] and as a consequence, the specific contribution of endogenous growth to explaining business cycle features remains unclear. More recently, Einarsson and Marquis (1997) have analyzed the contribution of an endogenous growth model with home production while retaining a single technology shock, but their main purpose is different. They seek to replicate both the positive correlation observed between market and home investment goods and the comovements in employment across consumption and investment sectors.

The aim of this paper is to assess the importance of endogenous growth models in order to characterize business cycle regularities focusing on the labor market while considering a single technology shock. This article considers a stochastic version in discrete time of the Uzawa-Lucas model[3] with two modifications. On the one hand, physical capital is in-

[1] See Hansen and Wright (1992) for more details.

[2] In fact, on the one hand, the main goal of Gomme is to explain the inflation costs on growth using a monetary model, which is really different from our purpose. On the other hand, the results obtained for the labor market in Ozlu (1996) depend crucially on the introduction of a second shock.

[3] We refer to the model studied by Uzawa (1965) and Lucas (1988) in which the

cluded as a production factor in the human capital sector as suggested by King, Plosser and Rebelo (1988b), Gomme (1993) and Ozlu (1996). On the other hand, following Becker's (1965) idea, we introduce qualified leisure as an additional argument of the utility function, and given the specification considered it is possible to distinguish between different degrees of qualification (see Ladrón-de-Guevara, Ortigueira and Santos, 1997, for more details). Our results show that considering physical capital as a factor in human capital production function provides a stronger propagation mechanism and it also brings about a quantitative improvement in the results obtained for the labor market, with no need to introduce another source of uncertainty. The higher the share is, the stronger the propagation mechanism is. Moreover, once this modification is considered, the propagation mechanism is even stronger when individuals value qualified leisure.

Another interesting finding is that regardless of the specification considered for the utility function, the correlations between consumption and output, productivity and output, and between hours and productivity are not robust to changes in the value of the relative risk aversion parameter when the generalized Uzawa-Lucas model is considered.

It is well known that dynamic stochastic general equilibrium models such as the one considered here have no analytical solution except for certain particular parameter values which unfortunately are not suitable. This means that the model has to be solved by using numerical methods[4]. This paper considers the method of parameterized expectations (PEA) suggested by Marcet (1988).

The rest of the paper is organized as follows. Section 2 shows a stochastic version of the generalized Uzawa-Lucas growth model with a more general utility function and describes the calibration procedure used. In Section 3 the quantitative results obtained are shown. Section 4 concludes.

2. The model

This paper considers a stochastic version of the Uzawa-Lucas model, in discrete time, with two modifications: on the one hand, physical capital is included as a production factor in the human capital sector as suggested by King, Plosser and Rebelo (1988b), Gomme (1993) and

production of new human capital involves no physical capital.

[4]Alternative methods are analyzed and compared in Taylor and Uhlig (1990).

Ozlu (1996)[5] and, on the other hand, following Becker's (1965) idea the marginal utility of leisure is a function which depends positively on the level of human capital.

The economy consists of a large number of productive families which own both the production factors and the technology used in two production activities: the production of the final good and the production of new human capital[6]. The population size is assumed to be constant. Individuals must decide what fraction of their time they devote to each of these activities, and how much time they set aside for leisure. The time endowment is standardized to one, so that l_t denotes the fraction of time given over to leisure and n_t the fraction of time devoted to the production of the consumption good. Given the specification considered physical capital can be used in both production processes. Individuals must also decide what fraction of physical capital they allocate to each sector. We denote by ϕ_t the fraction of physical capital devoted to the production of the consumption good.

The technology of the consumption good is described by a production function with constant returns to scale and positive but decreasing marginal product, which satisfies Inada's conditions. Formally, this can be expressed in *per capita* terms by the following Cobb-Douglas production function,

$$y_t = F^m(\phi_t k_t, z_t, n_t h_t) = A_m z_t (\phi_t k_t)^\alpha (n_t h_t)^{1-\alpha}, \; \textit{with} \; 0 < \alpha < 1$$

[5]Ozlu (1996) studies two types of endogenous growth models which differ from each other in the human capital accumulation process considered: a learning by doing model where human capital is accumulated through training, and a second model where endogenous human capital accumulation results from investing in human capital by considering the generalized Uzawa-Lucas model. In this second model, Ozlu treats the human capital production sector as an educational sector or schooling with a direct remuneration (contrary to the case considered here) and in accordance with Uzawa (1965) and Lucas (1980), who assume that human capital is intensive only in human capital, he considers a value close to zero for the share of physical capital in the human capital production function, which is much lower than the value considered in this paper (see section 2.1). In Gomme (1993), the generalized Uzawa-Lucas model is considered, but he assumes the same share of physical capital in both production processes, while there is a degree of consensus in this literature that its share is greater in the production of consumption goods than in the production of human capital.

[6]Unlike the model studied by King and Rebelo (1990), our model considers the production of human capital as an activity which is not directly remunerated (contrary to the case of an "education" sector) and is therefore not accounted for in National Accounting statistics. In this sense, here, human capital accumulation is considered as a "household" activity.

where $n_t h_t$ represents the qualified labor units, A_m is the parameter which measures the productivity of this sector, k_t and h_t are the stocks of physical capital and human capital in per-capita terms, respectively, and finally z_t is a technology shock characterized by the following autoregressive process:

$$log(z_t) = \rho \; log(z_{t-1}) + \varepsilon_t,$$

where ε_t is a white noise with variance σ_ε^2.

The final product is a homogenous good that can be allocated either to consumption or to saving. Part of the nonconsumed product can be transformed into physical capital through the following investment process:

$$k_{t+1} = F^m(\phi_t k_t, z_t, n_t h_t) - c_t + (1 - \delta_k) k_t,$$

where δ_k represents the depreciation rate of physical capital, which is assumed to be constant.

The fractions of physical capital and of time not devoted to producing the consumption good are devoted to producing new human capital. New human capital is assumed to evolve according to the following equation:

$$\begin{aligned} h_{t+1} &= F^h[(1 - \phi_t)k_t, (1 - l_t - n_t)h_t] + (1 - \delta_h)h_t \\ &= A_h((1 - \phi_t)k_t)^\theta((1 - l_t - n_t)h_t)^{1-\theta} + (1 - \delta_h)h_t, \end{aligned}$$

where F^h is the human capital production function, and A_h and δ_h measure the productivity of this sector and the rate of depreciation of human capital, respectively. The parameter θ measures the share of physical capital in the human capital production function. Due to the specification considered, if this parameter is positive we have the generalized Uzawa-Lucas model and if it is nil we have the Uzawa-Lucas model.

It is assumed that consumers derive their utility from the consumption of the final good and from the more or less qualified leisure units, which means that the marginal utility of leisure is an increasing function of the level of human capital. Future utility is discounted at a rate β and preferences are described by the following utility function[7]:

[7]Note that this function satisfies the conditions needed to ensure the existence of a balanced growth path. See King, Plosser and Rebelo (1988a), Rebelo (1991) and Ladrón-de-Guevara, Ortigueira and Santos (1997) for a more detailed discussion on this issue.

$$U(c_t, l_t h_t^\lambda) = \frac{[c_t^\omega (l_t h_t^\lambda)^{1-\omega}]^{1-\gamma}}{1-\gamma},\ 0 \leq \omega \leq 1\ ,\ \gamma > 0\ ,\ 0 \leq \lambda \leq 1\ , \gamma \neq 1.$$

Note that different degrees of qualified leisure can be considered depending on the value of λ (for a detailed discussion on this issue see Ladrón-de-Guevara *et al*, 1997).

As is well known, in the absence of external effects, public goods and distortionary taxation, the solution to the planner's problem is the competitive equilibrium allocation.

The problem faced by the central planner is to choose sequences for consumption, hours worked, leisure, physical capital, human capital and the fraction of physical capital devoted to the market sector that maximize the discounted stream of utility given by:

$$\max_{n_t, c_t, \phi_t, l_t, k_{t+1}, h_{t+1}} E_0 \sum_{t=0}^{\infty} \beta^t U(c_t, l_t h_t^\lambda),$$

$$s.t. \quad c_t + k_{t+1} \leq A_m z_t (\phi_t k_t)^\alpha (n_t h_t)^{1-\alpha} + (1-\delta_k) k_t,$$

$$h_{t+1} = A_h((1-\phi_t)k_t)^\theta ((1 - l_t - n_t) h_t)^{1-\theta} + (1-\delta_h) h_t,$$

$$log(z_t) = \rho\ log(z_{t-1}) + \varepsilon_t,$$

where z_0, k_0 and h_0 are given.

The first-order conditions for this problem are:

$$U_1 = \frac{U_2 h_t^{\lambda-1}}{F_2^m}, \qquad [1]$$

$$\frac{U_2 h_t^{\lambda-1}}{F_2^m} = \beta E_t \{ \frac{U_2' h_{t+1}^{\lambda-1}}{F_2^{m'}} [F_1^{m'} + 1 - \delta_k] \}, \qquad [2]$$

$$\frac{U_2 h_t^{\lambda-1}}{F_2^h} = \beta E_t \{ \frac{U_2' h_{t+1}^{\lambda-1}}{F_2^{h'}} [F_2^{h'} (1 - l_{t+1}) + 1 - \delta_h] + U_2' \lambda l_{t+1} h_{t+1}^{\lambda-1} \}, \quad [3]$$

$$\frac{F_1^m}{F_2^m} = \frac{F_1^h}{F_2^h}, \qquad [4]$$

$$h_{t+1} = A_h((1-\phi_t)k_t)^\theta ((1 - l_t - n_t) h_t)^{1-\theta} + (1-\delta_h) h_t,$$

$$k_{t+1} + c_t = A_m z_t (\phi_t k_t)^\alpha (n_t h_t)^{1-\alpha} + (1-\delta_k) k_t,$$

$$\lim_{t\to\infty} E_t\beta^t U_1 k_{t+1} = 0,$$

$$\lim_{t\to\infty} E_t\beta^t \frac{U_2 h_t^{\lambda-1}}{F_2^h} h_{t+1} = 0,$$

where the variables with a prime denote next period values and E_t is an operator whose expectations are conditional on the information available up to period t.

Equation [1] shows the optimal way of determining the fraction of time devoted to the production of goods. At the margin, the marginal utility reported by an additional labor unit has to be equal to its disutility.

Equation [2] governs the accumulation of physical capital. The right-hand side of [2] shows the expected return obtained by acquiring an additional unit of capital, evaluated in terms of current period utility. The left-hand term represents the cost of acquiring an additional unit of physical capital today. At the margin, the expected return must equal the cost.

Equation [3] governs the accumulation of human capital. Given that $1-l_t$ denotes the fraction of time not allocated to leisure, this equation establishes that, at the margin, the expected return in current period utility obtained by acquiring an additional unit of human capital must equal the cost it causes.

Equation [4] establishes an efficiency condition, since physical and human capital must receive the same rate of return when allocated to either sector.

As pointed out by Ladrón-de-Guevara, Ortigueira and Santos (1997), for some parameter values these equations give rise to multiple equilibria. For the sake of simplicity this paper only considers parameter values for which there is always a single steady state characterized by the constant growth rate of *per capita* variables k_t, h_t and c_t, while n_t and l_t remain constant. The constant rate of growth is determined by the rate of accumulation of human capital. We seek to obtain a stationary combination on the balanced growth path of the original variables. Stationary time series are obtained by expressing the variables that appear in the equations in relation to the stock of human capital. This also facilitates the use of computational techniques, as it reduces the number of state variables: the physical capital/human capital ratio and the technology shock. Hence, the first-order conditions for the planner's problem can be rewritten as:

$$U_1(\hat{c}_t, l_t) =$$

$$\beta(\frac{h_{t+1}}{h_t})^{\tau} E_t\{U_1(\hat{c}_{t+1}, l_{t+1})[F_1^m(\phi_{t+1}\hat{k}_{t+1}, n_{t+1}, z_{t+1}) + 1 - \delta_k]\}, \quad [5]$$

$$U_1(\hat{c}_t, l_t) = \frac{U_2(\hat{c}_t, l_t)}{F_2^m(\phi_t\hat{k}_t, n_t, z_t)}, \quad [6]$$

$$\frac{U_2(\hat{c}_t, l_t)}{F_2^h((1-\phi_t)\hat{k}_t, 1 - l_t - n_t)} =$$

$$\beta(\frac{h_{t+1}}{h_t})^{\tau} E_t\{\frac{U_2(\hat{c}_{t+1}, l_{t+1})}{F_2^h((1-\phi_{t+1})\hat{k}_{t+1}, 1 - l_{t+1} - n_{t+1})}, \quad [7]$$

$$[F_2^{h\prime}(1 - l_{t+1}) + 1 - \delta_h + \lambda F_2^{h\prime} l_{t+1}]\}, \quad [8]$$

$$\frac{F_1^m}{F_2^m} = \frac{F_1^h}{F_2^h}, \quad [9]$$

$$\frac{h_{t+1}}{h_t} = A_h((1-\phi_t)\hat{k}_t)^{\theta}(1 - l_t - n_t)^{1-\theta} + 1 - \delta_h, \quad [10]$$

$$\hat{c}_t + \hat{k}_{t+1}\frac{h_{t+1}}{h_t} = A_m z_t(\phi_t\hat{k}_t)^{\alpha} n_t^{1-\alpha} + (1-\delta_k)\hat{k}_t, \quad [11]$$

where $\tau = [\omega + \lambda(1-\omega)](1-\gamma) - 1$, $\hat{c}_t = \frac{c_t}{h_t}$ and $\hat{k}_t = \frac{k_t}{h_t}$.

In order to solve highly nonlinear stochastic models such as the one considered here, numerical solution methods are required, since analytical solutions cannot be obtained.

The solution method used in this paper was originally suggested by Marcet (1988) and is called the parameterized expectations approach (PEA). For more details see the appendix .

Calibration

This section assigns values to the parameters in order to solve, simulate and quantitatively evaluate the model. The dynamics of the synthetic series are then compared with the behaviour of the U.S. economy on the basis of the data covering the period 1954:1 - 1989:4.

In choosing parameter values for the model, we employ the following strategy: a subset of the parameters is determined on the basis of prior information in the literature and the rest are chosen to match steady state properties of the model with the first moments from the postwar U.S. data, simply working on the first order conditions. The calibration procedure followed is that suggested by Kydland and Prescott (1982). The structural parameters and steady state values are displayed in Table 1.

TABLE 1
Values for structural parameters and deterministic steady state*

	$\theta=0$	$\theta=0.2$	$\theta=0.2$	$\theta=0.2$	$\theta=0.2$
	λ=0 and σ=1.3	λ=0 and σ=1.3	λ=1 and σ=1.3	λ=0 and σ=2	λ=1 and σ=2
σ_ε	0.007	0.00245	0.002	0.0023	0.001775
δ_h	0.005	0.025	0.025	0.025	0.025
δ_k	0.025	0.025	0.025	0.025	0.025
α	0.360	0.360	0.360	0.360	0.360
A_m	1	0.07917	0.05987	0.07917	0.05987
A_h	0.02708	0.07917	0.05987	0.07917	0.05987
β	0.9946	0.9947	0.9956	0.99724	1.00015
ω	0.37269	0.35926	0.5522	0.35926	0.5522
γ	1.80496	1.83505	1.54328	3.78350	2.81094
v	0.0035	0.0036	0.0036	0.0036	0.0036
n	0.240	0.240	0.240	0.240	0.240

* For parameters with a time dimension. the unit of time is a quarter.

Parameter α was set at 0.36, which is the average share of physical capital in U.S. GNP during the period under study. The physical capital depreciation rate, δ_k, was set equal to 0.025, which is equivalent to 10% *per annum*, based on the study carried out by Kydland and Prescott (1982).

Parameter values for the autoregressive process that characterizes the productivity shock dynamics z_t, are usually chosen on the basis of calibration studies well known in this literature. Based on first moments from the Solow residual, we follow the suggestion of Prescott (1986) of $\rho = 0.95$. Moreover, the standard deviation σ_ε was chosen such that the standard deviation of output generated by the model matches that of *per capita* U.S. GNP[8].

Parameter A_h is chosen to match the 1.4% *per annum* growth rate in

[8]Similar exercises are performed by Gomme (1993), Hansen (1985) and Einarsson and Marquis (1997). Note that when $\theta = \lambda = 0$ the value used for σ_ε is 0.007, whereas the standard deviation needed is lower when $\theta = 0.2$ and $\lambda = 0$ and even smaller when $\theta = 0.2$ and $\lambda = 1$.

per capita GNP in the U.S. for the afore mentioned period. In view of the homogeneity of the utility and production functions, parameter A_m can be either normalized to one or made equal to A_h[9]. Due to the fact that human capital has no direct remuneration there are no data available to estimate the parameters θ or δ_h. Different values for θ have been considered (established ad-hoc) and changes in results have been analyzed. The capital share parameter θ is assumed to be zero in one case and greater than zero in the other. This allows us to analyze the sensitivity of the results to changes in this parameter. Even though a positive value for θ may be considered as reasonable, most researchers would agree that it must be lower than the corresponding share in the production of the good (contrary to the value suggested by Gomme, 1993). The physical capital share parameter in human capital production function, θ, when positive is set at 0.2. On the other hand, estimates for parameter δ_h range from approximately 0.6% to 13.3% per year (see Heckman, 1975 and Rosen, 1976). Here, it is assumed that the depreciation rates, δ_h and δ_k, have a common value when $\theta = 0.2$. This is not the case when $\theta = 0$. In this case we consider a lower value for δ_h[10].

The value for parameter ω, which governs the importance of consumption relative to leisure in the utility function, is established to guarantee that the fraction of time allocated to producing goods is 0.24 in the steady state, which is the fraction of time spent working by the U.S. working-age population, as suggested by Gomme (1993) and Greenwood and Hercowitz (1991).

The parameter value that measures the relative risk aversion, σ, was established to be within the interval [1,2], as suggested by Mehra and Prescott (1985). Since the utility function is multiplicatively separable, it can be written as $U(c, lh^{\lambda}) = u(c)v(lh^{\lambda})$, where u(c) is homogeneous of degree $1-\sigma$. Note that regardless of the value for λ, $(1-\gamma)\omega = 1-\sigma$. We have considered two values for σ: 1.3 and 2, which allows us to analyze the sensitivity of the results to changes in the value for this parameter. The value for γ can be derived from the expression $(1-\gamma)\omega = 1-\sigma$.

The discount factor, β, is chosen so that the real interest rate obtained

[9] As Gomme (1993) reported, this would be equivalent to changing the units in which the stock of human capital is measured.

[10] In fact, δ_h needs to be lower than δ_k in this case, in order to get a positive value for leisure. In any event, the results do not depend on the value of this parameter.

in the steady state is 1% per quarter. This value is derived from the fullfilment of the first-order condition [5] in the deterministic steady state, given the homogeneity properties of the utility function:

$$\beta(\frac{h_{t+1}}{h_t})^{[\omega+\lambda(1-\omega)](1-\gamma)-1}(1+r)=1,$$

where $\frac{h_{t+1}}{h_t}$ and r are the steady state real growth rate and the real interest rate, respectively.

Finally, the value for λ must be chosen. We know of no empirical evidence in this respect, so in principle any value in the interval [0,1] could reasonably be studied. This paper shows the results obtained for the most extreme cases (when we consider qualified leisure ($\lambda = 1$) and when we merely consider levels of pure leisure ($\lambda = 0$)).

3. Results

This section assesses the different models, comparing second order moments generated by the models with those obtained from U.S. economic data. The moments to be compared are the standard deviations of the key variables, their contemporaneous correlations with output and the cross-correlations over time. These characteristics reflect the amplitude of fluctuations, their procyclicality and the phase shift of a variable relative to real GNP, respectively. The data obtained from simulating the model and the U.S. data were treated in the same way: both were logged and then detrended by using the Hodrick and Prescott (1997) filter.

Once the numerical solution to the competitive equilibrium was obtained, the model was simulated, variables were converted back to their nonstationary form, logged and their cyclical component extracted by applying the aforesaid filter. Statistics were calculated on those filtered time series. Tables 2 to 4 show the sample means of the statistics across 500 simulations, which are 144 periods long (the number of quarters in our data set).

Tables 2 and 4 report the results for the Uzawa-Lucas model, when human capital exhibits constant returns to scale in its single production factor ($\theta = 0$) and consumers value pure leisure units. We first infer that although most fluctuations are due to technology shocks, some other factor still needs to be incorporated into the model because fluctuations in output are smaller than shown by the data. As it occurs with the U.S. economy, investment fluctuates much more than consumption and output. On the other hand, consumption is less volatile than output. However, the amplitudes of both fluctuations in both models are also smaller than those observed in actual U.S. data.

TABLE 2
Some cyclical properties of U.S. and Model Generated Time Series

	σ_y	σ_c	σ_i	σ_n	σ_l	σ_e	σ_w	σ_ϕ	$corr_{nw}$
U.S. Economy	1.71	0.84	5.38	1.65			0.83		≈ 0
θ = 0	1.60	0.46	4.52	1.13	0.08	0.77	0.54		0.810
	(0.18)	(0.06)	(0.50)	(0.12)	(9.8e-03)	(0.086)	(0.07)		
θ=0.2. λ=0. σ=1.3	1.70	0.179	3.04	1.59	0.038	0.858	0.196	1.11	0.514
	(0.169)	(0.025)	(0.304)	(0.158)	(6.0e-03)	(0.084)	(0.031)	(0.11)	
θ=0.2. λ=1. σ=1.3	1.70	0.158	2.56	1.62	0.0379	0.59	0.164	1.21	0.471
	(0.17)	(0.022)	(0.256)	(0.16)	(4.9e-03)	(0.059)	(0.027)	(0.12)	
θ=0.2. λ=0. σ=2	1.711	0.155	3.087	1.630	0.0403	0.871	0.185	1.141	0.395
	(0.168)	(0.023)	(0.304)	(0.159)	(7.0e-03)	(0.085)	(0.030)	(0.112)	
θ=0.2. λ=1. σ=2	1.705	0.136	2.584	1.659	0.035	0.613	0.151	1.244	0.265
	(0.167)	(0.021)	(0.255)	(0.163)	(4.7e-03)	(0.599)	(0.026)	(0.122)	

* All variables are in real *per capita* terms (1982 basis). They are quarterly data on the U.S. economy from 1954.1 to 1989.4 taken from Kydland and Prescott (1990) except the value for $corr_{nw}$, which is taken from Gomme (1993). Output is measures by GNP (variable *y*). consumption of nondurable goods and services (variable *c*) investment by gross fixed investment (variable *i*) and hours by total hours of persons in the business sector as recorded in the establishment survey (*n*). Productivity is defined as the ratio of output to hours worked and is denoted by *w*. The fraction of time devoted to human capital accumulation is denoted by *e*. Values in parentheses are standard deviations across simulations. Volatilities are expressed in percentage terms

TABLE 3
Cross correlation coefficients with U.S. GNP

Variable	$x(-5)$	$x(-4)$	$x(-3)$	$x(-2)$	$x(-1)$	x	$x(+1)$	$x(+2)$	$x(+3)$	$x(+4)$	$x(+5)$
GNP	-0.03	0.15	0.38	0.63	0.85	1	0.85	0.63	0.38	0.15	-0.03
Consumption	0.20	0.38	0.53	0.67	0.77	0.76	0.63	0.46	0.27	0.06	-0.12
Investment	0.09	0.25	0.44	0.64	0.83	0.90	0.81	0.60	0.35	0.08	-0.14
Hours	-0.23	-0.07	0.14	0.39	0.66	0.88	0.92	0.81	0.64	0.42	0.21
Productivity	0.40	0.46	0.49	0.53	0.43	0.31	-0.07	-0.31	-0.49	-0.52	-0.50

Individuals maintain a smooth path for leisure. Leisure is considerably less volatile than both hours worked and the fraction of time devoted to accumulating human capital, which indicates that individuals respond to fluctuations by varying the time allocated to each sector. Thus, in expansion periods, they decide to devote more time to producing goods, while in recession periods they have stronger incentives to accumulate human capital. Total hours in this model account for just over 60% of the fluctuations observed in the data, which indicates that

TABLE 4
Cross correlation coefficients of Model-Generated Time Series (with GNP)

Variable x	$x(-5)$	$x(-4)$	$x(-3)$	$x(-2)$	$x(-1)$	x	$x(+1)$	$x(+2)$	$x(+3)$	$x(+4)$	$x(+5)$
θ=0, λ=0 and σ=1.3											
GNP	-0.045	0.071	0.228	0.431	0.686	1	0.686	0.431	0.228	0.071	-0.045
Consumption	-0.251	-0.141	0.019	0.240	0.531	0.902	0.753	0.605	0.467	0.341	0.230
Investment	0.005	0.121	0.272	0.464	0.703	0.993	0.649	0.374	0.162	0.002	-0.113
Hours	0.049	0.162	0.307	0.489	0.712	0.980	0.613	0.324	0.105	-0.055	-0.168
Productivity	-0.241	-0.129	0.031	0.252	0.543	0.912	0.753	0.599	0.456	0.328	0.215
θ=0.2, λ=0 and σ=1.3											
GNP	-0.112	-0.013	0.134	0.340	0.624	1	0.624	0.340	0.134	-0.013	-0.112
Consumption	-0.422	-0.361	-0.237	-0.030	0.283	0.731	0.673	0.589	0.493	0.395	0.299
Investment	-0.095	0.004	0.150	0.354	0.632	0.999	0.613	0.323	0.114	-0.033	-0.131
Hours	-0.062	0.037	0.181	0.378	0.645	0.995	0.580	0.289	0.075	-0.072	-0.168
Productivity	-0.465	-0.418	-0.312	-0.124	0.168	0.596	0.630	0.607	0.550	0.472	0.384
θ=0.2, λ=1 and σ=1.3											
GNP	-0.110	-0.010	0.137	0.344	0.627	1	0.627	0.340	0.137	-0.010	-0.110
Consumption	-0.428	-0.366	-0.242	-0.036	0.276	0.722	0.670	0.591	0.499	0.402	0.308
Investment	-0.098	0.001	0.149	0.354	0.632	0.999	0.619	0.333	0.124	-0.023	-0.123
Hours	-0.067	0.033	0.178	0.377	0.646	0.996	0.598	0.301	0.087	-0.061	-0.158
Productivity	-0.480	-0.438	-0.338	-0.157	0.127	0.545	0.608	0.606	0.563	0.494	0.411
θ=0.2, λ=0 and σ=2											
GNP	-0.121	-0.027	0.116	0.322	0.611	1	0.611	0.322	0.116	-0.027	-0.121
Consumption	-0.461	-0.419	-0.316	-0.129	0.171	0.616	0.631	0.595	0.528	0.445	0.356
Investment	-0.105	-0.010	0.132	0.336	0.619	0.999	0.599	0.305	0.096	-0.047	-0.140
Hours	-0.072	0.022	0.163	0.361	0.633	0.994	0.575	0.270	0.057	-0.086	-0.176
Productivity	-0.484	-0.457	-0.371	-0.205	0.069	0.484	0.582	0.602	0.569	0.504	0.422
θ=0.2, λ=1 and σ=2											
GNP	-0.126	-0.034	0.107	0.313	0.604	1	0.604	0.313	0.107	-0.034	-0.126
Consumption	-0.475	-0.445	-0.354	-0.179	0.109	0.547	0.603	0.593	0.543	0.469	0.393
Investment	-0.115	-0.022	0.119	0.323	0.610	0.999	0.596	0.301	0.093	-0.048	-0.139
Hours	-0.084	0.008	0.148	0.347	0.623	0.996	0.573	0.268	0.057	-0.085	-0.173
Productivity	-0.496	-0.486	-0.423	-0.283	-0.037	0.347	0.518	0.586	0.584	0.538	0.465

the model fails to capture some important feature of the labor market. In the data, total hours worked are strongly procyclical and display a slight phase shift in the direction of lagging the cycle, whereas total hours in this model display no phase shift. Productivity in the U.S. economy is somewhat procyclical and leads the cycle while in this artificial economy it is highly procyclical and displays no phase shift. Furthermore, hours worked and productivity are highly correlated, in contrast to the results for the U.S. economy. In this model economy hours worked, consumption and investment are highly correlated with output, but the extent is exaggerated as commonly occurs in standard models. These high correlations are usually attributed to the existence of a single shock in the production function. Intuitively, these shocks cause shifts in the labor demand curve, but not in the labor supply curve, and this gives rise to a close degenerated relationship between hours worked and productivity. For this reason, RBC researchers tend to include additional sources of uncertainty to reduce this high procyclicality, as is done, for example, in Christiano and Eichenbaum (1992), Greenwood and Hercowitz (1991), Benhabib, Rogerson and Wright (1991) and Ozlu (1996).

Our purpose is to extend the model in order to reduce these correlations without including any other source of uncertainty. The first extension we consider is the introduction of physical capital as an input in the human capital production function. Next, we extend the generalized Uzawa-Lucas model to analyze the contribution of a non-standard utility function that enables us to consider different degrees of qualification for leisure by varying a single parameter.

3.1 The generalized Uzawa-Lucas model

This paper shows that shifts not only in the labor demand curve but also in the labor supply curve can be obtained by considering a direct influence of the single technology shock on both sectors, i.e. by considering interactions of physical and human capital in the human capital production sector (generalized Uzawa-Lucas model). To illustrate this intuition, it is useful to consider the analytical solution of the model for the following parameter values: $\sigma = 1$, $\delta_k = 1$ and $\delta_h = 1$. As shown by King, Plosser and Rebelo (1988b), under this parameterization both types of capital will evolve according to the following equations:

$$log(k_{t+1}) = a_1 + \alpha log(k_t) + (1 - \alpha) log(h_t) + log(z_t),$$

$$log(h_{t+1}) = a_2 + \theta log(k_t) + (1-\theta)log(h_t),$$

where θ measures the share of physical capital in the accumulation of human capital. From these two equations, the following univariate processes are obtained for both types of capital:

$$(1-L)[1-L(\alpha-\theta)]log(k_{t+1}) = \theta a_1 + (1-\alpha)a_2 + [1-(1-\theta)L]log(z_t),$$

$$(1-L)[1-L(\alpha-\theta)]log(h_{t+1}) = a_2(1-\alpha) + \theta a_1 + \theta log(z_{t-1}).$$

If the Uzawa-Lucas model with $\theta = 0$ is considered, shocks have no effect on the accumulation of human capital[11]. However, for positive values of the parameter θ both equations show a unit root, which induces permanent effects of shocks on output, consumption and investment, since they all depend on the evolution of physical and human capital. Note that Ozlu (1996) obtains these shifts for the labor supply curve by introducing a second shock in the human capital production function.

When more realistic depreciation rates and higher values for the relative risk aversion parameter are considered there is no analytical solution and the solution is approached by using a numerical solution method.

Table 1 shows the first major result: the standard deviation of the technology shock required is smaller when physical capital is considered as a factor in the production of human capital (i.e. when $\theta > 0$). For instance, the technology shock required to reproduce U.S. output volatility when $\theta = 0.2$ is up to three times smaller than that commonly used in this literature[12]. The propagation mechanism incorporated into this model is therefore stronger. This result is due to the existence of not only an intersectorial substitution of the fraction of time but also an intersectorial substitution of the fraction of physical capital, so as to reduce the productivity differentials between these two sectors caused by technology shocks.

To check how changes in θ affect the results, we compare the impulse response functions. Figure 1 shows the impulse response to a 1% technology shock when $\theta = 0$ and $\theta = 0.2$. We infer from this figure that when physical capital is included as a factor in the human

[11] When $\theta = 0$ the univariate processes for both types of capital are $(1-L)(1-\alpha L)log(k_{t+1}) = a_1(1-L) + a_2(1-\alpha) + (1-L)log(z_t)$ and $(1-L)log(h_{t+1}) = a_2$.

[12] Moreover, it can easily be shown that with higher values of θ the σ_ε needed to match U.S. GNP fluctuations in output is smaller.

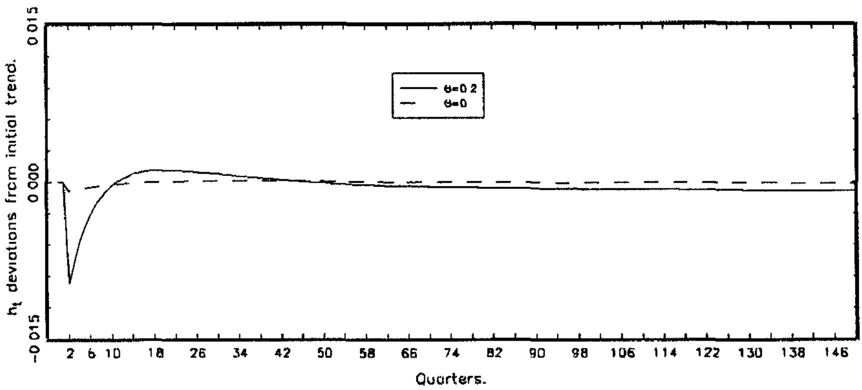
capital production function the response of hours is higher, since the technology shock has effects not only on the marginal productivity of hours but also on the marginal productivity of physical capital, and as a consequence more resources are allocated to the market sector (not only n_t but also ϕ_t). This implies noticeably lower transitory growth rates. Transformed variables return to their steady state values, but this is not the case for untransformed variables. As shown in Figure 1, a favorable technology shock has negative effects on $\frac{h_{t+1}}{h_t}$ in both cases, and the higher θ is, the greater the negative effects are.

Tables 2 and 4 also report the results of our simulations when $\theta = 0.2$. Note that hours fluctuate more than in the previous model due to its intersectorial substitution in the face of the productivity differentials between the two sectors. This, in turn, contributes to the increase in the volatility of GNP for a given size of the standard deviation of the technology shock. Furthermore, the correlations between output and consumption, hours and productivity, and between output and productivity are reduced, *there being no need to introduce any further source of uncertainty.* In fact, the incorporation of physical capital into the human capital production function brings about an improvement in terms of labor market fluctuations, since it not only increases the volatility of hours but also reduces both the correlation between hours and productivity and the correlation between output and productivity. Intuitively, a positive technology shock induces agents to increase hours worked, which in turn decreases the accumulation of human capital permanently. Agents take into account this negative wealth effect. The higher the value of θ, the greater the deviation from the initial situation. As a consequence, depending on the value of θ, technology shocks may shift not only the labor demand curve, but also the labor supply curve. The former produces a positive relation between productivity and hours, whereas the latter produces a negative one. The net effect depends on the value of θ. In this model economy total hours display no phase shift and productivity lags the cycle in contrast to what is observed in U.S. time series.

The predicted standard deviations of consumption and investment are lower than those obtained in the previous model since, when physical capital is included as an additional input in the human capital production function (i.e. $\theta > 0$), the effects of technology shocks on the level of income increase and they have a permanent character and this means a greater permanent deviation from the initial trend. Individuals take into account not only the permanent character of the effects but also the magnitude of the deviation from the initial situation. This magnitude increases when the production of new human capital involves using physical capital as an input. As shown in Figures 1 and 2, when $\theta = 0$ the $\frac{h_{t+1}}{h_t}$ deviation is so low that they behave as if a transitory change had occured, but this is not the case when $\theta = 0.2$. In this second case they take into account that an important permanent change has occured and they do not need to smooth consumption by saving since they already have available greater future consumption. In other words, the intertemporal substitution in consumption (and saving) is lower when $\theta = 0.2$. In equilibrium, saving and investment must be equal, so investment is also less volatile. These later figures show that the lower θ is, the greater the deviations of consumption and physical capital from the initial trend are.

FIGURE 1

Impulse response to a 1% technology shock: human capital



Impulse response to a 1% technology shock: physical capital

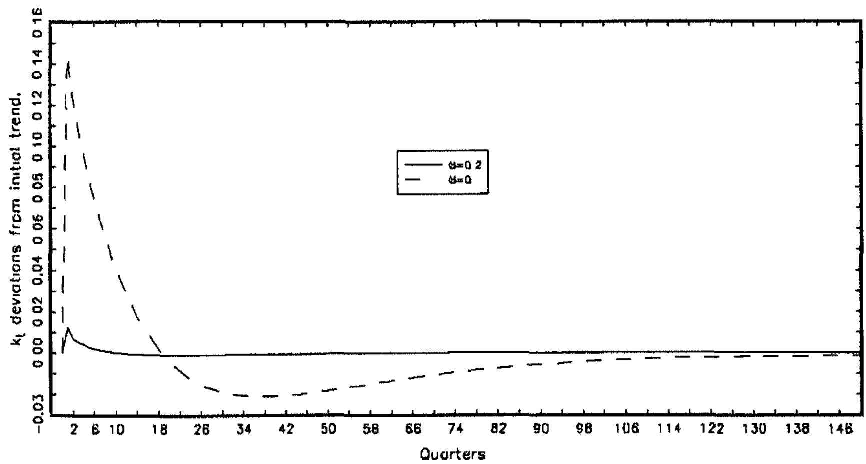
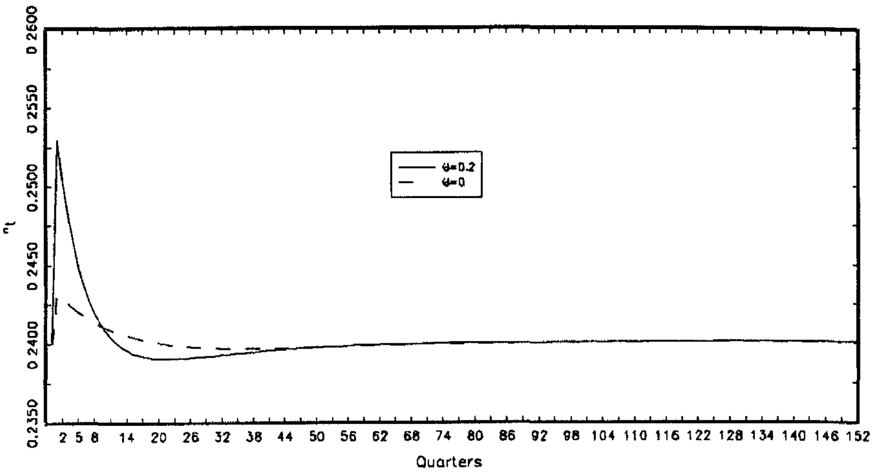
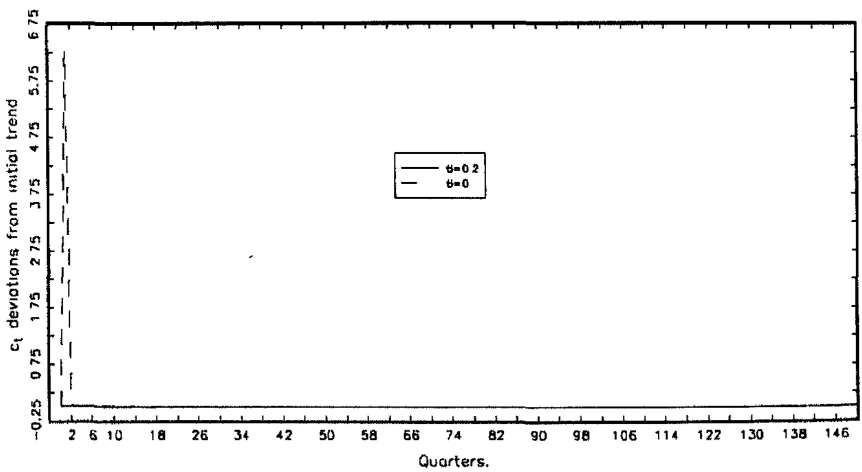


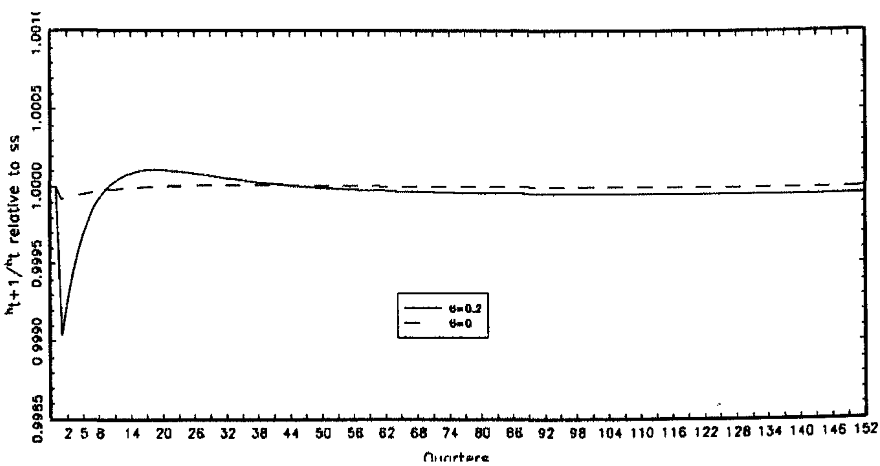
FIGURE 1 (cont.)
Impulse response to a 1% technology shock: working time



Impulse response to a 1% technology shock: consumption



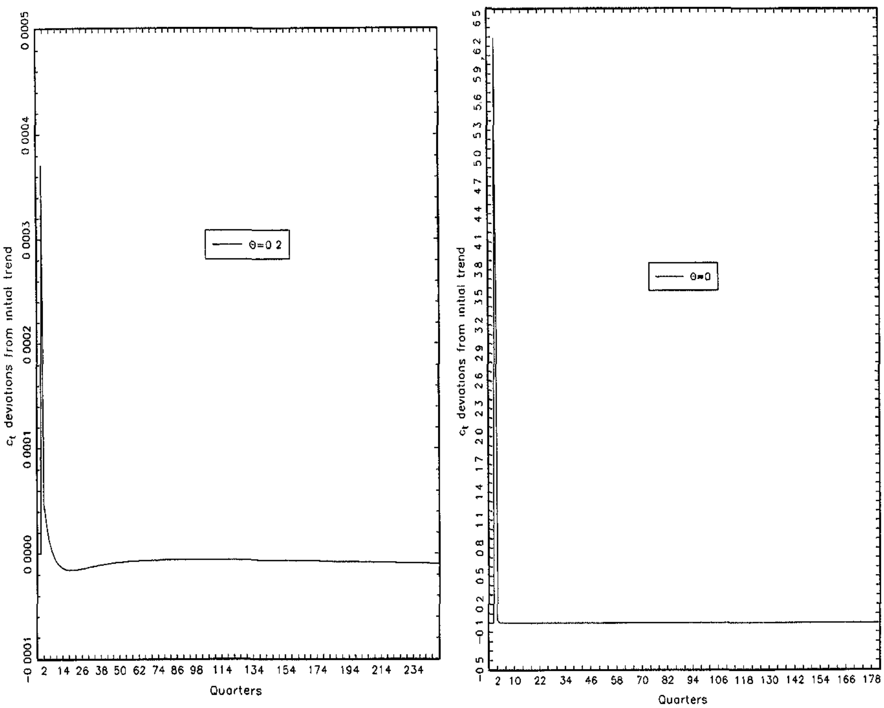
Impulse response to a 1% technology shock: human capital growth



3.2 *Qualified leisure*

Next, we extend the generalized Uzawa-Lucas model by introducing qualified leisure as an additional argument of the utility function. For the results, turn again to Tables 1, 2 and 4.

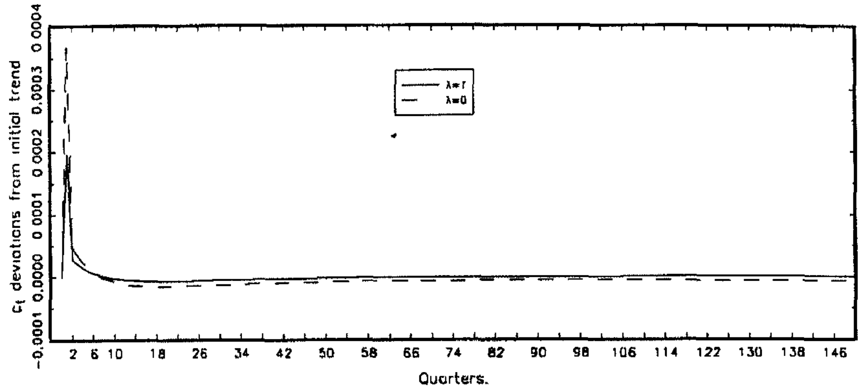
FIGURE 2
Impulse response to a 1% technology shock: consumption



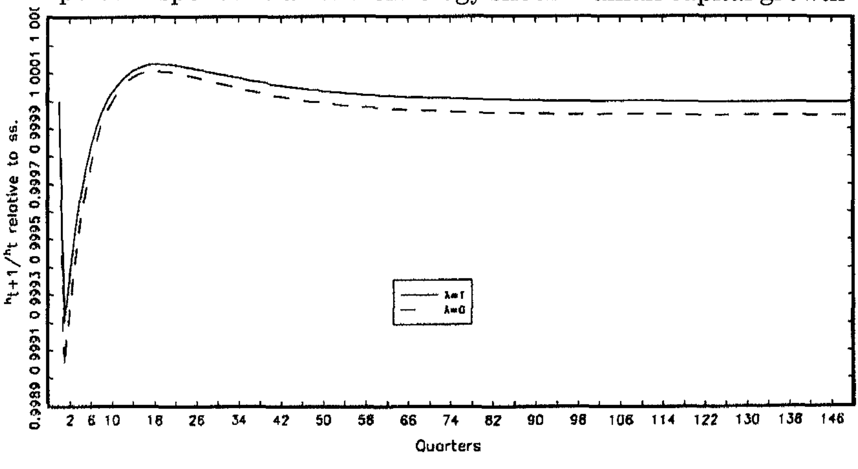
As shown in Table 1, the intensity of the propagation mechanism increases with the value of λ since the standard deviation required is smaller. Moreover, the results for labor market fluctuations improve quantitatively. When $\lambda = 1$, individuals value the qualified units of leisure. In this case, technology shocks also have effects on the qualification of leisure which affects individuals' incentives to work and accumulate human capital (see equations [1] and [3]), reducing the correlation between productivity and hours as well as between GNP and productivity as shown in Tables 2 and 4. Figure 3 shows that the response of hours is higher when individuals value qualified leisure than when they value pure leisure units. Note that individuals try to smooth consumption and qualified leisure, which leads to a higher response of hours worked and lower consumption and investment volatilities. On the other hand, regardless of the value for σ, the higher the value of λ, the longer the phase shift in the direction of lagging the cycle displayed by productivity.

FIGURE 3

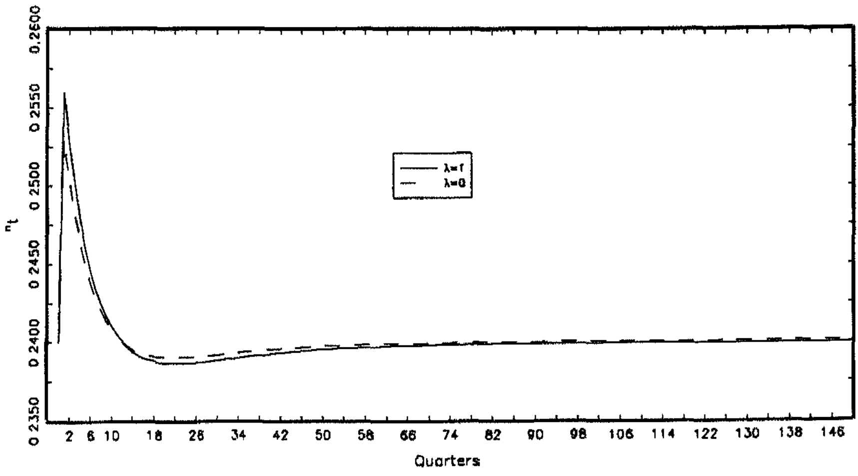
Impulse response to a 1% technology shock: consumption



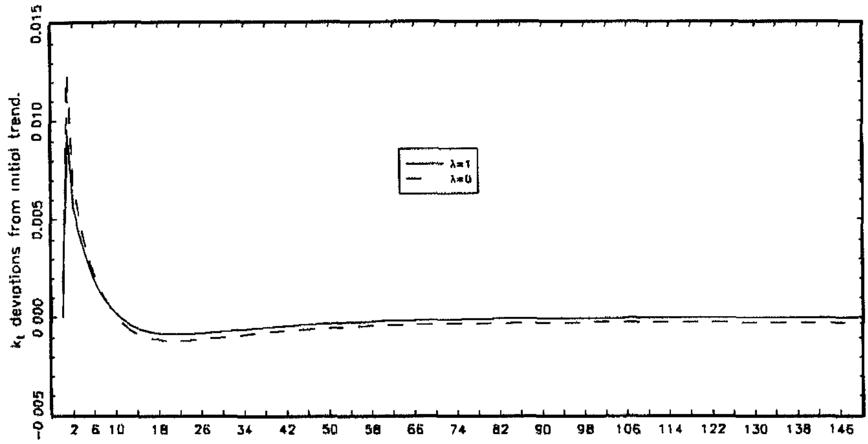
Impulse response to a 1% technology shock: human capital growth



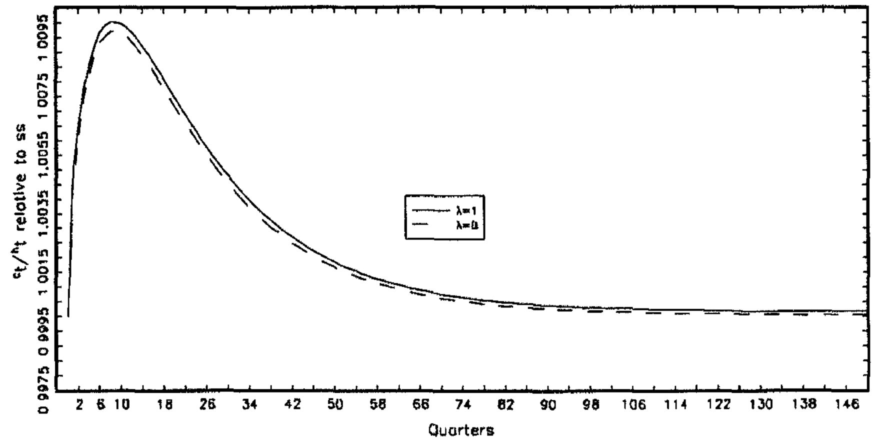
Impulse response to a 1% technology shock: working time



Impulse response to a 1% technology shock: capital stock



Impulse response to a 1% technology shock:
consumption over capital stock



3.3 Sensitivity analysis

Another interesting finding is that regardless of the specification considered for the utility function (that is, regardless of the value of λ), the correlations between consumption and output, productivity and output, and between hours and productivity are not robust to the choice of σ when the generalized Uzawa-Lucas model is considered (i.e. $\theta = 0.2$). Tables 2 and 4 show that the higher the value of σ is, the lower these cross correlations are. The parameter σ measures relative risk aversion. Note that $\frac{1}{\sigma}$ measures the intertemporal elasticity of substitution in consumption. The higher the degree of aversion, the greater the willingness to smooth consumption (i.e. the lower the intertemporal elasticity of substitution in consumption), which leads to a higher response of hours worked.

4. Conclusions

Most of the real business cycle literature has concentrated on exogenous growth models. This has raised criticisms concerning the weakness of the propagation mechanism involved. Moreover, although some extensions to the exogenous simple growth model show advances in quantitative terms in relation to the labor market, most of them need a second source of uncertainty in order to replicate some fluctuations as observed in U.S. data. The purpose of this study is to provide an answer to these criticisms. This is done by considering a discrete time stochastic version of the Uzawa-Lucas model with two modifications: the introduction of physical capital in the human capital production function and a more general utility function which allows for the valuation of leisure in qualified terms.

The results show that considering physical capital as a factor in human capital production function provides a stronger propagation mechanism and it also brings about a quantitative improvement in the results obtained for the labor market, with no need to introduce another source of uncertainty. The higher the share is, the stronger the propagation mechanism is. Once this modification is considered the intensity of the propagation mechanism is reinforced and certain correlation results improved if individuals value qualified leisure instead of pure leisure units. Finally, regardless of the specification considered for the utility function, some results are not robust to changes in the value of the relative risk aversion parameter when physical capital is included as a factor in the human capital production function.

These quantitative improvements, however, are not without cost. Fluctuations in consumption, investment and productivity are smoother in the generalized Uzawa-Lucas model due to the more persistent character of the effects of the technology shock. The bottom line of this paper is that a precise calibration of θ and σ is needed when endogenous growth models are considered, since several particularly important dynamic features of the model are not robust to changes in these parameters. Results for the fluctuations in consumption, investment and productivity could be improved by introducing a second source of uncertainty in the household's budget constraint, which would increase intertemporal substitution in both consumption and investment. This conclusion can be drawn, for instance, from Gomme (1993) and Ozlu (1996), which combine two shocks, although Gomme (1993) introduces a transitory wealth effect by a cash-in-advance restriction on consumption, which in turn allows him to explain the relation between inflation and growth.

Appendix

Den Haan and Marcet (1990) provide a complete description of the parameterized expectations approach (PEA). This procedure can be summarized as follows:

1.- Find the necessary conditions characterizing the equilibrium. Note that some equations involve conditional expectations. Choose a suitable functional form to approximate each conditional expectation. In this study there are two conditional expectations to be approximated, as shown by equations [5] and [7]. Since these conditional expectations are $g : R^2_+ \rightarrow R_+$ functions of the state variables $(\hat{k}_t, z_t)$, this method attempts to approximate these g functions by functional forms which depend upon the state variables and a vector of parameters to be estimated. This study considers the functional form $\eta_1 \hat{k}_t^{\eta_2} z_t^{\eta_3}$, since its image is always positive if the value for the initial η_1 is positive, as is the image of the g functions we want to approximate.

2.- Obtain the sequence of control variables in accordance with the parameterization chosen. They can be obtained from equations [5] to [10].

3.- Calculate the parameter η that will minimize the mean squared error derived from the approximation of the conditional expectations by running a nonlinear least squares regression. Repeat until a fix point is found, having established a criterion for convergence previously. This study considers accuracy of up to four digits.

4.- Letting $P_n(x)$ denote a polynomial of degree n on the vector x, the aforementioned functional form can be expressed as $exp(P_1(log(x)))$, where x denotes the state variable vector. Greater accuracy can be obtained by increasing the degree of the polynomial and comparing the (absolute) differences in the solutions obtained. Another possible comparison is based on the result obtained from the accuracy test proposed by den Haan and Marcet (1994), although this test is not very helpful here because the technology shock deviation is so low. This study considers second-order polynomials and the length for the simulated time series used to obtain the PEA solution is 40,000 observations.

In this Appendix the application of the PEA to the generalized Uzawa-Lucas endogenous growth model ($\theta = 0.2$) is shown. Equations [5]-[10] describe the equilibrium in this case.

We replace each conditional expectation in [5] and [7] by a function ψ, which depends on the state variables and a vector of parameters η that will be chosen in order to approach ψ as much as possible the conditional expectations. So the main goal is to find such ψ and η.

For a given η, and a given realization of z_t we can obtain the sequence of work and leisure from [5] and [7] by substituting the conditional expectations with a function $\psi(\hat{k}_t, z_t; \eta)$:

$$\begin{pmatrix} n_t^{\alpha} \\ l_t^{(1-\omega)(1-\gamma)-1} \end{pmatrix} = \beta \begin{pmatrix} \delta_1 \hat{k}_t^{\delta_2} z_t^{\delta_3} \\ \gamma_1 \hat{k}_t^{\gamma_2} z_t^{\gamma_3} \end{pmatrix}.$$

$\hat{c}_t, \phi_t, \frac{h_{t+1}}{h_t}$ and $\hat{k}_{t+1}$ are obtained from [6], [8], [9] and [10], respectively.

Let us define $S : R^m \rightarrow R^m$ where m is the dimension of η, as:

$$S(\eta) = \arg\min_{\overline{\eta}} E[\varphi - \psi(\hat{k}_t, z_t; \overline{\eta})]^2,$$

where φ denotes the function inside the conditional expectation to be approached. We choose η_f to satisfy $\eta_f = S(\eta_f)$. Good initial conditions for η^0 are needed. We have started with the nonstochastic steady state value with $\sigma_\varepsilon = 0.0001$ and this value has been changed in a systematic way. It is possible to obtain greater accuracy by increasing the order of the polynomial.

TABLE A.1

η_f for the Uzawa-Lucas model and the generalized Uzawa-Lucas model

η_f	$\theta = 0$	$\theta = 0.2$ and $\sigma = 1.3$		$\theta = 0.2$ and $\sigma = 2.0$	
		$\lambda = 0$	$\lambda = 1$	$\lambda = 0$	$\lambda = 1$
δ_1	7.55303	0.25295	0.16657	0.22379	0.12047
δ_2	-0.64876	-7.61023	-0.92200	-0.86583	-1.15154
δ_3	-0.58288	4.26574	6.73647	2.09137	2.75531
δ_4	-0.00474	2.06379	3.13090	-	-
δ_5	0.00448	-	-	-	-
δ_6	-0.05639	-3.78491	-5.77187	-2.11796	4.56090
δ_{7*}	-	-	-	123.08730	426.71174
δ_{8*}	-	-	-	-	-52302.49230
γ_1	2.72570	7.54087	20.51690	39.86594	81.82800
γ_2	0.12164	0.18152	0.16598	0.34752	0.24867
γ_3	0.09367	-0.17244	-0.22413	-0.04105	-0.16688
γ_4	0.01637	-0.09067	-0.07444	-	-
γ_5	-0.01073	-	-	-	-
γ_6	-0.00043	0.58582	0.64604	0.20589	-1.37366
γ_{7*}	-	-	-	-30.76379	-70.94054
γ_{8*}	-	-	-	-	9482.65820

* Parameters δ_7. δ_8. γ_7 y γ_8 are associated with $(log(z_t))^3$ and $(log(z_t))^4$.

The results in Tables 1 and 4 are obtained with second-order polynomials[13], i.e. $\psi(\hat{k}_t, z_t; \eta) = exp(log(\eta_1)+\eta_2 log(\hat{k}_t)+\eta_3 log(z_t)+\eta_4 log(\hat{k}_t)log(z_t)+\eta_5(log(\hat{k}_t))^2+\eta_6(log(z_t))^2)$ and the η_f used in each case is given in Table A.1[14]:

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[13] Some terms are redundant and so we can ignore them without losing any predictive power.

[14] Programs are available from the author.

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Resumen

La contribución de los modelos de crecimiento endógeno para explicar las fluctuaciones económicas ha sido analizada por autores como Gomme (1993) y Ozlu (1996). Sin embargo, estos autores incorporan fuentes adicionales de *incertidumbre para reproducir ciertos comportamientos cíclicos del mercado de trabajo y, por lo tanto, la contribución específica de los modelos de crecimiento endógeno a la literatura de los ciclos reales permanece difusa. Este trabajo trata de identificar las claves del avance que muestran algunos modelos de crecimiento endógeno en la reproducción de ciertos aspectos clave del comportamiento del mercado de trabajo manteniendo una única perturbación. Este trabajo muestra que la introducción de una actividad que compita con la producción del bien final puede ayudar a explicar algunas características del mercado de trabajo sin necesidad de introducir una fuente adicional de incertidumbre.*

Palabras clave: Ciclos económicos reales, fluctuaciones, crecimiento endógeno, mecanismo de propagación.

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