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Research article

Can shocks to the discount factor explain business cycle fluctuations in Bulgaria (1999–2018)?

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Abstract: A stochastic discount factor is introduced into a real-business-cycle setup with a government sector. The model is calibrated to Bulgarian data for the period 1999–2018, which is after the introduction of the currency board arrangement. The quantitative importance of shocks to the discount factor is investigated for the propagation of cyclical fluctuations in Bulgaria. In particular, allowing for a stochastic discount factor in the setup improves the model fit vis-a-vis data by increasing variability of employment and wages. However, those improvements are at the cost of increasing the volatility of consumption and investment.

Keywords: business cycles; stochastic discount factor; Bulgaria

JEL Codes: E24, E32

1. Introduction and motivation

The standard real-business-cycle (RBC) model was introduced in modern quantitative dynamic macroeconomics as a modelling tool that allows researchers to create artificial economies, which approximate those of existing countries along important aggregate dimensions, and use those simulated environments to generate artificial, or model-predicted time series, which are then compared to the properties of empirical (observed) time series. In this way the models could be interpreted as disciplined data-generating mechanisms for data matching akin to the general method of moments (GMM) in econometrics. Alternatively, those simulated data series could be interpreted as a maximum likelihood estimation (MLE), investigating how likely is that the observed time series were produced by the theoretical model. In addition, and in important contrast to ad hoc dynamic econometric models (e.g., Vector-Auto-Regressions, or VARs) used in time series analysis, the important transmission mechanisms (based on inter- and intra-temporal optimality principles) in these theoretical model economies are explicit, as those setups are based on micro-foundations, so macroeconomic researchers could gain a deeper insight about how the real economy works. Finally, those model economies could be used for computational experiments, which could produce quantitative assessments of policies and reforms that are not yet implemented. This is again a strong advantage to econometric estimation, which is not useful in such contexts.

The technical procedure used in the quantitative theoretical macroeconomic literature to assign values of the parameters in the model is called *calibration*. In contrast to what many applied researchers think/believe, calibration is not done in an arbitrary fashion; In particular, calibration is preferred to estimation in cases when we already have data for certain parameters, or we have a *target from data* that we need to match in the model, which will constrain the calibration procedure and determine ("identify" in econometric language) the value of that parameter. In addition, calibration is preferred in cases when we do not have information on the parameter, and want to investigate how the model predictions change when the parameter changes over a certain (plausible) range, *i.e*, how robust is the model to slight changes in certain parameters. Then, after calibrating all model parameters, we can proceed to simulate the model to produce artificial time series.

With regard to the individual variability of the parameter estimates above, the question "why just settle for a particular point estimate?" may be raised. In particular, the core of the criticism raised by some economists is that by giving up the variability in the parameter (or parameters), researchers are giving up information, which might be potentially useful.[*] We can thus argue that holding the discount factor parameter fixed over the cycle might lead researchers to wrong conclusions. We thus allow the discount factor to vary in order to evaluate the importance of the information contained in the variability of this parameter.[†] It is thus plausible to assume that household's discount factor can change over the business cycle. In the model setup, the discount factor parameter shows up in the dynamic optimality condition for the household, which determines how capital is allocated across periods, so a shock to the discount factor in turn will interest rates, wages, and thus labor, capital, production, investment, and consumption decisions as well. Therefore, allowing for a stochastic discount factor in the theoretical setup can generate additional interesting interactions among model variables.

This proposal is taken seriously, and this paper incorporates a stochastic discount factor in an otherwise standard real-business-cycle (RBC) model with a detailed government sector. The model is calibrated for Bulgaria in the period 1999–2018, as Bulgaria provides a good testing case for the theory.[‡] The paper then proceeds to quantitatively evaluate the effect of such a stochasticity as a mechanism of business cycle propagation. This is the first study on the issue using modern macroeconomic modelling techniques, and thus an important contribution to the field. Unfortunately, for reasonable degree of discount factor variability, the quantitative effects are tiny.In particular, allowing for a stochastic discount factor in the setup improves the model fit vis-a-vis data by increasing variability of employment and wages. However, those improvements are at the cost of increasing the volatility of consumption and investment. The small effect of the discount factor stochasticity can be

[*] As pointed out in Vasilev (2020), an alternative approach in macroeconomic modelling is to estimate those RBC models using techniques based on Bayesian statistical approach. In particular, those researchers take each parameter to follow a distribution, and thus, in addition to the mean, also take into consideration the standard deviation of the distribution.

[†] Parkin (1988) uses such a technique (which he refers to as "strip mining") as a test whether RBC model parameters are structural. Similarly, for Bulgaria Vasilev (2020) studies the effect of a stochastic capital share, Vasilev (2019a) studies the effect of a stochastic leisure preference parameter, while Vasilev (2019b) investigates the quantitative effect of an endogenously determined depreciation rate.

[‡] Before the introduction of proportional income taxation of 10 percent in 2008, Bulgaria operated a progressive income taxation regime during the period 1993–2007 with the same effective rate. In addition, the corporate income tax rate has been reduced, in several steps, to a proportional rate of 10 percent in 2007 as well, to avoid incentives to move earnings across the income categories.

viewed as a validation of the robustness of the standard real business cycle model with a constant rate of discounting.

The remaining of the paper is organized as follows: Section 2 presents the model framework and defines the market equilibrium, Section 3 explains the calibration procedure, and Section 4 computes the steady-state model solution. Sections 5 proceeds with the general dynamics of model variables, and compared the theoretical second moments of model variables against their empirical counterparts. Section 6 concludes.

2. Model description

In the model, there is a representative household, which derives utility out of private consumption and leisure. The total time available to the household can be used as a labor resource, or as leisure. The government taxes private consumption, and levies a proportional tax rate on labor and capital income, in order to finance government consumption and public transfers. On the production side, there is a stand-in firm, which uses labor and capital to produce final output, which could be used for consumption, investment, or government spending.

2.1. Households

There is a representative household, which maximizes its discounted utility function

$$\max E_0 \sum_{t=0}^{\infty} \beta_t^t \Big\{ \ln c_t - \gamma h_t \Big\} \tag{1}$$

where E_0 is the household's expectation operator as of period 0, c_t refers to household's private consumption in period t, h_t are hours spent working in period t, $0 < \beta_t < 1$ is the stochastic discount factor, and $\gamma > 0$ is the relative utility weight attached to leisure.

The household begins with a positive initial stock of physical capital $k_0 > 0$, and chooses how much to increase it via investment. The evolution of physical capital is as follows:

$$k_{t+1} = i_t + (1 - \delta)k_t \tag{2}$$

where $0 < \delta < 1$ is the linear depreciation rate. Next, the real interest rate is denoted by r_t, thus the before-tax capital income of the household in period t is represented by $r_t k_t$. In addition, the household can earn labor income: the going hourly wage rate of w_t, so pre-tax labor income generated is $w_t h_t$. Lastly, the household is a sole owner of the firm in the economy and receives all of the firm's profit, π_t.

The household's problem becomes

$$\max E_0 \sum_{t=0}^{\infty} \beta_t^t \Big\{ \ln c_t - \gamma h_t \Big\} \tag{3}$$

s.t.

$$(1 + \tau^c)c_t + k_{t+1} - (1 - \delta)k_t = (1 - \tau^y)[r_t k_t + \pi_t + w_t h_t] + g_t^t \tag{4}$$

where where τ^c is the tax on consumption, τ^y is the proportional income tax rate on labor ($0 < \tau^c, \tau^y < 1$), and g_t^t are government transfers. The household takes the tax rates $\{\tau^c, \tau^y\}_{t=0}^{\infty}$, government spending categories, $\{g_t^c, g_t^t\}_{t=0}^{\infty}$, profit $\{\pi_t\}_{t=0}^{\infty}$, the realized technology process $\{A_t\}_{t=0}^{\infty}$, the process followed by the discount factor $\{\beta_t\}_{t=0}^{\infty}$, prices $\{w_t, r_t\}_{t=0}^{\infty}$, and chooses allocations $\{c_t, h_t, k_{t+1}\}_{t=0}^{\infty}$ to maximize its discounted expected utility subject to the budget constraint.[§] The first-order optimality conditions as as follows:

$$c_t \quad : \quad \frac{1}{c_t} = \lambda_t(1+\tau^c) \tag{5}$$

$$h_t \quad : \quad \gamma = \lambda_t(1-\tau^y)w_t \tag{6}$$

$$k_{t+1} \quad : \quad \lambda_t = E_t\beta_{t+1}\lambda_{t+1}\Big[1+[1-\tau^y]r_{t+1}-\delta\Big] \tag{7}$$

$$TVC \quad : \quad \lim_{t\to\infty}\beta_t^t\lambda_t k_{t+1} = 0 \tag{8}$$

where λ_t denotes the Lagrangean multiplier attached to household's budget constraint in period t. In turn, the first-order conditions above are interpreted as follows: for each household, at the optimum, the marginal utility of consumption balances the marginal utility of wealth, corrected for the consumption tax rate. Next, when choosing optimal labor supply, a balance is achieved between the benefit from working, and the cost in terms of lower utility. The third equation is referred to as the "Euler condition," which indirectly determines how the household optimally allocates physical capital across any two congruent periods. Note that the stochastic discount factor will disturb the Euler condition. The last condition is referred to as the "transversality condition" (TVC): ithis is a boundary condition, which states that beyond the optimization horizon, capital becomes worthless.

2.2. *Firm problem*

There is a stand-in firm in the economy, which produces all final output. The price of output is chosen to be the numeraire. The production technology is assumed to be Cobb-Douglas, which requires both capital, k_t, and labor, h_t, to produce and maximize firm's static profit

$$\Pi_t = A_t k_t^{\alpha} h_t^{1-\alpha} - r_t k_t - w_t h_t \tag{9}$$

where A_t denotes the level of total factor productivity in period t. As the firm rents the inputs from the market, the problem of the firm collapses to a sequence of static profit maximizing problems. In equilibrium, each factor of production is priced competitively, *i.e.*:

$$k_t \quad : \quad \alpha\frac{y_t}{k_t} = r_t \tag{10}$$

$$h_t \quad : \quad (1-\alpha)\frac{y_t}{h_t} = w_t \tag{11}$$

In equilibrium, given that the inputs of production are paid their marginal products, $\pi_t = 0, \forall t$.

2.3. *Government*

In this model economy, the government is levying taxes on labor and capital income, as well as consumption, in order to finance spending on wasteful government purchases, and government transfers. The government period budget constraint is as follows:

$$g_t^c + g_t^t = \tau^c c_t + \tau^y[w_t h_t + r_t k_t + \pi_t] \tag{12}$$

[§] Note that by choosing k_{t+1} the household is implicitly setting investment i_t optimally.

In the calibration section later, income and consumption tax rates and government consumption-to-output ratio would be chosen to match the average share in data, while transfers would be determined residually to keep the government budget balanced.

2.4. Dynamic Competitive Equilibrium (DCE)

For a given processes followed by total factor productivity and the stochastic discount factor, $\{A_t, \sigma_t\}_{t=0}^{\infty}$, the two tax schedules $\{\tau^c, \tau^y\}_{t=0}^{\infty}$, initial value of the physical capital stock $\{k_0\}$, the DCE for this economy is a list of sequences $\{c_t, i_t, k_t, h_t, g_t^c, g_t^t\}_{t=0}^{\infty}$, and input prices $\{w_t, r_t\}_{t=0}^{\infty}$ such that (i) the representative household maximizes its discounted expected utility function subject to its budget constraint; (ii) the stand-in firm maximizes total profit; (iii) government runs a balanced budget; (iv) all markets clear.

3. Data and model calibration

To characterize the business cycle fluctuations in Bulgaria, we focus on the period 1999–2018, which is after the introduction of the currency board (1999–2018). Quarterly data on output, consumption and investment was collected from the National Statistical Institute (2020), while the real interest rate series is taken from Bulgarian National Bank Statistical Database (2020). The calibration strategy described in this section is standard: first, as in Vasilev (2016), the steady-state discount factor, $\beta = 0.982$, is chosen to match the equilibrium capital-to-output ratio in Bulgaria, $k/y = 13.964$. Next, labor share, $1 - \alpha = 0.571$, was set to the average value of labor income in aggregate output over the period 1999–2018. Next, the average income tax rate was set to its average effective rate in data, $\tau^y = 0.1$. Similarly, the average tax rate on consumption is set to its value over the period, $\tau^c = 0.2$.

Next, the relative weight attached to the utility out of leisure in the household's utility function, γ, is calibrated to match the steady-state hours worked. Next, capital depreciation rate, $\delta = 0.013$, was set equal to the average quarterly depreciation rate over the period. Finally, an AR(1) process was fit on the total factor productivity series. Due to the lack of data, we make use of the same parameters for the stochastic discount factor process in the computational experiments performed later. Table 1 below summarizes the values of all model parameters used in the paper.

Table 1. Model parameters.

Parameter	Value	Description	Method
β	0.982	Discount factor	Calibrated
α	0.429	Capital Share	Data average
γ	0.873	Relative utility weight, leisure	Calibrated
δ	0.013	Depreciation rate, physical capital	Data average
τ^y	0.100	Income tax rate	Data average
τ^c	0.200	VAT/consumption tax rate	Data average
ρ_a	0.701	AR(1) persistence coefficient, TFP process	Estimated
σ_a	0.044	st. error, TFP process	Estimated
ρ_β	0.701	AR(1) persistence coefficient, discount factor	Set
σ_β	0.044	st. error, discount factor	Set

4. Steady-state

Given the model parameters, the steady-state equilibrium system can be now solved, and the "big ratios" can be compared to their empirical averages. The results are reported in Table 2 below. The stochastic discount factor plays no role in these computation. Next, the model matches quite well consumption-to-outpu, government purchases ratio, and investment ratios are also closely approximated. Labor and capital income shares of income are also identical to those in data, which follows from the Cobb-Douglas form of the aggregate production function. The after-tax return on capital, denoted by $\bar{r} = (1 - \tau^y)r - \delta$ is also relatively well-approximated by the model economy.

Table 2. Data Averages and Long-run Solution.

Variable	Description	Data	Model
y	Steady-state output	N/A	1.000
c/y	Consumption-to-output ratio	0.648	0.674
i/y	Investment-to-output ratio	0.201	0.175
k/y	Capital-to-output ratio	13.96	13.96
g^c/y	Government consumption-to-output ratio	0.151	0.151
wh/y	Labor income-to-output ratio	0.571	0.571
rk/y	Capital income-to-output ratio	0.429	0.429
h	Share of time spent working	0.333	0.333
$\bar{r}$	After-tax net return on capital	0.014	0.016

5. Out of steady-state model dynamics

For the general case, the model in this paper does not possess an analytical solution, so we need to solve it numerically. We do this by log-linearizing the original system of equations around the steady-state, which produces a first-order system of stochastic difference equations; Those are easy to solve for. Next, we present the effects of an isolated shock to the total factor productivity process and the discount factor; then we fully simulate the model to compare the theoretical moments of the model against the empirical ones.

5.1. *Impulse response analysis*

This subsection documents the impulse responses of model variables to a 1% surprise innovation to total factor productivity, and the discount factor. The impulse response functions (IRFs) are presented in Figure 1 and Figure 2 for the ttotal factor productivity and the discount-factor shocks, respectively. As a result of the one-time shock to total factor productivity, output increases contemporaneously, which expands the availability of all resources in the economy; hence, all uses of output—consumption, investment, and government consumption also increase upon impact.

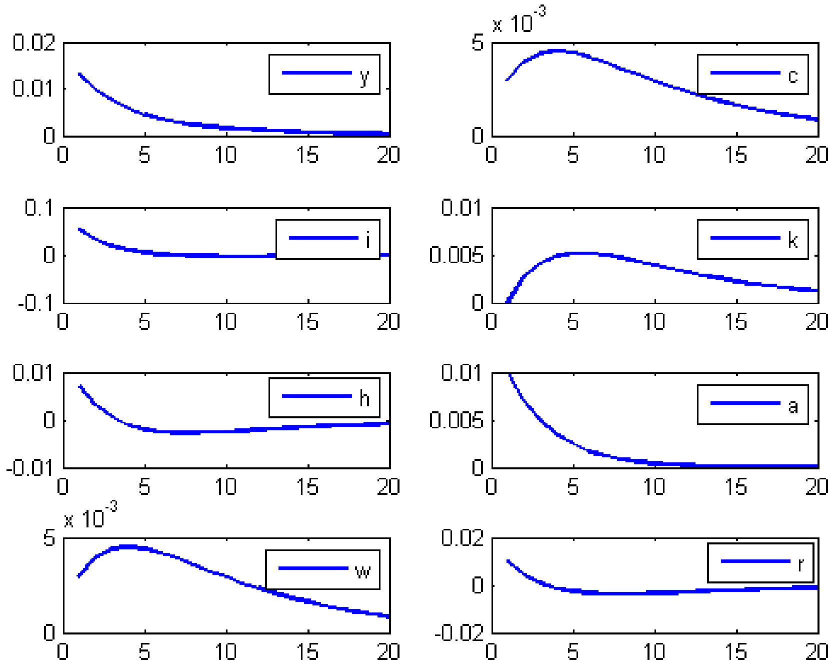

Figure 1. Impulse Responses to a 1% surprise innovation in technology.

At the same time, the jump in total factor productivity increases the two input prices, those of labor and capital. The representative households then respond to these developments and begins to accumulate capital, and works more. In turn, the increase in capital and labor use in production increases output further.

Over time, as capital stock increases, decreasing returns kick in, and its after-tax marginal product begins to decrease, which lowers the households' incentives to invest, and capital returns to its steady-state in a hump-shaped fashion. The rest of the model variables return to their old steady-states following a monotone pattern.

The second shock is a one-time innovation to the discount factor. The results are summarized in Figure 2 on the next page. Overall, the effect of this shock is quite small, so changes in discount factor are unlikely candidates for business cycle propagators. In particular, upon impact of the shock, the Euler equation is disturbed. Investment increases, and capital accumulation speeds up. Next, due to the complementarity between capital and labor, the marginal product of labor increases, and hours worked increase. The increase in hours worked increases directly output, and indirectly capital through the increase in the marginal productivity of capital, the interest rate, which incentivizes the household to invest in capital. In the short run the increase in investment is at the cost of current consumption, so it falls upon impact of the shock. Overall, the effect of the shock to the discount factor is very short-lived, and variables return quickly to their old steady-states.

5.2. Simulation and moment-matching

As in Vasilev (2017b), we proceed to fully simulate the model for the length of the data horizon. Both the actual and simulated data is detrended using the Hodrick-Prescott (1980) filter. Table 3 on the

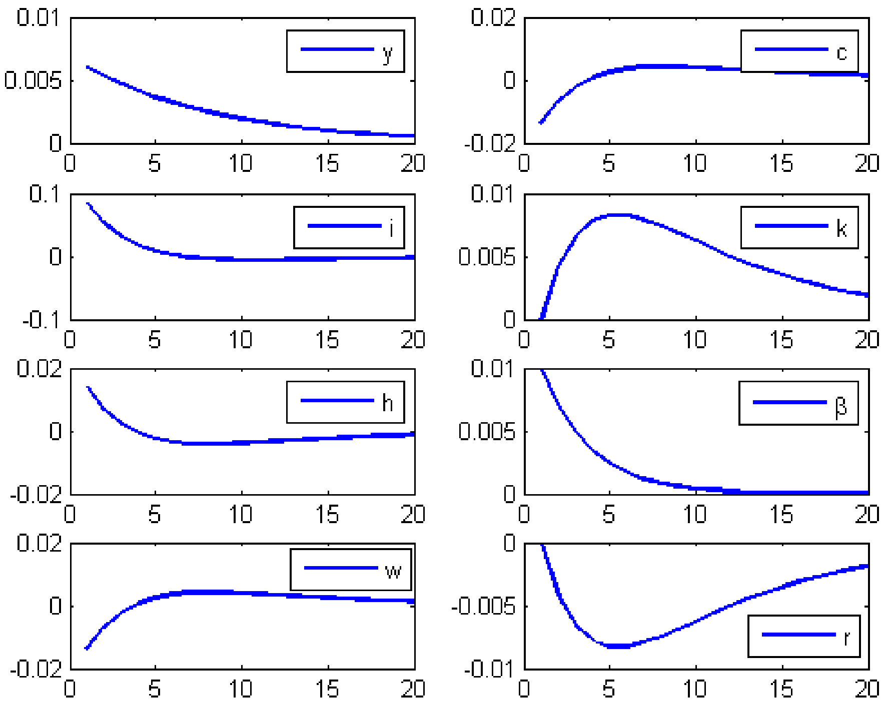

Figure 2. Impulse Responses to a 1% surprise innovation in discount factor.

next page summarizes the second moments of data vs the model predicted ones. The generated results are the case with both shocks, and discount-factor, and technology shocks only, respectively.

As in Vasilev (2016, 2017b, 2017c), the models match quite well the absolute volatility of output and investment. In addition, the predicted consumption and investment volatilities are too high. Still, the models are qualitatively consistent with the pattern that consumption is smoother than output, while investment is much more variable than output. The model with both shocks at work generates a more variable consumption, investment, wage- and employment series, as compared to a model with only total factor productivity at work. Therefore, it can be argued that the addition of stochasticity in the discount-factor improves the model performance vis-a-vis data, as it adds disturbance in the Euler equation, which is a central equation in the model.

Looking at the labor market variables, the variability of employment and wages in the model with both shocks is higher than that in data, which confirms that the assumption of perfect competition, e.g. Vasilev (2009), as well as the benchmark calibration here, is not a good approximation of reality. Next, in terms of correlations with output, the model with both shocks systematically under-predicts the pro-cyclicality of consumption, investment, and over-predicts the pro-cyclicality of government consumption. Next, the correlation of employment with output in the model is too low, while wages are predicted to be highly pro-cyclical, which is a puzzle, as in data wages are acyclical. This mismatch follows from the wage being equal to the labor productivity condition produced by the model.

Table 3. Business cycle moments.

	Data	Both Shocks	Beta shocks only	Technology Shocks only
σ_y	0.05	0.05	0.05	0.05
σ_c/σ_y	0.55	0.92	1.01	0.85
σ_i/σ_y	1.77	3.42	4.92	2.24
σ_g/σ_y	1.21	1.00	1.00	1.00
σ_h/σ_y	0.63	0.71	1.01	0.48
σ_w/σ_y	0.83	0.92	1.01	0.85
$\sigma_{y/h}/\sigma_y$	0.86	0.92	1.01	0.85
$corr(c, y)$	0.85	0.66	0.35	0.90
$corr(i, y)$	0.61	0.65	0.66	0.80
$corr(g, y)$	0.31	1.00	1.00	1.00
$corr(h, y)$	0.49	0.31	0.35	0.39
$corr(w, y)$	−0.01	0.80	0.35	0.90

In the next subsection, as in Vasilev (2016), we turn our attention to the dynamic correlation between labor market variables and output. To this end, the autocorrelation functions (ACFs) are compared and contrasted to the simulated ones from the model economy.

5.3. Auto- and cross-correlation

This subsection presents and analyzes the auto-(ACFs) and cross-correlation functions (CCFs) of the main variables featured in the model. In particular, the coefficients empirical ACFs and CCFs are presented in Table 4 below against the simulated ones.[¶] To economize on space, we only present the case with both total factor productivity and discount-factor shocks.

As seen from Table 4 above, the model specification featuring both shocks compares relatively well vis-a-vis empirical labor market autocorrelations. The persistence of labor market variables are also relatively well-approximated by the simulated model dynamics. Overall, the model with both total factor productivity- and discount factor shocks generates too much persistence in output and hours, and is again subject to the critiques of Nelson and Plosser (1992), Cogley and Nason (1995) and Rotemberg and Woodford (1996b), who blaim the RBC class of models for their lack of a strong internal propagation mechanism when there is little persistence in the TFP process. In addition, as in Vasilev (2009), and in the current one, labor market is assumed to be perfectly-competitive, and output and employment series feature little persistence. Next, as seen from Table 5 below, labor productivity leads hours in data. This pattern cannot be captured by the model, as the total factor productivity shock shifts the labor demand curve only; the effect between hours and labor productivity is then only a contemporaneous one, and a stochastic discount factor does not improve the model fit in this direction.

¶ Following Canova (2007), this is used as measure capturing overall goodness-of-fit of the model.

Table 4. Autocorrelations for Bulgarian data and the model economy.

		k			
Method	Statistic	0	1	2	3
Data	$corr(n_t, n_{t-k})$	1.000	0.484	0.009	0.352
Model	$corr(n_t, n_{t-k})$	1.000	0.952	0.893	0.825
	(s.e.)	(0.000)	(0.029)	(0.055)	(0.080)
Data	$corr(y_t, y_{t-k})$	1.000	0.810	0.663	0.479
Model	$corr(y_t, y_{t-k})$	1.000	0.957	0.906	0.846
	(s.e.)	(0.000)	(0.025)	(0.048)	(0.070)
Data	$corr(a_t, a_{t-k})$	1.000	0.702	0.449	0.277
Model	$corr(a_t, a_{t-k})$	1.000	0.956	0.902	0.839
	(s.e.)	(0.000)	(0.027)	(0.052)	(0.075)
Data	$corr(c_t, c_{t-k})$	1.000	0.971	0.952	0.913
Model	$corr(c_t, c_{t-k})$	1.000	0.955	0.900	0.838
	(s.e.)	(0.000)	(0.027)	(0.052)	(0.075)
Data	$corr(i_t, i_{t-k})$	1.000	0.810	0.722	0.594
Model	$corr(i_t, i_{t-k})$	1.000	0.952	0.892	0.822
	(s.e.)	(0.000)	(0.030)	(0.058)	(0.084)
Data	$corr(w_t, w_{t-k})$	1.000	0.760	0.783	0.554
Model	$corr(w_t, w_{t-k})$	1.000	0.959	0.909	0.853
	(s.e.)	(0.000)	(0.024)	(0.047)	(0.069)

Table 5. Dynamic correlations for Bulgarian data and the model economy.

		k						
Method	Statistic	−3	−2	−1	0	1	2	3
Data	$corr(h_t, (y/h)_{t-k})$	−0.342	−0.363	−0.187	−0.144	0.475	0.470	0.346
Model	$corr(h_t, (y/h)_{t-k})$	−0.044	−0.073	−0.115	−0.803	−0.537	−0.444	−0.353
	(s.e.)	(0.326)	(0.286)	(0.240)	(0.232)	(0.269)	(0.296)	(0.321)
Data	$corr(h_t, w_{t-k})$	0.355	0.452	0.447	0.328	−0.040	−0.390	−0.57
Model	$corr(h_t, w_{t-k})$	−0.044	−0.073	−0.115	−0.803	−0.537	−0.444	−0.353
	(s.e.)	(0.326)	(0.286)	(0.240)	(0.232)	(0.269)	(0.296)	(0.321)

6. Conclusions

A stochastic discount factor is introduced into a relatively standard real-business-cycle setup with a government sector. The model is calibrated to Bulgarian data for the period 1999–2018, which is after the introduction of the currency board arrangement in 1997. The quantitative importance of the presence of shocks to the discount factor is investigated for the propagation of cyclical fluctuations in Bulgaria. In particular, allowing for a stochastic discount factor in the setup improves the model fit vis-a-vis data by increasing variability of employment and wages. However, those improvements are at the cost of increasing the volatility of consumption and investment. Overall, the quantitative effect of such stochasticity is found to be very small, and thus not important for business cycle propagation.

Conflict of interest

The author declares no conflicts of interest in this paper.

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