Capital utilization and habit formation in a small open economy model

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Abstract. This paper shows the effects of endogenous capital utilization and habit formation in consumption on the predictions of a small open economy model calibrated to Canada. Capital utilization improves the fit of the model by increasing the volatility of output, investment, and hours worked, while habit formation improves the fit of the model by improving the dynamic properties of consumption and the current account. It is also shown that while shocks to the world interest rate sometimes improve the fit of the baseline model, they do not improve the fit of the model with capital utilization and habit formation. JEL classification: E32, F32

Utilisation du capital et formation d'habitudes dans un modèle de petite économie ouverte. Ce mémoire étudie les effets de l'utilisation endogène du capital et de la formation d'habitudes de consommation sur les prévisions d'un modèle de petite économie ouverte calibré pour le Canada. L'utilisation du capital améliore l'ajustement du modèle en accroissant la volatilité de l'output, de l'investissement et des heures travaillées, alors que la formation d'habitudes améliore l'ajustement du modèle en améliorant les propriétés dynamiques de la consommation et du compte courant. On montre que si des chocs affectant les taux d'intérêt au niveau mondial améliorent parfois l'ajustement du modèle de base, ils n'améliorent pas l'ajustement du modèle quand il y a utilisation de capital et formation d'habitudes.

1. Introduction

A fair amount of research has been devoted to improving the intertemporal model of the current account. Small open economy models driven by real shocks (and world interest rate shocks) have had some success. However, it has proved particularly difficult to extend these models in such a way that they

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reproduce both the dynamics of consumption and the current account (or trade balance). For example, the model of Mendoza (1991) fails to produce a trade balance that is sufficiently counter-cyclical to match the data (see Mendoza's tables 2 and 6). His model also dramatically fails to reproduce the persistence of the trade balance observed in the data. Correia, Neves, and Rebelo (1995) show that a small open economy model where the momentary utility function is such that the elasticity of intertemporal substitution associated with leisure is zero produces better dynamics in consumption and the current account than a model with more 'standard preferences' (as in Hansen's 1985 divisible labour model). Still, the trade balance is not sufficiently counter-cyclical in their model. Also it has difficulties reproducing the observed volatility in consumption and the trade balance.

Recent macroeconomic literature pays a good deal of attention to models with endogenous factor utilization. Models of the business cycles driven by real shocks now routinely include endogenous factor utilization. Factor utilization reduces the variance of the innovation in productivity shocks necessary to match the observed volatility of output and as a result reduces the likelihood of a technological regress. This point has been made by Burnside, Eichenbaum, and Rebelo (1993), Burnside and Eichenbaum (1996), and King and Rebelo (1999) in closed-economy RBC models. More recently, Baxter and Farr (2001) show that endogenous capital utilization also improves the predictions of a two-country RBC model. As in closed-economy models, smaller productivity shocks are needed to match the volatility of output. Also, endogenous capital utilization takes the two-country model closer to the data by substantially increasing the cross-country correlation of consumption, investment, hours, and real wages. Since endogenous capital utilization affects the dynamic properties of investment, it can potentially change the dynamic properties of the current account (the difference between national savings and investment) in a small open economy RBC model.

Recent literature also pays a good deal of attention to models with habit formation, since it has been shown that habit formation can address the equity premium puzzle (see Constantinides 1990 and Campbell and Cochrane 1999). Lettau and Uhlig (2000) show that when habit formation in consumption is included in an otherwise standard closed-economy RBC model the response of consumption is greatly affected (lower volatility and correlation with output). Accordingly, the introduction of habit formation in a small open economy RBC model could change the dynamic properties of the current account (mainly) via its effect on the dynamics of savings.

In this paper I show the effect of endogenous capital utilization and habit formation in consumption (separately and together) on the predictions of a small open economy model in a detailed application to Canada (1981Q1–2001Q4). I find that endogenous capital utilization increases the volatility of hours, output, and investment enough to match Canadian data despite productivity shocks that are less volatile than in the baseline model. Moreover, it accomplishes this without significantly changing the dynamic properties of the current account in the model. The findings of Lettau and Uhlig (2000) indicate that we can expect the addition of habit formation to be beneficial, since in the baseline model and in the model with capital utilization, consumption is more volatile than in the data, consumption is more highly correlated with output than in the data, and it is not serially correlated enough. I find that adding habit formation in consumption (in a moderate amount) to the small open economy RBC model with capital utilization significantly improves the fit of the model. Among other things, the model is consistent with all of the moments of the current account investigated (volatility, volatility relative to that of output, correlation with output, and autocorrelation).

Also, the paper shows that adding shocks to the world interest rate can sometimes improve the fit of the baseline model but does not improve that of a richer model with endogenous capital utilization and habit formation in consumption.

This paper is organized as follows. In section 2 I describe a small open economy model with endogenous capital utilization and habit formation. In section 3 I explain the calibration of the model. In section 4 I discuss the implications of three models: (1) the baseline model with constant capital utilization and no habit formation, (2) the model with endogenous capital utilization and no habit formation and, (3) the model with both endogenous capital utilization and habit formation. In section 5 I summarize the findings and offer some concluding comments.

2. Small open economy model

The small open economy model analysed in this paper builds on the models of Mendoza (1991) and Correia, Neves, and Rebelo (1995). Two main departures are the addition of endogenous capital utilization and habit formation in consumption. The economy is subject to three types of random disturbances: (1) productivity shocks, (2) government spending shocks, and (3) shocks to the world interest rate. While the first two types of shock are routinely included in RBC models, there is some debate about the benefits of including a random world interest rate in small-open economy models. Mendoza (1991), Correia, Neves, and Rebelo (1995) and Schmitt-Grohé (1998) find few benefits, while Blankenau, Kose, and Yi (2001), Nason and Rogers (2003) and Letendre (2003) suggest that a random world interest rate is important to improve the performance of their models. In this paper I contribute to this debate by comparing models with constant and stochastic world interest rates.

The economy has a large number of identical consumers and firms. Therefore, we focus on the problem of a representative household whose utility depends on consumption (C) and on hours worked (n)

$$E_0 \sum_{t=0}^{\infty} \beta^t U(C_t, C_{t-1}, n_t), \qquad 0 < \beta < 1, \tag{1}$$

where E_0 denotes the rational expectation operator and β is a subjective discount factor. The momentary utility function is

$$U(C_t, C_{t-1}, n_t) = \frac{\left[(C_t - \omega C_{t-1}) - \mu X_t n_t^{\nu}\right]^{1-\alpha}}{1-\alpha}, \qquad \alpha > 0, \mu > 0, \nu > 1, \omega > , \tag{2}$$

where X_t is a deterministic labour augmenting productivity trend. We need the labour augmenting productivity trend X_t in the momentary utility function for the model to have a balanced growth path, where the growth rates of the variables are non-zero. The presence of X_t in the utility function can be interpreted as representing technological progress in home production activities (see Hercowitz and Sampson 1991 for more details).

A special case of utility function (2) where there is no habit formation ($\omega = 0$) was initially proposed by Greenwood, Hercowitz, and Huffman (1988). Devereux, Gregory, and Smith (1992) find that a two-country real business cycle model with utility function (2) where $\omega = 0$ generates more realistic cross-country consumption correlations than a model with separable utility. Correia, Neves, and Rebelo (1995) show that a standard small open economy model with utility function (2), where $\omega = 0$, generates more realistic consumption volatility and a counter-cyclical trade balance, two features that are difficult to produce in a basic small open economy model with the more ‘standard’ momentary utility function

$$\frac{[C_t^{\mu}(1-n_t)^{1-\mu}]^{1-\alpha}}{1-\alpha}. \tag{2'}$$

The household faces the budget constraint

$$C_t + I_t + G_t + A_{t+1} = Y_t + R_t A_t, \tag{3}$$

where I_t is investment in physical capital, G_t is government consumption financed by lump-sum taxes, Y_t is output, A_t is the stock of foreign assets on hand at the beginning of period t, and R_t is the (gross) interest rate faced by the households in the small open economy. This rate is the sum of the world interest rate R^{ω} (which can be constant or stochastic) and a ‘risk premium’ that depends on aggregate assets ($\bar{A}$) and aggregate output ($\bar{Y}$)[1]

1 This risk premium is strictly decreasing and is included to avoid the well-known problem associated with a unit root in asset accumulation. See Schmitt-Grohé and Uribe (2003) for more details about modelling devices targeted at this specific problem.

$$R_t = R_t^{\omega} + P(\bar{A}_t/\bar{Y}_t) = R_t^{\omega} + \psi_2\left(e^{\psi_1 - \bar{A}_t/\bar{Y}_t} - 1\right), \qquad \psi_2 > 0. \tag{4}$$

The production function has the usual Cobb-Douglas form,

$$Y_t = z_t(u_t K_t)^{\theta}(X_t n_t)^{1-\theta}, \qquad 0 < \theta < 1, \tag{5}$$

where z_t is a stationary productivity shock and u_t is the utilization rate of capital. Physical capital accumulation is subject to quadratic adjustment costs

$$K_{t+1} = (1-\delta_t)K_t + I_t - \frac{\phi_k}{2}\left(\frac{I_t}{K_t} - (\delta_t + \gamma - 1)\right)^2 K_t, \qquad \gamma > 1, \phi_k \geq 0, \tag{6}$$

where the depreciation rate is $\delta_t = \delta u_t^{\eta}$ (where $0 < \delta < 1$ and $\eta > 1$) and ϕ_k governs the adjustment costs. The adjustment costs function has the property that the model with adjustment costs has the same steady state as the model without them.

The exogenous variables in this economy evolve according to

$$X_t = \gamma X_{t-1}, \quad g_t \equiv G_t/X_t \tag{7}$$

$$\ln g_{t+1} = lng^{*}(1-\rho_g) + \rho_g \ln g_t + \varepsilon_{g,t+1} \tag{8}$$

$$\ln z_{t+1} = \rho_z \ln z_t + \varepsilon_{z,t+1} \tag{9}$$

$$\ln R_{t+1}^{\omega} = \ln R^{\omega *}(1-\rho_R) + \rho_R \ln R_t^{\omega} + \varepsilon_{R,t+1} \quad \text{or} \quad R_{t+1}^{\omega} = R^{\omega}, \tag{10}$$

where ln g^* and ln $R^{\omega *}$ are the unconditional means of ln g_t and ln R_t^{ω}, respectively. The innovations in the stationary AR(1) processes (8)–(10) have variances σ_z^2, σ_g^2, σ_R^2, and are allowed to be correlated with each other.

The model has a balanced growth path where X, G, and all endogenous variables except n and u grow at a constant rate γ. Therefore, to work in a stationary environment all variables are divided by the deterministic trend. Lowercase variables denote detrended variables: $c_t = C_t/X_t$, $a_{t+1} = A_{t+1}/X_{t+1}$, and so on. Using the normalization $X_0 = 1$, the growth adjusted discount factor is $\hat{\beta} \equiv \beta\gamma^{(1-\alpha)}$. In the stationary economy, the optimization problem is to maximize

$$E_0 \sum_{t=0}^{\infty} \hat{\beta}^t \frac{\left[(c_t - \omega\gamma^{-1}c_{t-1}) - \mu n_t^{\nu}\right]^{1-\alpha}}{1-\alpha}, \tag{11}$$

subject to

$$c_t + i_t + g_t + \gamma a_{t+1} = z_t(u_t k_t)^{\theta} n_t^{1-\theta} + R_t a_t \tag{12}$$

$$\gamma k_{t+1} = (1 - \delta u_t^{\eta})k_t + i_t - \frac{\phi_k}{2}\left(\frac{i_t}{k_t} - (\delta u_t^{\eta} + \gamma - 1)\right)^2 k_t. \tag{13}$$

Carrying out the household's dynamic programming problem and then imposing the consistency of individual and aggregate decisions ($a_t = \bar{a}_t$, $y_t = \bar{y}_t$, etc.) and using equation (4) yield the first-order conditions

$$\nu\mu n_t^{\nu-1}\left[(c_t - \omega\gamma^{-1}c_{t-1}) - \mu n_t^{\nu}\right]^{-\alpha} = (1-\theta)\lambda_{1t}\frac{y_t}{n_t} \tag{14}$$

$$\lambda_{1t} = \left[(c_t - \omega\gamma^{-1}c_{t-1}) - \mu n_t^{\nu}\right]^{-\alpha} - \hat{\beta}\omega\gamma^{-1}E_t\left\{\left[(c_{t+1} - \omega\gamma^{-1}c_t) - \mu n_{t+1}^{\nu}\right]^{-\alpha}\right\} \tag{15}$$

$$\lambda_{1t} = \lambda_{2t}\left[1 - \phi_k\left(\frac{i_t}{k_t} - (\delta u_t^{\eta} + \gamma - 1)\right)\right] \tag{16}$$

$$\gamma\lambda_{1t} = \hat{\beta}E_t\left\{\lambda_{1t+1}\left[R_{t+1}^{w} + \psi_2(\exp(\psi_1 - a_{t+1}/y_{t+1}) - 1)\right]\right\} \tag{17}$$

$$\theta\lambda_{1t}\frac{y_t}{u_t} = \lambda_{2t}\left[\delta\eta u_t^{\eta-1}k_t - \delta\eta\phi_k\left(\frac{i_t}{k_t} - (\delta u_t^{\eta} + \gamma - 1)\right)k_t u_t^{\eta-1}\right] \tag{18}$$

$$\gamma\lambda_{2t} = \hat{\beta}E_t\left\{\theta\lambda_{1t+1}\frac{y_{t+1}}{k_{t+1}} + \lambda_{2t+1}\left[1 - \delta u_{t+1}^{\eta} - \frac{\phi_k}{2}\left(\frac{i_{t+1}}{k_{t+1}} - (\delta u_{t+1}^{\eta} + \gamma - 1)\right)^2 + \phi_k\left(\frac{i_{t+1}}{k_{t+1}} - (\delta u_{t+1}^{\eta} + \gamma - 1)\right)\frac{i_{t+1}}{k_{t+1}}\right]\right\}, \tag{19}$$

where λ_1 and λ_2 denote the Lagrange multipliers associated with the budget constraint (12) and the accumulation equation (13), respectively. Equation (14) states that the marginal utility cost of working one more unit of time is equal to its marginal utility benefit. Equation (15) reflects the household's consumption decision. As usual, the Lagrange multiplier λ_{1t} represents marginal utility of consumption. In a model with habit formation, period t consumption enters the period $t+1$ momentary utility function. As a result, the marginal utility of c_t is composed of two terms in (15). The presence of capital adjustment costs drives a wedge between the shadow price of consumption and investment as shown in (16). First-order condition (17) is the usual bond Euler equation. First-order condition (18) reflects the optimal choice of capital utilization. Increasing the capital utilization rate generates more output (left-hand side) but increases the depreciation rate of capital (right-hand side). Finally, equation (19) is the usual capital Euler equation rendered more complicated by the capital adjustment costs.

The solution to the model is a set of stochastic processes for the endogenous variables that satisfies the budget constraint (12), the transition equation for capital (13), the first-order conditions (14)–(19) and the relevant transversality conditions.

3. Calibration

The model presented above is solved numerically using the linearization method suggested by King, Plosser, and Rebelo (1988). Values for most parameters are available from previous studies. I use these values to facilitate comparison with the literature.[2] The discount factor is set at $\beta = 0.993$, the share of capital in output is set at $\theta = 0.32$, and the coefficient of relative risk aversion is set at $\alpha = 2$. These values are commonly used in models calibrated to Canada (see, e.g., Mendoza 1991 and Nason and Rogers 2003). The parameter value for the parameter ν is borrowed from Correia, Neves, and Rebelo (1995). Accordingly, I set $\nu = 1.7$. There is no direct evidence on the value of the habit formation parameter ω for Canada. Johri and Letendre (2002) report estimates ranging from 0.3 to 0.97 for the U.S. economy. Two 'middle of the road' cases are considered: 0.4 and 0.7.

As is commonly done in the RBC literature, the extra parameter in the utility function, μ, is set to insure that households allocate 20% of their time to market production in steady state (e.g., King and Rebelo 1999). Accordingly, $\mu = 1.932$ when $\omega = 0.4$ and $\mu = 0.989$ when $\omega = 0.7$. The growth rate γ is set to 1.0038, the average gross growth rate of Canadian output per capita over our sample period (1981Q1–2001Q4). This corresponds to an annual growth rate of 1.5%.

Given numerical values for α, β, and γ, a value for η is selected to ensure that the steady-state depreciation rate is equal to the average depreciation rate $\bar{\delta} = 0.02$ estimated by Burnside and Eichenbaum (1996) for the US economy.[3] The average utilization rate in Canada over the period 1981Q1–2001Q4 was $\bar{u} = 0.816$. Given numerical values for α, β, γ, and η, a value for δ is selected to ensure that the steady-state utilization rate is 81.6%. Accordingly, I set $\eta = 1.7359$ and $\delta = 0.02846$.[4] The capital adjustment costs parameter ϕ_k is set to ensure that the model matches exactly the ratio of the standard deviation of investment to the standard deviation of output. In our sample, this ratio equals 2.97. The mean of the government spending shocks is set so that the steady-state G/Y ratio is equal to 0.2162, the average G/Y ratio for the Canadian economy over the period 1981Q1–2001Q4.

To estimate the stochastic processes (8)–(10), we need to measure detrended government consumption (g_t), productivity shocks (z_t), and the world interest rate (R_t^{ω}) using Canadian data (see the data appendix for a description of the data). The stochastic processes are jointly estimated, using a just-identified GMM estimator. The estimation results are reported in table 1.

I detrend government consumption using a linear regression (in logs) to calculate a time series for g_t. As shown in the top panel of Table 1, government consumption is highly persistent (its estimated autocorrelation is 0.96).

2 Alternatively, one could use a GMM or maximum likelihood estimator to estimate the structural parameters of the model.

3 Nason and Rogers (2003) centre their prior for the depreciation rate at 2% per quarter.

4 The elasticity of marginal depreciation to utilization (denoted ζ in Baxter and Farr 2001) is equal to $\eta - 1$. Based on Basu and Kimball (1997), the 95% confidence interval for ζ is $[-0.2, 2]$. The values of η used in the simulations are always consistent with an elasticity between 0 and 1.

TABLE 1
Estimation of shocks processes

• Process for government consumption [equation (8)]

	ρ_g	σ_g
Estimate	0.95589	0.00931
(s.e.)	(0.02710)	(0.00066)

• Process for technology shocks [equation (9)]

Constant capital utilization			Endogenous capital utilization		
	ρ_z	σ_z		ρ_z	σ_z
Estimate	0.94436	0.00599	Estimate	0.93012	0.00509
(s.e.)	(0.02929)	(0.00042)	(s.e.)	(0.03785)	(0.00041)

• Process for world interest rate [equation (10)]

Based on equation (20)			Based on equation (21)		
	ρ_R	σ_R		ρ_R	σ_R
Estimate	0.53113	0.00681	Estimate	0.27565	0.00104
(s.e.)	(0.08427)	(0.00043)	(s.e.)	(0.12749)	(0.00012)

NOTE: Parameters are jointly estimated using a just-identified GMM estimator.

Since the calculation of the productivity shocks depends on the assumption about factor utilization (constant *vs* endogenous), I measure productivity shocks two different ways. When assuming endogenous capital utilization, I calculate factor productivity from the production function using data on industrial capacity utilization

$$\log\ (z_t X_t^{1-\theta}) = \log Y_t - \theta \log K_t - \theta \log u_t - (1-\theta)\log n_t.$$

This productivity measure is linearly detrended to separate the deterministic productivity trend from the productivity shocks. When capital utilization is constant, I follow the steps described above, but the term in log u_t in the latter equation is dropped. The middle panel in table 1 shows the GMM estimates of ρ_z and σ_z. As expected, productivity shocks are smaller (in a variance sense) when capital utilization rates are included in the production function. The difference between the two standard deviations (0.00599 *vs* 0.00509) is statistically significant at the 5% level.[5]

5 Testing the null hypothesis of equal standard deviations against the alternative that σ_z is larger when capital utilization is constant yields a p-value of 2%.

In this paper, three alternative measures of the world interest rate (R_t^ω) are used. The first case is simply a constant world interest rate. Note that even if R^ω is constant, the interest rate faced by the households is still time varying because of the risk premium. Second, the world interest rate is calculated as the ex ante real rate earned by a Canadian investor investing in a U.S. three-month treasury bill. An investment made in period t earns the real return

$$R_{t+1}^\omega = \frac{1 + i_{t+1}^{tb}}{1 + \pi_{t+1}} \frac{e_{t+1}}{e_t}, \tag{20}$$

where i^{tb} is the U.S. three-month treasury bill rate, π is the Canadian CPI inflation rate, and e is the Canada-U.S. bilateral exchange rate (in Canadian dollars). I calculate the ex ante rate by regressing the ex post rate calculated in equation (20) on its first and third lags.[6] As reported in the bottom panel of table 1, when the world interest rate is measured this way, the estimates are $\rho_R = 0.53113$ and $\sigma_R = 0.00681$. The high volatility in the growth rate of the exchange rate creates highly volatile interest rate shocks (more volatile than the productivity shocks). Since there is evidence that the nominal exchange rate is a random walk, the expected depreciation (conditional on period t information) is zero. Therefore I also consider a measure of the interest rate where exchange rate depreciation is omitted[7]

$$R_{t+1}^\omega = \frac{1 + i_{t+1}^{tb}}{1 + \pi_{t+1}}. \tag{21}$$

I calculate the ex ante rate by regressing the ex post rate calculated in equation (21) on its first lag.[8] The estimates are then $\rho_R = 0.27565$ and $\sigma_R = 0.00104$. The correlations among the various shocks are reported in table 2.
As is common in the small-open economy literature the steady-state world interest rate is set such that $\hat{\beta}\bar{R}^\omega = \gamma$. This restriction and first-order condition (17) pin down the asset-output ratio in steady state.

The parameter ψ_1 appearing in the equity premium is equal to the steady-state value of the ratio A/Y. Accordingly, I set $\psi_1 = -0.35$ (historical average). I set $\psi_2 = 0.001$ so that the 'baseline' model (constant capital utilization rates and no habit formation) is consistent with the observed volatility in the current-account-output ratio. I examine the sensitivity of the results to this parameter.

6 I looked at first-, second-, third-, and fourth-order autoregressions. The second and fourth lags were never statistically significant. The residuals of the autoregressions display statistically significant autocorrelation when using a first-order autoregression but none when the first and third lags are included.

7 If we assume the nominal exchange rate is a random walk and that the conditional covariance between e_{t+1}/e_t and $1/(1+\pi_{t+1})$ is zero, and noting that i_{t+1}^{tb} is included in the time-t information set, we have $E_t R_{t+1}^\omega = (1 + i_{t+1}^{tb}) E_t[1/(1+\pi_{t+1})]$ for both measures of the world interest rate.

8 I looked at first-, second-, third-, and fourth-order autoregressions. The second, third, and fourth lags were never statistically significant.

TABLE 2
Statistical moments of exogenous shocks

- Productivity shocks take into account capacity utilization.
  World interest rate calculated as in (20)
  corr (ε_z,ε_R) = 0.01135, corr (ε_z,ε_g) = 0.04778, corr (ε_g,ε_R) = −0.05087.

- Productivity shocks take into account capacity utilization.
  World interest rate calculated as in (21)
  corr (ε_z,ε_R) = 0.08509, corr (ε_z,ε_g) = 0.04778, corr (ε_g,ε_R) = −0.25906.

- Productivity shocks do not take into account capacity utilization.
  World interest rate calculated as in (20)
  corr (ε_z,ε_R) = 0.01701, corr (ε_z,ε_g) = 0.00708, corr (ε_g,ε_R) = −0.05087.

- Productivity shocks do not take into account capacity utilization.
  World interest rate calculated as in (21)
  corr (ε_z,ε_R) = 0.18701, corr (ε_z,ε_g) = 0.00708, corr (ε_g,ε_R) = −0.25906.

4. Results

4.1. Baseline model

Before investigating the properties of the model described in section 2, I report the results for a 'baseline' model, where there is no habit formation and where capital utilization rates are constant.[9] Table 3 reports a set of statistical moments for the Canadian economy and for three versions of the baseline model. The model Baseline-1 has a constant world interest rate. It is consistent with the fact that consumption, labour, the trade balance, and the current account are less volatile than output and that investment is more volatile than output. It is also consistent with the high positive correlation of consumption, investment and labour with output and the negative correlation of the trade balance and current account with output. Finally, the variables in the model are positively serially correlated as they are in the data.

To evaluate the fit of a particular statistical moment, I use the method proposed by Gregory and Smith (1991) to construct confidence intervals for each of the statistical moments shown in tables 3, 4, and 5. By simulating the model 1,000 times, I get 1,000 realizations of the statistical moments of interest. For each of these moments, the 1,000 realizations are sorted and stored in a vector. Then, the lower (upper) bound of a 95% confidence interval is given by the twenty-fifth (975th) element of the sorted vector. Similarly, the lower (upper) bound of a 99% confidence interval is given by the fifth (995th)

9 In the baseline model, $\omega = 0$, $\mu = 3.51$, $\rho_z = 0.94$, $\sigma_z = 0.00599$ and the capital depreciation rate is constant and set to 0.02.

TABLE 3
Moments from Canadian data and baseline model

	Canada	Baseline-1	Baseline-2	Baseline-3
	Standard deviations (%)			
Consumption	0.93	1.16**	1.16**	1.16**
Labour	1.25	0.75	0.74	0.75
Output	1.72	1.27*	1.26*	1.27*
Investment	5.13	$3.78_{\dagger\dagger}$	$3.68_{\dagger\dagger}$	$3.78^{*}_{\dagger\dagger}$
Trade balance over output	0.87	0.30	$0.82^{**}_{\dagger\dagger}$	0.31
Current account over output	0.29	0.29**	0.58	0.30**
	Correlation with output			
Consumption	0.80	0.99	0.99	0.99
Labour	0.91	1.00	1.00	1.00
Investment	0.77	0.97	0.49	0.97
Trade balance over output	−0.29	−0.62	0.25	−0.58*
Current account over output	−0.26	−0.64	0.35	−0.62
	Autocorrelation			
Consumption	0.83	0.69*	0.68*	0.69*
Labour	0.92	0.69	0.68	0.69
Output	0.91	0.69	0.68	0.69
Investment	0.88	0.66	0.46	0.67
Trade balance over output	0.67	0.68**	0.40	0.63**
Current account over output	0.68	0.69**	0.41	0.65**

NOTES: Baseline-1: constant world interest rate. Baseline-2: $\rho_R = 0.53$, $\sigma_R^2 = 0.00681^2$, corr $(\varepsilon_z, \varepsilon_R) = 0.01701$, corr $(\varepsilon_g, \varepsilon_R) = -0.05087$. Baseline-3: $\rho_R = 0.28$, $\sigma_R^2 = 0.00104^2$, corr $(\varepsilon_z, \varepsilon_R) = 0.18701$, corr $(\varepsilon_g, \varepsilon_R) = -0.25906$. Canadian data are per capita. They were logged (except for trade-balance-output and current-account-output ratios) and HP filtered with smoothing parameter 1600 before computing the moments. Moments from all models are averages of 1,000 replications of length 100. They were computed using HP filtered % deviations from steady state. For symmetry with Canadian data, artificial data on the trade balance-output and current account-output ratios are not expressed in % deviation from steady state. The superscripts ** and * indicate that a moment is not statistically different from its empirical counterpart at the 5% and 1% levels of significance, respectively. The subscripts $_{\dagger\dagger}$ and $_{\dagger}$ indicate that the ratio of standard deviation of the variable to that of output is not statistically different from its empirical counterpart at the 5% and 1% levels of significance, respectively.

element of the sorted vector.[10] The standard deviation of consumption and the current account are not statistically different from their empirical counterparts at the 5% level. The standard deviation of output is not statistically different from its empirical counterpart at the 1% level. However, investment, labour, and especially the trade balance are less volatile than in Canadian data.

Consumption, labour, and investment are more highly correlated with output in the model than in the data, whereas the trade balance and the

10 In the tables, the superscripts ** and * indicate that a moment is not statistically different from its empirical counterpart at the 5% and 1% levels of significance, respectively. The subscripts $_{\dagger\dagger}$ and $_{\dagger}$ indicate that the ratio of standard deviation of the variable to that of output is not statistically different from its empirical counterpart at the 5% and 1% levels of significance, respectively.

current account are too highly negatively correlated with output. The perfect correlation of labour and output is easily seen by combining first-order conditions (14) and (15) and setting $\omega = 0$:

$$n_t^{\nu} = \left(\frac{1-\theta}{\nu\mu}\right) y_t. \tag{22}$$

Since $0 < \theta < 1$, $\mu > 0$, and $\nu > 0$, labour and output are perfectly positively correlated.

As is common with these types of model, the internal propagation is weak and the autocorrelation of consumption, labour, output, and investment are noticeably lower than their empirical counterparts (although the autocorrelation in consumption is not statistically different from its empirical counterpart at the 1% level). The observed autocorrelation in the trade balance and the current account are very closely reproduced by the model.

The effect of having interest rate shocks is seen by comparing the moments of the model Baseline-1 with those of Baseline-2 (world interest rate as calculated in (20)) and Baseline-3 (world interest rate as calculated in (21)). Comparing Baseline-1 and Baseline-2, we see that the addition of interest rate shocks has three effects. First, it increases the volatility of the trade balance sufficiently to match the data. Second, it increases too much the correlation of the trade balance and current account with output and reduces too much the correlation of investment with output. Third, it significantly reduces the serial correlation in investment, the trade balance, and the current account. These reductions in serial correlation take the model further away from the data. Overall, when the calibration of the stochastic process for the world interest rate is based on the measure in equation (20), I find that shocks to the world interest rate do not improve the predictions of the small open economy RBC model.

The latter finding is not robust to changes in the calculation of the world interest rate. When the calibration of the stochastic process for the world interest rate is based on the measure in equation (21), interest rate shocks slightly improve the overall fit of the model. All the moments that are matched at the 5% level in Baseline-1 are also matched at the 5% level in Baseline-3. In addition, the relative volatility of investment and the correlation of the trade balance with output are matched at the one percent level in Baseline-3. Therefore, there is an argument to be made in favour of including interest rate shocks in the small open economy RBC model. However, the measure of the world interest rate used to estimate the persistence and volatility of the shocks to the world interest rate matters.[11]

11 Sensitivity analysis showed that both the persistence and volatility in the world interest rate shocks have significant effects on the statistical moments of the trade balance, current account, and investment. The correlation between interest rate shocks and other shocks seems unimportant.

4.2. Model with endogenous capital utilization

A number of studies have demonstrated the gains from incorporating capital utilization in a closed-economy RBC model (Burnside and Eichenbaum 1996 and King and Rebelo 1999) and in a two-country RBC model (Baxter and Farr, 2001). First, single and two-country RBC models with capital utilization are able to match the volatility of output with smaller (i.e., less volatile) productivity shocks. Smaller productivity shocks reduce the likelihood of technological regress. Second, capital utilization improves the fit of two-country models by increasing the cross-country correlation of consumption, investment, real wages and hours.

The model with endogenous capital utilization is a special case of the model described in section 2, where $\omega = 0$ (and $\mu = 3.19$). The moments of the variables in this model under various calibrations for the process driving the world interest rate are reported in table 4. The model labelled Utilization-1 has a constant world interest rate. This model dominates the three versions of the baseline model on a number of dimensions. Using shocks that are smaller than in the Baseline model (σ_z is 17% smaller), Utilization-1 matches the volatility of output, investment and the current account at the 5% level and the volatility of consumption and labour at the 1% level. The relative volatility of the current account closely matches the data. The other moments (correlation with output and autocorrelation) are mostly left unchanged by the addition of endogenous capital utilization.

It may appear strange that the addition of endogenous capital utilization (which increases the volatility of investment significantly) leaves the current-account-output correlation essentially unchanged. This result is explained by the presence of capital adjustment costs. Since the parameter ϕ_k is adjusted so that the ratio of the standard deviation of investment relative to that of output is always equal to 2.97 the effect on the current account of adding endogenous capital utilization (making investment less volatile relative to output) is undone by lowering ϕ_k to re-establish var (i)/var $(y) = 2.97^2$. When the value $\phi_k = 3.42$ (used in Baseline-1) is used in Utilization-1, the standard deviation of investment relative to that of output is 2.31 (instead of 2.97), the standard deviation of the current account is 0.15 (instead of 0.26) and the current-account-output correlation is 0.27 (instead of −0.67). The latter result is not surprising, since the current-account-output ratio depends negatively on the investment-output ratio. When investment is less volatile relative to output, the investment-output ratio does not increase as much in response to a positive productivity shock, and, as a result, the current-account-output ratio does not fall as much or could actually increase. This is confirmed in figure 1,[12] where the current-account-output ratio initially *falls* following a productivity shocks when $\phi_k = 1.84$ (value used in Utilization-1) whereas it *increases* when $\phi_k = 3.42$.

12 The impulse response functions in figures 1 and 2 present the responses of the current account-output ratio and consumption to a productivity shock equal to one standard deviation.

TABLE 4
Moments from Canadian data and model with capital utilization

	Canada	Utilization-1	Utilization-2	Utilization-3
	Standard deviations (%)			
Consumption	0.93	1.28*	1.29*	1.28*
Labour	1.25	0.91*	0.91*	0.91*
Output	1.72	1.55**	1.54**	1.55**
Investment	5.13	4.59**††	4.53**††	4.59**††
Trade balance over output	0.87	0.27	0.95**††	0.32
Current account over output	0.29	0.26**††	0.71	0.29**††
	Correlation with output			
Consumption	0.80	1.00	0.99	1.00
Labour	0.91	1.00	1.00	1.00
Investment	0.77	0.98	0.55	0.97
Trade balance over output	−0.29	−0.67	0.27	−0.52*
Current account over output	−0.26	−0.67	0.36	−0.56
	Autocorrelation			
Consumption	0.83	0.68*	0.67*	0.68*
Labour	0.92	0.68	0.67	0.68
Output	0.91	0.68	0.67	0.68
Investment	0.88	0.66	0.47	0.65
Trade balance over output	0.67	0.67**	0.40	0.50**
Current account over output	0.68	0.68**	0.41	0.52**

NOTES
Utilization-1: constant world interest rate.
Utilization-2: $\rho_R = 0.53$, $\sigma_R^2 = 0.00681^2$, corr $(\varepsilon_z, \varepsilon_R) = 0.01135$, corr $(\varepsilon_g, \varepsilon_R) = -0.05087$.
Utilization-3: $\rho_R = 0.28$, $\sigma_R^2 = 0.00104^2$, corr $(\varepsilon_z, \varepsilon_R) = 0.08509$, corr $(\varepsilon_g, \varepsilon_R) = -0.25906$.
See notes to table 3.

The difference in the initial response of the current-account-output ratio for the two values of ϕ_k explains in large part why we get a counter-cyclical current account-output ratio when $\phi_k = 1.84$ and a pro-cyclical current account-output ratio when $\phi_k = 3.42$.[13]

The case for including interest rate shocks in a model with capital utilization is not very strong. The model Utilization-2 (world interest rate calculated as in (20)) reproduces well the volatility and relative volatility of the trade balance. However, it fails to reproduce both the autocorrelation of the trade balance and the current account and the sign of their correlation with output. It also fails to match the volatility and relative volatility of the current account. Using the alternative measure of the interest rate (equation (21)), Utilization-3 does a slightly better job at matching the correlation of the current account and trade balance with output, but does a slightly worse job at matching the serial correlation in those variables.

13 The response of output to a productivity shocks changes very little with ϕ_k.

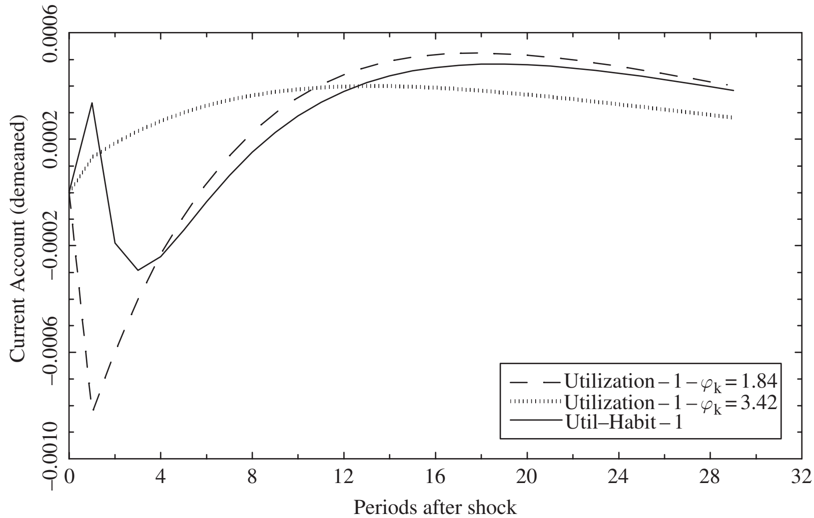

FIGURE 1 Current account in models with capital utilization and habit formation

4.3. Model with capital utilization and habit formation in consumption

There are a number of reasons to expect a model with habit formation in consumption to improve the fit of the small open economy RBC model. Lettau and Uhlig (2000) show that adding habit formation in consumption in an otherwise standard closed-economy RBC model reduces the volatility of consumption and its correlation with output. In their model the fall in the volatility of consumption is substantial, leading them to conclude (see their abstract) that 'utility functions with a habit then give rise to a puzzle of consumption volatility in place of the asset pricing puzzles when agents can choose consumption and labour optimally in response to more fundamental shocks.' As shown in table 4, the volatility of consumption and its correlation with output in the model with endogenous capital utilization are larger than in the data, while its serial correlation is smaller. Therefore, habit formation can potentially improve these three properties of consumption in the small-open economy model.

If habit formation truly has non-negligible effects on the dynamic properties of consumption (and small effects on the dynamic properties of output), then one can expect that habit formation will change the dynamic properties of the current-account-output ratio.

Table 5 reports the moments of three models with habit formation. The first two models have a moderate amount of habit formation ($\omega = 0.4$) and the third has stronger habit formation ($\omega = 0.7$). As can be seen by comparing Utilization-1 with Util-Habit-1, Utilization-3 with Util-Habit-2 and Utilization-1 with Util-Habit-3, introducing habit formation in consumption reduces the volatility of consumption (and its volatility relative to output), reduces its correlation with

TABLE 5
Moments from data and model with capital utilization and habit formation

	Canada	Util-Habit-1	Util-Habit-2	Util-Habit-3
	Standard deviations (%)			
Consumption	0.93	1.11**	1.11**	$0.86^{**}_{\dagger\dagger}$
Labour	1.25	0.91*	0.91*	0.91*
Output	1.72	1.55**	1.55**	1.54**
Investment	5.13	$4.59^{**}_{\dagger\dagger}$	$4.58^{**}_{\dagger\dagger}$	$4.58^{**}_{\dagger\dagger}$
Trade balance over output	0.87	0.20	0.28	0.29
Current account over output	0.29	$0.20^{*}_{\dagger\dagger}$	$0.26^{**}_{\dagger\dagger}$	$0.29^{**}_{\dagger\dagger}$
	Correlation with output			
Consumption	0.80	0.94	0.94	0.77**
Labour	0.91	1.00	1.00	1.00
Investment	0.77	0.99	0.97	0.99
Trade balance over output	−0.29	−0.23**	−0.12**	0.55
Current account over output	−0.26	−0.20**	−0.12**	0.58
	Autocorrelation			
Consumption	0.83	0.83**	0.83**	0.90*
Labour	0.92	0.68	0.68	0.68
Output	0.91	0.68	0.68	0.68
Investment	0.88	0.66	0.65	0.66
Trade balance over output	0.67	0.60**	0.36	0.47*
Current account over output	0.68	0.61**	0.39	0.48*

NOTES
Util-Habit-1: $\omega = 0.4$ and constant world interest rate.
Util-Habit-2: $\omega = 0.4$, $\rho_R = 0.28$, $\sigma_R^2 = 0.00104^2$, corr $(\varepsilon_z, \varepsilon_R) = 0.08509$, corr $(\varepsilon_g, \varepsilon_R) = -0.25906$.
Util-Habit-3: $\omega = 0.7$ and constant world interest rate.
See notes to table 3.

output and increases its autocorrelation. These changes in the properties of consumption are also apparent in the response of consumption to a productivity shock shown in figure 2. The response of consumption is initially weaker (lower volatility) but has a hump shape (higher persistence). The response of consumption in the model with both capital utilization and habit formation modifies the response of the current account-output ratio to a productivity shock as shown in figure 1. In model Util-Habit-1, the current-account-output ratio increases for one period, then decreases for two periods before starting to increase again.

Table 5 shows that the model with a constant world interest rate (Util-Habit-1) matches the data more closely than the model with interest rate shocks (Util-Habit-2) where shocks are calibrated following the measure in equation (21). Adding interest rate shocks makes the trade balance more volatile and investment less pro-cyclical. However, these changes are not large enough to help to match the data even at the 1% level. In addition, the correlations of the current account and trade balance with output in the model with interest rate shocks are closer to zero. Finally, the serial correlations in the trade balance and current account are very low in the model with interest rate

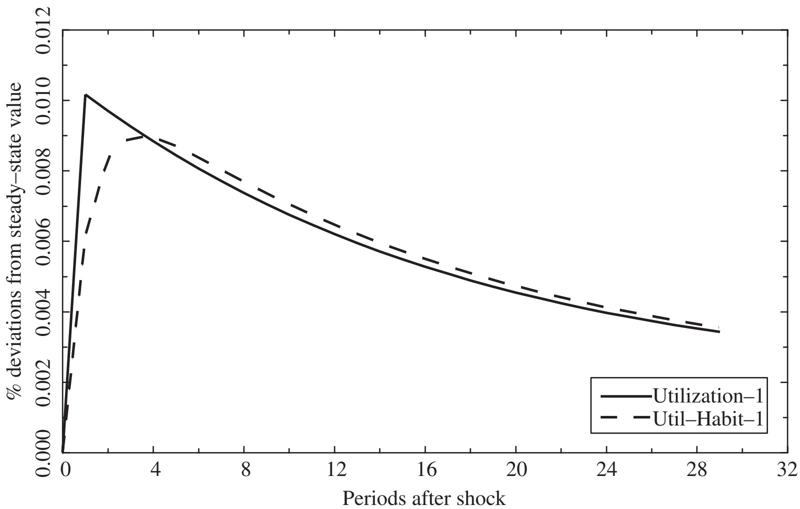

FIGURE 2 Consumption in models with capital utilization and habit formation

shocks. Using the other calibration of the interest rate shock process (not reported in table 5 for space considerations) generates a current account and trade balance that are strongly pro-cyclical and have very low serial correlation. Therefore, the results in table 5 suggest that adding shocks to the world interest rate to a model with capital utilization and habit formation in consumption clearly worsens the fit of the model.

Even though model Util-Habit-1 improves on the model with capital utilization only, it still leaves the relative volatility of consumption and its correlation with output much larger than in the data. In other words, despite its good performance as a model of the current account, model Util-Habit-1 is unable to match all aspects of the behaviour of the current account and of consumption simultaneously. This point is confirmed by model Util-Habit-3, where the parameter ω is raised to 0.7 (and the world interest rate is constant). In this model, the volatility of consumption, its volatility relative to output, its correlation with output, and its serial correlation all match the data at the 1% or 5% levels. However, the current account and trade balance are now strongly pro-cyclical.[14] Also, the overall fit of model Util-Habit-3 is worsened by the addition of world interest rate shocks.

As stated in section 3, a value for the parameter ψ_2 appearing in the equity premium in equation (4) is selected so that the baseline model reproduces the volatility in the current account. The good performance of model Util-Habit-1 is quite robust to a change in the parameter ψ_2. When ψ_2 is set to 0.01 instead

14 Sensitivity analysis found no value of ω where the model is consistent with all moments of consumption and the current account.

of 0.001, the standard deviation of the current account falls from 0.20 to 0.14 and is now statistically different from its empirical counterpart. However, all other moments that are not statistically different from their empirical counterparts in the third column of table 4 still match the data when $\psi_2 = 0.01$. Overall, the fit of the model does not depend crucially on ψ_2.

The fit of the model also does not depend crucially on the value of the parameter ν appearing in the utility function. For example, setting $\nu = 2$ (instead of $\nu = 1.7$) in the model with capital utilization and habit formation in consumption affects the qualitative results very slightly.[15]

The fit of the model does depend importantly on the value of the parameter controlling capital adjustment costs (ϕ_k). This is not surprising, since the dynamic properties of the trade balance and the current account depend significantly on the dynamic properties of investment. Recall that for each set of results reported in tables 3, 4 and 5, ϕ_k is set such that the standard deviation of investment relative to that of output is 2.97. If we set $\phi_k = 3.42$ for all cases in tables 3, 4, and 5, the quantitative results are quite different. Still, a number of qualitative results are unaffected by holding ϕ_k equal to 3.42 for all cases. Adding endogenous capital utilization helps the small-open economy RBC model to better match the volatility of labour and output with smaller productivity shocks. Adding habit formation in consumption helps the model, matching the volatility and autocorrelation of consumption and its correlation with output.[16]

5. Conclusion

This paper adds endogenous capital utilization and habit formation in consumption to a baseline small open economy RBC model driven by technology shocks and government spending shocks (some versions of the model also include interest rate shocks) calibrated to Canada.

First, another look is taken at the effect of shocks to the world interest rate on the fit of the baseline model. Mendoza (1991), Correia, Neves, and Rebelo (1995) and Schmitt-Grohé (1998) find little benefits from having shocks to the world interest rates while Blankenau, Kose, and Yi (2001), Nason and Rogers (2003) and Letendre (2003) suggest that shocks to the world interest rate are important to improve the performance of their models. In the current paper, when the calibration is based on a world interest rate measured as the real rate on a U.S. three-month treasury bill, then interest rate shocks improve the fit of the model. However, when the calibration is based on a world interest rate measured as the real return earned by a Canadian investor on a U.S. three-month treasury bill, interest rate shocks do not improve the overall fit of the model.

15 Results are available upon request.

16 See the accompanying appendix posted on the author's Web site for the results with $\phi_k = 3.42$ for all cases. That appendix also includes the steady-state solution and the linearized systems for all models discussed in this paper.

Second, endogenous capital utilization is added to the baseline model. As expected from previous studies incorporating endogenous capital utilization in one- and two-country models, a small open economy model with this feature is better able to match the volatility of consumption, output, labour, investment, and the current account using smaller productivity shocks than used in the baseline model.

Third, a model with both endogenous capital utilization and habit formation in consumption is analysed. Overall, this model outperforms all other models investigated in this paper. With a moderate amount of habit formation in consumption, the model matches the volatility of the variables as well as the model with endogenous capital utilization only. In addition, it matches very closely the correlation of the current account and trade balance with output and their autocorrelation. Even though this model has lower volatility of consumption and lower output-consumption correlation than the other models, these moments are still too large to match the data. When stronger habit formation is used, the model matches consumption very well but predicts strongly pro-cyclical trade balance and current account which is inconsistent with Canadian data. In this richer model, the addition of shocks to the world interest rate hurts the overall fit of the model.

In summary, the results in this paper suggest that (1) adding capital utilization to the baseline small open economy RBC model makes it a better model of the business cycle in the sense that it reproduces the volatility of labour, output and investment better, and (2) adding a moderate amount of habit formation in consumption to the small-open economy RBC model makes it a better model of the current account.

The model with endogenous capital utilization and habit formation in consumption analysed here can be extended in numerous directions to verify the robustness of the results. One may want to add an intratemporal relative price channel (perhaps by adding a non-traded good) to the intertemporal price channel (interest rate) included in the model. One may also want to introduce additional shocks. For example, the work of Bergin and Sheffrin (2000) suggests that terms of trade shocks may be important to understanding movements in the current account. One may also be interested in extending the model by introducing money and sticky prices. The extended model would then contribute to the rapidly expanding literature addressing open-economy macroeconomics issues using open-economy sticky-price models (the so called new open economy macroeconomics).

Data appendix

Data are from the Canadian Socio-economic Information and Management (CANSIM) database. CANSIM labels are in parentheses.

Data description
Population: Quarterly estimates of population for Canada (D1)
Output: real gross domestic product (D100126)
Consumption: personal expenditure on non-durable goods (D100106) and services (D100107)
Government expenditure: Government current expenditure on goods and services (D100108)
Investment: investment in machinery and equipment (D100115), non-residential structures (D100114) and residential structures (D100112)
Exports: exports of goods and services (D100119)
Imports: imports of goods and services (D100122)
Capital stock: straight-line end-year net stock, total all industries (D993333). This series is only available at an annual frequency. It was converted to a quarterly frequency using the procedure interpol in RATS
GDP deflator: ratio of nominal GDP (D14816) and real GDP (D100126)
Employment: employment age 15+ (D980595)
Current account: total nominal current account balance (D59832) deflated using the GDP deflator
Net foreign assets: Canada's international investment position – year ends – all foreign countries (D65219)
Utilization rates: Industrial capacity utilization rates in Canada, total non-farm goods producing industries (D883644)
Exchange rate: Canada-U.S. exchange rate in Canadian dollars noon spot rate (B3400)
U.S. safe rate: three-month treasury bill rate, secondary market averages of business days (TB3MS)
CPI: consumer price index, all items (P100000)

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