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Endogenous growth and the Taylor principle

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HIGHLIGHTS

- Endogenous growth increases the space of indeterminacy.
- Taylor principle does not ensure determinacy in an endogenous growth setup.
- Indeterminacy increases with spillovers from actual to potential output.

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ABSTRACT

This paper analyzes conditions for equilibrium determinacy in a new Keynesian model with endogenous growth. Endogenous growth shrinks the determinacy region considerably. Complying with the Taylor principle is not sufficient for equilibrium determinacy.

1. Introduction

Slow recoveries and hysteresis following the Great Recession (Ball, 2014; Fatas and Summers, 2016) are indicative of spillovers from aggregate demand to potential output (Summers, 2014; Yellen, 2016). Monetary policy, however, is typically analyzed in an exogenous growth setup, which abstracts from such spillovers.

Until now, the literature analyzing monetary policy in an endogenous growth setup has focused on optimal policy (Lai and Chin, 2010; Annicchiarico and Rossi, 2013; Ikeda et al., 2014). This paper augments a monetary model with endogenous growth and contributes to the literature by deriving sufficient conditions for determinacy of a rational expectations equilibrium. We show that the central bank has to be more aggressive in fighting inflation to eliminate self-fulfilling expectations. Contrary to an exogenous growth setup, complying with the Taylor principle, adjusting nominal interest rates more than one for one to inflation, is not sufficient for equilibrium determinacy.

2. The model

2.1. Representative household

The economy is populated by infinitely many households with unit mass one. The representative household derives utility from consumption C, disutility from working L, and maximizes expected lifetime utility

$$E_0 \sum_{t=0}^{\infty} \left(\log\left(C_t\right) - \chi \frac{{L_t}^{1+\eta}}{1+\eta} \right) . \tag{1}$$

β represents the household's discount factor, η represents the inverse of the Frish elasticity, and χ is used to calibrate the steady state labor input. Utility maximization is subject to the budget constraint

$$P_t C_t + B_t = P_t w_t L_t + \left(1 + r^B_{t-1}\right) B_{t-1} + P_t \Pi_t . \tag{2}$$

P is the price level, B are one period bonds that pay the nominal interest rate r^B, w is the real wage, and Π is the household's share of real firm profits. The household's first order conditions are the

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Euler (3) and the labor supply equation (4):

$$C_t{}^{-1} = \beta E_t \left(C_{t+1}{}^{-1}\right)\left(1 + r_t^B\right) E_t \left(\frac{P_t}{P_{t+1}}\right) \tag{3}$$

$$C_t{}^{-1} w_t = \chi L_t{}^{\eta}. \tag{4}$$

2.2. Final good firms

Perfectly competitive firms combine intermediate goods $Y_t(f)$ to final good bundles Y_t. Firms minimize expenditures for intermediate goods $\int_0^1 P_t(f) Y_t(f) df$, where $P_t(f)$ is the price of the intermediate good of type f. They face the production function

$$Y_t = \left(\int_0^1 (Y_t(f))^{\frac{\theta-1}{\theta}} df\right)^{\frac{\theta}{\theta-1}} \tag{5}$$

with elasticity of substitution θ. The demand for the individual intermediate good follows with $Y_t(f) = \left(\frac{P_t(f)}{P_t}\right)^{-\theta} Y_t$.

2.3. Intermediate good firms

Infinitely many intermediate good firms operate under monopolistic competition. An individual firm f produces output $Y_t(f)$ using labor $L_t(f)$ as input factor.

$$Y_t(f) = Z_t L_t(f). \tag{6}$$

Z is a freely available stock of knowledge that determines labor productivity. It can be thought of as a learning by doing externality, which has been labeled as serendipitous learning (Annicchiarico et al., 2011). This stock of knowledge is exogenous to the individual firm but endogenous on the aggregate level.

$$Z_t = \varphi_{t-1}(Y_{t-1})^{\alpha}. \tag{7}$$

φ and α determine how aggregate production affects the stock of knowledge. We use φ to pin down balanced growth, α determines how strong fluctuations in economic activity affect potential output. For $\alpha = 0$, the model collapses to a standard new Keynesian model.

Cost minimization yields an expression for real marginal cost RMC.

$$RMC_t = \frac{w_t}{Z_t}. \tag{8}$$

Intermediate good firms set intermediate good prices to maximize profits. We assume staggered price setting a la Calvo. Each period, only the share $1 - \omega$ of firms is able to adjust prices. This results in the optimal price P_{jt} for firms that are able to adjust prices:

$$\frac{P_{jt}}{P_t} = \frac{\theta}{\theta - 1} \frac{E_t \sum_{i=0}^{\infty} (\omega\beta)^i C_{t+i}{}^{-1} Y_{t+i} \left(\frac{P_{t+i}}{P_t}\right)^{\theta} RMC_{t+i}}{E_t \sum_{i=0}^{\infty} (\omega\beta)^i C_{t+i}{}^{-1} Y_{t+i} \left(\frac{P_{t+i}}{P_t}\right)^{\theta-1}}. \tag{9}$$

The law of motion for the price level is

$$P_t{}^{1-\theta} = (1-\omega) P_{jt}{}^{1-\theta} + \omega P_{t-1}{}^{1-\theta}. \tag{10}$$

2.4. Aggregation

In equilibrium, markets clear. Aggregate production equals aggregate consumption

$$Y_t = C_t. \tag{11}$$

The aggregate production function of intermediate good producers reads

$$D_t Y_t = Z_t L_t \tag{12}$$

with $L_t = \int_0^1 L_t(f) df$, price dispersion $D_t = \int_0^1 \left(\frac{P_t(f)}{P_t}\right)^{-\theta} df$, and the law of motion for price dispersion

$$D_t = (1-\omega)\left(\frac{P_{jt}}{P_t}\right)^{-\theta} + \omega \left(\frac{P_{t-1}}{P_t}\right)^{-\theta} D_{t-1}. \tag{13}$$

2.5. Balanced growth

The economy is described by Eqs. (3), (4), (7), (8), (9), (10), (11), (12), (13), and a rule for monetary policy. This system is instationary due to serendipitous learning. We stationarize the system by expressing all variables in terms of deviations from balanced growth. We define $x^* = \frac{x_t}{Z_t} \forall x_t \in \{y_t, c_t, w_t\}$, $\gamma_t = \frac{Z_t}{Z_{t-1}}$, and $\varphi^* = \frac{\varphi_t}{Z_t{}^{1-\alpha}}$. The last equality implies that efficiency of serendipitous learning φ increases in the stock of knowledge. This assumption is necessary to ensure balanced growth for $\alpha \in (0, 1)$.

2.6. Monetary policy

The central bank adjusts nominal interest rates to deviations of inflation (π_t) from the inflation target (π) and to deviations of real output from its balanced growth path (y^*).

$$\frac{1 + r_t^b}{1 + r^b} = \left(\frac{\pi_t}{\pi}\right)^{\phi_\pi} \left(\frac{y_t^*}{y^*}\right)^{\phi_y}. \tag{14}$$

3. Interest rate policy and aggregate stability

We rewrite the system, which allows us to derive analytical results for the regions of determinacy. We define $\kappa = (1+\eta)\frac{(1-\omega)(1-\beta\omega)}{\omega}$.

$$\begin{pmatrix} E_t\left(\hat{\pi}_{t+1}\right) \\ E_t\left(\hat{y^*}_{t+1}\right) \end{pmatrix} = \underbrace{\begin{pmatrix} \frac{1}{\beta} & -\frac{\kappa}{\beta} \\ \phi_\pi - \frac{1}{\beta} & 1 - \alpha + \phi_y + \frac{\kappa}{\beta} \end{pmatrix}}_{A} \begin{pmatrix} \hat{\pi}_t \\ \hat{y^*}_t \end{pmatrix}. \tag{15}$$

The rational expectations equilibrium is stable if both eigenvalues of A lie outside the unit circle. This is true if (i) $\det A > 1$, $\det A - \operatorname{tr} A > -1$ and $\det A + \operatorname{tr} A > -1$ or (ii) $\det A - \operatorname{tr} A < -1$ and $\det A + \operatorname{tr} A < -1$ (Woodford, 2003 Appendix C.1). As the trace $(1 - \alpha + \phi_y + \frac{\kappa}{\beta} + \frac{1}{\beta})$ and the determinant $(\frac{1}{\beta}\left(1 - \alpha + \phi_y + \kappa\phi_\pi\right))$ of A are strictly positive given plausible calibrations, (ii) is clearly violated.

Turning to (i), as the determinant and the trace of A are strictly positive, $\det A + \operatorname{tr} A > -1$ is always satisfied. The remaining two conditions for a stable equilibrium can be summarized by[1]

$$\phi_\pi > \begin{cases} \frac{\beta - 1 + \alpha}{\kappa} - \frac{1}{\kappa}\phi_y & \text{for } \phi_y \le \frac{\kappa + 1 - \beta - \alpha\beta}{-\beta} \\ 1 + \alpha\frac{1-\beta}{\kappa} - \frac{1-\beta}{\kappa}\phi_y & \text{for } \phi_y > \frac{\kappa + 1 - \beta - \alpha\beta}{-\beta}. \end{cases} \tag{16}$$

To illustrate the effect of endogenous growth on aggregate stability, we calibrate the model. The calibration is standard and presented in Table 1. The only unconventional parameter is α, the

[1] For the new Keynesian model with exogenous growth ($\alpha = 0$) and $\phi_y \ge 0$, $\phi_y > \frac{\kappa+1-\beta}{-\beta}$ is always satisfied. Therefore, the condition for uniqueness collapses to $\kappa(\phi_y - 1) + (1-\beta)\phi_\pi > 0$ as in Bullard and Mitra (2002).