ON THE IMPACT OF THE GAPS IN MONETARY BASE AND INDUSTRIAL PRODUCTION ON THE BEHAVIOUR OF SOLUTIONS IN A MODEL OF CENTRAL BANKING

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Abstract

The qualitative behaviour of macroeconomic processes over time is of considerable interest, particularly in a neighbourhood of the corresponding equilibrium. Bifurcation theory of differential equations provides an appropriate mathematical framework for the investigation of such problems. In the present paper, Asada's two-dimensional nonlinear model of monetary policy is extended by incorporating monetary base and industrial production gaps. Attention is devoted to the influence of these additional variables on the local stability of the equilibrium and on the conditions under which endogenous business-cycle oscillations are generated. By enriching the original model with both demand-side and supply-side factors, a broader description of the transmission mechanisms affecting inflation dynamics and central bank interest rate policy is obtained. The theoretical results are complemented by numerical simulations illustrating the qualitative behaviour of the model under selected parameter settings. The simulations provide additional insight into the interaction between monetary policy, real economic activity and macroeconomic stability.

Key words: dynamic model, equilibrium, stability, limit cycle, monetary base, industrial production

JEL Code: E32, E44

Introduction

The financial instability hypothesis proposed by Minsky (1982, 1986), according to which a financially dominated capitalist economy is inherently unstable, has attracted renewed attention

in recent decades. A series of economic crises, including the prolonged deflationary stagnation experienced by the Japanese economy during the 1990s and early 2000s and the global financial crisis triggered by the collapse of the U.S. mortgage market in 2008, has provided substantial empirical support for this view. Nevertheless, Minsky did not regard such instability as uncontrollable. On the contrary, he argued that an unstable economy could be stabilised through appropriately designed fiscal and monetary policies implemented by governments and central banks, thereby following the Keynesian tradition (Keynes, 1936).

Motivated primarily by the experience of the Japanese economy, Asada (2011) proposed a simple Keynesian macrodynamic model describing the interaction between the nominal interest rate and expected inflation. Although the model captures the essential features of monetary policy dynamics, its analytical treatment remained rather limited, and no numerical simulations were presented. A more rigorous mathematical investigation was subsequently carried out by Asada et al. (2016), Asada et al. (2019), Murakami and Asada (2018), Murakami and Zimka (2020), Murakami and Zimka (2021), where the stability properties of the equilibrium and the existence of limit cycles were analysed in detail.

In our previous contribution Zimka et al. (2025) the original Asada model was extended by introducing a nonlinear control function. It was shown that such an extension gives rise to Bautin bifurcation, leading to the coexistence of an unstable inner limit cycle and a stable outer limit cycle. Consequently, two stability corridors were shown to exist in a neighbourhood of the equilibrium.

The present paper continues this line of research from a different perspective. Instead of introducing an additional control function, the original Asada model is extended by incorporating monetary base and industrial production gaps. The objective is to investigate how these additional macroeconomic variables influence the local dynamics of the model, with particular emphasis on the stability of the equilibrium and the emergence of endogenous business-cycle oscillations.

The paper is organised as follows. Section 1 introduces the extended model and investigates its local dynamic properties. Conditions guaranteeing the occurrence of Hopf bifurcation and the existence of limit cycles are derived. Section 2 presents numerical simulations illustrating the theoretical results. Finally, concluding remarks and possible directions for future research are provided.

1 Model

The original model proposed by Asada (2011) is given by the system

$$\dot{r} = \alpha\left(\pi - \bar{\pi}\right) + \beta\left(Y - \bar{Y}\right) \tag{1}$$

$$\dot{\pi}^e = \gamma\left[\theta\left(\bar{\pi} - \pi^e\right) + \left(1-\theta\right)\left(\pi - \pi^e\right)\right] \tag{2}$$

$$Y = Y\left(r - \pi^e, G, \tau\right),\ \pi = \varepsilon\left(Y - \bar{Y}\right) + \pi^e,\ 0 < \tau < 1,\ 0 \le \theta \le 1, \tag{3}$$

where Y denotes real national income, $\bar{Y}$ is the natural level of output corresponding to the natural rate of unemployment, G represents real government expenditure, τ is the marginal tax rate, π is the inflation rate, π^e denotes the expected inflation rate, $\bar{\pi}$ is the target inflation rate, r is the nominal interest rate, and $r - \pi^e$ represents the expected real interest rate. Furthermore, all adjustment parameters are assumed to be positive.

For the purposes of the present study, the standard specification of real national income is adopted,

$$Y = C + G + I, \tag{4}$$

where consumption C is given by the relation $C = c\left(Y - T\right) + C_0$, tax T by the relation $T = \tau\, Y - T_0$, investment I by the relation $I = \dfrac{k}{e^{r-\pi^e}}$, and government expenditures G is supposed to be fixed. From (4) the expression for real national income by small arrangement were received

$$Y = \frac{cT_0 + C_0 + G}{1 - c\left(1-\tau\right)} + \frac{1}{1 - c\left(1-\tau\right)}\frac{k}{e^{r-\pi^e}}. \tag{5}$$

Adding to the original Asada´s model given by equations (1) and (2) expressions (5) for the real national income Y, the monetary base $M = \dfrac{1+\pi^e}{\delta}Y$ and the industrial production $V = \sigma\, Y$ together with their optimal values $\bar{M}$ and $\bar{V}$, the enlarged Asada´s model, enabling also to investigate impacts of monetary base and industrial production gaps on the behaviour of solutions is proposed

$$\dot{r} = \alpha\left(\varepsilon\left(Y - \bar{Y}\right) + \pi^e - \bar{\pi}\right) + \beta\left(Y - \bar{Y}\right) + \mu\left(M - \bar{M}\right) \tag{6}$$

$$\dot{\pi}^e = \gamma\left[\theta\left(\bar{\pi} - \pi^e\right) + \left(1-\theta\right)\varepsilon\left(Y - \bar{Y}\right)\right] + \eta\left(V - \bar{V}\right), \tag{7}$$

where $\alpha, \beta, \gamma, \delta, \varepsilon, \sigma, \theta, \mu, \eta$ are positive parameters.

Throughout the remainder of the paper, this extended system will be referred to as Model (K), in honour of Michał Kalecki (1935, 1954), whose work has made a lasting contribution to modern macroeconomic theory.

To get important information on the existence of Model (K)´s equilibrium, its stability/instability and the existence of limit cycles in a small neighbourhood of the equilibrium, the following steps will be performed:

a) to find the equilibrium point of Model (K),

b) to find the conditions on Model (K)´s parameters $\alpha,\beta,\gamma,\delta,\varepsilon,\sigma,\theta,\mu,\eta$ guaranteeing that its Jacobian matrix has a pair of purely imaginary eigenvalues.

1.1 Equilibrium point of Model (K)

An equilibrium point of Model (K) is a point $E=\left(r^*,\pi^{e*}\right)$ which values satisfy the relations $\dot{r}=\dot{\pi}^e=0,$ what means that it is determined by the system of equations

$$\begin{aligned}&\alpha\left(\varepsilon\left(Y-\bar{Y}\right)+\pi^e-\bar{\pi}\right)+\beta\left(Y-\bar{Y}\right)+\mu\left(M-\bar{M}\right)=0\\&\gamma\left[\theta\left(\bar{\pi}-\pi^e\right)+\left(1-\theta\right)\varepsilon\left(Y-\bar{Y}\right)\right]+\eta\left(V-\bar{V}\right)=0.\end{aligned}\tag{8}$$

Further on the numerical values which approximately reflect the Czech economy were chosen

$$\begin{aligned}&c=0.8,C_0=10,\tau=0.310709,T_0=2,G=120,k=3,\delta=1,\sigma=0.8,\\&\bar{Y}=300,\bar{M}=315,\bar{V}=240\end{aligned}\tag{9}$$

and arbitrary positive values of parameters $\alpha,\beta,\gamma,\varepsilon,\mu,\eta$ with $\theta,0<\theta<1.$

Remark 1. The calibration in (9) was based on official macroeconomic data for 2023 obtained from the Czech Statistical Office (CZSO, 2025), accessed in December 2025.

It can be shown that the values $r^*=0.06,\pi^{e*}=0.05$ satisfy system (8), what means that

$$E=\left(r^*=0.06,\pi^{e*}=0.05\right)\tag{10}$$

is the equilibrium point of Model (K).

Remark 2. The values of parameters $\alpha,\beta,\gamma,\varepsilon,\mu,\eta$ do not change the values of the equilibrium point $E=\left(r^*=0.06,\pi^{e*}=0.05\right)$.

1.2 Purely imaginary eigenvalues of Model (K)

For further investigation it is suitable to transform the equilibrium point of Model (K) into the origin $E_0 = \left(x_1^* = 0, x_2^{e*} = 0\right)$ by the shifting $x_1 = r - r^*, x_2 = \pi^e - \pi^{e*}$.

Model (K), considering (9), is transformed into the following system

$$\begin{aligned}
\dot{x}_1 &= \left(-6.62142 + 6.62142\mathrm{e}^{-x_1+x_2}\right)\beta + \alpha\left(x_2 + \left(-6.6214532 + 6.62142\mathrm{e}^{-x_1+x_2}\right)\varepsilon\right) \\
&\quad + \left(-315 + \frac{\left(293.37858 + 6.62142\mathrm{e}^{-x_1+x_2}\right)\left(1.05 + x_2\right)}{\delta}\right)\mu \\
\dot{x}_2 &= -240\eta + \left(-6.62142 + 6.62142\mathrm{e}^{-x_1+x_2}\right)\gamma\varepsilon\left(1-\theta\right) \\
&\quad - x_2\gamma\theta + \left(293.37858 + 6.62142\mathrm{e}^{-x_1+x_2}\right)\eta\sigma.
\end{aligned} \tag{11}$$

As we are interested in the impacts of the gaps in monetary base and industrial production on the behaviour of Model (K)′s solutions, we analyse first the case of monetary base, and then the case of industrial production.

1.3 The impact of the gap in monetary base on the behaviour of Model (K)′s solutions

Choosing μ as the bifurcation parameter, the Jacobian matrix of system (11) takes the form

$$J\left(E_0; x_1 = 0, x_2 = 0; \mu = 1 + \kappa\right) = \begin{pmatrix} F_{11} & F_{12} \\ F_{21} & F_{22} \end{pmatrix}, \tag{12}$$

$$F_{11} = \frac{-6.62142\beta\delta - 6.62142\alpha\delta\varepsilon - 6.95249\left(1+\kappa\right)}{\delta},$$

$$F_{12} = \frac{1.\alpha\delta + 6.62142\beta\delta + 6.62142\alpha\delta\varepsilon + 306.95249\left(1+\kappa\right)}{\delta},$$

$$F_{21} = \gamma\varepsilon\left(-6.62142 + 6.62142\theta\right) - 6.62142\eta\sigma,$$

$$F_{22} = \gamma\varepsilon\left(6.62142 - 6.62142\theta\right) - 1.\gamma\theta + 6.62142\eta\sigma.$$

At the values

$$\alpha = 0.1, \gamma = 2, \varepsilon = 1, \theta = 0.43, \delta = 1, \sigma = 0,8, \eta = 1 \tag{13}$$

we get

$$Tr\,J\left(E_0;x_1=0,x_2=0,\mu=1+\kappa\right)=-6.62142\beta-6.62142\,\alpha\varepsilon$$
$$+\gamma\varepsilon\left(6.62142-6.62142\theta\right)-1.\gamma\theta-\frac{6.95249\left(1+\kappa\right)}{\delta}+6.62142\,\eta\sigma=0, \tag{14}$$
$$\text{Det}\,J\left(E_0;x_1=0,x_2=0;\mu=1+\kappa\right)=3861.49685+5.69442\,\beta+3859.64\,\kappa,$$

From (14) utilizing (13) we receive $\beta=0.66012-1.05\,\kappa$ and at $\kappa=0$ the value $\beta_0=0.66012.$

At the values (13) and $\beta_0=0.66012$ we get

$$J\left(E_0;x_1=0,x_2=0;\mu=1+\kappa\right)=\begin{pmatrix}-11.98556-6.95249\kappa & 312.08555+306.95249\,\kappa\\ -12.84555 & 11.98555\end{pmatrix}.$$

Eigenvalues of $J\left(E_0;x_1=0,x_2=0;\mu=1+\kappa\right)$ are

$$\lambda_1=0.5\left(-6.95249\,\kappa+\sqrt{-15461.02338-15438.57143\,\kappa+48.33706\,\kappa^2}\right)$$
$$\lambda_2=0.5\left(-6.95249\,\kappa-\sqrt{-15461.02338-15438.57143\,\kappa+48.33706\,\kappa^2}\right) \tag{15}$$

and at $\kappa=0$ $\lambda_1=62.1712$ i, $\lambda_2=-62.1712$ i.

As the value of Det $J\left(E_0,x_1=0,x_2=0;\mu=1\right)$ at $\beta_0=0.66012$ is positive for small values of κ and $Tr\,J\left(E_0,x_1=0,x_2=0;\mu=1\right)$ is zero we get that Model (K) enables the existence of cycles.

Denote in shorten way system (11) as

$$\dot{x}=X\left(x;\mu\right),\ x=\left(x_1,x_2\right). \tag{16}$$

Perform in system (16) transformation

$$x=H\,y, \tag{17}$$

where a matrix $H=\begin{pmatrix}h_{11} & h_{12}\\ h_{21} & h_{22}\end{pmatrix}$ consists of the eigenvectors corresponding to the eigenvalues (15),

$$h_{11}=-1.\left(-0.933-0.270\kappa+0.038\sqrt{-15461.023-15438.5713\kappa+48.337\kappa^2}\right)$$

$$h_{12}=-1.\left(-0.933-0.270\kappa-0.038\sqrt{-15461.023-15438.571\kappa+48.337\kappa^2}\right)$$

$$h_{21}=1,\ h_{22}=1.$$

We receive a system with the Jordan linear approximation matrix

$$\begin{aligned} \dot{y}_1 &= \lambda_1 y_1 + Y_1\left(y_1, y_2; \mu\right) \\ \dot{y}_2 &= \lambda_2 y_2 + Y_2\left(y_1, y_2; \mu\right), \end{aligned} \tag{18}$$

where $y_2 = \overline{y}_1, Y_2 = \overline{Y}_1,$ and the symbol $\left(\overline{*}\right)$ means complex conjugate expression.

Polynomial transformation

$$y = w + h\left(u_1, u_2; \mu\right),\ y = \left(y_1, y_2\right),\ w = \left(u_1, u_2\right),\ h = \left(h_1, h_2\right),$$

$$h_j\left(u_1, u_2; \mu\right) = \sum_{p_1 + p_2 + p \geq 2,\, p \in \{0,1\}}^{4-2p} h_j^{(p_1, p_2, p)} u_1^{p_1} \left(u_2\right)^{p_2} \mu^p, \quad j = 1, 2,$$

transforms model (18) to the partial normal form

$$\begin{aligned} \dot{u}_1 &= \lambda_1 u_1 + \delta_1 u_1 \mu + \delta_2 \left(u_1\right)^2 u_2 + U^*\left(u_1, u_2; \mu\right) \\ \dot{u}_2 &= \lambda_2 u_2 + \overline{\delta}_1 u_2 \mu + \overline{\delta}_2 u_1 \left(u_2\right)^2 + \overline{U}^*\left(u_1, u_2; \mu\right), \\ (*)^*&\left(\sqrt{|\mu|} u_1, \sqrt{|\mu|} u_2, \mu\right) = O\left(\left(\sqrt{|\mu|}\right)^5\right), j = 1, 2. \end{aligned} \tag{19}$$

Resonant terms δ_1 and δ_2 in (19) are determined by the formulae

$$\delta_1 = \frac{\partial^2 G_1}{\partial y_1 \partial \mu},$$

$$\delta_2 = \frac{1}{2\lambda_2} \frac{\partial^2 G_1}{\partial \left(y_1\right)^2} \frac{\partial^2 G_1}{\partial y_1 \partial y_2} + \frac{1}{\lambda_1} \frac{\partial^2 G_1}{\partial y_1 \partial y_2} \frac{\partial^2 G_2}{\partial y_1 \partial y_2} + \frac{1}{6\lambda_1} \frac{\partial^2 G_1}{\partial \left(y_2\right)^2} \frac{\partial^2 G_2}{\partial \left(y_1\right)^2} + \frac{1}{2} \frac{\partial^3 G_1}{\partial \left(y_1\right)^2 \partial y_2},$$

while all derivatives are calculated at the values $y_1 = 0, y_2 = 0,$ and $\mu = 0.$

In polar coordinates $u_1 = \rho e^{i\varphi}$, $u_2 = \rho e^{-i\varphi}$ dynamic model (19) has the form

$$\begin{aligned} \dot{\rho} &= \rho\left(\zeta \rho^2 + \vartheta \mu\right) + H^*\left(\rho, \varphi; \mu\right) \\ \dot{\varphi} &= \omega_0 + \sigma_1 \mu + \nu \rho^2 + \frac{1}{\rho} \Phi^*\left(\kappa, \varphi, w_1, w_2; \mu\right), \end{aligned}$$

where $\zeta = \operatorname{Re} \delta_2, \vartheta = \operatorname{Re} \delta_1, \sigma_1 = \operatorname{Im} \delta_1, \nu = \operatorname{Im} \delta_2.$

The equation

$$\zeta\ \rho^2 + \vartheta\ \mu = 0 \tag{20}$$

is the bifurcation equation of dynamic model (11).

Based on Bibikov (1979), Wiggins (1990) and Kuznetsov (2004), the following theorem can be stated.

Theorem. *Suppose that the following conditions hold for the coefficients* ζ *and* ϑ *in the bifurcation equation (20):*

(1) If $\zeta < 0$, *then there exists in the dynamic system (11) a stable limit cycle for every small enough* $\mu > 0$ *if* ϑ *is positive, and for every small enough* $\mu < 0$ *if* ϑ *is negative.*

(2) If $\zeta > 0$, *then there exists in the dynamic system (11) an unstable limit cycle for every small enough* $\mu < 0$ *if* ϑ *is positive, and for every small enough* $\mu > 0$ *if* ϑ *is negative.*

Considering the values of critical parameters $\alpha = 0.1, \beta = 0.66012, \gamma = 2, \varepsilon = 1, \theta = 0,43$, and the value of bifurcation parameter $\mu = 1$, we received for the resonant terms δ_1, δ_2 the values $\delta_1 = -8.88178 \times 10^{-16} + 0.13029\,\mathrm{i}$, $\delta_2 = -0.21681 - 237.592\mathrm{i}$. This means, that the bifurcation equation is

$$-0.21681\rho^2 - 8.88178 \times 10^{-16}\mu = 0. \qquad (21)$$

According to Theorem business cycles are stable and on the left side of the bifurcation value $\mu = 1$.

1.4 The impact of the gap in industrial production on the behaviour of Model (K)´s solutions

In this subsection we analyse the impact of the gap in industrial production on the behaviour of Model (K)´s solutions. Performing analogously the same process, which was done in the case 1.2.a, but this time taking for the bifurcation parameter primarily critical parameter η, we get for the resonant coefficients δ_1, δ_2 the values

$\delta_1 = -8.88178 \times 10^{-16} + 3.55271 \times 10^{-15}\mathrm{i}$, $\delta_2 = -0.21681 - 237.592\mathrm{i}$.

This means, that the bifurcation equation is

$$-0.21681\rho^2 - 8.88178 \times 10^{-16}\eta = 0. \qquad (22)$$

According to Theorem business cycles are stable and on the left side of the bifurcation value $\eta = 1$.

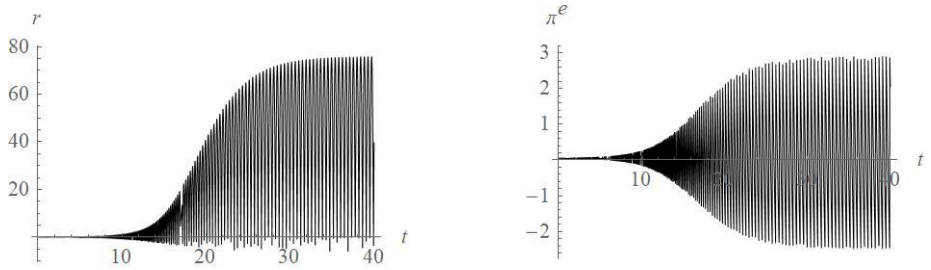
We see that the types of cycles in both cases are identical as the real parts of their corresponding resonant coefficients are identical. The differences are only in the way how the solutions in these two cases are approaching their corresponding cycles in the speed and the size.

2 Presentation of solutions achieved

2.1 Solutions in a neighbourhood of equilibrium with respect to bifurcatioparameter $\mu = 1$

Solutions in a neighbourhood of equilibrium with respect to bifurcation parameter $\mu = 1$ are presented in Figure 1 and Figure 2.

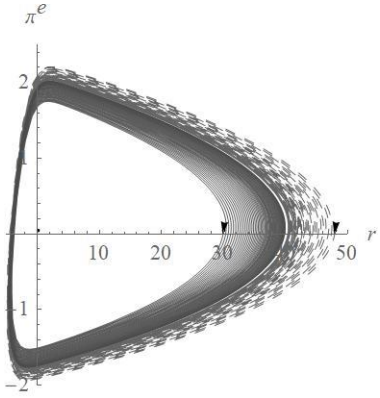
Fig. 1 Evolution of the nominal interest rate and expected inflation for initial conditions inside the stable limit cycle



Source: the authors.

Phase portrait is illustrating trajectories starting inside and outside the stable limit cycle. It displays the evolution of variables r and π^e starting inside the stable cycle with initial values $r(0) = 1.5 \times r^*, \pi^e(0) = \pi^{e*}$.

Fig. 2 Trajectories converging to the stable limit cycle in the monetary base gap bifurcation



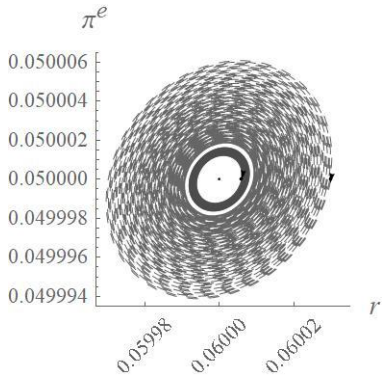
Source: the authors.

Projection of solutions r and π^e into the plane $O_{r\pi^e}$. Solid solution starting inside the stable cycle with initial values $r(0) = 1.500 \times r^*, \pi^e(0) = \pi^{e*}$. Dashed solution starting outside the stable cycle with initial values $r(0) = 1.800 \times r^*, \pi^e(0) = \pi^{e*}$.

2.2 Solutions in a neighbourhood of equilibrium with respect to bifurcation parameter $\eta = 1$

Phase portrait illustrating trajectories converging to the stable limit cycle for the industrial-production-gap bifurcation. The solid trajectory starts inside the stable cycle, whereas the dashed trajectory starts outside the stable cycle.

Fig. 3 Trajectories converging to the stable limit cycle in the industrial production gap bifurcation



Source: the authors.

Projection of solutions r and π^e into the plane $O_{r\pi^e}$. Solid solution n starting inside the stable cycle with initial values $r(0) = 1.0001 \times r^*, \pi^e(0) = \pi^{e*}$. Dashed solution starting outside the stable cycle with initial values $r(0) = 1.0005 \times r^*, \pi^e(0) = \pi^{e*}$.

Conclusion

The results obtained in this paper demonstrate that the incorporation of monetary base and industrial production gaps preserves the ability of the original Asada model to generate endogenous business-cycle oscillations. At the same time, the extended model provides a richer description of the interaction between monetary policy and real economic activity. The

qualitative analysis confirms that both extensions exhibit similar local dynamic properties, although differences are observed in the rate at which trajectories converge towards the corresponding stable limit cycles.

For future investigation of this expanded Asada's model, it could be interesting to find out how the releasing of both parameters μ and η affects the behaviour of solutions.

Acknowledgements

This research was financially supported by the grant schemes VEGA 1/0346/25 and VEGA 1/0084/23 of the Ministry of Education, Research, Development and Youth of the Slovak Republic.

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