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Stability thresholds and oscillatory regimes in Taylor rule dynamics with firm heterogeneity

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Abstract

We analyze the stability of Taylor rule dynamics in a heterogeneous economy with loan-dependent firms. We identify an explicit threshold ϕ_π^* such that monetary policy stabilizes inflation if and only if the policy coefficient lies in the bounded interval (1, ϕ_π^*). The threshold depends on the share of loan-dependent firms and their interaction strength. When a nonlinear Phillips curve is introduced, crossing the threshold produces a stable limit cycle rather than divergence.

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1. Introduction

One of the main tasks of central banks is controlling the rate of inflation in a country. When inflation spikes, interest rates are hiked: this is the idea behind Taylor rules (Taylor (1993)). However, when applied in such a simplistic way, Taylor rules are a blunt weapon against inflation and, as we will prove, may sometimes even be counterproductive.

To see this before entering into more technical details, we provide a simple example. Suppose a grocery store depends on loans to function, and that it must earn a minimum profit to survive. If the costs of higher interest rates must be passed on to the prices of the food the store sells, and demand does not decrease, then hiking interest rates will generate inflation, which in turn will produce another increase in prices. If the rule of thumb used is that interest rates increase linearly with inflation, this might raise inflation (although our analysis will show that a little more than just this is needed: interaction).

We propose simple models illustrating the different possibilities that arise when using Taylor rule to adjust inflation, showing that its application might require a deeper analysis of the economy. Related to our work is Benhabib et al. (2001), where the authors, using a dynamical systems approach, show that given an active monetary policy and a locally unique equilibrium point, there are infinitely many trajectories that converge to a liquidity trap, an unintended consequence of the policy (and hence the title "the Perils of Taylor rules").

Our model is based on a heterogeneous economy, in which we divide firms into two classes: those that are loan-dependent and those that are not. In this case, loan-dependent firms will pass their financial burden on to their prices, and thus a hike in interest rates will affect either their output or their financial costs, which will in turn affect prices. But this alone would not be a cause for concern: it is the interaction between loan-dependent firms that might destabilize inflation if Taylor's rule is too aggressive or if the interaction between loan-dependent firms is strong.

Our main contribution is to identify an explicit stability threshold for Taylor rule dynamics in the presence of firm heterogeneity and interaction (this is different in spirit from the analysis performed in Cochrane (2016) and Cochrane (2022), since we show in our model that what destabilizes the Taylor rule is the interaction between loan-dependent firms). In particular, we show that the effectiveness of monetary policy is non-monotonic: while increasing the policy response to inflation initially stabilizes the system, beyond a critical level it destabilizes it (which, among other aspects makes our work qualitatively different from Benhabib et al. 2001). This yields a bounded interval of admissible policy responses, outside of which inflation either diverges or enters persistent oscillations. The threshold depends explicitly on the share of loan-dependent firms and on the strength of their interaction, providing a structural link between financial dependence, networks, and macroeconomic stability.

2. Models

We will examine three different models: one without interaction between loan-dependent firms, one in which this interaction exists and its strength is measured by a parameter $\rho \in [0, 1]$, and another in which high inflation is somewhat self-regulating. We consider a deterministic, continuous-time framework under perfect foresight, so that expected inflation coincides with realized inflation at all times. This allows us to isolate the structural transmission of monetary policy through cost and interaction channels, foregoing possible complications due to expectation-driven dynamics.

2.1. No Interaction Model

We first show a case in which the rate policy can help lower inflation. In this case, even if some firms are loan-dependent, there is no possibility of entering an inflation spiral. The model is as follows. Assume that there are two types of firms, A and B. Firms of type A are dependent on loans and they pass these financial costs on through the price of their products. Firms of type B do not depend on loans. We assume that there is no interaction between firms of type A. Thus, inflation due to firms of type A is given by

$$\pi_A = \beta_y y + \beta_r r,$$

with $\beta_y, \beta_r \geq 0$, where y represents aggregate demand and r the rate of interest set by the Central Bank. On the other hand, for firms of type B, their contribution to inflation is given by

$$\pi_B = \beta_y y.$$

Therefore, if the residual proportion of loan-dependent firms whose market share cannot be absorbed by Type B firms is $\alpha \in [0,1]$, then the fundamentals-implied total inflation is given by

$$\pi^* = \beta_y y + \alpha \beta_r r.$$

Note, in passing, that α represents a best-case scenario for aggregate inflation passthrough: any loan-dependent firm whose customers can switch to Type B goods ceases to contribute to α. Later on, we will demonstrate that even in this most favorable case, a strong interaction among the remaining firms can trigger instability; but first we will make the analysis assuming no interaction at all.

The law of motion assumed for this dynamical system is

$$\dot{\pi} = \theta(\pi^* - \pi), \qquad \dot{y} = -\sigma(r - \pi) \quad (\sigma > 0).$$

The rationale is as follows. The first equation states that inflation π is adjusting toward the level implied by the current fundamentals (output and the interest rates), which is given by π^*, at a rate $\theta > 0$. The second equation is the hypothesis that aggregate demand goes down if there is a hike in interest rates that is above real inflation.

Manipulating the equations above, and using Taylor's rule, which is given by

$$r = \bar{r} + \varphi_\pi(\pi - \pi_0),$$

where π_0 is the acceptable level of inflation set by the Central Bank's policy, we obtain the set of equations

$$\begin{cases} \dot{\pi} = \theta\big[(\alpha\beta_r\varphi_\pi - 1)\pi + \beta_y y + \alpha\beta_r(\bar{r} - \varphi_\pi\pi_0)\big], \\ \dot{y} = -\sigma\big[(\varphi_\pi - 1)\pi + \bar{r} - \varphi_\pi\pi_0\big]. \end{cases} \tag{1}$$

Next, we analyze the dynamics predicted by this set of equations.

2.1.1. Analysis of the Dynamics

The steady state is given by

$$\pi^{ss} = \frac{\varphi_\pi \pi_0 - \overline{r}}{\varphi_\pi - 1}, \qquad y^{ss} = \frac{(1-\alpha\beta_r)(\varphi_\pi \pi_0 - \bar{r})}{\beta_y(\varphi_\pi - 1)}. \tag{2}$$

Notice that when $\overline{r} = \pi_0$, $\pi^{ss} = \pi_0$ and $y^{ss} = (1-\alpha\beta_r)\,\pi_0/\beta_y$. The Jacobian of the system is

$$J = \begin{pmatrix} \theta(\alpha\beta_r\varphi_\pi - 1) & \theta\beta_y \\ -\sigma(\varphi_\pi - 1) & 0 \end{pmatrix}.$$

We compute the determinant and the trace of J:

$$\det(J) = \theta\sigma\beta_y(\varphi_\pi - 1), \qquad \mathrm{tr}(J) = \theta(\alpha\beta_r\varphi_\pi - 1).$$

Assuming $\varphi_\pi > 1$, then $\det(J) > 0$, and if $\mathrm{tr}(J) < 0$ the steady state is stable; if $\mathrm{tr}(J) > 0$ it is unstable.

From the equations, we then obtain the following. Let $\alpha^* = 1/(\beta_r\varphi_\pi)$.

(i) If $0 \leq \alpha < \alpha^*$, the steady state is stable.

(ii) If $\alpha > \alpha^*$, the steady state is unstable.

In fact, the stability is global. Define $x = \pi - \pi^{ss}$ and $z = y - y^{ss}$. Then the following is a Lyapunov functional for the system:

$$V(x,z) = \frac{1}{2\theta\beta_y}x^2 + \frac{1}{2\sigma(\varphi_\pi - 1)}z^2.$$

Along a trajectory solution of the system (1), we have

$$\dot{V} = \frac{\alpha\beta_r\varphi_\pi - 1}{\beta_y}x^2,$$

which is < 0 if $\alpha < \alpha^*$, and hence the steady state is globally stable. Notice that if $\alpha = \alpha^*$, we have an elliptic orbit around the steady state.

2.1.2. Economic Realism

Under the assumptions of this model, entering an unstable regime in which inflation gets out of control is not something to worry about. Indeed, for some realistic values, $\alpha^* > 1$, and hence we cannot have $\alpha > \alpha^*$ since $\alpha \in [0,1]$. However, this model exposes the possibility of a regime in which applying Taylor's rule might lead to uncontrollable inflation. We demonstrate this possibility in our next model, where we include a possible interaction between loan-dependent firms.

2.2. Interaction Model

In this model, we assume that there is interaction between firms of type A. In this case, also assuming instantaneous transmission of costs, the contribution to inflation from firms of type A is now

$$\pi_A = \beta_y y + \beta_r r + \rho \pi_A, \tag{3}$$

where $\rho \in (0, 1]$, and the term $\rho\pi_A$ reflects the interaction between loan-dependent firms and its effect on inflation. This static specification can be seen as the continuous-time limit of a discrete-time process in which inflation contributed by loan-dependent firms depends on current output and interest rates as well as on the past inflation of other loan-dependent firms. To see this more clearly, let $\pi_{A,t}$ denote the inflation contribution of type A firms in period t. Then

$$\pi_{A,t} = \beta_y y_t + \beta_r r_t + \rho\, \pi_{A,t-\delta t},$$

where the term $\rho\pi_{A,t-\delta t}$ captures the idea that a firm's price is influenced by the prices set by other loan-dependent firms in the previous period of time (due to interaction between type A firms). Thus,

$$\pi_{A,t} \approx \beta_y y_t + \beta_r r_t + \rho(\pi_{A,t} - \delta t\, \dot{\pi}_{A,t}),$$

and assuming instantaneous transmission in this interaction channel ($\delta t \to 0$) gives (3). In this way, we obtain

$$\pi_A = \tilde{\beta}_y y + \tilde{\beta}_r r, \qquad \tilde{\beta}_y = \frac{\beta_y}{1-\rho}, \quad \tilde{\beta}_r = \frac{\beta_r}{1-\rho}.$$

Thus, the multiplier $1/(1-\rho)$ amplifies the sensitivity of inflation to both output and the interest rate. The reader must observe that assuming instantaneous transmission in this channel introduces two timescales in the model: the interaction channel among loan-dependent firms clears instantaneously, whereas the inflation π adjusts towards π^* gradually.

Microeconomically, the parameter ρ captures the (average) share of intermediate inputs that loan-dependent firms source from other loan-dependent firms within the production network. When Firm X raises its price to cover higher interest expenses, this price increase becomes a cost shock for any downstream Firm Y that relies on X's output as an input. If Firm Y is also loan-dependent, it passes this combined cost pressure forward. This roundabout production structure generates a multiplier effect formally equivalent to $1/(1-\rho)$, akin to the input-output amplification mechanisms identified in network models of pricing (see Acemoglu et al. 2012).

The set of equations of motion now reads:

$$\begin{cases} \dot{\pi} = \theta\big[(\alpha\tilde{\beta}_r\varphi_\pi - 1)\pi + \tilde{\beta}_y y + \alpha\tilde{\beta}_r(\bar{r} - \varphi_\pi\pi_0)\big], \\ \dot{y} = -\sigma\big[(\varphi_\pi - 1)\pi + \bar{r} - \varphi_\pi\pi_0\big]. \end{cases} \tag{4}$$

We proceed to its analysis next.

2.2.1. Analysis

The analysis of the dynamics of this model is similar to the previous one: the only change is that we have new effective parameters $\tilde{\beta}_y$ and $\tilde{\beta}_r$, which depend on the original quantities and on the strength of the interaction between loan-dependent firms. The steady state is given by (2) with the β's changed to the effective $\tilde{\beta}$'s. In this model, entering a regime of uncontrolled inflation becomes a real possibility, since if ρ is close enough to 1, the constants $\tilde{\beta}_y$ and $\tilde{\beta}_r$ become large, and a value of α^* that falls into the relevant range (that is, $\alpha^* \in (0,1)$) becomes possible. Thus, the value of α surpassing it under an aggressive Taylor rule also becomes possible.

A striking implication is that even a small proportion α of loan-dependent firms can trigger instability if the interaction parameter ρ is sufficiently close to 1. Since $\alpha^* = (1-\rho)/(\beta_r\varphi_\pi)$, we have $\alpha^* \to 0$ as $\rho \to 1$. Hence, a highly interconnected credit network amplifies the financial channel of monetary policy, making the economy fragile even when few firms are directly loan-dependent.

Also, the predictions of this model can be seen in a different light. Given α, there is a threshold for a stabilizing Taylor rule; namely, for Taylor rule to have its expected inflation-stabilizing effect, it cannot go beyond a certain threshold given by $\varphi_\pi^* = (1-\rho)/(\beta_r\alpha)$. Together with the standard Taylor principle $\varphi_\pi > 1$ (required for determinacy in most New Keynesian models), an effective monetary policy exists only if

$$1 < \varphi_\pi < \frac{1-\rho}{\beta_r\alpha}.$$

Thus, for a given economy (characterized by α, ρ, and β_r), the central bank's policy coefficient φ_π must lie in a bounded interval. If φ_π is too low (lower than 1), expectations become indeterminate; if φ_π is too high, the interaction among loan-dependent firms destabilizes inflation. This is the central non-monotonic effect: raising φ_π initially stabilizes the economy, but beyond φ_π^* it destabilizes it.

We summarize our findings in the following.

Proposition 1. *Fix $\alpha \in (0,1]$, $\rho \in [0,1]$, and $\beta_r > 0$. There is a threshold*

$$\varphi_\pi^* = \frac{1-\rho}{\beta_r\alpha}$$

such that if $1 < \varphi_\pi < \varphi_\pi^*$ the steady state is stable and if $\varphi_\pi > \varphi_\pi^*$ the steady state is unstable.

3. Model: a Nonlinear Phillips Curve

Here we set

$$\begin{cases} \dot{\pi} = \theta\big[(\alpha\beta_r\varphi_\pi - 1)\pi + \tilde{\beta}_y y + \alpha\tilde{\beta}_r(\bar{r} - \varphi_\pi\pi_0)\big] - \gamma(\pi-\pi_0)^3, \\ \dot{y} = -\sigma\big[(\varphi_\pi - 1)\pi + \bar{r} - \varphi_\pi\pi_0\big]. \end{cases} \tag{5}$$

This is a macroeconomic model in which the Phillips curve "is flat when inflationary pressure is subdued and steep when inflationary pressure is elevated," as proposed by Harding et al. (2022). In Harding et al. (2022), the authors derive a nonlinear Phillips curve from basic principles and real data, and use it to explain post-Covid inflation empirically. In our approach, we postulate it directly as a reduced-form equation which can be justified as an inflation self-regulating mechanism, and we use it to prove a Lyapunov stability result, and to show that in cases such as this, there is a stable limit cycle in the dynamics; that is, given an aggressive enough Central Bank policy through the Taylor rule, inflation would oscillate and never settle towards its intended equilibrium. The reader must observe the similarity of (5) with the Van der Pol equations for which it is well known that there is a stable cycle.

3.1. Analysis

To simplify notation, we write the previous system as

$$\dot{x} = ax + bz - \gamma x^3, \qquad \dot{z} = -cx, \tag{6}$$

with $a = \theta(\alpha\tilde{\beta}_r\varphi_\pi - 1)$, $b = \theta\tilde{\beta}_y$, $c = \sigma(\varphi_\pi - 1)$ and $\gamma > 0$, with $x = \pi - \pi^{ss}$ and $z = y - y^{ss}$. We show that the nonlinearity in this case has a stabilizing effect, and that if $\alpha > \alpha^*$, then the system tends to a stable cycle.

In this case, we consider the Lyapunov candidate function

$$V(x, z) = \frac{c}{2}x^2 + \frac{b}{2}z^2. \tag{7}$$

Note that V is positive definite since $b, c > 0$. Computing its time derivative along trajectories of system (6), we obtain

$$\begin{aligned}\dot{V} &= cx\dot{x} + bz\dot{z} = cx\big(ax + bz - \gamma x^3\big) + bz(-cx)\\ &= acx^2 + bcxz - \gamma cx^4 - bcxz = cx^2\big(a - \gamma x^2\big).\end{aligned}$$

We now analyze the dynamics in each regime.

Case $\alpha < \alpha^*$ (stable regime). When $\alpha < \alpha^*$, we have $a = \theta(\alpha\tilde{\beta}_r\varphi_\pi - 1) < 0$. Since $\gamma > 0$ and $c > 0$,

$$\dot{V} = cx^2(a - \gamma x^2) < 0$$

for all $(x, z) \neq (0, 0)$. Hence V is a strict Liapunov function for the system, and the steady state is globally asymptotically stable. In this regime, the Taylor rule is effective.

Case $\alpha = \alpha^*$ (critical regime). When $\alpha = \alpha^*$, we have $a = 0$, and hence

$$\dot{V} = -\gamma cx^4 \leq 0,$$

with equality if and only if $x = 0$. On the set $\{x = 0\}$, the dynamics reduce to $\dot{x} = bz$ and $\dot{z} = 0$, so the only invariant subset of $\{x = 0\}$ is the origin. By LaSalle's invariance principle, the steady state is globally asymptotically stable at the critical threshold as well.

Case $\alpha > \alpha^*$ (unstable regime with limit cycle). When $\alpha > \alpha^*$, we have $a > 0$. In this case, $\dot{V} > 0$ for $|x|$ small (near the origin), so the steady state is unstable. However, for $|x|^2 > a/\gamma$, we have $\dot{V} < 0$, meaning trajectories that are sufficiently far from the origin are driven inward.

More precisely, the level sets of the Lyapunov function, $\{x : V(x) = \omega\}$ for $\omega > 0$ sufficiently large, are invariant from the outside: trajectories cross them inward. Since the steady state is unstable and the flow is bounded, the Poincaré–Bendixson theorem guarantees the existence of at least one stable limit cycle in the annular region between the origin and the large level set.

The amplitude of the limit cycle can be estimated as follows. Setting $\dot{V} = 0$ gives $|x|^2 = a/\gamma$, which suggests that the limit cycle oscillates around the curve $|x| \approx \sqrt{a/\gamma}$ (the reader should compare with the case of the Van der Pol equation). In terms of the original parameters,

$$|x| \approx \sqrt{\frac{\theta(\alpha\tilde{\beta}_r\varphi_\pi - 1)}{\gamma}},$$

so the amplitude of the inflation oscillations grows as α moves further above α^*, and shrinks to zero as $\alpha \to \alpha^*$ from above, consistent with a supercritical Hopf bifurcation at $\alpha = \alpha^*$.

4. Conclusion

The three regimes above have a clear economic interpretation. When the proportion of loan-dependent firms α is below the threshold α^*, the Taylor rule successfully stabilizes inflation regardless of initial conditions. At the threshold, stability is maintained, but the economy is at the boundary of controllability. Above the threshold, the Taylor rule loses its stabilizing power: inflation does not converge to target but instead enters a persistent oscillatory regime. The nonlinear Phillips curve prevents the oscillations from diverging to infinity—the economy does not collapse—but neither does it settle.

As shown in the last two models, the policymaker faces a situation in which more aggressive interest rate hikes (increasing φ_π) paradoxically lower α^*, making instability easier to trigger. Moreover, when ρ is close to 1, the threshold α^* becomes very small, so even a modest presence of loan-dependent firms can push the economy into the oscillatory regime. This highlights a non-monotonic effect of financial interconnectedness: moderate interaction may be harmless, but high interaction magnifies the destabilizing potential of an aggressive Taylor rule.

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