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Ruling out unstable New Keynesian equilibria: A note

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Abstract

Aside from a knife-edge case, unstable nominal equilibria in New Keynesian models imply real explosions. We show how unstable nominal equilibria can be ruled out using a Taylor-type rule with a trigger strategy designed to prevent bubbles. Hence, a 'cashless' monetary policy ensures stable, determinate inflation. These results provide support for the convention of selecting the unique stable solution in the literature. We establish these results using a baseline, linear three-equation New Keynesian model, but the main conclusions are robust to some extensions and non-linearities.

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1 Introduction

The New Keynesian model with a Taylor rule is the current workhorse model of inflation determination. In these models, the central bank sets nominal interest rates to influence inflation and the output gap, subject to sticky prices and microfoundations. If interest rates are set appropriately, inflation will be determinate (unique) and stable (non-explosive).

However, several recent works have challenged the way that standard New Keynesian models determine inflation. In effect, the central bank promises to set interest rates such that, should any but one equilibrium occur, it will proceed to 'blow up' inflation; this threat is assumed to coordinate expectations on the unique stable path. Cochrane (2011) argues that nominal explosions should be included in the set of equilibria if they do not violate transversality conditions; he thereby questions the credibility of the usual assumption that expectations coordinate on the stable equilibrium. Similarly, Minford and Srinivasan (2011) take such inflationary equilibria seriously in their analysis, but they show that a trigger strategy which promises to switch from a Taylor rule to a *money* supply rule can rule out nominal bubbles, thus giving a role for a monetary anchor in New Keynesian models.

In this note, we revisit unstable nominal equilibria in New Keynesian models. We first present conditions for which unstable nomimal equilibria imply *real* explosions, which are absent in the above papers. We then show that such equilibria can be ruled out by a Taylor-type rule with a trigger strategy for *interest rates* designed to prevent inflationary bubbles; note that this finding implies that credible interest rate setting alone is sufficient to rule out instability, without having to rely on monetary aggregates as a backstop.

While Minford and Srinivasan (2011, p. 247) infer from their trigger strategy that "money cannot be avoided in the NK set-up" (p. 247), we show that a Taylor-type rule will rule out the unstable nominal equilibria while preserving the standard 'cashless' approach in the literature. Our proposed rule combines a response to inflation of more than one – the Taylor principle – with an 'escape clause' that promises an even stronger response of nominal interest rates to inflation, should an explosive path be selected by private agents. This threat is sufficient to rule out the unstable nominal equilibria, so is never exercised.[1]

Differently to Cochrane (2011) and Minford and Srinivasan (2011), we study the *real* implications of unstable nominal equilibria in New Keyensian models. Aside from a knife-edge case, we show that such equilibria have the implausible implication of *real* explosions: output explodes to either $+\infty$ or $-\infty$ (latter is 0 in levels). Thus, there is a good reason for agents to select the unique stable equilibrium, as assumed in the New Keynesian literature.

Bubble-free interest rate rules have been studied by Loisel (2009), who considers some New Keynesian examples with Taylor-type rules *absent* trigger strategies. In order to rule out bubbles, Loisel suggests a rule which responds to the natural rate of interest; however, the latter is unobservable in practice, thus raising questions about the credibility of such rules. By comparison, we present a Taylor-type rule that does *not* require knowledge of the natural rate, a task which poses a non-trivial problem for central banks in practice.

Our interest rate rule is inspired by the "robust real rate rules" in Holden (2024). They show that such rules make inflation determinate under somewhat weaker assumptions than

[1] The central bank chooses an interest rate rule and the private sector forms its expectations. The trigger strategy describes the central bank's policy response to certain (inflationary or deflationary) expectations.

in previous work, assuming the stable equilibrium is selected, as in much of the literature (e.g. King, 2000; Walsh, 2017). We study the 'flip side' of such rules – the excluded unstable equilibria – but find little cause for concern: (i) unstable nominal paths have *implausible* real implications and so (we argue) are unlikely to be coordinated on by rational agents; and (ii) the unstable equilibria can be ruled out by policy via our extended Taylor-type rule which has no explicit role for money aggregates nor any response to the natural rate of interest.

Our main results are shown using a baseline linear New Keynesian model. We consider some extensions and empirical issues after the main results have been presented.

2 Baseline New Keynesian model

We consider a baseline log-linear New Keynesian model (e.g. Walsh, 2017). The model consists of a New Keynesian Phillips curve, a dynamic IS curve, and a Taylor-type rule:

$$\pi_t = \beta E_t \pi_{t+1} + \kappa x_t \tag{1}$$

$$x_t = E_t x_{t+1} - \sigma(i_t - E_t \pi_{t+1} - r_t^n) \tag{2}$$

$$i_t = r_t + \phi \pi_t, \quad \phi > 1 \tag{3}$$

where π_t is the inflation rate, i_t and r_t are the nominal and real interest rate, $x_t \in \mathbb{R}$ is the output gap (the gap between output and its flex-price value), and E_t is the conditional expectations operator. Variable r_t^n is an exogenous shock (natural rate) with bounded support.

The New Keynesian Phillips curve (1) has a term in expected future inflation, due to *sticky prices*, and discounting $\beta \in (0, 1)$; the microfounded slope is $\kappa > 0$. The IS curve (2) is a linearized version of the Euler equation, with elasticity of substitution $\sigma > 0$. Finally, following Cochrane (2011), the Taylor-type rule sets the nominal interest rate equal to the real interest rate r_t, plus a response $\phi > 1$ to deviations of inflation from a zero target.

There is no arbitrage between real and nominal bonds, so the Fisher equation holds:

$$i_t = r_t + E_t \pi_{t+1}. \tag{4}$$

Combining (3) and (4) gives:

$$\pi_t = \phi^{-1} E_t \pi_{t+1}. \tag{5}$$

2.1 Nominal bubbles

Equation (5) has many solutions. Since $\phi > 1$ (Taylor principle), all these solutions except one have explosive inflation. The standard approach in the New Keynesian literature is to *exclude* explosive equilibria, by selecting the unique stable solution, $\pi_t = 0$. The latter is the only solution that satisfies the no-bubbles condition, $\lim_{T\to\infty} \left[\phi^{-T} E_t \pi_{t+T}\right] = 0$. In short, we have stable and determinate inflation, albeit by assumption not as an implication.

If we do *not* exclude the unstable equilibria, there are many 'sunspot' solutions to (5):

$$\pi_t = \lim_{T\to\infty} \left[\phi^{-T} E_t \pi_{t+T}\right] = b_t \qquad \Longrightarrow \qquad \pi_t = \phi \pi_{t-1} \tag{6}$$

where $b_t = \phi b_{t-1}$ is a deterministic bubble and $b_0 \in \mathbb{R}$ is an arbitrary initial value.[2]

The unique stable solution $\pi_t = 0$ is the special case $b_0 = 0$ (no bubble), while for $b_0 \neq 0$ we have perpetually-growing inflation (if $b_0 > 0$) or ever-deepening deflation (if $b_0 < 0$).

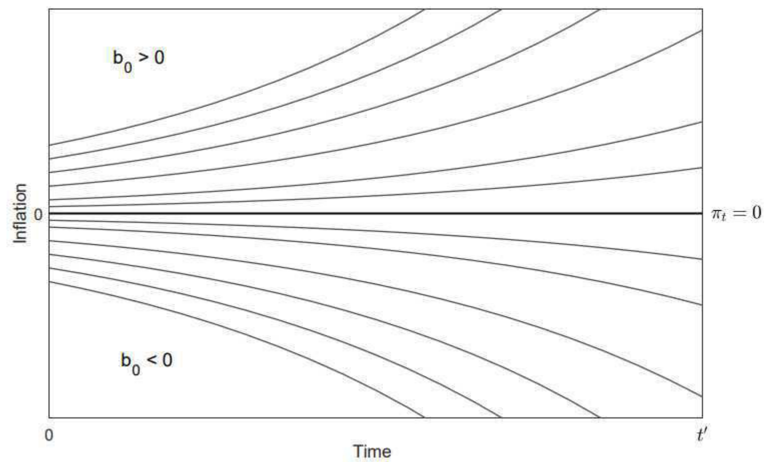

Figure 1: Bubble paths in the New Keynesian model. Each line shows the evolution of inflation from a different initial condition b_0. On bubble paths $\pi_t = \phi \pi_{t-1} \neq 0$, so $\frac{\Delta \pi_t}{\pi_{t-1}} = \phi - 1$.

The many 'bubble solutions' in (6) are unattractive from an inflation stabilization perspective, as shown by the subset of explosive solutions plotted in Figure 1 (grey curves). There are infinitely-many such paths, each being indexed by a different initial condition $b_0 \neq 0$. The speed of explosion depends on the extent to which the parameter ϕ exceeds 1.

2.2 Real implications

What are the real implications of nominal explosions? In this model, unstable nominal equilibria – i.e. solution paths with explosive inflation – usually have output exploding, too.

Using (6) and the New Keynesian Phillips curve (1), the output gap is

$$x_t = (1 - \beta\phi)\kappa^{-1}\pi_t \tag{7}$$

where $\kappa > 0$ is the slope of the Phillips curve.

Equation (7) shows that explosive inflation implies an explosive output gap for any response coefficient $\phi \neq \beta^{-1}$; thus output $y_t = x_t + y_t^n$ will diverge from its flex-price value.[3]

Output will explode in the same direction as inflation if $\phi < \beta^{-1}$, and in the *opposite* direction if $\phi > \beta^{-1}$. Intuitively, there is a 'wedge' between current and discounted future inflation *unless* the policy parameter ϕ in the Taylor rule happens to equal the inverse private discount factor β^{-1}. So, aside from a knife-edge case, unstable nominal equilibria imply *real*

[2]Let us guess there is a solution of the form $\pi_t = b_t$ for all $t \geq 1$, where $b_t = \phi b_{t-1}$ (we consider a deterministic bubble for simplicity). Then $\pi_t = \lim_{T\to\infty} \left[\phi^{-T} E_t \pi_{t+T}\right] = \lim_{T\to\infty} \left[\phi^{-T} E_t b_{t+T}\right] = b_t$ (since $b_{t+T} = \phi^T b_t$) and combining this with $b_t = \phi b_{t-1}$ gives $\pi_t = \phi\pi_{t-1}$, with initial condition $\pi_0 = b_0$.

[3]The output gap is $x_t := y_t - y_t^n$, where y_t is output and y_t^n is the flex-price level of output (both in logs). In the simple model here, y_t^n depends on exogenous (aggregate) productivity; see e.g. Walsh (2017, Ch. 8).

explosions. Such real explosions are clearly *implausible*: output will either grow without bound despite stable productivity ($x_t \to \infty$ as $t \to \infty$) or permanently contract toward *zero*, i.e. economic extinction ($x_t \to -\infty$ as $t \to \infty$); recall $y_t = x_t + y_t^n$ is output in natural logs.

In the knife-edge case $\phi = \beta^{-1}$, explosive inflation is *not* accompanied by an exploding output gap (see (7)) because discounting of future inflation exactly offsets the growth rate of inflation, ϕ, so that a zero output gap, $x_t = 0$ for all t, is 'backed out' from (7). In this case, implausible real implications are *absent*, but we now show that all the unstable equilibria can be ruled out by a well-designed interest rate rule (essentially an extended Taylor rule).

3 Ruling out unstable equilibria using interest rates

The many 'bubble solutions' in (6) are clearly unattractive from a stabilization perspective; hence we would like to rule them out. Minford and Srinivasan (2011) present a *monetary* trigger strategy that does so and argue that "money cannot be avoided in the NK [New Keynesian] set-up" (p. 247). However, we now show a Taylor-type rule for interest rates can rule out the unstable equilibria while preserving the 'cashless' approach and avoiding a response to the natural rate of interest, different to the bubble-free rules in Loisel (2009).

We thus look for a trigger strategy that imposes a *terminal condition* on beliefs that rules out bubble equilibria, thereby providing a foundation for the standard assumption that the unique stable solution is selected by agents in a 'cashless economy'.

Our proposed policy has the form:

$$i_t = \begin{cases} r_t + \phi\pi_t & \text{if } \pi_0, \dots, \pi_{t-1} = 0 \\ i_t^* & \text{otherwise} \end{cases}, \quad \text{for all } t \geq 1 \tag{8}$$

where i_t^* is the 'trigger' interest rate.

Rule (8) says the central bank will follow the standard Taylor rule (3) in period t if the stable solution of zero inflation was realized in all past periods; however, if a bubble led to inflation different from zero, the interest rate would switch to the trigger value i_t^*.

The question is: how to set i_t^* to rule out instability, assuming that the threat is credible? Solving (5) forward T periods yields:

$$\pi_t = \phi^{-T} E_t \pi_{t+T}$$

so a terminal condition $E_t \pi_{t+T} = 0$ will ensure $\pi_t = 0$, and this can be achieved by setting:

$$i_t^* = r_t + \tilde{\phi}(E_t \pi_{t+1} + \phi\pi_t), \qquad \tilde{\phi} = 1. \tag{9}$$

The interest rate (9) 'works' as combining $i_t = i_t^*$ and the Fisher equation (4) implies $\pi_t = 0$. Hence, agents forecasting inflation at some future date $t + T$ will expect *no* inflation:[4]

$$\pi_t = \phi^{-T} E_t \pi_{t+T} = 0$$

so a bubble cannot get started!

[4]Suppose $\pi_{t'} \neq 0$ at some date $t' \geq 1$. Then $\pi_{t'+1} = 0$ by (8), as $i_{t'+1} = i^*_{t'+1}$. Since $i_t = r_t + \phi\pi_t$ for $t = 1, ..., t'$, $\pi_t = \phi^{-1}\pi_{t+1}$ for such t by (5). But for $t = t'$, $\pi_{t'} = \phi^{-1}\pi_{t'+1} = 0$, which contradicts $\pi_{t'} \neq 0$.

Inflation is thus zero for all $t \geq 1$. Intuitively, with the amended Taylor rule (8)–(9) the expectation that $i_{t+T} = i^*_{t+T}$ in some future period $t + T$, if inflation prior to $t + T$ were non-zero, will ensure $E_t \pi_{t+T} = 0$. As a result, the bubble paths unravel by backward induction and are not equilibria.[5] Observe that the trigger interest rate i^*_t in (9) implies a stronger response to inflation than the original rule (3); furthermore, because it is a simple rule and easy to communicate, it may be more credible than a complex or obscure rule.[6]

4 Discussion

We have seen that inflationary New Keynesian equilibria can have the implausible implication that output will permanently grow or contract towards zero. Sticky prices matter here since a New Classical Phillips curve $\pi_t = E_{t-1}\pi_t + \tilde{\kappa} x_t$ (see King, 2000) implies *no* real explosion as $E_{t-1}\pi_t = \phi\pi_{t-1} = \pi_t$ by (6). The 'real explosion' result casts doubt on whether rational agents would coordinate on unstable equilibria, but the result is absent in a 'knife-edge' case.

Minford and Srinivasan (2011) do not study the *real* implications of explosive inflation, while Cochrane (2011) notes in passing that "output may...explode in the linearized nonlocal equilibria" (p. 593), but dismisses this as a problem with the model itself. By contrast, we provide conditions for which real explosions do (or do not) occur, which could guide policymakers when considering the design of Taylor-type rules. Crucially, policymakers can *rule out* all of the unstable equilibria using a well-designed interest rate rule: (8)–(9).

Relative to Loisel (2009), our interest rate rule (8)–(9) has the advantage that policymakers do not need to know the natural rate of interest, r^n_t, to follow the rule. The 'trigger strategy' part of the rule has the intuitive interpretation that there is a stronger response to inflation, although the threat is never exercised as the zero-inflation solution prevails. Hence, a central bank that can *credibly* threat to switch its rule to (9) will execute only the more conventional "robust real rate rule", (3), in the terminology of Holden (2024). Lastly, note that the trigger interest rate rule i^*_t in (9) can be amended to allow a response to contemporaneous inflation different to ϕ while still implementing the zero-inflation solution.[7]

Minford and Srinivasan (2011) argue "the Taylor rule is an incomplete description of monetary policy" and "money cannot be avoided in the NK set-up" (p. 247), but we have shown that unstable nominal equilibria can be ruled out by a Taylor-type rule, preserving the 'cashless' approach. Our proposed rule is a complete description of monetary policy and makes interest rates the central bank's policy instrument as in practice, rather than combining interest rate setting with a money supply rule. Our interest rate rule (3), and its extension (8)–(9), does ignore the *zero lower bound* on nominal interest rates; however, there are bubble equilibria, where the constraint is slack, under weak conditions.[8]

Our conclusions are robust to some common extensions of model (1)–(4). The IS curve

[5] In (6) we consider deterministic bubbles; so a bubble, once stopped, cannot start up again. Entertaining stochastic bubbles would not change the zero-inflation result: expectations are at zero in all periods.

[6] By (5) and (9), $i^*_t = r_t + \tilde{\phi}(E_t\pi_{t+1} + \phi\pi_t)$, so $i^*_t = r_t + 2\phi\pi_t$ given that $\tilde{\phi} = 1$ and $E_t\pi_{t+1} = \phi\pi_t$.

[7] Any trigger rule of the form $i^*_t = r_t + E_t\pi_{t+1} + \hat{\phi}\pi_t$, where $\hat{\phi} > 0$, gives the zero-inflation solution.

[8] With a zero lower bound, $i_t = \max(r_t + \phi\pi_t, 0)$. Note that $i_t = r_t + \phi\pi_t$ if $\pi_t \geq -\phi^{-1}r_t$, where $r_t = r^n_t + \sigma^{-1}(E_t x_{t+1} - x_t)$ by (2). Since r^n_t is bounded below, a growing or fixed output gap $(E_t x_{t+1} - x_t) \geq 0$, combined with growing inflation and a sufficiently large initial value $\pi_0 = b_0$, implies slackness for all t.

(2) simply 'backs out' the real interest rate r_t, so our results are unaffected by extensions that alter only this equation. Adding a lag in the New Keynesian Phillips curve does not affect our policy rule (8)–(9) and leaves intact the result of real explosions in unstable equilibria, except for a 'knife-edge' Taylor rule coefficient, different from the value in (7). Similarly, cognitive discounting as in Gabaix (2020) only affects the knife-edge value of ϕ.[9] The 'trigger' interest rate i_t^* is affected by Fisher equation 'wedges' such as risk premia (Holden, 2024); to make expected inflation *zero* the nominal rate should respond one-to-one to such wedges.

Finally, McCallum (2009) argues that unstable nominal equilibria in New Keynesian models can be ruled out on the basis of the least-squares learnability criterion, thereby giving a different rationale for assuming coordination on the unique stable solution.

5 Nonlinearities and empirical considerations

Thus far, we have studied baseline linear New Keynesian models, where some important nonlinearities are absent, and ignored empirical considerations. We now consider these issues.

5.1 Nonlinearities

Linear New Keynesian models, as studied thus far, can be derived as a first-order approximation to non-linear models. Importantly, non-linear models do not assume a local approximation around a fixed inflation rate (usually zero) as is in log-linearized models, an assumption which is at odds with explosive inflation. Linear New Keynesian models also abstract from the zero lower bound on nominal interest rates; however, as noted in Section 4, our main conclusions remain intact if a zero lower bound is added to the model.

Cochrane (2011) acknowledges that non-linearities in New Keynesian models should be taken into account but argues that bubble paths should be taken seriously provided they do *not* violate transversality conditions (needed for optimality). In the benchmark non-linear New Keyesian model (Walsh, 2017) there are transversality conditions for bond holdings, which will hold under explosive inflation if bonds are in *zero* net supply (as often assumed);[10] further, McCallum (2009) notes that adding a transactions demand for money may mean that transversality conditions are satisfied even if the net supply of bonds is not zero.

It is known that the Calvo price-setting equations widely used in New Keynesian models impose an upper bound on inflation (e.g. Andreasen and Kronborg, 2022). Since growing inflation implies this upper bound will be exceeded, such paths may be ruled out, reinforcing our original conclusion about the implausibility of bubble paths. The log-linearized model misses this conclusion because the first-order approximation breaks down at high inflation levels; however, there is no such upper bound in the case of Rotemberg price adjustment.

There is also the question of whether all equilibrium conditions in the non-linear model will hold when inflation is explosive: let us suppose so. Then, under perfect foresight, the

[9]If the Phillips curve (1) were augmented with lagged inflation as in $\pi_t = \beta(1-\rho)E_t\pi_{t+1} + \rho\pi_{t-1} + \kappa x_t$, where $\rho \in (0,1)$, there is still a single knife-edge value of ϕ. Cognitive discounting implies a smaller positive discount factor $\tilde{\beta} \in (0,\beta)$, so the knife-edge inflation-response coefficient will increase to $\phi = 1/\tilde{\beta}$; see (7).

[10]E.g. the transversality condition for real bonds is $\lim_{T\to\infty} b_{T+1}\beta^{T-1}\lambda_T = 0$, where λ_t is the Lagrange multiplier on the household budget constraint and $\beta \in (0,1)$ is the discount factor (see e.g. McCallum, 2009).

Euler equations for real and nominal bonds give a non-linear Fisher equation $R_t = r_t^{real}\Pi_{t+1}$ in gross terms. An interest rate rule $R_t = r_t^{real}\Pi_t^{\phi}$ yields $\Pi_t^{\phi} = \Pi_{t+1}$, i.e. $\ln \Pi_t = \phi^{-1} \ln \Pi_{t+1}$, as the linear case, which has a unique stable solution $\Pi_t = 1$; however, this equation also holds for growing or declining inflation.[11] Adding a trigger strategy with a trigger interest rate $R_t^* = r_t^{real}\Pi_t^{\phi}/\Pi_{t+1}^{-1}$ will rule out unstable nominal paths but preserve the stable solution. Relaxing perfect foresight will change the algebra, but not in a fundamental way.[12]

Since the central difference equation $\Pi_t^{\phi} = E_t\Pi_{t+1}$ comes from a Taylor-type rule and the Fisher equation (without resort to sticky prices), unstable nominal equilibria can arise in a range of models. Christiano and Takahashi (2018, 2020) present a non-linear monetary model with a stable equilibrium and many explosive nominal equilibria when the Taylor principle holds, and they show how policy can anchor expectations at the stable equilibrium.

5.2 Empirical considerations

How much importance should policymakers attach to the theoretical possibility of unstable nominal equilibria, as we have highlighted above? Periods of high and rising inflation or hyperinflation are not merely a theoretical curiosity but an empirical reality. Thus, a key question seems to be whether these episodes are essentially expectations-driven as in our examples or primarily the result of other factors, such as money supply growth.

Empirical work has documented many hyperinflations. In such episodes, inflation has typically risen sharply over a period of months or years until the hyperinflation hit an abrupt end, which often coincided with a fiscal crisis or a currency collapse. Relatively few studies have tried to study expectations during hyperinflations, but Reghezza et al. (2020) find the German hyperinflation of the 1920s was consistent with rational expectation formation.

It is also known that episodes of hyperinflation and high inflation tend to go hand in hand with money supply growth of similar magnitude to the inflation rate itself, so that inflation and money growth have a strong positive correlation over long time periods or over the course of hyperinflations (McCandless and Weber, 1995; Feenstra and Taylor, 2012). However, this relationship does not imply that there is no role for inflation expectations in starting or sustaining hyperinflations, and a strong correlation between monetary aggregates and inflation may arise even if interest rates are the main policy instrument.

In fact, modern central banks put considerable effort into "managing expectations" of inflation and other variables, and that requires credibility and clear communication of policy. To the extent that central banks can influence expectations through such announcements, they may be able to coordinate inflation expectations, to some extent, on a low inflation rate. However, if such communication is not effective, or if credibility is lost, then inflation expectations may become unanchored and contribute to shifts in actual inflation rates. Equally, periods of high inflation or hyperinflation may be ended by establishing credible plans to lower inflation, as with Argentina's Convertibility Plan (currency board) in 1991. Our trigger strategy rests on a similar logic of credible commitment to stabilize inflation.

From a policy perspective, it seems desirable to use a range of models in which the

[11]Note that $\Pi_t = 1$ for all t satisfies $\Pi_t^{\phi} = \Pi_{t+1}$, but so does $\Pi_t = \Pi_{t-1}^{\phi}$ for all $\Pi_0 \in (0, \infty) \setminus \{1\}$.

[12]The Euler equations are $1 = r_t^{real}E_t m_{t+1}$, $1 = R_t E_t\left[m_{t+1}\Pi_{t+1}^{-1}\right]$ and m_{t+1} is the stochastic discount factor. The Fisher equation is $R_t = r_t^{real}\frac{E_t m_{t+1}}{E_t\left[m_{t+1}\Pi_{t+1}^{-1}\right]} := R_t^F$, and $\Pi_t^{\phi} = E_t\Pi_{t+1}$ follows if $R_t = R_t^F\Pi_t^{\phi}/E_t\Pi_{t+1}$.

consequences of anchored versus unanchored expectations can be studied – at least until we gain a better understanding of expectation formation and the drivers of nominal explosions.

6 Conclusion

We have argued that explosive nominal equilibria in New Keynesian models have implausible *real* implications and so are unlikely to be coordinated on by rational agents; we also showed how unstable equilibria can be *ruled out* using bubble-free interest rate rules that do not require knowledge of the natural rate of interest. These results cast doubt on critiques of equilibrium selection in New Keynesian models. Indeed, we have provided a good reason to think the stable equilibrium will be selected by rational agents ('real explosions'), as well as a 'cashless' policy – an extended Taylor rule – that makes it the unique equilibrium.

These conclusions, derived using a linear benchmark New Keynesian model of three core equations, are robust to some extensions and non-linearities; however, further research would be beneficial, including empirical analysis that connects theory and reality.

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