Monetary policy with investment-saving imbalances*

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Abstract
This paper has been motivated by a few issues that can be found in the past and present literature concerning one of the cornerstones of the predominant macroeconomic framework for monetary policy analysis, namely the so-called "natural rate of interest" in the New Neoclassical Synthesis (NNS). These issues converge to one single question: What does the natural interest rate concept in its integrity imply for modern macroeconomic models for monetary policy? The key point is that the natural rate is, by definition, the real interest rate which equates saving and investment in general equilibrium. It is widely agreed that a variety or shocks and/or "frictions" may drive a wedge between the market real rate and the natural rate. Hence "investment-saving imbalances" (ISI) are also a logical implication in any such situation, but they are not contemplated by standard macroeconomic models. This paper's aim is to take a first step into the analysis of monetary policy in the context of ISI. First, a dynamic model of a flex-price, competitive economy is presented where ISI are allowed to develop. Second, upon introducing different types of interest-rate rules, some indications for the conduct of monetary policy emerge which are at variance with the standard view: in particular, the robustness of "adaptive" instead of "optimizing" interest-rate rules when direct information on the natural rate is not available; the central bank's bounded responsiveness to excess inflation/deflation (or the irrelevance of the so-called "Taylor principle"); the emergence of a trade-off between small gaps vs. smooth paths in the design of the rule as a convergence control tool.

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1. Introduction

This paper has been motivated by a few issues that can be found in the literature concerning one of the cornerstones of the predominant macroeconomic framework for monetary policy analysis, namely the so-called "natural rate of interest" in the New Neoclassical Synthesis (NNS). These issues converge to one single question: What does the natural interest rate concept in its integrity imply for modern macroeconomic models for monetary policy?

In the standard NNS model (e.g. Woodford (2003, ch. 4)), the natural interest rate plays a doubly pivotal role. It is given by households' rate of time preference and hence governs the optimal intertemporal allocation of consumption, which determines aggregate demand – the so-called New Keynesian IS function. The natural rate also provides the "anchor" for the nominal interest rate in the rule that guides monetary policy. "Interest-rate gaps", deviations of the market real interest rate (the nominal rate set by central bank minus expected inflation) from the natural rate, are a major driver of aggregate-demand dynamics.

In the same book cited above, Woodford recalls that the natural rate is a concept due to Knut Wicksell (1898a,b), the founder of the so-called "Swedish School" at the turn of the XIX century and of much of subsequent macroeconomic theory\(^1\). Woodford also highlights two important analogies between the NNS and Wicksell's macroeconomics (see 2003, esp. ch. 1)\(^2\). The first is with Wicksell's interest-rate theory of the price level, epitomized in the following widely cited passage evoking the other Wicksellian hallmark – the "cumulative processes" of changes in prices:

At any moment in time in any income situation there is always a certain rate of interest, at which the exchange value of money and the general level of commodity prices have no tendency to change. This can be called the normal rate of interest; its level is determined by the current natural rate of interest, the real return on capital in production, and must rise or fall with this. If the rate of interest on money deviates downwards, be it ever so little, from this normal level, prices will, as long as the deviation lasts, rise continuously; if it deviates upwards, they will fall indefinitely in the same way (1898a, p. 82).

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\(^1\) Keynes remained in the Wicksellian tradition, and made use of the concept of natural rate, up to his major book prior to the General Theory, the Treatise on Money (1930).

\(^2\) In Woodford's view this parentage seems so close and important that he gave his book the same title, Interest and Prices, as Wicksell's (1898b)
The second analogy is with Wicksell’s view of the role of monetary policy associated with his theory of the price level, one which seems to foreshadows the NNS prescription for interest-rate rules and inflation targeting as testified by another very popular Wicksellian passage:

So long as prices remain unaltered, the [central] bank’s rate of interest is to remain unaltered. If prices rise, the interest rate is to be raised, and if prices fall, the rate of interest is to be lowered; and the rate of interest is henceforth to be maintained at the new level until a further movement of prices calls for a change in one direction or the other (1898b, p.102).

Given this state of the art, the first issue that arises is that, following Woodford’s Wicksellian recollections, one realizes (as Woodford does in ch. 5) that the NNS standard model is too simple to accommodate the concept of natural rate in its integrity. According to Wicksell, and to subsequent neoclassical general-equilibrium economics, the natural interest rate is the [real] rate of interest at which the demand for loan capital and the supply of savings exactly agree, and which more or less corresponds to the expected yield on newly created capital (1901, II, p. 193)

As he said elsewhere, the natural rate is the result of the forces of "productivity and thrift". Hence, in the NNS standard model we see only one force at work, "thrift". The other is missing because the demand for capital, investment, is missing. Therefore, in order to respect the integral concept of natural rate, in the first place it is necessary to design models that incorporate both saving and investment. Examples in the NNS framework are those by Woodford (2003, ch. 5) and Casares and McCallum (2000).

A second issue surrounding the natural interest rate is more empirical in nature. It is worth starting from Wicksell again. The widely quoted sentence about the manoeuvre of the interest rate by the central bank reported above is preceded by the caveat that the natural rate is to be conceived as a volatile entity subject to various disturbances hitting the real determinants of the economy ("deep parameters" in modern parlance). Actually, this is the key reason why, in Wicksell’s theory, discrepancies can ever arise between the market and the natural rate3. Hence it is by no

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3 It should also be recalled that in Wicksell's view these discrepancies are located in the private economy, namely in the banking sector. Banks are regarded as setting nominal interest rates on loans. Savers and investors compare these rates with the respective incentives to save or invest (in this sense, they need not know what the natural rate is). When the bank rates are not consistent with the natural rate, ISI may arise. Banks nonetheless have the capacity to allow these excesses to
means obvious that the central bank could, or should, target the natural rate. As a matter of fact, Wickell argues, it is not necessary (1898b, p. 102). For much of its history, the natural interest rate has been interpreted more as a conceptual point of reference than as a measurable parameter.

The natural rate is an abstraction; like faith, it is seen by its works. One can only say that if the bank policy succeeds in stabilizing prices, the bank rate must have been brought in line with the natural rate, but if it does not, it must not have been (J. Williams (1931), p. 578; quoted by Orphanides and Williams (2002, p. 63))

Concern about risks involved in monetary policy rules with mismeasurement of the natural interest rate largely prevailed in the past, starting from Wicksell himself, to whom one may add Keynes, Friedman, Greenspan (Orphanides (2006)). Scepticism concerning the practical use of the natural interest rate for monetary policy is now mounting again. Up-to-date econometric research is by no means encouraging on the possibility that central banks can ever obtain all information necessary to target the natural rate precisely (see e.g. D’Amato (2005), Garnier and Wilhelmsen (2005), and Caresma et al. (2005) for recent surveys). This problem is now openly recognized by economists engaged in the application of the NNS framework (e.g. Galì and Gertler (2007)). Therefore, it seems that a form of capital market imperfection, informational in nature, is another necessary ingredient for the market-rate/natural-rate misalignments to meaningfully play the role they are given also in the NNS standard model.

A growing literature is now concerned with (re)introducing so-called "financial frictions" in the NNS framework together with an explicit banking and/or financial sector (e.g. Iacoviello (2005), Christiano et al. (2007a,b), Goodfriend and McCallum (2007), Canzoneri et al. (2008))

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4 I have suggested that these "frictions" are being re-introduced in the NNS framework because they are usually based on earlier "New Keynesian" works that were motivated by the idea that capital market imperfections, basically asymmetric information between borrowers and lenders, are central to understanding macroeconomic phenomena (e.g. Greenwald and Stiglitz (1987, 1993), Bernanke and Gertler (1989, 1990), Bernanke et al. (1996)).
frictionless market. Another strand of models addresses the problem of monetary policy under no direct information about the various "natural rates" of the NNS model leading to mismanagement of the nominal interest rate (e.g. Sims (1998), Sargent (1999), Primiceri (2006), Orphanides and Williams (2002, 2006)).

Further Wicksellian explorations, however, reveal that current extensions to investment, "financial frictions" or central bank's limited information miss a further critical issue. In these models, whenever the market real interest rate, for whatever reason, deviates from the natural rate, households reallocate resources towards present/future consumption along a new **intertemporal equilibrium** path with an equivalent impact on aggregate demand. This is a consistent transmission mechanism as long as there are no capital goods (Woodford (2003, sec. 4.1)). But when there are capital goods to be purchased, and there is a market for loanable funds made by independent (intermediated) borrowers and lenders, it **must** be the case that households wish to save less (more) whereas firms wish to invest more (less) (Wicksell (1901, II, p. 193)). In modern parlance: neither side of the market can achieve intertemporal equilibrium of plans\(^5\). The point is that "**investment-saving imbalances**" (ISI) are a **logical implication** in any theory admitting discrepancies between the market real interest rate and the natural rate, which is, by definition, the interest rate which equates saving and investment in the general-equilibrium steady state (Leijonhufvud (1981))\(^6\).

As a consequence, the delimitation of the NNS to economies that are constantly in intertemporal equilibrium (Blanchard (1997)) is not consistent with an integral adoption of the concept of natural interest rate with an aim at studying dynamical processes involving interest-rate gaps. The latter, by

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\(^5\) In fact, in Wicksell's theory, excess inflation, or better the cumulative process of changes in the price level, is a different phenomenon than in the NNS standard model. It is a symptom that the economy is on a **disequilibrium path** in that excess **investment** is being accommodated at the "wrong" real interest rate (e.g. 1898a, pp. 77 and ff.; see also Boianovsky and Trautwein (2004)).

\(^6\) It is worth recalling that ever since the origins of macroeconomics with Wicksell, going through Keynes and early Keynesians, and until the advent of Monetarism and more forcefully of the New Classical, inflation, unemployment and business cycles had been thought and taught mainly as **problems** related to intertemporal disequilibrium originating from ISI due to some form of malfunctioning of capital markets (e.g. Leijonhufvud (1981) for a reconstruction).
contrast, require us to explore how the economy behaves as long as it is out-of-equilibrium intertemporally. This is largely an unexplored domain, or better an abandoned one by post-Lucasian macroeconomics, for methodologic inhibitions that are too well-known to be repeated here.

That this may be more than a deprecable theoretical curiosity is testified, for instance, by the current debate about the Fed’s responsibility in the financial crisis for keeping the interest rate "too low for too long" (e.g. Taylor (2009)). In the NNS framework itself, this sentence can only mean that the nominal interest rate and the anticipated inflation rate resulted in a market real interest rate "too low with respect to the natural rate. However, in the NNS framework, the result would only be excess inflation (with respect to target) of goods prices along the intertemporal equilibrium path of the economy. By contrast, extensive research on past and present financial crises has provided systematic evidence that the eruption of financial crises is provoked by, and is a way to correct, financial imbalances that almost by definition imply misallocation of resources along the time dimension of the economy. The typical macroeconomic pattern is one of rapid debt growth, and excess investment (or components of it) over aggregate saving triggered by wrong prices of financial resources that turn out to be unsustainable in the long run (e.g. Borio and Lowe (2001), Borio (2008), Reinhart and Rogoff (2008), Gerdesmeier et al. (2009)).

In summary, the macroeconomic models based on the natural rate of interest but with no allowance for ISI beg some key questions for monetary policy: How do interest-rate rules work once ISI are in motion? Are there rules able to correct ISI and stabilize the economy? Are there effective rules that dispense the central bank from being perfectly informed about the natural rate?

With a view to improving and extending the theoretical framework of monetary policy in order to address these questions, my aim with this paper is to take a first step into the analysis of macroeconomic processes with ISI in a way that allows monetary policy to be consistently studied in connection

7 Against this background, it is worth bearing in mind that “the problem is that the new theories, the theories embedded in general equilibrium dynamics […] don’t let us think about the US experience in the 1930s or about financial crises and their consequences […] We may be disillusioned with the Keynesian apparatus for thinking about these things, but it doesn’t mean that this replacement apparatus can do it either” (Lucas (2004, p. 23)).
with these phenomena. The basic ingredients I have used are those emerged from the previous discussion: a competitive, flex-price model with investment and saving admitting intertemporal general equilibrium and the natural interest rate associated with it; a central bank with limited information about the natural rate, and that may misalign the nominal interest rate giving rise to ISI; an explicit solution for the ensuing out-of-equilibrium dynamics\(^8\). The model is then used to assess whether an effective interest-rate rule can be devised to stabilize the economy once ISI are in motion. A byproduct of the model is methodological: to dispell the belief that disequilibrium processes are not amenable to rigorous treatment within the boundaries of rational forward-looking agents and market clearing. A caveat is in order. The stage of treatment in this paper is still remotely connected with the full-fledged financial structure of the economy and it is therefore only propaedeutic to proper study of financial phenomena, let alone financial crises. To repeat, the focus is only on the origin, and hopefully pre-emptive policy implications, of one (the first?) of the genes of full-blown financial phenomena, namely ISI.

The paper is organized into three parts. First, section 2 presents the ISI model ending in two log-linear out-of-equilibrium dynamic equations, one for output and one for inflation, directly comparable with the NNS counterparts. Dynamic processes are driven by interest-rate gaps. Out-of-equilibrium means that ISI are non-zero and that output and inflation diverge from their intertemporal equilibrium values. At this stage, the model clarifies that 1) ISI imply a dynamic structure that differs from the NNS standard model, 2) out-of-equilibrium dynamics persists as long as the interest-rate gap perists.

Then, section 3 introduces monetary policy in the form of interest-rate rules. The question to be addressed is whether this approach to monetary policy is effective in stabilizing the economy in the event of ISI. First, I examine an interest-rate rule obtained from a standard optimization problem of the central bank. In the absence of direct information on the natural interest rate, following this rule boosts ISI and fails to stabilize the economy. By contrast, it is shown that, once ISI are in motion, the economy

\(^8\) I have opted for a competitive flex-price economy for two reasons. The first is that this was the economy also considered by Wicksell. The second, and more substantial, is that neither monopolistic competition nor sticky prices play any necessary role in the issues being examined here.
can be stabilized by means of a more parsimonious rule, that is an "adaptive" rule whereby the nominal interest rate is simply raised or lowered in response to the cyclical condition of output and inflation, with no interest-rate target whatsoever. Stabilization occurs only under some conditions, however. In particular, 1) the central bank’s *bounded responsiveness* to excess inflation/deflation (or the irrelevance of the so-called "Taylor principle"); 2) the emergence of a trade-off, not between output and inflation, but between *small gaps vs. smooth paths* in the design of the rule as a convergence control tool. The model also warns that a crucial role is played by the cyclical sensitivity of inflation. If this is very low (the so-called "missing inflation" problem), identifying and correcting ISI via inflation gaps may become rather difficult, and the ongoing disequilibrium process may persist for a long time.

Finally, section 4 summarizes and concludes.

2. A model of investment-saving imbalances

In this section I introduce the general-equilibrium model of a simple, competitive, flex-price economy with endogenous investment and a corporate bond market. For the sake of concreteness and comparison with the standard NNS model, I also posit common well-behaved functional forms for the production function and the utility function.

2.1. The natural interest rate and intertemporal general equilibrium

The supply side of the economy is characterized by:

- A constant-return-to-scale production function such that output $Y_t$ is a homogeneous good that can be either consumed or used as input (capital),

$$Y_t = AK_t^aL_t^b,$$  
$a + b = 1$

where $L_t$ is the current input of labour, and $K_t$ is the available capital stock.

- A capital accumulation technology such that the share of output transformed into capital at time $t$ takes 1 period of time to become operative, and the depreciation rate of capital is 100% per period, that is

$$K_{t+1} = I'_t + (1 - \delta)K_t,$$

where $I'_t$ is gross investment inclusive of capital replacement, and $\delta = 1$ is the depreciation rate.
Firms that are price takers and seek to maximize their expected profit stream, given (1) and the gross income distribution constraint

\[ Y_t = w_t L_t + R_t K_t \]

where \( w_t \) is the real wage rate, and \( R_t \equiv (1 + r_t) \) is the real gross return to be paid on the capital stock purchased at time \( t-1 \) and operative at time \( t \).

The demand side of the economy consists of households that claim on the economy’s capital stock, supply their whole labour force \( L \) inelastically, and choose a consumption plan in order to maximize their lifetime expected utility

\[ U(C_t) + E_t \left[ \sum_s \Theta^s U(C_{t+s}) \right], \quad s = 1, ..., \infty \]

with period utility

\[ U(C_t) = \ln C_t \]

given each period's budget constraint

\[ C_t + S'_t = Y_t \]

where \( S'_t \) is gross saving, \( \Theta \equiv 1 + \theta \), and \( \theta > 0 \) is the rate of time preference.

All the previous variables are in real terms, while factors and output are traded at nominal prices denominated in a single unit of account. As far as capital is concerned, firms can finance investment out of household saving by issuing one-period bonds bearing a nominal interest rate \( i_t \). Consistently with physical capital, bonds are time-indexed by their maturity, i.e. \( t+1 \) denotes bonds issued at time \( t \) with maturity at \( t+1 \). Note, therefore, that the market real interest rate relevant to the saving-investment decisions in period \( t \) is given by \( R_{t+1} = (1 + r_{t+1}) = E_t[(1 + i_t)/(1 + \pi_{t+1})] \), where \( \pi_{t+1} \) is the rate of inflation of the output price \( P_t \) (whereas the actual real interest rate that households earn in each \( t \) is given by \( (1+i_{t-1})/(1 + \pi_t) \)).

Consequently, households' budget constraint can also be written as

\[ B_{t+1} = H_t + R_t B_t - C_t \]

where \( B_t \) is the outstanding real stock of bonds, and \( H_t \equiv w_t L_t \) is labour income. Note, therefore, that \( B_{t+1} \geq B_t \) occurs if \( H_t + R_t B_t - C_t = S'_t \geq B_t \), i.e. if gross saving is equal to (greater than) the existing (expiring) stock of bonds.

The economy includes a central bank which has an inflation target \( \pi^* \), and exerts some leverage on the nominal interest rate \( i_t \) by trading bonds in the open market. In other words, the central bank is allowed to behave as
an intermediary which stands ready to buy and sell bonds at the rate $i_t^9$. For expository purposes, it is convenient to treat the central bank's policy in two steps. In this section, policy simply consists of pegging the rate $i_t$. As a result, it will be possible to examine how ISI develop and evolve dynamically. Analysis of the best policy response will be introduced in the next section. Hence, let us assume the following unconditional policy scheme:

- at the beginning of each $t$ the central bank announces a target inflation rate $\pi^*$ and pegs the nominal interest rate $i_t$
- all agents form their (unique) inflation-rate forecast, $\pi_{t+1}$, consider their objective functions and constraints, and make their plans accordingly
- exchanges occur in all markets, and $[Y_t, \pi_t]$ are realized.

The inflation forecast of agents is open to various specifications. To begin with, we know that an intertemporal general equilibrium (IGE) solution should include $\pi_{t+1} = \pi^*$ for all $t$. A well-known issue in the theory of monetary policy arises: Is the policy stance $[i_t, \pi^*]$ chosen by the central bank consistent with the economy's IGE? Here this problem will be addressed by backward reasoning. Let agents believe in the central bank's inflation target: then, the problem is the conditions such that $\pi^*$ is indeed the rational expectation of the inflation rate, or else, the conditions such that the actual inflation rate does converge to $\pi^*$ over time$^{10}$.

The first-order conditions for households' and firms' optimal plans include, respectively

\begin{align}
(7) & \quad U'(C_t) = E_t [U'(C_{t+1})R_{t+1}/\Theta] \\
(8) & \quad F'(K_{t+1}) = R_{t+1}
\end{align}

The posited production and utility functions ensure that there exists an equilibrium between saving (demand for bonds) and investment (supply

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9 This arrangement may be seen as a simplification of the role of the banking sector in Wicksell's theory (see fn. 3).
10 In fact, this approach is also usual in policy games where the central bank moves first. Indeed, this is the origin of Wicksell's intuition of the central bank as "manager of expectations" highlighted by Woodford, and it is the key problem of monetary policy from the Wicksellian point of view. A cost of this approach is that it precludes analysis of endogenous expectation formation schemes that were deemed critical by Wicksell himself and no doubt represent a challenging aspect of ISI processes. An example is developed in Tamborini (2008). However, as stated from outset, the scope of this paper is limited to the first-stage, intertemporal equilibrium consistency problem of the central bank's policy stance $[i_t, \pi^*]$. 
of bonds). We can thus consider the steady-state solution where the employment of labour is normalized to 1, \(L^* = 1\) \((F'(1) = w)\), and \(R_{t+1} = \Theta = R^*\), \(F'_K(K^*) = R^*\), so that for all \(t\), \(C_t = C^*\), \(B_t = K_t = K^*\), \(Y_t = Y^* = H^* + R^*K^*\). Note that \(S'_t = I'_t = K^*\), and once account is taken of capital replacement, net investment and saving are nil\(^{11}\). Hence \(R^*\) is the natural interest rate, and the Fisher equation, \((1 + i_t) = R^*(1 + \pi^*)\), should hold for all \(t\).

2.2. A closed-form solution for investment-saving imbalances, and out-of-equilibrium dynamics

Having established the conditions for IGE, we can move to the next problem. The capital market is affected by a tiny imperfection in that the central bank has no direct information on the natural rate. Hence let us now consider any period \(t\) in which the central bank has announced \([\pi^*, i_t]\) and it happens that \(R_{t+1} \neq R^*\)\(^{12}\). The model is fully worked out in Appendix A.1, and here I provide a brief non-technical rendition.

As long as \(R_{t+1} \neq R^*, \text{ cet. par.},\) there is excess investment/saving in the capital market: that is to say, the demand for bonds differs from supply. In order to maintain the peg, however, the central bank should be ready to fill any gap between demand and supply of bonds in the private sector (i.e. buy extra-bonds if \(I_t > S_t\) and sell extra-bonds if \(S_t > I_t\)). As a result, households and firms are allowed to save and invest as much as they want; however, the underlying consumption and production plans are not mutually consistent, resulting in present as well as future aggregate demand-supply imbalances. More precisely, the flaw lies in "wrong budgeting" in that the real value of bonds in the economy does no longer match the real stock of capital. Hence trading at the false interest rate in the capital market propagates disequilibrium across markets and over time.

\(^{11}\) Abstracting from technical progress or technical shocks, this is in fact a Sidrausky-type steady state, where the key allocational variable in the capital market is precisely the rate of intertemporal preferences in consumption, \(\Theta\).

\(^{12}\) Do private agents always know the true natural interest rate? This is an interesting and important question, but here it turns out to be less relevant than in a standard setup with a single representative saver-investor. In fact, all the ISI model needs is that households optimize upon observing \(R_{t+1}/\Theta\) and that firms optimize \(\text{vis-à-vis } R_{t+1}/F'_K(K_{t+1})\). Each agent need not know whether \(R_{t+1}\) is the natural rate or not.
The next question is: if we want the economy to obey the principle of market clearing, how can the demand-supply imbalances be corrected? In words, the answer is that for a given "interest-rate gap" at time $t$, measured by $\hat{R}_{t+1}/R^*$, there should be a re-combination in the vectors of present and future output and general price level such that households' "wrong budgeting" is corrected ex-post, and the actual trades in the output market are made mutually consistent. Technically speaking, these new vectors solve the intertemporal optimization problem of households and firms, given $\hat{R}_{t+1} \neq R^*$ and output market-clearing at all dates. The thrust of the model is that, as a consequence of trading at a false interest rate at any point in time, all markets do clear continuously, but both current and future output and inflation rates will differ from those $(Y^*, \pi^*)$ that would result in the IGE associated with the natural interest rate $R^*$.

In fact, following Woodford’s procedure of relating actual output and inflation at each point in time, $Y_t, \pi_t$, to their IGE values, $Y^*, \pi^*$, the assumed functional forms yield the following closed-form solutions in terms of “gaps”:

\begin{align*}
\hat{Y}_t &= \hat{R}_{t+1}^{-1/(1-\alpha)}, \quad \hat{Y}_{t+1} = \hat{R}_{t+1}^{-\alpha/(1-\alpha)} \\
\hat{\Pi}_t &= \hat{Y}_t^{\alpha/(1-\alpha)}, \quad \hat{\Pi}_{t+1} = \hat{Y}_{t+1}^{\alpha/(1-\alpha)}
\end{align*}

where $\hat{Y}_{t+s} \equiv Y_{t+s}/Y^*$ and inflation $\hat{\Pi}_{t+s} \equiv (1 + \pi_{t+s})/(1 + \pi^*)$.

These expressions can also be easily transformed into log-linear equations directly comparable with the standard NNS model. Since $\hat{Y}_t$ and $\hat{Y}_{t+1}$ have $\hat{R}_{t+1}$ as common factor, they can expressed as a linear combination. The resulting ISI model is the following:

\begin{align*}
\hat{y}_{t+1} &= \rho \hat{y}_t - \alpha \hat{i}_t \\
\hat{\pi}_{t+1} &= \beta \hat{y}_{t+1}
\end{align*}

with $\hat{y}_t \equiv \ln \hat{Y}_t \approx y_t - y^*$, $\hat{\pi}_{t+1} \equiv \ln \hat{\Pi}_{t+1} \approx \pi_{t+1} - \pi^*$, $\hat{i}_t \equiv i_t - i^*$

Consider an interest-rate gap at time $t$, $R_{t+1}/R^*$. Then, $\ln R_{t+1}/R^* = i_t - \pi^* - r^*$. The variable $i^* \equiv r^* + \pi^*$ is often called the "non-accelerating inflation rate of interest" (NAIRI), and can be used as direct benchmark for the nominal rate $i_t$ (of course, $i_t = i^*$ is exactly equivalent to the equality between the market real interest rate and the natural one considered so far).

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13 Let $\hat{Y}_t = Z_t^\rho$ and $\hat{Y}_{t+1} = Z_t^n$. Then it is possible to write $\hat{Y}_{t+1} = \hat{Y}_t^\rho Z_t^\alpha$ for linear combinations of the parameters $\rho$ and $\alpha$, such that $\rho m + \alpha = n$. 
Given $\dot{i}_t \neq 0$, output gaps will open up at time $t$ and $t+1$: equation (11) describes output dynamics off the IS schedule that would result in the natural-rate IGE. The output gap in $t+1$ is measurable as a proportion $-\alpha$ of the interest-rate gap, and a proportion $\rho$ of the uncorrected output gap, as of time $t^{14}$. It is worth noting that (9) generates time series of output gaps that, ex post, display two main features: 1) dependence on the lagged value of interest-rate gaps, 2) some degree of serial correlation or "inertia". These two features mark a substantial difference with the standard NNS "forward-looking" formulation of the IS equation, where the current gap between the market and the natural interest rate only impinges upon the current output gap, whereas the future (expected) output gaps only depend on the future (expected) interest-rate gaps\textsuperscript{15}. Yet a dynamic structure like (11) is consistent with recurrent empirical estimates of IS equations (see e.g. Wilhelmsen and Garnier (2005), Laubach and Williams (2003), Caresma et al. (2005), Orphanides and Williams (2006)). These empirical regularities are not easily accommodated in the NNS model unless it is filled with additional ad hoc "frictions", usually interpreted as the outcome of "backward-looking" behaviour of agents\textsuperscript{16}. Here they result directly from forward-looking agents and the fact that intertemporal disequilibrium connects each period's variables in a way that is not captured by the NNS model.

Equation (12) describes the associated price/output dynamics off the AS curve associated with the natural-rate intertemporal equilibrium, where the structural parameter $\beta = a/b$, determined by the production-function parameters, determines the deviation of current inflation from the expected inflation rate necessary for competitive firms to supply one unit of profit-maximizing output above/below potential. There are two key points in this equation that distinguish it from the AS of the NNS model, apart from firms being price takers. First, price stickiness is not an issue: the price level

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\textsuperscript{14} This is, in fact, "spurious" correlation due to the fact that both $\dot{Y}_t$ and $\dot{Y}_{t+1}$ depend on the common factor $R_{t+1}/R^*$.

\textsuperscript{15} The standard log-linearized formulation of the IS equation is $x_t = E_t x_{t+1} - \sigma (i_t - E_t \pi_{t+1} - r^*)$ where $x_t$ is a measure of the output gap (the difference between current output and the flex-price DSGE level of output), and $\sigma$ is the intertemporal elasticity of substitution of private expenditure. Clearly, $x_t$ and $E_t x_{t+1}$ are serially independent.

\textsuperscript{16} Examples of inertial market frictions are provided in Woodford (2003, ch. 5), Aghion et al. (2004, Part I).
changes as much as is necessary to equate demand and supply at the given expected inflation rate. Of course, different microeconomic assumptions and values of the parameter \( \beta \) may lead to different quantitative results and different combinations of price-quantity changes (see also below, Section 3.2). Second, excess inflation is, however, a disequilibrium phenomenon in the expectational sense. As long as, for the given pair \([i_t, \pi^*] \) set by the central bank, there exist interest-rate gaps, and hence output gaps, for the goods market to clear the economy must be off the price level path indicated by \( \pi^* \).

System (11)-(12) is a non-homogeneous system of two first-order difference equations in the three gaps \([\hat{y}_{t+1}, \hat{\pi}_{t+1}, \hat{i}_t] \). Consequently, (P1) A permanent interest-rate gap determines permanent output and inflation gaps. Conversely, the output and inflation gaps are nil only if the interest-rate gap is also nil.

[Proof: Appendix A.2]

For example, suppose that \( \hat{i}_0 < 0 \). The model reproduces a prototypical Wicksellian "cumulative process" (e.g. 1898a, pp. 77 ff.). If the system starts at a constant price level \((\pi_0 = \pi^* = 0)\), the general price level will rise indefinitely. If \(\rho \in [0, 1] \) it will rise at a constant rate\(^{18}\). For any \(\pi_0 = \pi^* > 0\), the result is that the rate of change of the price level will deviate from \(\pi^*\) forever. Though the market clears, the result is not an intertemporal equilibrium. If instead \(\hat{i}_0 > 0\), the model reproduces a Keynesian story, with output settling down below potential. The model, however, corrects the simplistic view that Wicksellian processes affect only the price level whereas Keynesian processes affect only output.

There are three essential points and messages for monetary policy. First, as anticipated above, excess inflation is a disequilibrium phenomenon in the expectational sense. Second, changes in the price level alone, no matter how large or quick the may be, are unable to drive the economy onto the right path as long as they do not affect the nominal interest rate. Third,

\(^{17}\) This was in fact the fundamental idea behind Wicksell’s "cumulative processes" in the price level, that is to say, the symptom that excess investment (excess saving) is being accommodated at the wrong market rate and the economy driven out of the intertemporal equilibrium path (e.g. 1898a, pp. 75 ff.)

\(^{18}\) More complex dynamic patterns may arise from different expectational mechanisms than the one assumed here. On this point, which is however not crucial here, see e.g. Chiarella and Flaschel (2005), Tamborini (2008).
and consequently, the Wicksellian legacy, that setting an inflation target and pegging the nominal interest rate unconditionally may not be a consistent policy, is confirmed (unless the peg is by fluke exactly the NAIRI: Leijonhufvud (1981), McCallum (1986)).

3. Monetary policy

The previous conclusions elicit a conception of monetary policy as a visible hand possibly keeping the interest rate on the right track. The core of the modern theory of monetary policy, in fact, concerns the definition of a class of interest-rate rules that support a determinate rational-expectations equilibrium consistent with the targets of inflation and output. It has been demonstrated that the Taylor rule, under some conditions, belongs to this class of rules (Woodford (2003)). This section re-examines the Taylor rule and its properties in the context of the ISI model presented above. The relevant models with proofs are developed in Appendix A2.

3.1. The non-optimality of the optimal rule with imperfect information

In the NNS, increasing emphasis has been placed on the design of optimal monetary policy rules with reference to some welfare benchmark of the economy. Generally, it is shown that interest-rate reaction functions can be derived from a central bank’s optimal control problem like the following (see e.g. Clarida et al. (1999)):

\[
\max L_t = -\sum_{s=0}^{\infty} \frac{1}{2} \left[ (y_t + s - y^*)^2 + \eta(\pi_t + s - \pi^*)^2 \right] \\
\text{s.t. } (\pi_t - \pi^*) = \beta(y_t - y^*)
\]

In this formulation, the central banker aims at minimizing the absolute value of the inflation and output gaps along the dynamic path of the system, with \( \eta \) measuring the relative degree of inflation (variation) aversion. By applying the same procedure as Clarida et al. (1999), one obtains

\[
i_t = i^* + \phi(y_t - y^*) + \gamma(E_t[\pi_t+1 | i_{t-1}] - \pi^*)
\]

with \( \phi = \rho/\alpha \), and \( \gamma = \eta\beta/\alpha \).

The most important features of this formulation are the following. First, there is an explicit target for the interest rate, which is just the NAIRI \( i^* \). Second, the coefficients \( \phi \) and \( \gamma \) are not arbitrary, but are determined by the structural parameters of the economy and of the central
bank’s loss function. Third, the informational inflation rate used to assess the cyclical position of the economy is \( E_t[\pi_{t+1} | i_{t-1}] \), the forecast of the inflation rate in the absence of policy interventions (see also (Woodford (2003, ch. 8) and Svensson (1997)).

Let us first examine the dynamic properties of the economy under rule (14). If we shift the term \( i^* \) to the l.h.s., use the structural model to solve for \( E_t[\pi_{t+1} | i_{t-1}] \), and move one period forward, we can add this equation to (11)-(12) to obtain a homogeneous system in the three gaps \( \{\hat{y}_{t+1}, \hat{\pi}_{t+1}, \hat{i}_{t+1}\} \). It is a general property of homogenous systems that a steady-state solution with zero gaps exists. Therefore, since the optimal rule is simply a homogenous transformation of the interest-rate variable, it is sufficient to grant the existence of a zero-gaps steady state. In other words: the optimal rule prescribes the central bank to target the NAIRI; as a result, \( \hat{i}_{t+1} = 0 \) in all \( t \), whatever the value of the natural rate, which implies \( \{\hat{y}_{t+1}, \hat{\pi}_{t+1}\} = 0 \) in all \( t \). Therefore, the economy is constantly kept in the zero-gaps steady state and no ISI process would ever arise.

On the one hand, this result may be interpreted in the sense that the optimal rule gives the central bank the right prescription and indicator in order to prevent ISI. On the other hand, the same result may be regarded as trivial or empty; in fact, in order to target the NAIRI the central bank should know the true natural interest rate at any point in time, but ISI may arise just because central banks do not have direct information about the natural rate. Hence the relevant question is whether the optimal rule is also "robust", that is, whether it can lead the economy to the zero-gaps steady state even though the informational requirement of the central bank is relaxed and ISI unfold. Let us thus turn to the assumption made in our basic model, namely that the central bank has no direct information on the natural interest rate, or let \( i^* \) be replaced by \( \tilde{i} \). The following proposition holds:

(P2) The adoption of an interest-rate target in the optimal rule implies that, if the central bank has no direct information on the natural rate and the interest-rate target is wrong, the system will never converge to the zero-gaps steady state.

[Proof: Appendix A2].

The intuition is that a central bank with a wrong NAIRI in the optimal rule, which implies that at any point in time it may be the case that
\( \hat{i}_t \neq 0 \) brings the system back to the case with an exogenously pegged nominal interest rate that is not consistent with the natural-rate IGE.

The conclusion in therefore that the optimal rule is not robust in the face of a small informational error of the central bank. A consistent implication might be that, in all relevant cases, the optimal rule ought to be switched off. Yet a rule that is switched off in particular circumstances is no longer a rule in the sense of the modern normative theory of central banking. Moreover, if the central bank is misinformed about the natural interest rate, it is also unlikely to realize that the rule should be switched off. The argument that the central bank will sooner or later realize that the economy displays permanent output and inflation gaps is not so obvious. For in reality output and inflation are hit by their own shocks to which the central bank will respond by shifts of \( i_t \) around \( \hat{i} \), so that it may not be so easy to detect that output and inflation are not on their IGE trend. Another argument in the same vein will be discussed at the end of this section.

Poor stabilization performance, whether it be towards excess inflation or deflation, may arise not because of the lack of the "right" rule but because of the lack of the "right" information for that rule. This conclusion is shared by the literature on monetary policy under imperfect information on "natural rates" (of output, unemployment, etc.: e.g. Orphanides and Williams (2002, 2006, 2008), Primiceri (2006))\(^{19}\).

### 3.2. Adaptive rules

The theoretical as well as operational problems surfacing around the informational requirements of optimal interest-rate rules have paved the

\(^{19}\) It has been argued that under suitable learning rules (and stochastic processes), the central bank can learn the true value of the natural rate(s) and update the rule in real time, with the process converging towards a "self-confirming" equilibrium which generates optimal policy responses (e.g. Sims (1998), Sargent (1999), Primiceri (2006)). The estimates and simulations of the NNS model with mismeasurement of natural rates and central bank's learning presented by Orphanides and Williams (2002, 2008) do not lend empirical support to the convergence prediction. Instead, the simulation presented by Primiceri (2006) concerning the post-war learning process of the Fed about the parameters of the US Phillips curve suggests that, in the long run, the process has eventually been successful. However, the "long run" covers the fifteen years between the late Sixties and the early Eighties resulting in the American "Great Inflation". Therefore, it is not clear whether this evidence reduces, or increases, concerns about attempts to pursue the natural rate(s) in the conduct of monetary policy.
way for research of more parsimonious, "robust" rules which dispense with "natural rates" altogether; these may not match theoretical criteria of optimality but allow for reliable stabilization policy (e.g. Orphanides and Williams (2002, 2006, 2008)).

In this perspective, a hint may be provided by an interpretation of Wicksell's thought according to which he saw the natural rate, not as a variable observable by anyone in the system, but as a "hidden attractor" of the system where the latter is driven by agents reacting to observable market signals. Wicksell also thought that cumulative processes might be self-correcting, since banks would simply raise their lending rates in accordance with the acceleration of prices if only they and their client entrepreneurs had expectations anchored to the "normal" price level (e.g. 1898a). For these reasons, he also concluded that it was not necessary that the central bank kept track of the natural rate (1898b, p. 102).

If one conceives the interest-rate rule as a reduced form of the behaviour of the banking system as a whole anchored to the target inflation rate $\pi^*$, one may examine this mechanism by replacing the NAIRI with the interest rate from the previous period, and use the current inflation rate as informational input. One thus obtains an "adaptive" rule, meaning that the central bank simply lowers or raises the nominal interest rate according to the output and inflation gaps, with no explicit reference to the natural interest rate.

$$(15) \quad i_t = i_{t-1} + \phi(y_t - y^*) + \gamma(\pi_t - \pi^*)$$

This specification may be further specialized in various directions. Setting $\phi = 0$ captures Wicksell's own view of the monetary policy rule with no reference to output at all. This would also be the simplest possible format for a pure inflation-targeting rule. Setting $y^* = y_{t-1}$, one obtains the "first difference" specification put forward by Orphanides and Williams (2002), which retains the signal provided by output dynamics but dispenses with information about the "natural rate of output". The change in the nominal interest rate dictated by the output and inflation gaps may also be "smoothed", in which case a less than unit parameter should be appended to the lagged term $i_{t-1}$. These variations on the theme will not be developed here, given that they (qualitatively) share the same dynamic properties that we are going to study for our simpler adaptive rule (15).

Subtracting $i^*$ from both sides of equation (15), writing it one period forward, and adding it to system (11)-(12), we again obtain a homogeneous
system of three first-order difference equations in the three gaps \( \hat{y}_{t+1}, \hat{\pi}_{t+1}, \hat{i}_{t+1} \). Therefore, an adaptive rule may well support a determinate rational-expectations steady state with zero gaps.

As to convergence and stability, the system now displays a richer dynamic structure, and a different parametric choice setup, with respect to the one with the optimal rule. As before, let us first consider the main properties of this system.

(P3) Dynamic regimes: The system presents different dynamic regimes according to the critical values of the compound coefficient \( \Omega \equiv \phi/\beta + \gamma \) displayed below:

\[
\begin{array}{ccc}
0 & (1-\sqrt{\rho})^2/\alpha\beta & 2(1+\rho)/\alpha\beta \\
\text{monotonic convergence} & \text{oscillatory convergence} & \text{oscillatory divergence}
\end{array}
\]

(P4) Boundedness of the rule coefficients: The output and inflation coefficients in the rule cannot be chosen independently. The scope for the choice of the two policy parameters is bounded by the requirements of system’s stability and regime choice.

[Proof: Appendix A.2]

The first proposition highlights the key role played by the compound coefficient \( \Omega \), which measures the compound response of the interest rate to one unit of inflation gap. The compound parameter \( \Omega \), and not its composition, matters because the interest rate reacts to both inflation and output gaps which are interdependent via the AS function, and because, in this case where an ISI perturbs only aggregate demand, the output and inflation gaps are positively correlated. Hence, stabilizing inflation is also to stabilize output – or, for that matter, the other way round – and the mechanical application of the Taylor rule implies that the interest rate reacts twice to the same signal\(^{20}\). That is why, as \( \Omega \) increases, the system switches from monotonic to oscillatory stability, and from stability to instability.

This phenomenon immediately leads to the second proposition. The boundedness of the rule coefficients, and hence of the interest-rate

\(^{20}\) Indeed, this is also the case with the standard NNS model when only aggregate demand shocks are considered.
responsiveness to inflation gaps, is an important characteristic of the ISI model that deserves careful consideration. In fact, this issue involves the so-called "Taylor principle", which plays a key role in the NNS. Woodford's version of the Taylor principle refers precisely to the compound parameter $\Omega$ (2003, pp. 253-254), and he establishes that $\Omega > 1$ must hold. Hence, Woodford sets a lower bound, whereas we have an upper bound for stability. The latter may admit or not admit $\Omega > 1$ depending on the values of $\rho$, $\alpha$, $\beta$.

This major difference is closely related to the structural difference in the ISI equations pointed out in section 2, namely the comovement of future with present output gaps in response to present interest-rate gaps as long as the economy faces imbalances in the capital market. The, apparently sound, popular argument that in order to curb inflation the central bank should overreact on the nominal interest rate to the extent necessary for the market real interest rate to rise does not take into account that the future inflation gaps will be affected directly. By overreacting to current inflation gaps, the interest rate may overshoot and push the economy onto a divergent path. It is therefore intuitive that higher $\alpha$ and $\beta$ call for slighter interest-rate adjustments; for these parameters transmit interest-rate impulses to output and eventually inflation over time. Note in particular the role played by the AS parameter $\beta$. When this parameter is large, small corrections of output gaps induce large effects on inflation gaps; hence the system's stability requires gentle interventions on the interest rate.

Therefore, as far as stability analysis of monetary policy under ISI is concerned, two conclusions can be drawn at this stage. First, once the role of the rule coefficients has been properly understood and controlled, adaptive rules may have desirable out-of-equilibrium dynamic properties with relatively limited information (namely no direct reference to the NAIRI). Second, in this perspective, the Taylor principle is not necessary in general for stability, and it may be harmful in specific conditions. High sensitivity by the central bank towards inflation gaps is only justified to the extent that inflation is not highly responsive to output gaps because in this case disequilibrium gaps (albeit small) would persist for a long time (see also section 3.4 below).

3.3. Small gaps vs. smooth paths

A subsequent interesting issue concerns the fact that, as argued above, the processes under consideration do not generate any
inflation/output trade-off for the central bank, so that one wonders whether there is any other scope for the choice of the Taylor-rule coefficients. The possibility of different dynamic regimes raises the choice problem of parameters in a way that is seldom scrutinized in the empirical literature on the Taylor rule.

Let us retain the sum of square gaps as a measure of losses in the central bank's objective function. Then, two properties of the adaptive rule (15) should be noted. First, the dynamic paths of output and inflation, and the ensuing respective total losses, are univocally determined by the value of $\Omega$, so that they cannot be traded-off by shifting the weights of the respective coefficients. Second, the total loss of each variable decreases as $\Omega$ increases\(^{21}\). Therefore, an adaptive central banker may wish to set $\Omega$ as large as possible regardless of the relative weights of the two coefficients. However, as we have seen, the largest value of $\Omega$ consistent with stability generates oscillatory convergence. Hence if any trade-off arises in this setup, it concerns the choice of small gaps vs. smooth paths in the process as a whole\(^{22}\).

Although it is reasonable to presume that central bankers may not be willing to set the economy on an oscillatory path, albeit convergent, the linear-quadratic format of the standard loss function prevents any treatment of the preference for monotonic vs. oscillatory paths. To gauge the practical importance of this issue, it is convenient to look at some empirical estimates of the relevant structural parameters $\rho$, $\alpha$, $\beta$. Table 2 reports possible values of these parameters taken from the empirical literature.

The first three columns report values obtained by means of direct estimates of IS-AS equations like (11) and (12). The fourth column is borrowed from Rotemberg and Woodford's (1997) calibration of their own NNS model for the US economy. The fifth makes reference to the ISI model and it is added solely for the sake of comparison between possibly different economic structures. Considering the model specification obtained in Appendix 1, given that we can take a parameter $\alpha$ of, say, 0.15 as an empirical regularity, and $a = 0.4$, $b = 0.6$ as representative figures of factor income shares in industrialized countries, we can exploit the model's

\(^{21}\) Proof available on request.

\(^{22}\) "Fast" and "small" oscillatory convergence may yield a lower value of the loss function than does "slow" and "wide" monotonic convergence
restrictions on the parameters to "calibrate" the others, namely $\rho = a - \alpha b = 0.31$, and $\beta = a/b = 0.67$

Table 1. Sets of parameters for the stability upper bound of the interest-rate rule (monotonic convergence)

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$</td>
<td>0.45$^a$</td>
<td>0.42$^c$</td>
<td>0.45$^c$</td>
<td>n. a.$^d$</td>
<td>0.31</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>0.10$^b$</td>
<td>0.06</td>
<td>0.18</td>
<td>0.16</td>
<td>0.15</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.05$^b$</td>
<td>0.05</td>
<td>0.10</td>
<td>0.02</td>
<td>0.67</td>
</tr>
<tr>
<td>Upper bound$^e$</td>
<td>20.82</td>
<td>41.28</td>
<td>6.02</td>
<td>33.86</td>
<td>1.96</td>
</tr>
</tbody>
</table>

(a) Average value of two-year lags across different estimation techniques
(b) Average value across different estimation techniques
(c) Average value of two-year lags
(d) Set equal to 0.40 in subsequent computations
(e) Maximum compound response $\Omega$ of the Taylor rule to 1 point of inflation gap

$\Omega = \left(1 - \sqrt{\rho}\right)^2/\alpha - \beta \gamma$

In the first place, I have used the values in the table to compute the stability upper bound of the interest-rate rule (the maximum value of $\Omega$), taking monotonic convergence as the reference case. The figures exemplify that, under all parameter sets, the central banker can comply with the Taylor principle ($\Omega > 1$), if s/he so wishes, but the ISI model sets an upper bound to $\Omega$ substantially more binding than the others. In the second place, I have also plotted in Figure 1 the stability frontiers of the Taylor rule coefficients, that is, the relationship between the coefficients $\phi$ and $\gamma$ consistent with the stability upper bound of $\Omega$. The lines represent the maximum output-gap coefficient as a function of the inflation-gap coefficient$^{23}$, and the dots identify some credited estimates of the Taylor rule coefficients. Clearly, the output/inflation frontier imposed by the ISI model is much steeper than the others.

[Figure 1]

A glance at the table suggests that these differences between our model economy and the "real" economies should ultimately be due to the single parameter whose value differs the most, namely $\beta$. As a matter of fact, the ISI model portrays a competitive, flex-price economy, whereas the

$^{23}$That is to say, $\phi = (1 - \sqrt{\rho})^2/\alpha - \beta \gamma$
others in the table capture various goods market imperfections reflected in the low AS parameter. As explained above, high inflation-to-output response requires only slight corrections in the interest rate and hence less global sensitivity of the rule. By contrast, small values of $\beta$ inject substantial slackness into the system and justify stronger sensitivity of the nominal interest rate to the gaps. Price stickiness is not the cornerstone of the ISI approach, but this phenomenon obviously matters in practice in order to design an efficient interest-rate rule.

Nevertheless, the existence of an upper bound to the rule coefficients (instead of a lower bound) remains a key implication of the ISI model of general value. Consider, for instance, the simulation of the ISI model with the adaptive rule reproduced in Figure 2. For convenience, the variables (output, inflation and nominal interest rate) are represented in levels (not in gaps) and are normalized to 100 basis points. The simulation consists of an unobserved initial negative interest-rate gap (10 basis points, the true NAIRI is 110). The parameter values are those given in Table 1. At outset, the consequence is excess output and inflation.

[Figure 2]

The figure reproduces the dynamic paths of the economy with two specifications of the adaptive rule. In case A the rule coefficients have been chosen beyond the monotonic stability frontier, and they satisfy the Taylor principle, i.e. $\phi = 1.0, \gamma = 2.0 (\Omega = 3.5)$. The system converges to the zero-gaps steady state with (slight) oscillations. In case B the rule’s coefficients have been set below the stability frontier and do not comply with the Taylor principle, i.e. $\phi = 0.2, \gamma = 0.6 (\Omega = 0.9)$. Also this rule (even with no Taylor principle) drives all the variables on their respective targets along a smooth path. The interesting difference between the two cases lies in the respective total losses (the square sums of the gaps that appear in parentheses for each variable). As explained above, case B (low $\Omega$) delivers larger gaps with smoother paths than does case A (high $\Omega$), which delivers the reverse. On the other hand, any other combination of $\phi$ and $\gamma$ yielding the same values of $\Omega$ would also yield exactly the same dynamic profiles in the two respective cases.

Going back to real data, it should be noted that not all estimated interest-rate rules in Figure 1 satisfy all estimated "realistic" monotonic stability frontiers. For instance, Taylor's (1993) original estimate for the Fed would (slightly) violate the frontier with the US parameters found by
Garnier and Wilhelmsen (2005), while subsequent estimates by Judd and Rudebusch (1998), and Clarida et al. (2000), would also violate the frontier set by the Rotemberg and Woodford (1997) data. A glance at the marked oscillation in the federal funds rate occurred between 2001 and 2008 (see Figure 3) suggests that the question of the extent of the small gaps/smooth paths alternative perceived by central banks warrants further investigation. [Figure 3]

3.4. The "missing inflation" puzzle

It is fair to conclude with the limitations of adaptive rules as well. The most interesting one concerns the key signalling role of excess inflation. It is clear that the entire adjustment process hinges on the fact that inflation (typically, consumer price inflation) does respond to output gaps (excess demand) to an extent that should be deemed significant by the central bank. This fact entails that the combination of preference for smooth monetary policy (small \( \Omega \)) and low cyclical sensitivity of inflation (small \( \beta \)) may determine an extremely slow, if not flat, adjustment path of the economy vis-à-vis the development of ISI\textsuperscript{24}. In this context – to borrow from Borio and Lowe (2002) – monetary policy may let financial imbalances mount up which remain disguised in a benign economic environment. ‘Benign’ means low inflation and sustained economic activity, which is precisely the scenario along the adjustment path of the economy indicated by the ISI model when the parameter \( \beta \) is as low as can been seen from estimates in Table 1.

As a simple experiment, let us consider the latest estimates of parameters for the US economy in Table 1 (Garnier and Wilhelmsen (2005)), and those of the Fed’s rule in Figure 1 (Orphanides (2003): \( \phi = 0.18, \gamma = 1.9 \)). As shown by the figure, these parameter values are consistent with

\textsuperscript{24} Recent analyses of these phenomena may provide further arguments. First, the "flattening" of the Phillips curve (i.e. a fall in our parameter \( \beta \)) has been largely documented, though not conclusively explained (see e.g. Mishkin (2008)). Second, Borio and Lowe (2002) put forward some important reasons why larger financial imbalances, sustained economic activity and moderate inflation may reinforce each other endogenously. The basic model presented in this paper does not take these complex feedback effects into account, but it does imply that as long as firms are allowed to invest in excess of saving, the production capacity in the economy increases, and a stronger activity level may be sustained with less inflationary pressure.
monotonic stability: the implied value of $\Omega$ is 3.7 vis-à-vis an upper bound of 6.02. Note that this value of $\Omega$ is of the same order of magnitude as the one used in our previous simulation of the ISI model, case A. Yet in that context (large value of $\beta$) $\Omega$ resulted larger than the upper bound. As a consequence, if we now repeat the same simulation as before (a negative10-basis-points interest-rate gap) with this new set of parameters, we obtain that convergence is much slower than in the previous case A. A measure of this is given by the square sum of gaps, which is now 51.2 (8.8 in the previous case A) for output, and 0.5 (3.9 in the previous case A) for inflation. The extraordinarily good performance in terms of price stability is entirely due to the structural low sensitivity of inflation. The other side of the coin is that output gaps, which indicate the ongoing ISI process, persist for much longer and reach a much larger cumulated value.

This seemingly golden age may mislead the monetary authority (and the public opinion at large) if it is not tested against the ISI hypothesis and is instead mistaken as a sustainable intertemporal equilibrium. This result may also lead to the more radical criticism that (consumer price) inflation targeting per se, or the use of this measure of inflation as a "catch-all" cyclical indicator à la Bernanke and Gertler (2001), may be misleading in the event of ISI processes, so that broader measures or alternative indicators for monetary policy are advocated (e.g. Borio and Lowe (2002), Crockett (2003), Cecchetti et al. (2000), Leijonhufvud (2008))25.

If the problem is limited to the structural low sensitivity of inflation, an immediate alternative suggested by the ISI model itself is that output gaps, instead of inflation gaps, convey stronger signals that a disequilibrium process is under way. Adding more weight to output gaps, to the extent that

25 By contrast, Bean (2003) has argued that "flexible", forward-looking, inflation targets are enough to control for the development of financial imbalances. However, Bean's point rests on the traditional assumption that "significant financial instability will also have a significant impact on activity and inflation" (p. 18). Hence it is not clear how longer-run forecasts of the future developments of economic activity may overcome the "missing inflation" problem if this is due to a low $\beta$ parameter. For instance, if in the simulation of the ISI process with the Garnier-Wilhelmsen-Orphanides US parameter values, we introduce the one period baseline expected inflation rate, instead of the current rate, into our adaptive Taylor rule, the cumulative square sum of output gaps reduces from 51.2 to 44.4, which however remains a remarkably large figure compared with the simulation with a high $\beta$ value.
it raises the value of $\Omega$, may lead to a faster correction of the problem. Yet this simplistic solution cannot be taken at face value. First, the small-gaps/smooth-paths trade-off created by ISI processes is still there. Second, detecting output gaps correctly is by no means simpler than detecting where the true NAIRI is; measurement errors may equally destabilize the system\textsuperscript{26}. Relatedly, it may be difficult for a central bank to explain that a tight monetary restriction is necessary when economic activity is high and inflation is low. Therefore, from the point of view of the ISI approach, the search for a broader set of direct indicators of financial imbalances seems necessary.

4. Conclusions

The aim of this paper has been to take a first step forward in the analysis of monetary policy in the context of ISI, that is to say, the gene of intertemporal out-of-equilibrium processes.

Interest-rate management has placed monetary policy at the very core of the investment-saving regulating mechanism, yet central banks can hardly collect all the relevant information about the determinants of investment-saving equilibrium. Thus, misalignment of the nominal interest rate with its intertemporal equilibrium value (NAIRI) is a likely phenomenon giving rise to ISI. The thrust of the model presented here is that ISI trigger \textit{out-of-equilibrium} business cycles with endogenous real as well as nominal effects. These processes persist as long as the original misalignment of the nominal interest rate persists. Wage-price stickiness is not the only problem, wage-price flexibility is not the only solution. ISI, by way of forward-looking agents' allocations, transmit the effects of present interest-rate gaps to present as well as future output gaps and hence inflation gaps. As a result, these variables display endogenously the autocorrelated dynamic structure that is typically observed in the data, while the forward spillover effect of interest-rate gaps considerably modifies the dynamic properties of the system with respect to the NNS standard model.

\textsuperscript{26} On the other hand, as recalled at the beginning, the output gap with respect to potential output can be replaced by the observed growth rate. The ensuing dynamic properties of the system are closer to those presented here the smaller is the product of parameters $\phi\alpha$. 
As for monetary policy, main implications can be summarized as follows.

- Interest-rate rules may operate to correct ISI. The critical element that eventually determines whether a rule is good or bad is information. Rules relying upon an explicit interest-rate target and requiring timely and precise information about the natural interest rate are hazardous in that wrong information may seriously destabilize the system.
- In general, adaptive rules, using step-by-step adjustments of the interest rate *vis-à-vis* observable conditions in the economy with no explicit interest-rate target are preferable in that they produce adjustment paths which are generally slower but safer.
- Under ISI no trade-off arises between stabilizing output or inflation. The emphasis placed on rules that optimize the output-inflation trade-off may overlook more compelling requirements of (possibly monotonic) convergence and stability.
- In this perspective, the choice of the rule coefficients also needs careful scrutiny. The Taylor principle is not necessary, and may be harmful, for stability. Contrary to the NNS intertemporal equilibrium dynamics, in the course of out-of-equilibrium dynamics monetary policy should have a bounded reaction to inflation and output gaps because of the inbuilt reactivity of the present and future state of the economy to interest-rate gaps.
- In this context, however, central banks may face a trade-off, not between inflation and output control, but between small gaps and smooth paths in the adjustment process. The preference for smooth paths entails a bounded reaction of the central bank to inflation and output gaps, and longer persistence of imbalances.
- Inflation targeting *per se* may be ineffective, however, if the cyclical sensitivity of inflation is very low – as indicated by many empirical studies. Identifying and correcting ISI via inflation gaps may become quite difficult, and the ongoing disequilibrium process may persist for a long time in a seemingly golden age of low inflation and high economic activity. As far as the open debate on alternative indicators is concerned, the ISI model suggests that output gaps, instead of inflation gaps, may provide stronger appropriate signals. Yet this simplistic alternative may also have serious limits, so that the search for direct indicators of financial imbalances is to be pursued more forcefully.
References


D'Amato J. (2005), "The Role of the Natural Rate of Interest in Monetary Policy", BIS Working Papers, n. 171.


Figure 1. Monotonic stability frontiers of the Taylor rule

Garnier-Whilelmsen EU

ISI model

Laubach-Williams US

Rotemberg-Woodford US

Garnier-Whilelmsen US

-0.5 0 0.5 1 1.5 2
inflation-gap coefficient

Orphanides (2003) FED

Taylor (1993) FED

Judd-Rudebusch (1998)

Clarida et al. (2000)

Hagen-Brueckner ECB (2002)
Figure 2. Simulation of a permanent increase in the natural interest rate (10 basis points) with adaptive Taylor rule.

**(A) Θ = 3.5**

**(B) Θ = 0.9**
Figure 3. U.S. Federal Funds Rate and Yields on AAA long-term corporate bonds, 2000:1-2008:4 (monthly data)

Source. FRED Online database, Federal Reserve of St. Louis.
Appendix

A1. Determination of the relationship between interest rate gaps, output gaps and inflation gaps.

This appendix expounds the procedure to obtain the output-gap and inflation-gap equations (9) and (10) in the main text. The model consists of the assumptions in section 2

Natural rate of interest and intertemporal equilibrium

In the first place, I examine households’ consumption-saving choices, that is,

\[
\text{(A1)} \quad \max: V_t = \ln C_t + E_t \left[ \sum_{s=1}^{\infty} \Theta^{-s} \ln C_{t+s} \right]
\]

s.t. \[ C_t + E_t \sum_{s=1}^{\infty} (C_{t+s} + B_{t+s+1}) R(t,s) = H_t + E_t \sum_{s=1}^{\infty} H_{t+s} R(t,s) + R_t B_t \]

where the budget constraint is obtained by iteration of (6), \[ R(t,s) = \prod_{s=1}^{\infty} R^{-t+s} \] is the compound discount factor, and the transversality condition imposes that \( \lim_{s \to \infty} B_{t+s} R(t,s) = 0 \)

The f.o.c. for a maximum yields

\[
\text{(A2)} \quad C_t = E_t \left( C_{t+1} \Theta / R_{t+1} \right)
\]

This admits of a steady-state solution where the employment of labour is normalized to 1, \( L^* = 1 \), and \( R_{t+1} = \Theta \equiv R^* \), so that \( C_t = C^* \) for all \( t \). For the given Cobb-Douglas production function, the constant real interest rate also yields a constant capital stock such that \( F'(K^*) = R^* \) and hence constant output and factor incomes. As long as optimal saving is equal to optimal investment, the real value of outstanding bonds coincide with the operating capital stock, \( B_{t+1} = B_t = K^* \). Consequently, the resource constraint is satisfied for

\[
\text{(A3)} \quad C^* (1 + \sum_{s=1}^{\infty} R^{*-s}) = H^* (1 + \sum_{s=1}^{\infty} R^{*-s}) + R^* K^*
\]

Since \( \lim_{s \to \infty} \sum_{s} R^{*-s} = 1/r^* \), the following values result

\[
\text{(A4)} \quad C^* + K^* = Y^*
\]

\[
\text{(A5)} \quad K^* = (Aa/R^*)^{1/b}
\]

\[
\text{(A6)} \quad Y^* = AK^a
\]
The real interest rate $R^*$ associated with intertemporal equilibrium is the natural rate. Note, also, that $S_t' = I_t = K^*$, that is, net saving and investment are nil in all $t$, and the economy only replaces the optimal stock of capital $K^*$. Finally, it should be that $(1 + i_t) = R^*(1 + \pi^*)$, or $R_{t+1} \equiv (1 + i_t)/(1 + \pi^*) = R^*$, for all $t$

**Interest-rate gaps and output gaps**

I now examine the allocations that result if, starting in the steady state, at time $t$ the market real interest rate differs from the natural rate. As explained in the main text, if saving exceeds investment the central bank sells extra bonds, if investment exceeds saving the central bank buys extra bonds. As explained in the text, any $R_{t+1} \neq R^*$ is assumed to be constant.

To begin with, let us examine the plan of households. Given $\Theta = R^*$, $B_t = K^*$, $R_{t+1} \neq R^*$, their optimal consumption path (A2) would be

(A7) \[ C_t = E_t \left( C_{t+1} R^* / R_{t+1} \right) \]

Therefore

(A8) \[ S_t' = H_t + R_t K^* - C_t \]

*Ceteris paribus*, with respect to the steady state, $R_{t+1} \neq R^*$ shifts consumption to the present (if $R_{t+1} < R^*$) or to the future (if $R_{t+1} > R^*$). As a result, saving is decreased or increased, respectively.

Now let us see investment of firms, that is

$I_t = K_{t+1} = (Aa / R_{t+1})^{1/b}$

Hence investment is increased (if $R_{t+1} < R^*$) or decreased (if $R_{t+1} > R^*$).

Consequently, there is a unique relationship between interest-rate gaps and saving-investment gaps, namely

- if $R_{t+1} > R^*$: \( S_t' > I_t \)
- if $R_{t+1} < R^*$: \( S_t' < I_t \)

As long as the central bank pegs $R_{t+1} \neq R^*$, it allows households and firms to finance their saving and investment plans. However, these plans are not mutually consistent in the capital market, and therefore, by Walras Law, they are not consistent in the output market either. In fact,

- if $R_{t+1} > R^*$, consumption is shifted from $t$ to $t+1$, while investment in $t$, and the capital stock available in $t+1$, are reduced: there is excess supply in $t$ and excess demand in $t+1$
- if $R_{t+1} < R^*$, the excesses are reversed.

How can these inconsistent plans be transformed into mutually consistent actual plans?
To address this point, I follow the same procedure as in the NNS model, namely I plug each period budget constraint (A16) directly into households' Euler equation (A2):

\[(A9) \quad (H_t + R_t K^* - B_{t+1}) = E_t [(H_{t+1} + R_{t+1} B_{t+1} - B_{t+2}) R^*/ R_{t+1}]\]

Here the saving-investment inconsistency can also be seen in the fact that \(B_{t+s} \neq K_{t+s}\) for all \(s > 1\): the real value of the stock of bonds owned by households differs from the actual capital stock of firms at each point in time, and wrong resource accounting results. As long as \(R_{t+1} \neq R^*\), the actual consumption path consistent with \(B_{t+1} = K_{t+1}\) should satisfy

\[(A10) \quad (Y_t - K_{t+1}) = (Y_{t+1} - K_{t+2}) R^*/ R_{t+1}\]

where \(Y_t = H_t + R_t K^*, Y_{t+1} = H_{t+1} + R_{t+1} K_{t+1}\). This reformulation of households' consumption path leads to the following propositions:

1) \textit{Given the capital stock chosen by firms for } \(R_{t+1} \neq R^*\, \text{there exists a unique intertemporal vector of output realizations associated with consistent ex-post output market clearing.}\)

2) \textit{These output realizations correspond to non-zero gaps with respect to the level of "potential output" given by the capital stock that would obtain with the natural rate of interest } \(R^*.\)

The proof goes as follows. First, since, for \(R_{t+1} \text{ constant, } K_{t+2} = K_{t+1},\)

\[(A10) \quad (Y_t - K_{t+1}) = (Y_{t+1} - K_{t+2}) R^*/ R_{t+1}\]

\(\text{can be rewritten as}\)

\[Y_t = Y_{t+1} R^*/ R_{t+1} + K_{t+1}(1 - R^*/ R_{t+1})\]

\(\text{Now divide both sides by } Y^* \text{ to obtain the intertemporal relationship between output gaps}\)

\[\dot{Y}_t = \dot{Y}_{t+1} R^*/ R_{t+1} + (K_{t+1}/Y^*)(1 - R^*/ R_{t+1})\]

\(\text{Upon recollecting the following relationships}\)

\[Y_{t+1} = AK^a_{t+1}, K_{t+1} = (aA/R_{t+1})^{1/b}, \quad Y^* = AK^*, K^* = (aA/R^*)^{1/b}\]

\(\text{the two output gaps result}\)

\[(A11) \quad \dot{Y}_t \approx (R_{t+1}/R^*)^{1/b}\]

\[(A12) \quad \dot{Y}_{t+1} = (R_{t+1}/R)^{a/b}\]

\(\text{where the approximation concerns the multiplicative term } (1 - a(1/R_{t+1} - 1/R^*)) \text{ which, for sufficiently small rates, is close to 1.}\)

\(\text{Therefore, } (A11) \text{ and } (A12) \text{ show that the main implication of the market real interest rate being set above (below) the natural rate is a sequence of intertemporal negative (positive) output gaps each depending on the current interest-rate gap } (R_{t+1}/R^*).\)

\(\text{Furthermore, since } \dot{Y}_t \text{ and } \dot{Y}_{t+1} \text{ share the common factor } (R_{t+1}/R^*) \text{ it is, in general, possible to express them in a single reduced form displaying}\)
autocorrelation. In fact, let \( Y_t = Z_t^m \) and \( Y_{t+1} = Z_t^p \). Then it is always possible to write \( Y_{t+1} = \hat{Y}_p Z_t^a \) for linear combinations of the parameters \( p \) and \( a \), namely \( pm + a = n \). Note that the autocorrelation between \( \hat{Y}_{t+1} \) and \( \hat{Y}_t \) should be understood as a *spurious* correlation due to the common factor \( Z_t \). The log of the previous expression yields the dynamic equation in the main text.

**Inflation gaps**

As to price determination in relation to output gaps, let us assume that all nominal prices and wages are fully indexed to the inflation rate \( \pi \). Given the general-equilibrium real wage rate \( w^* \) and capital stock \( K^* \), potential output at any time \( t \) can also be expressed as

\[
Y^* = K^* (b/w^*)^{b/a}
\]

Let the nominal wage rate for \( t \) be given by indexing \( w^* \) with the expected inflation rate \( \pi^* \), i.e. \( W_t = w^* P_t (1 + \pi^*) \). Therefore, firms can still adjust output for \( t \) by choosing the labour input upon observing the current real wage rate \( w_t = W_t / P_t \), where \( P_t = P_{t-1} (1 + \pi_t) \). As a result,

\[
Y_t = K^* \left( \frac{b}{w^*} \frac{1 + \pi_t}{1 + \pi^*} \right)^{b/a}
\]

Cet. par., profit-maximizing firms are ready to expand (contract) output as long as \( \pi_t \), being greater (smaller) than \( \pi^* \), increases (reduces) the current nominal value of the marginal product of labour *vis-à-vis* \( W_t \). Conversely, we can derive the Marshallian supply curve of firms, that is, the inflation gap \( \hat{\Pi}_t = (1 + \pi_t)/(1 + \pi^*) \) which supports a given output gap. Using (A14) in (A13) we obtain

\[
\hat{\Pi}_t = (\hat{Y})_{a/b}
\]

This expression generates the log-linear equation in the main text.

**A2. Analytical solutions of the systems of linear dynamic equations**

**Exogenous interest-rate gap**

Let us start with the initial structural model (9)-(10), which is reproduced here for convenience:

\[
\begin{align*}
\dot{y}_{t+1} & = \rho \dot{y}_t - \alpha \dot{i}_t \\
\dot{\pi}_{t+1} & = \beta \dot{y}_{t+1}
\end{align*}
\]
I first introduce the general solution method used in all subsequent cases. To begin with, the above system can be written in the general matrix form for non-homogenous first-order difference systems, i.e.

\[(A18) \quad g_{t+1} = Ag_t + Bx\]

where \(g\) is the vector of endogenous variables, \(x\) is a vector of exogenous variables, and \(A\) and \(B\) are matrices of coefficients. If the non-zero matrix \((I - A)^{-1}\) exists, system (A18) has a steady-state solution \(g^*\) given by

\[(A19) \quad g^* = (I - A)^{-1}Bx\]

In the case under consideration, with an initial value \(\hat{i}_0\) taken as a constant exogenous variable, we have \(g' \equiv [\hat{y}, \hat{\pi}], x' \equiv [\hat{i}_0, 0],\)

\[A \equiv \begin{bmatrix} \rho & 0 \\ \beta \rho & 0 \end{bmatrix}, \quad B \equiv \begin{bmatrix} -\alpha & 0 \\ -\beta \alpha & 0 \end{bmatrix},\]

and

\[(A20) \quad g^* = \begin{bmatrix} \alpha & 0 \\ -1-\rho & 0 \\ \beta \alpha & 0 \end{bmatrix} \begin{bmatrix} \hat{i}_0 \\ 0 \end{bmatrix}\]

Therefore, for any \(\hat{i}_0 \neq 0, g^* \neq 0,\) and a steady-state solution with zero endogenous gaps only exists if \(\hat{i}_0 = 0.\)

To study the dynamic properties of the system, let us examine the eigenvalues of matrix \(A.\) These are the roots of its characteristic polynomial, which in the 2x2 case is a quadratic equation of general form

\[k^2 - \text{tr}(A)k + \text{det}(A) = 0\]

In the case under consideration we have \(\text{tr}(A) = \rho,\) and \(\text{det}(A) = 0.\) Therefore, the characteristic equation has two real roots: \(k_1 = \rho, k_2 = 0.\) Hence, for stability it is necessary and sufficient that \(\rho \in [-1, 1],\) whereas \(\rho \in [0, 1]\) ensures monotonic stability.

**A2. Endogenous interest-rate gap**

Formally, the introduction of an "interest-rate rule", that is, an equation that determines the time path of the nominal interest rate in relation to output and inflation gaps, amounts to endogenizing the interest-rate gap with respect to the previous system. In general, it is obtained a new first-order difference system with the matrix form (A18), where now \(g' \equiv [\hat{y}, \hat{\pi}, \hat{i}].\) Therefore, for this class of rules to admit a zero-gaps steady-state solution \(g^* = 0,\) it is first necessary that \(x = 0,\) that is, a zero vector of
exogenous gaps. In other words, the interest-rate rule should provide a homogeneous transformation of the system,

\[ g_{t+1} = A g_t \]

Subsequently, the conditions of stability and convergence only depend on the coefficient matrix \( A \), and specifically on the parameters of the interest-rate rule.

Let us begin with the optimal of Taylor rule considered in the text:

\[ i_t = i^* + \phi (y_t - y^*) + \gamma (E_t[\pi_{t+1} | i_{t-1}] - \pi^*) \]

where \( i^* \) is the NAIRI, \( E_t[\pi_{t+1} | i_{t-1}] \) indicates the inflation forecast for time \( t+1 \), elaborated at time \( t \), conditional upon not intervening on the nominal interest rate set at time \( t-1 \), and \( \phi = \rho/\alpha \), \( \gamma = \eta/\alpha \). Let us now consider the system (A16)-(A17)-(A22). Using the structural model to obtain \( E_t[\pi_{t+1} | i_{t-1}] \), and upon algebraic manipulations, it is possible to obtain a homogenous system like (A21). As recalled above, a homogenous system generally admits a zero-gaps steady-state solution. It is immediate to see that as long as \( i_t = i^* \), or \( \hat{i}_t = 0 \), all \( t \), the system is constantly in, or jumps immediately to, the zero-gaps steady state.

The main text also introduces the case where the central bank follows a rule like (A22), but with no direct information about the true NAIRI \( i^* \). To this effect, let \( \tilde{i} \) be the target interest rate adopted by the central bank; the new rule is

\[ i_t = \tilde{i} + \phi (y_t - y^*) + \gamma (E_t[\pi_{t+1} | i_{t-1}] - \pi^*) \]

and \( \varepsilon = \tilde{i} - i^* \) the relevant informational error. As a result, the new system (A16)-(A17)-(A22)' is again a non-homogenous system with \( x' \equiv [0, 0, \varepsilon] \). Consequently, the system cannot achieve a zero-gaps steady state as long as \( \varepsilon \neq 0 \).

The second specification of the interest-rate rule is an "adaptive" Taylor rule in the form:

\[ i_t = i_{t-1} + \phi (y_t - y^*) + \gamma (\pi_t - \pi^*) \]

Subtracting \( i^* \) from both sides, and taking one period forward, we re-obtain a homogenous system in the matrix form (A25). Hence, the adaptive Taylor rule is consistent with a zero-gaps steady state of the economy.

As to convergence and stability analysis, first note that upon substituting the inflation-gap equation into the interest-rate rule, the system can be decomposed into a block with only two endogenous gaps \( g' \equiv [\hat{y}, \hat{i}] \), the inflation gap being fully determined by the path of \( \hat{y} \), given by the previous block. The coefficient matrix of this reduced-form system is
\[ A = \begin{bmatrix} \rho & -\alpha \\ \rho \beta \Theta & 1 - \alpha \beta \Theta \end{bmatrix} \]

where \( \Theta \equiv \phi/\beta + \gamma \). Hence, \( \text{tr}(A) = 1 + \rho - \alpha \beta \Theta \), and \( \text{det}(A) = \rho \). Consequently, the two roots of the characteristic equation of \( A \) may be complex or real. The roots are complex if

\( (1 - \sqrt{\rho})^2 / \alpha \beta < \Theta < (1 + \sqrt{\rho})^2 / \alpha \beta, \)

and the system can only achieve oscillatory convergence provided that \( \rho < 1 \).

The roots are real if

\( \Theta < (1 - \sqrt{\rho})^2 / \alpha \beta, \quad (1 + \sqrt{\rho})^2 / \alpha \beta < \Theta \)

In this case, since \( \text{det}(A) > 0 \), there may be either two negative roots (if \( \text{tr}(A) < 0 \)) or two positive roots (if \( \text{tr}(A) > 0 \)). The system is convergent if the roots lie inside the unit circle. If the roots are negative, the system displays oscillatory convergence. If the roots are positive, the system displays monotonic convergence. Therefore, ordering the foregoing conditions yields the following dynamic regimes depending on the value of \( \Theta \):

- \( 0 \) for oscillatory convergence
- \((1 - \sqrt{\rho})^2 / \alpha \beta \) for oscillatory divergence
- \( 2(1 + \rho) / \alpha \beta \) for monotonic convergence

\[ \Theta \]

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monotonic convergence  oscillatory convergence  oscillatory divergence