Inflexibility of Inflation Targeting Revisited: Modelling the Anchoring Effect

Jan Libich[1]
La Trobe University and CAMA

Abstract

Opponents of explicit inflation targeting (including ex-Chairman Greenspan) have argued that a commitment to a numerical inflation target reduces the policy's flexibility, and may hence increase output volatility. Our paper demonstrates that this claim may fail to account for the *anchoring* effect of explicit targets on expectations and wages (that has been established empirically in various studies). This is done in a novel, more dynamic game theoretic framework that incorporates the concept of 'economically rational expectations' by making the frequency of players' moves (both the private sector's and the central banker's) endogenous. We show that under an explicit long-term inflation target and costly processing information/wage resetting, the public may find it optimal to look-through shocks and alter expectations and wages only *infrequently.* Due to such 'rational inattention', wages and expectations will be anchored at the target level, whereby the more explicit the target the stonger the anchoring. This is shown to make the policymaker's short-term interest rate instrument more effective in stabilization, giving it greater leverage over the real rate. As a consequence, an explicit inflation target improves the variability tradeoff, ie it makes both inflation and output less variable in equilibrium. Our analysis thus adds another dimension to the 'rule vs discretion debate' by showing that a *long-run rule* may be compatible with (and in fact enhance the effectiveness of) *short-run discretion.* It further offers several insights about the role of transparency and communication in the magnitude of the beneficial anchoring effect, and about the relationship between inflation targeting and central bank independence. We conclude by showing that our results are empirically supported.

Keywords: explicit inflation targeting, stabilization flexibility, output volatility, nominal anchor, commitment, dynamic games, asynchronous moves, rule, discretion, wage rigidity.

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'The extent to which inflation targeting regimes impair central bank flexibility is a matter of professional dispute.'
McCallum (2003), 'Inflation Targeting for the United States', Shadow Open Market Committee, available at http://www.somc.rochester.edu/May03/McCallum.pdf

'Inflation targeting, even without imposing a rigid rule, would unduly reduce the flexibility of the Fed to respond to new economic developments in an uncertain world.'
Rudebusch and Walsh (1998), 'U.S. Inflation Targeting: Pro and Con', FRBSF Economic Letter, 98-18

'The argument that inflation targeting might increase output fluctuations can be turned on its head. I would argue that inflation targeting can actually make it easier to reduce output fluctuations and probably has done so. First, the presence of an inflation target provides an effective nominal anchor...'
Mishkin (2004), 'Why the Federal Reserve Should Adopt Inflation Targeting', International Finance', Volume 7, Issue 1

1. Introduction

The 1990s was a decade of central banking reform. Most significantly, a number of countries adopted a regime known as inflation targeting (thereafter IT).[2] This paper focuses specifically on one advantage and one conflicting disadvantage of IT identified in the literature, and associated with the regime's defining feature – the policy's *explicit* (ie legislated) commitment to a numerical inflation target.

On one hand, it has been argued that explicit numerical targets are beneficial in stabilization as they better *anchor* inflation expectations and wages (eg Mishkin (2004) above). On the other, it has been believed that such a commitment constrains the policymaker's *stabilization flexibility* (eg Rudebusch and Walsh (1998) above), which may lead to higher output volatility and be inconsistent with monetary policy's 'dual mandate'.[3] Our paper contributes to the IT debate by (i) explicitly modelling both the anchoring and the flexibility channels, and (ii) establishing a novel link between them that may be crucial in assessing the regime's desirability. Specifically, it is shown that the inflexibility concerns of IT sceptics indeed seem what Woodford coined '*traditional prejudice of central bankers*'.

This is done using a novel game theoretic framework developed in Libich and Stehlík (2007a), which is a generalization of alternating move games (Maskin and Tirole (1988)). In contrast to the commonly used rational expectations solution or a repeated game setting, this framework has several advantages. First, unlike these standard setups that

[2]For extensive treatments of IT see Bernanke et al. (1999), Svensson (1999), Blejer et al. (2000), Mishkin and Schmidt-Hebbel (2001), Truman (2003), Bernanke and Woodford (2005)). For the heated debate on the desirability of IT for the U.S. see Bernanke (2003), Goodfriend (2003), Kohn (2003), McCallum (2003), Friedman (2004), Mishkin (2004), or Lacker (2005).

[3]The meaning of 'stabilization flexibility' has not been precisely defined in the literature. We will use it in the sense of Bernanke (2003) as the ability '*to choose the best policies in the future*' in terms of inflation and output stabilization. It has been forcefully argued that even central banks with a legal 'unitary' or 'hierarchical' mandate (in which price stability is the sole or primary goal) attempt to stabilize output in practice, see eg Cecchetti and Ehrmann (1999) or Kuttner (2004).

are static (expectations and the policy instrument are always adjusted simultaneously), our framework allows for a more *dynamic* interaction between the policymaker and the public (that combines synchronized and *asynchronous* moves).[4] Second, unlike these standard setups in which gathering/processing information, updating expectations, or renegotiating wages is commonly costless, our framework enables us to incorporate some *costs* of these activities. Third, agents' actions may be infrequent due to such costs (unlike the standard setting in which players commonly move every period). This is in line with the increasingly popular concepts of 'economically rational expectations' (Feige and Pearce (1976)) and 'rational inattention' (Sims (2003) and Reis (2006)).[5] Fourth, the *frequency* of the players' decisions can be made *endogenous*, ie optimally selected by the agents based on cost-benefit calculations.[6]

Motivation and Intuition. The 'inflexibility view' of IT sceptics (see eg Kohn (2003), Friedman (2004) or Greenspan (2003)) seems to be grounded in the following simple intuition due to Rogoff (1985). Let the following be the policymaker's objective function: $U = -\alpha var(x) - var(\pi)$, where x, π, and $\alpha \geq 0$ denote the output gap, inflation, and their relative weight. A common way to think about IT is a *lower* α, which Rogoff coined a 'conservative' central banker. It is straightforward to show that, in the presence of aggregate supply shocks, a lower α indeed translates into higher output volatility.[7]

Is it however true that explicit IT implies stricter IT (lower α)? The answer is clearly affirmative if the inflation target is specified as a *short-run* objective that must be achieved at every point in time. In contrast, a number of researchers have argued that the answer is negative if the inflation target is specified as a *long-term* objective (with the horizon being indefinite or the business cycle as in most industrial IT countries, see Mishkin and Schmidt-Hebbel (2001)). This is because shocks have a zero mean so they do not affect long-run/average levels of inflation and output. It then follows that such '*explicit long-run IT*' does not imply stricter IT, ie it does not necessarily affect the parameter α, the stabilization flexibility, nor the volatility of targeted variables.

We join the latter body of work but go a step further. Our theoretical analysis first formalizes the anchoring effect of IT that has been reported by empirical studies, eg Gurkaynak, Sack and Swanson (2005). It then shows that, due to this effect, the policy's flexibility may in fact increase (and output volatility decrease) under IT, contrary to what IT opponents conjecture.

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[4]For example Lagunoff and Matsui (1997) argue that *'[w]hile the synchronized move is not an unreasonable model of repetition in certain settings, it is not clear why it should necessarily be the benchmark setting...'*.

[5]In addition, there is a growing body of literature in this spirit that examines some sort of inertia/stickiness/rigidity in updating/forming expectations (see eg Ball (2000), Mankiw and Reis (2002), Carroll (2003), Carroll and Slacalek (2006), Morris and Shin (2006)) or renegotiating wages (see Fischer (1977), Taylor (1979) and the subsequent papers).

[6]The third and fourth points are called for by Tobin (1982) (quoted in Reis (2006)): *'Some decisions by economic agents are reconsidered daily or hourly, while others are reviewed at intervals of a year or longer... It would be desirable in principle to allow for differences among variables in frequencies of change and even to make these frequencies endogenous'.*

[7]Therefore, α is sometimes referred to as the flexibility parameter, see Svensson (1997) and Cukierman and Gerlach (2003). The extreme case of $\alpha = 0$ denotes 'strict IT' ('inflation nutters', King (1998)).

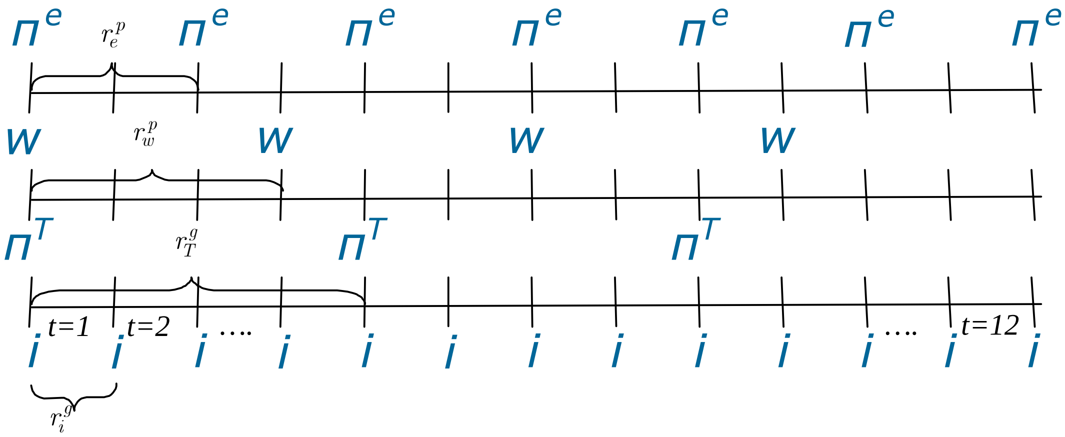

FIGURE 1. An asynchronous game: an example of the timing using a time line with $r_e^p = 2, r_w^p = 3, r_T^g = 4, r_i^g = 1$.

This parallels the recent finding of Orphanides and Williams (2005), and echoes the arguments of Bernanke (2003), Goodfriend (2003), and Mishkin (2004), that the extra credibility gained by IT may enable central banks to reduce the interest rate more aggressively in response to cost-push shocks without 'upsetting' inflation expectations. Our finding is similar in the sense that an explicit long-run inflation target better anchors the public's behaviour, which makes the policymaker's interest rate instrument more effective in stabilization. Our result however differs in that this anchoring leads to an improved variability tradeoff, and therefore lower volatility of both output and inflation is achieved by a *less* aggressive interest rate response. Since interest rate volatility is disliked (see eg Woodford (1999)), this constitutes an additional advantage of explicit long-run IT.

Framework. We adopt the standard New Keynesian setup of Clarida, Gali and Gertler (1999), but extend it in terms of (i) the number of the players' instruments (choice variables), (ii) the timing of the players' actions, and (iii) the costs associated with the frequency of actions. First, each player has two 'instruments'. The public, player p, forms inflation expectations, π^e, and sets wage inflation, w. The policymaker, player g, chooses the short-run (SR) interest rate, i, and the level of the long-run (LR) inflation target, π^T (whose horizon is indefinite for convenience). In addition, each player has two other choice variables, namely they optimally select (at the beginning of the game) the *frequency* with which the levels of these instruments will be reconsidered throughout. The moves that get set repeatedly then proceed as follows (see figure 1). After a simultaneous initial move of all instruments, each player j's instrument m can be adjusted every $r_m^j \geq 1$ periods, where $j \in \{g, p\}$, $m \in \{\pi^e, w, \pi^T, i\}$, and $r_m^j \in \mathbb{N}, \forall j, m$.

While both the public and the policymaker are forward looking, they may rationally choose to move infrequently - high r_m^j. This is either to minimize the associated cost, C_m (that is a function of r_m^j), or to commit. We will refer to r_e^p as *expectations anchorness*, to r_w^p as *wage anchorness (or rigidity)*, and to r_T^g as *explicitness of IT*. The latter is because arguably the more explicitly the inflation target is stated in the central banking legislation, the less frequently it can be altered (in the Taylor (1979) deterministic sense), or the less likely it is (in the Calvo (1983) probabilistic sense).[8]

As we provide a formal introduction and a thorough discussion of the framework below let us here only outline how the paper proceeds. The main objective of the paper is examining the interaction between the two instruments of the policymaker, namely the effect of explicit LR IT, r_T^g, on the flexibility of the SR interest rate instrument, i, and the resulting stabilization outcomes, $var(x^*)$ and $var(\pi^*)$. In the terminology of Kydland and Prescott (1977), we examine the impact of a 'LR rule' on 'SR discretion'. In doing so we establish an indirect link between then through the anchorness of the public's behaviour, r_w^p and r_e^p.

Results. Our main result is composed of two findings. In the first step, called the 'LR game', it is shown that if the target is sufficiently explicit, then the equilibrium anchorness levels, r_m^p, are increasing in the degree of the IT's explicitness, $\frac{\triangle r_m^{p*}}{\triangle r_T^g} > 0, \forall r_T^g, m$.[9] This implies that the public will then optimally 'look through' shocks (see Brash (2002)) to save some cost of updating expectations and renegotiating wages. Wages and expectations will therefore be anchored at the inflation target level.[10] As the second step, the 'SR game' shows that the variability of inflation and output in equilibrium is decreasing in the degree of anchorness, $\frac{\triangle var(\pi^*,x^*)}{\triangle r_m^p} < 0, \forall r_m^p$. This is because the public's 'rational inattention' to shocks gives the policymaker greater leverage over the real interest rate and the economy. Combining these two findings implies that the more explicit IT, the better the stabilization of both goal variables and the instrument, $\frac{\triangle var(\pi^*,x^*,i^*)}{\triangle r_T^g} < 0, \forall r_T^g$.

The paper further finds that there exists substitutability between the explicitness of IT and the regime's strictness (central bank conservatism/independence) in securing the target's credibility, $\frac{\partial r_T^{g*}}{\partial \alpha} > 0, \forall \alpha$. This may explain why inflation targets have been implemented more explicitly by countries that had lacked central bank independence in the late 1980s such as New Zealand, Canada, UK, and Australia, rather than those with an independent central bank such as the US, Germany and Switzerland. We later

[8] The fact that there has only been few changes in the level of the inflation target since the first explicit IT in 1990 provides support for this interpretation. As a real world example of our *deterministic* r_T^g, the 1989 Reserve Bank of New Zealand Act states that the inflation target may only be changed in a Policy Target Agreement between the Minister of Finance and the Governor, and this can only be done on *pre-specified regular* occasions (e.g. when a new Governor is appointed). Two other issues regarding r_T^g should be mentioned. First, the absence of a legislated numerical target may not necessarily imply $r_T^g = 1$; it has been argued that many countries pursue an inflation target *implicitly* (including the U.S., see eg Goodfriend (2003), or the Bundesbank and the Swiss National Bank in the 1980s, see Bernanke et al. (1999)). In such cases we have some $r_T^g > 1$. Second, r_T^g can be interpreted as *LR commitment*. However, the setup makes it apparent that this commitment concept is very different from the standard pre-commitment solution (timeless perspective) popularized by Woodford (1999) and Clarida, Gali and Gertler (1999) in which $r_T^g = r_i^g = 1$ are implicit. We discuss the links between the two concepts in Section 7.

[9] We utilize throughout the standard definition of forward differences due to the discreteness of r_m^j: $\triangle f = f(.+1) - f(.)$.

[10] We show that if the target is not sufficiently explicit then wages and expectations are either not anchored at all, or anchored at a suboptimal level, in which case the target 'lacks credibility'.

extensively discuss the existing empirical evidence related to our results and show that while it is not conclusive, there exists fair support for all our findings.

The rest of the paper is structured as follows. Section 2 describes the model. Section 3 first presents the standard repeated game and then introduces our generalized asynchronous framework in which moves may be infrequent. Section 4 examines the LR outcomes whereas Section 5 considers the SR outcomes. Section 6 presents related empirical evidence. Section 7 discusses the robustness of the results and a number of extensions. Section 8 summarizes and concludes.

2. The Model

The economy is described by two equations, namely a Phillips curve and an IS curve as in Clarida, Gali and Gertler (1999).[11] Both are however extended to feature w, the rate of change of nominal wages (wage inflation) as in eg Rogoff (1985). Using the notation of Section 1 we have

$$\pi_t = \lambda x_t + \gamma \pi_t^e + (1-\gamma) w_t + u_t, \tag{1}$$

$$x_t = -\kappa(i_t - \pi_t^e) - \varphi(i_t - w_t) + q_t, \tag{2}$$

where $t \in \mathbb{N}$ denotes time and $\lambda > 0$, $\gamma = [0,1]$, $\kappa \geq 0$, $\varphi \geq 0$ are parameters.[12] The disturbances follow the usual AR1 processes

$$u_t = \rho u_{t-1} + \hat{u}_t \text{ and } q_t = \mu q_{t-1} + \hat{q}_t, \tag{3}$$

where $0 \leq \rho, \mu < 1, \hat{u} \sim \text{iid}(0, \sigma_u^2)$ and $\hat{q} \sim \text{iid}(0, \sigma_q^2)$. Throughout, both the public and the policymaker (the central bank or the government)[13] are assumed to be rational, have common knowledge of rationality, and complete information about the economy and the structure of the game. Further, they do not discount the future for simplicity and without affecting the nature of the results (see Section 7). Finally, the players may suffer some cost associated with the frequency of their actions, $C_m(r_m^j)$. The policymaker's one-period preferences are as postulated in Section 1

$$U_t^g = -\alpha(x_t - x^T)^2 - (\pi_t - \pi^O)^2 - C_T - C_i, \tag{4}$$

where the inflation target is at the socially optimal level (which we throughout set to zero, $\pi^O = 0$). The output gap target can be positive, negative or zero, $x^T \in \mathbb{R}$.[14] As discussed above, α expresses the degree of *conservatism/strictness of IT*. Further, C_T is

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[11] How these (type of) equations arise from a micro-founded model featuring optimizing households and firms see for example Woodford (2003).

[12] The timing of π_t^e will be specified below. It will however become apparent in Section 7 that the intuition of our findings holds for various specifications of expectations π_t^e: both forward looking (eg $E_t\pi_{t+1}$ or $E_{t-1}\pi_t$, where E is a rational expectation operator) and backward looking.

[13] While central bank (goal) independence is not explicitly modelled we will later follow the literature and interpret it in the Rogoff (1985) sense as synonymous to conservatism/strictness. See Hughes Hallett and Libich (2006) for explicit modelling of the government's delegation of monetary policy to a central bank.

[14] $x_T \neq 0$ can be due to mismeasurement of potential output (eg Orphanides et al. (2000)), market imperfections (eg Kydland and Prescott (1977), Barro and Gordon (1983)), political economy reasons (eg Faust and Svensson (2001)), or a shortcut way to reflect asymmetry in the policymaker's preferences (as in eg Cukierman (1999), Ruge-Murcia (2004), and Cukierman and Gerlach (2003)).

an *explicit IT cost* and C_i is a Monetary Policy Committee *meeting/decision cost* (both will be postulated below). The public's one-period utility function is the following

$$U_t^p = -\beta(\pi_t - \pi_t^e)^2 - (\pi_t - w_t)^2 - C_\pi - C_w - C_e, \tag{5}$$

where C_π is an *inflation cost*, C_w is a *wage bargaining cost*, and C_e is an *expectation updating cost* (all will be postulated below). The intuition of the first three components is standard (and equivalent to rational expectations, see Backus and Driffill (1985)). An inflation averse public attempts to correctly expect the inflation rate in order to set wages at the market clearing level (for justification based on Fischer-Gray contracts that are consistent with our setting see Canzoneri (1985)). The fourth and fifth elements underlie the body of work on rational inattention (Sims (2003) and Reis (2006)), and will enable us to formalize the concept of 'economically rational expectations' of Feige and Pearce (1976), in which the players' frequency of updating expectations is a result of cost-benefit calculations.

3. The Game Theoretic Setup

3.1. **Standard Timing: Frequent and Synchronized Moves.** The policy has been, at least since Barro and Gordon (1983), commonly studied as an (infinitely) repeated game. Under discretion, as well as under pre-commitment (timeless perspective), players' instruments are chosen *simultaneously* at *each* period t, ie $r_m^j = 1, \forall j, m$.[15] Under this special case our model yields outcomes analogous to the New Keynesian setting of eg Clarida, Gali and Gertler (1999). To see this, set up the usual Lagrangian, disregard the costs C in (4)-(5), and impose rational expectations to obtain the familiar targeting rule under discretion

$$\pi_t = -\frac{\alpha}{\lambda}(x_t - x^T). \tag{6}$$

Substituting (6) into the Phillips curve yields the values of inflation and the output gap in equilibrium (denoted by '*star*' throughout)

$$\pi_t^* = \frac{\alpha}{\lambda^2}(u_t + \lambda x^T) \text{ and } x_t^* = -\frac{1}{\lambda}u_t, \tag{7}$$

In order to demonstrate the independence of LR levels from SR disturbances, ie the mutual consistency of the two instruments of the policymaker, note that the supply shock does not affect the LR values due to its zero mean. Formally, denoting all LR variables by a 'bar' and using $\bar{u} = 0$ with (7) yields the following equilibrium LR levels

$$\bar{\pi}^* = \frac{\alpha}{\lambda}x^T \text{ and } \bar{x}^* = 0. \tag{8}$$

This independence means that the policymaker can be, in some period t in which a supply shock occurs, *consistently* committed to the optimal LR inflation target, $\bar{\pi}^O$, but choose a different level of inflation, $\pi_t^* \neq \bar{\pi}^O$, that maximizes its objective function according to (6)-(7).[16]

[15] As mentioned above the rational expectations solution is equivalent to this repeated game; it implicitly assumes that expectations and the policymaker's instrument can be readjusted simultaneously every period.

[16] It is important to note that this feature is not specific to our model but is generally present in most settings used in monetary analysis including Clarida, Gali and Gertler (1999).

3.2. **Generalized Timing: Possibly Infrequent and Asynchronous Moves.** Our framework is a generalization of the asynchronous (alternating) move setups of Maskin and Tirole (1988) and Lagunoff and Matsui (1997), drawing on the intuition of games with endogenous timing, eg Bhaskar (2002).[17]

Definition 1. *The variable* $r_m^j \in \mathbb{N}$*, where* $j \in \{g, p\}$ *and* $m \in \{\pi^e, w, \bar{\pi}^T, i\}$*, expresses the number of periods for which the respective action is not reconsidered.*

Assumptions: Game Theoretic. The version of the framework used here adopts all the main features of a standard repeated game – a number of game theoretic modifications are examined in our companion papers, Libich and Stehlík (2007a,b,c), and discussed in Section 7 (they are indicated here by italics). First, time is *discrete*. Second, all r_m^j's are *deterministic* in the spirit of Taylor (1979). Third, all r_m^j's are *constant* and *observable* by the players. Third, the opponent's preceding periods' moves can be observed (ie games of *perfect monitoring*). Fourth, the game starts with a simultaneous move of all actions for comparability with the standard repeated game. We postulate the following *timing* that we find most realistic in the monetary policy context.

(1) The policymaker selects r_T^g and r_i^g. Observing these, the public chooses r_e^p and r_w^p. All these choices apply throughout the whole game.
(2) At the beginning of every period t there is a realization of shocks, u_t and q_t.
(3) In period 1 observing all r_m^j as well as u_1 and q_1, the players simultaneously set the levels of $\{\pi^e, w, \bar{\pi}^T, i\}$.
(4) The $\{\pi^e, w, \bar{\pi}^T, i\}$ levels can then be reset every $\{r_e^p, r_w^p, r_T^g, r_i^g\}$ periods respectively, observing current and past shocks.[18]

Strategies and Equilibria. A strategy for a certain player is a function that, for all histories, assigns a probability distribution to the players' action space. As common in macroeconomics, in this paper we will restrict our attention to pure strategies. A strategy of player j is then a vector that, for all histories, specifies the player's play in its every node. The asynchronous game will commonly have multiple Nash equilibria. To select among these we will use a standard equilibrium refinement, subgame perfection, that eliminates non-credible threats. Subgame perfect Nash equilibrium (SPNE) is a strategy vector that forms a Nash equilibrium after any history. Following the macroeconomic literature, we will only focus on Markov perfect equilibria, see eg Maskin and Tirole (2001).

Assumptions: Macroeconomic. In terms of $C_i(r_i^g)$ the literature has not put forward any reasons for a non-zero value – this is because the cost of more frequent *committee meetings* seems negligible relative to the macroeconomic consequences. Therefore,

[17]In doing so it follows the recommendation of Cho and Matsui (2005): *'[a]lthough the alternating move games capture the essence of asynchronous decision making, we need to investigate a more general form of such processes. . . '*.

[18]This full information assumption follows the standard assumption of the New Keynesian framework and is made for modeling purposes. It makes it possible to attribute the public's inattention, $r_m^p > 1$, to not-processing the available information rather than to not-possessing some information. Therefore, C_e has been labelled as the cost of updating expectations rather than cost of acquiring information. For analyses of a situation in which the policymaker has private information about shocks see the 'transparency' literature initiated by Cukierman and Meltzer (1986).

we will assume $C_i(r_i^g) = 0, \forall r_i^g$. Similarly, we will set $C_T(r_T^g) = 0, \forall r_T^g$. This is because (i) the possible *inflexibility* cost of explicit IT is formally examined in this paper, and (ii) other related costs (such as an *implementation* cost) are arguably negligible.[19]

In contrast, the fact that there exist non-trivial inflation and wage bargaining costs, $C_\pi > 0, C_w > 0$, is uncontroversial. In terms of the former see eg Romer and Romer (1997) or McCallum and Nelson (2004). In terms of the latter Mankiw and Reis (2002) discuss the existence of costs related to *'changing wage contracts and information-gathering, decision making, negotiation and communication'* (see also the literature on wage rigidity initiated by Fischer (1977) and Taylor (1979) and its empirical evidence, eg Bewley (2002)).

We therefore assume the following costs in (5). The inflation cost is a fixed *per-period* cost that incurs if LR inflation differs from the optimal LR level, ie

$$C_\pi = \begin{cases} c_\pi > 0 & \text{if} \quad \bar{\pi} \neq \bar{\pi}^O, \\ 0 & \text{if} \quad \bar{\pi} = \bar{\pi}^O. \end{cases} \tag{9}$$

The wage bargaining cost is a *per-period* fee increasing in the number of wage negotiations, $\frac{\triangle C_w}{\triangle r_w^p} < 0, \forall r_w^p$. For simplicity we use the following functional form

$$C_w = \frac{c_w}{r_w^p}, \tag{10}$$

where $c_w > 0$. In order to make the exposition of the paper more illustrative and the game theoretic analysis more transparent, several simplifying assumptions will be made. The first set relates to the need to *separate* the effects of anchored (rigid) wages and anchored (sticky) expectations.[20] For most of the paper we will restrict our attention to the former since: (i) wage rigidity is a more established concept with sufficient empirical support, (ii) the modelling is notably simpler, and most importantly, (iii) it is shown in Section 7 that the intuition and impacts of the two effects are analogous.

In focusing on wage anchorness we will follow the mainstream literature and assume $C_e(r_e^p) = 0, \forall r_e^p$, and in line with this $\kappa = \gamma = 0$. It then follows from (5), in combination with $\beta > 0$ and (7), that the public will choose to update expectations every period, $r_e^{p*} = 1, \forall r_T^g, r_i^g, r_w^p$. Intuitively, the supply shock may occur every t, and it affects π_t^* (see (7)), which the public attempts to correctly expect, $\pi_t^{e*} = \pi_t, \forall t$ (from (5)). This in turn, combined with the assumed full information, implies $\pi_t^e = \pi_t, \forall t$, and has two advantages. First, it coincides with the assumption underlying the rational expectation solution. Second, the analysis will be simplified as the public will be setting wages using the 'correct' inflation expectations. Nevertheless, in Section 7 we also examine the cases $C_e, \kappa, \gamma > 0$ (and hence $r_e^{p*} > 1$) and show that due to the analogous effect of anchored wages and expectations the intuition of the findings is unchanged.

Two Stage Analysis. Due to the same expositional considerations we will split the game into two interconnected parts (horizons): the 'LR game' and the 'SR game'. The LR game will ocus on the LR/average/trend outcomes (primarily on setting the inflation target and trend wage growth) and will therefore consider the game under the

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[19]It will become evident that even if we allow for these costs to be positive, our findings will be unchanged as long as the costs are below a certain threshold, $0 < C_T \leq \tilde{C}_T$ and $0 < C_i \leq \tilde{C}_i$.

[20]This is a matter of experimental control - since π^e is used in setting w these two actions are interconnected.

		Public	
		$\overline{w}^O$	$\overline{w}^S$
Policymaker	$\overline{\pi}^O$	$a = -\alpha\,,\ 0$	$b = -4\alpha\,,\ -1$
	$\overline{\pi}^S$	$c = -1\,, -2$	$d = -\alpha - 1\,,\ -1$

FIGURE 2. The stage game payoffs: for illustration, we normalized $c_\pi = x_T^2$ and $c_w \to 0$; and then divided all payoffs by x_T^2 without loss of generality.

assumption of no shocks. This part is in the spirit of the Barro and Gordon (1983) literature and it will derive the LR conditions for the anchoring effect to occur, and communicate the intuition of the asynchronous game and its solution.

In contrast, the SR game will feature shocks and study the resulting deviations from the LR outcomes. This part is in the spirit of the New Keynesian literature and it will derive the SR conditions for anchoring and show its stabilization effects.

4. The LR Game

Under the LR assumption $u_t = q_t = 0, \forall t$, current inflation always equals LR inflation, $\pi_t = \bar{\pi}_t, \forall t$. Therefore, the setting of π_t will be suppressed in this section (as well as the related setting of i_t and r_i^g), and only the $\{r_T^g, r_w^p, \bar{\pi}_t^T, \bar{w}_t\}$ choices will be focused on.[21] We denote the latter by $\bar{w}_t$, and the resulting output gap by $\bar{x}_t$ to indicate that these variables should also be, in the absence of shocks, interpreted as LR values.

Normal Form Game. In order to be able to present the game in the normal form we follow the game theoretic literature (eg Cho and Matsui (2005)) and restrict the LR game to two levels of the inflation target and wage inflation. We choose two levels of interest: one optimal, O, and one sub-optimal, S - specifically, the inflation and output target levels[22]

$$\bar{\pi}^T \in \{\bar{\pi}^O = 0, \bar{\pi}^S = \lambda x^T\} \ni \bar{w}. \tag{11}$$

Using this with (1), (4), and (5) we can derive the payoff matrix of the standard (one period) stage game (that is unaffected by r_m^j's). It is reported in Figure 2, in which $\{a, b, c, d\}$ denote the respective payoffs of the policymaker.

Due to the specific choice of the LR action sets in (11), we need to make two technical assumptions (that only apply in the LR game). First, in order for the players to always have a choice between two *different* levels, we need to exclude the case in which the O and S levels are the same by imposing $\bar{\pi}^S = \lambda x^T \neq \bar{\pi}^O$. Note however, that $\bar{\pi}^S$

[21] As discussed above we have $r_e^{p*} = 1$ and hence $\pi_t^e = \pi_t, \forall t$.

[22] The output target in (11) is normalized by λ to simplify the payoff functions, which will be apparent in Figure 2. Under different O and S values the results differ quantitatively, but their qualitative nature is intact, see Libich and Stehlík (2007a).

can still be both greater and less than $\bar{\pi}^O$. Second, in order to still preserve the time inconsistency feature in our truncated game, ie for $c > a$ to hold, we only consider the cases $\alpha > 1$[23]. Finally, we will focus our attention on the intuitive special case in which $r_T^g = nr_w^p$ or $r_w^p = nr_T^g$ where $n \in \mathbb{N}$. While this will somewhat restrict the asynchronicity of the r_T^g and r_w^p moves, Libich and Stehlík (2007a) demonstrate that this special case is representative of the more asynchronous cases. It will become evident that the amount of dynamics is still sufficient to produce new insights.

Horizon and Repetition. The LR game can be solved by backwards induction, which follows from the fact that even if the horizon of the game is assumed to be infinite, the same extensive game gets regularly repeated. Specifically, this happens every M periods - where $M \in \mathbb{N}$ is the 'least common multiple' of all r_m^j. To demonstrate, in the example of Figure 1 we have $M(r_e^p = 2, r_w^p = 3, r_T^g = 4, r_i^g = 1) = 12$. We will refer to the M period horizon as an *unrepeated asynchronous LR game.* The fact that M is finite follows from $r_m^j \in \mathbb{N}, \forall j, m$.

While this asynchronous game can be repeated we will restrict our attention to the unrepeated game. This is possible because in the LR game we will be interested in conditions under which the sole *efficient* outcome $(\bar{\pi}^O, \bar{w}^O)$ *uniquely* obtains on the equilibrium path of the unrepeated game. Then repeating the game, and allowing for reputation building of some form, would not affect the reported equilibrium.[24]

Let us define the following concept drawing upon the intuition of the literature, eg Faust and Svensson (2001).

Definition 2. *An inflation target will be called* ***credible*** *if the public (i) expects this inflation level on average in equilibrium,* $\bar{\pi}_t^{e*} = \bar{\pi}^O, \forall t$*, and therefore, (ii) optimally sets trend wage growth at this level,* $\bar{w}_t^* = \bar{w}^O = \bar{\pi}^O, \forall t$*.*

Three things are worth noting. First, the definition extends the standard credibility concept from expectations to wages. Second, as the inflation target is a LR objective, its credibility depends on expectations of average inflation and average wages. Third, time-consistency of the target is a necessary condition of credibility but not a sufficient one - if there are multiple time-consistent levels then the public could still expect a different, sub-optimal level. This is further related to our solution concept, subgame perfection, and the following definition.

Definition 3. *Any subgame perfect Nash equilibrium (SPNE) that has, on its equilibrium path, all players in the LR game playing the optimal levels in all their moves, ie* $\bar{\pi}_t^{e*} = \bar{w}_t^* = \bar{\pi}_t^{O*}, \forall t$ *(implying* $\bar{x}_t^* = 0, \forall t$*), will be called* ***Ramsey****.*

We can now propose three sets of results for the LR game - the next section shows them to obtain even in the SR game with disturbances. Their order is implied by the backwards induction solution of the game used. The first proposition reports findings about the effect of r_T^g on average inflation, wages, and the inflation target's credibility (treating both r_T^g and r_w^p as exogenous). The second focuses on the relationship between

[23]Note again that this is a purely technical restriction related to the choice of $\bar{\pi}^S$ that should *not* be interpreted as imposition of a 'liberal' policymaker.

[24]For the fact that the Folk theorem may not apply in asynchronous games see eg Takahashi and Wen (2003).

r_T^g and r_w^p and reports the anchoring effect (ie treating r_T^g as exogenous but r_w^p as endogenous). The third proposition relates to the policymaker's optimal IT explicitness decision, and shows under what circumstances anchoring will occur in equilibrium (ie treating both r_T^g and r_w^p as endogenous). The empirical evidence to all these findings will be left to Section 6.

Proposition 1. *(i)* ***IT Credibility****: The optimal inflation target is credible if and only if it is sufficiently explicit. (ii)* ***IT Substitutability****: Explicitness of IT and strictness of IT (conservatism) are substitutes in achieving the target's credibility.*

Proof. Let us throughout denote various threshold levels by a 'tilde'. The proposition states that (i) if and only if the target's explicitness is above some threshold $\tilde{r}_T^g$, then $\bar{w}_t^{O*} = \bar{\pi}_t^{e*} = \bar{\pi}_t^{O*}, \forall t, \alpha, x^T$. Specifically, Appendix A shows the *sufficient* condition to be

$$r_T^g > \tilde{r}_T^g = 3\alpha r_w^p. \tag{12}$$

This also proves claim (ii) by showing that the threshold $\tilde{r}_T^g$ is a decreasing function of the policy's conservatism/strictness (increasing in α). □

Interestingly, unlike in the standard repeated game of the Barro and Gordon (1983) type, the optimal inflation target may be time consistent and credible even if $\alpha > 0$ and $x^T \neq 0$; and this is true even in a finite game without reputation. To achieve this, the target must be sufficiently explicit. Intuitively, under $r_T^g > r_w^p$ the public gets to adjust wages *after* it has observed the level of inflation (with the exception of all periods in which the players move simultaneously, $t = (n-1)M + 1, \forall n \in \mathbb{N}$). Therefore, if the policymaker plays the S level then the public will get to 'punish' him with S level wages.[25]

The proof shows that if $r_T^g > \tilde{r}_T^g$, then this punishment is long enough to offset the possible output benefit of the policymaker from surprise inflating/deflating, and eliminate his temptation to do so even if $x^T \neq 0$. Knowing this, the public sets expectations and wages at the O level, and $\bar{\pi}^O$ becomes credible. Put differently, the policymaker's explicit IT provides a *LR commitment* by sufficiently tying the policymaker's hands in terms of *average* inflation.

Let us briefly report several additional results implied by the proof of Proposition 1.

Remark 1. *Initial conditions matter. After an inflationary/deflationary period a more explicit and/or stricter IT may be necessary to ensure the credibility of the optimal inflation target.*

In the proof of Proposition 1 we have shown that the *neccessary* credibility condition is $r_T^g > \alpha r_w^p$. Combining this with the sufficient condition in (12) implies that under $\frac{r_T^g}{r_w^p} \in [\alpha, 3\alpha]$ there exist multiple SPNE, including both Ramsey and non-Ramsey SPNE. Then the selected outcome is likely to depend on the past, ie players will continue playing the current SPNE. Therefore certain degrees of IT's explicitness and strictness that may have been sufficient for credibility in a stable price level environment, may

[25]Note that unlike in Barro and Gordon (1983), the punishment in the asynchronous world is not arbitrary but it is the public's *optimal* play and its length is uniquely determined by the length of the wage contract.

be insufficient in the aftermath of a prolonged inflationary or deflationary period. Note that this is true in our model even under a purely forward-looking public, ie not due to adaptive expectations.

This may perhaps help explain why institutional arrangements such as explicit IT and conservative/independent central bankers may not have been needed before the 1970s, but were imperative for credibility afterwards. Similarly, it points to a solution to the deflationary problem of Japan of the past two decades (that is in line with Svensson (2001)) – an appointment of an explicit and strict(er) inflation targeter.

Remark 2. *A sufficiently explicit IT ensures that any policymaker (with any output target $x^T \in \mathbb{R}$) behaves 'as if' he targets the natural rate, $x^T = 0$. This observational equivalence suggests that caution should be exercised in concluding that a track record of low inflation necessarily indicates a conservative policymaker without any temptation to over-stimulate output.*

A number of authors, eg McCallum (1997) and Blinder (1997), argued that a simple recognition of the fact that $x^T \neq 0$ leads to undesirable outcomes is sufficient to constrain the policymaker's behaviour, ie he then acts 'as if' $x^T = 0$. They do not however discuss under what circumstances such behaviour will be credible in the eyes of the public. Our analysis offers an answer by deriving the *sufficient* degree of IT's explicitness, $\tilde{r}_T^g$, that ensures optimal expectations and wages throughout.

Proposition 2. ***Anchoring Effect (LR)**: If the inflation cost is greater than the wage bargaining cost, $c_\pi > c_w$, then a sufficiently explicit IT, $r_T^g > 3\alpha$, anchors wages. Specifically, wage anchorness is increasing in the degree of IT's explicitness.*

Proof. The proposition claims that $\frac{\triangle r_w^{p*}}{\triangle r_T^g} > 0, \forall r_T^g > 3\alpha$ and $c_\pi > c_w$. In particular, the optimal wage anchorness is derived in Appendix B to be

$$r_w^{p*} = \tilde{r}_w^p = \frac{r_T^g}{3\alpha}. \tag{13}$$

This shows that r_w^{p*} is an increasing function of r_T^g. □

Intuitively, the public faces a tradeoff in its r_w^p choice between *minimizing* the wage bargaining cost (by selecting long contracts, high r_w^p) vs the inflation cost (by selecting sufficiently short contracts, $r_w^p \leq \tilde{r}_w^p$, and hence ensuring $\bar{\pi}^{O*}$). If $c_\pi > c_w$ then the public settles for the latter, but chooses the highest possible r_w^p that still delivers the optimal average inflation level, the $\tilde{r}_w^p$ implied by (12).

Proposition 3. ***Optimal IT Explicitness (LR)**: If $c_\pi > c_w$ then the policymaker will choose to make the inflation target sufficiently explicit. This will not only ensure the target's credibility and optimal LR inflation and wage outcomes, but also the anchoring effect to be present.*

Proof. It is claimed that if $c_\pi > c_w$ then $r_T^{g*} > \tilde{r}_T^g$, which will lead to $\bar{w}_t^{O*} = \bar{\pi}_t^{O*}, \forall t$, as well as to $\frac{\triangle r_w^{p*}}{\triangle r_T^{g*}} > 0$. Moving backward from the r_w^p choice, consider the policymaker's r_T^g choice. Given his inflation aversion, he prefers the Ramsey SPNE to the non-Ramsey alternatives with sub-optimal inflation (recall that $\bar{x}_t^* = 0, \forall t, r_T^g$). Combining this with the fact that there is no (non-trivial) cost of explicit IT, $C_T = 0$, implies that the policymaker will select some level of r_T^g above the threshold in (12),

$$r_T^{g*} > \tilde{r}_T^g = 3\alpha r_w^p. \tag{14}$$

Then Proposition 2 showed that $r_w^{p*} = \frac{r_T^g}{3\alpha}$, and Proposition 1 demonstrated that $\bar{w}_t^{O*} = \bar{\pi}_t^{O*}, \forall t, \alpha, x^T$. □

5. The SR Game

In this section there exist shocks as specified in (1)-(3). Let us first revisit our results of the LR game and show that they all carry over to this stochastic environment. In terms of Proposition 1, both claims still obtain under shocks. Since shocks have a zero mean they do not affect the LR inflation level (see (8)), and hence LR expectations and wages, and hence the credibility of the inflation target (see Definition 2). In terms of Proposition 2, we will prove the anchoring effect to still exist in the presence of shocks (under one additional condition on the magnitude of the supply shock σ_u^2). In terms of Proposition 3, we will show that since the anchoring effect is beneficial in stabilization, it provides an additional reason for the policymaker to make IT sufficiently explicit.

To be able to focus on the SR deviations in this section we will start off by simply assuming the latter result to be true, ie $r_T^{g*} > \tilde{r}_T^g = 3\alpha r^p$, and proving it ex-post (in Proposition 7). We have shown this to lead to $\bar{\pi}_t^* = \bar{w}_t^* = \bar{x}_t^* = 0, \forall t$, which enables us to only examine the $\{r_i^g, i_t, w_t\}$ choices in the SR game. Our first SR game result relates to the policymaker's optimal choice of r_i^g, the frequency of the policy meetings (ie potential interest rate decisions).

Proposition 4. ***Frequency of Policy Decisions:*** *The policymaker will find it optimal to have the ability to adjust the interest rate every period, $r_i^{g*} = 1$.*

Proof. Under $r_T^g > 3\alpha r^p$ the optimal LR levels obtain, so the game is played 'as if' $x^T = 0$ (see Remark 2). Therefore, the optimal targeting rule in (6) effectively becomes, $\forall x^T$

$$\pi_t = -\frac{\alpha}{\lambda} x_t. \tag{15}$$

The simplest way to prove that $r_i^{g*} = 1$ is to note that under $r^p = 1$ the (π, x) combination is consistent with the optimal targeting rule in (15) in *every* period and under *any* circumstances, and show that under $r_i^g > 1$ there exist circumstances that lead to (π, x) deviating from (15), which we do in Appendix C. □

This results is intuitive. Since shocks occur every period, being able to respond to them promptly (the period they occur) clearly enhances the effectiveness of stabilization. The next proposition reports the macroeconomic effect of anchored wages, and shows it to be beneficial for stabilization as it leads to an improved variability tradeoff.

Proposition 5. ***Effect of Anchorness:*** *Assume that $\alpha \geq \tilde{\alpha}$, where $\tilde{\alpha}$ is some positive threshold level. Then wage anchorness decreases the variability of both inflation and output in equilibrium. Persistence of supply shocks has the opposite effect as it reduces the stabilization benefit of the anchoring effect.*

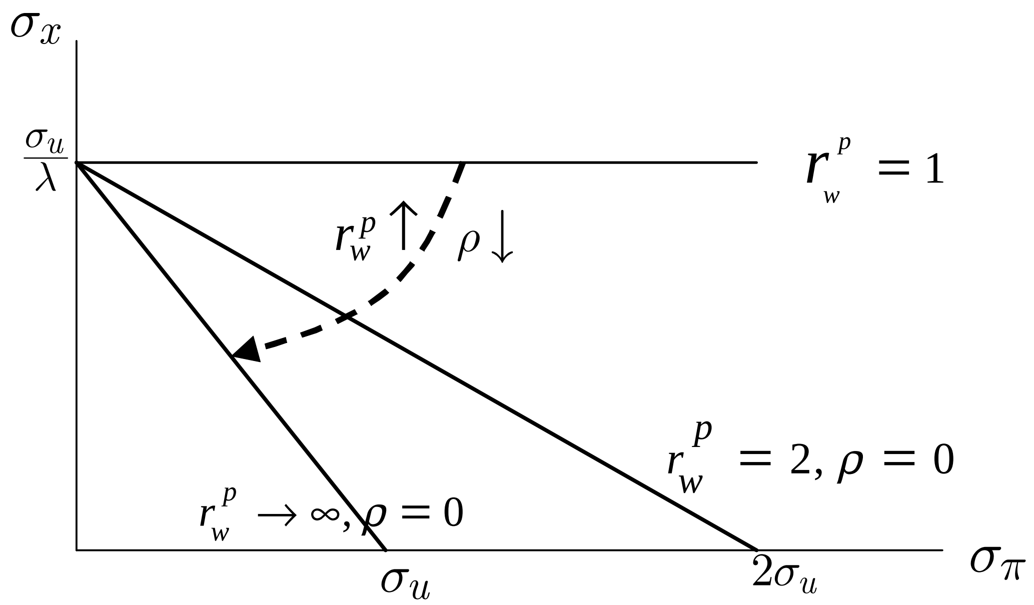

FIGURE 3. A schematic demonstration of the efficient policy frontier (Taylor curve) in Cournot periods as a function of r_w^p and ρ.

Proof. The proposition claims that if $\alpha \geq \tilde{\alpha} > 0$ then $\frac{\triangle var(\pi^*, x^*)}{\triangle r_w^p} < 0, \forall r_w^p, \alpha$ and $\frac{\partial var(\pi^*, x^*)}{\partial \rho} > 0, \forall \rho$. Appendix D presents the proof and shows that $\tilde{\alpha}$ is, for realistic values of λ, very close to zero, ie the claim obtains for all 'reasonable' parameter values. □

We follow Clarida, Gali and Gertler (1999) and demonstrate the policy tradeoff by constructing the efficient policy frontier – the so-called Taylor curve. Figure 3 depicts the locus of points that characterize how σ_π and σ_x under the optimal policy vary with r_w^p. It shows that the policy tradeoff in Cournot periods improves (the frontier shifts in) with an increasing value of wage anchorness r_w^p and decreasing persistence of supply shocks ρ.

Corollary 1. *Wage anchorness increases the policymaker's stabilization flexibility.*

Recall that our definition of stabilization flexibility follows Bernanke (2003): it is the ability 'to choose the best policies in the future'. We interpret it to refer to inflation and output variability, since these are the two objectives in the policymaker's utility function. The claim is then implied by Proposition 5(i).

Let us now specify the conditions under which the anchoring affect, established in Proposition 2, will be present even if shocks exist.

Proposition 6. ***Anchoring Effect (SR):*** *Assume that the wage bargaining cost is less than the inflation cost but sufficiently large relative to the magnitude of supply shocks,*

$c_\pi > c_w \geq \tilde{c}_w(\sigma_u^2)$, *where* $\frac{\partial \tilde{c}_w}{\partial \sigma_u^2} > 0$. *Then a sufficiently explicit IT,* $r_T^g > 3\alpha$, *anchors wages (for all* $\alpha \geq \tilde{\alpha}$*).*

Proof. It is shown in Appendix E that under the stated conditions we have $\frac{\triangle r_w^{p*}}{\triangle r_T^g} > 0$. □

Intuitively, the public's choice of r_w^p under shocks features the same tradeoff as in the LR game. A short wage contract, low r_w^p, is costly (implies higher C_w), but ensures better alignment of wages with inflation (which is even more important in the SR game due to shocks). Clearly, under very large supply shocks, high σ_u^2, the public will choose to have fully flexible wages to respond promptly, $r_w^{p*} = 1$, in which case wages are not anchored. In contrast, for sufficiently small σ_u^2 (relative to c_w) longer term contracts will be optimal. In such case r_w^{p*} is, even in the presence of shocks, a monotonically increasing function of r_T^g, ie the anchoring effect occurs.

Corollary 2. *Under a sufficiently explicit IT, the existence of shocks may not affect the public's optimal frequency of wage negotiations.*

This is implied by (13) in which r_w^{p*} is, under the conditions of Proposition 6, not a function of σ_u^2. The following result revisits the choice of r_T^{g*} in the SR game.

Proposition 7. ***Optimal IT Explicitness (SR):*** *It is optimal for the policymaker to make its LR inflation target sufficiently explicit even in the presence of shocks.*

Proof. The proposition claims that $r_T^{g*} > \tilde{r}_T^g$ even if $\sigma_u^2 > 0$. Recall Proposition 3 which showed that the policymaker's motive for a sufficiently explicit IT commitment is to ensure the target's credibility. This motive still exists in the SR game, and is unaffected by the existence of disturbances, since the inflation target is a LR objective. In addition to this motive the policymaker wants to ensure the beneficial anchoring effect (Proposition 5). This, combined with $C_T = 0$, implies $r_T^{g*} > \tilde{r}_T^g = 3\alpha r_w^p$, and completes the proof. □

We can now combine the above findings to formulate the main result of the paper.

Proposition 8. ***Effect of IT Explicitness:*** *If* $c_\pi > c_w \geq \tilde{c}_w(\sigma_u^2)$ *and* $\alpha \geq \tilde{\alpha}$ *then a sufficiently explicit IT,* $r_T^g > 3\alpha$*: (i) increases the policymaker's stabilization flexibility, (ii) reduces the volatility of output, inflation and the interest rate, and hence (iii) improves social welfare.*

Proof. It is shown in Appendix F that under the stated circumstances, we have claim (ii), namely $\frac{\triangle var(x^*,\pi^*,i^*)}{\triangle r_T^g} < 0, \forall r_T^g$. Claim (i) follows by combining this with Corollary 1. Claim (iii) is then implied by combining these findings; (4)-(5) show that the utility of both the policymaker and the public (and hence social welfare) is improved by a sufficiently explicit IT. In terms of the former player, it is due to the lower variability of inflation and output. In terms of the latter player, it is also due to a lower wage bargaining cost. □

It should be said that our paper is not the first to suggest that explicit IT may lead to an improved variability tradeoff. Orphanides and Williams (2005) model the public's learning about the policymaker's inflation target and similarly find that numerical targets - through their emphasis on price stability - reduce the 'responsiveness' of expectations to observed inflation, and hence reduce the volatility of both inflation and output.

6. Empirical Evidence

Short-Run Findings. Let us first survey the existing empirical literature on the stabilization effects of IT. While the evidence is far from conclusive on the majority of issues, it seems to speak in favour of our results.[26] In terms of the *anchoring effect* Levin, Natalucci and Piger (2004) find evidence that IT plays a significant role in anchoring long-term inflationary expectations and in reducing the persistence of inflation. Similarly, Kuttner and Posen (1999) and Gurkaynak, Sack and Swanson (2005) find that in IT countries compared to non-IT countries longer-run inflation expectations are less sensitive to economic developments. In contrast, Johnson (2002) and Ball and Sheridan (2003) find no evidence that IT reduces the variability of inflation expectations.[27]

In terms of *output variability*, the findings are even more inconclusive on the basis of which McCallum (2003) argues: *'There is probably no way that this disagreement [on IT's flexibility] can be settled in the present state of economic knowledge'* - see eg Cecchetti and Ehrmann (1999), Eijffinger and Geraats (2006), and Demertzis and Hughes Hallett (2003). There are three recent exceptions. Corbo, Landerretche and Schmidt-Hebbel (2001)) and Arestis, Caporale and Cipollini (2002) find IT to *improve* the variability tradeoff. Fatas, Mihov and Rose (2004) similarly find that *'having a quantitative de jure target for monetary authority tends to smooth business cycles'*.

In terms of *interest rate variability* Siklos (2004) and Neumann and von Hagen (2002) report evidence that IT countries have reduced the nominal interest rate and its volatility to a larger extent than non-IT countries. Further, Eijffinger and Geraats (2004) show that policy transparency reduces interest rates.

Furthermore, it is interesting to note that our findings are consistent with the recent empirical results of Levin et al. (2005), who find that the performance of optimal policy is closely matched by a simple operational rule that focuses solely on stabilizing nominal wage inflation. The authors show that this simple *wage stabilization rule* is robust and stress *'the importance of additional research regarding the structure of labor markets and wage determination'*.

Lastly, the fact that explicit inflation targets have been accompanied by high degree of transparency in all other respects (publishing data, models etc) as well as by increased accountability ('Open letter procedure' etc) and a general improvement in the central bank's communication, is consistent with our findings. This is because all these arrangements are likely to lead to a stronger anchoring effect and further improve the efficiency of IT.

Long-Run Findings. Propositions 1 and 3 imply that a less conservative (less strict) policymaker needs to (and will) commit more strongly to secure the credibility of the optimal LR inflation level. This may explain why some countries have been more explicit in formulation of their price stability objective than others. If we use the standard interpretation of α as the degree of central bank (goal) independence (CBI) in the spirit of Rogoff

[26] In addition to the relatively short time span and a small sample problems, the main issue is the fact the countries are commonly treated as either an inflation targeter or a non-targeter. Our analysis implies that the explicitness of IT should be treated as a continuous variable (for an argument in this spirit see eg Gertler (2003)).

[27] See also Gertler (2003) for objections to the latter paper.

(1985), and proxy the degree of IT's explicitness r_T^g by the degree of accountability/goal-transparency (pivotal features of the regime), several testable hypotheses are implied. All seem to be consistent with the real world and previous empirical findings of the literature.

First, a number of empirical studies found inflation to be decreasing in CBI, eg Grilli, Masciandaro and Tabellini (1991), Cukierman, Webb and Neyapti (1992), Alesina and Summers (1993), Eijffinger and Schaling (1993), and Eijffinger, Hoeberichts and Schaling (1998). Second, Briault, Haldane and King (1997) show that accountability, too, is associated with low inflation, and Chortareas, Stasavage and Sterne (2002) report the same to be true for transparency. Third, Debelle (1997) finds explicit IT to improve credibility. Finally, Briault, Haldane and King (1997), de Haan, Amtenbrink and Eijffinger (1999) and Sousa (2002) report a negative correlation between (goal) independence and accountability (see Figure 4).

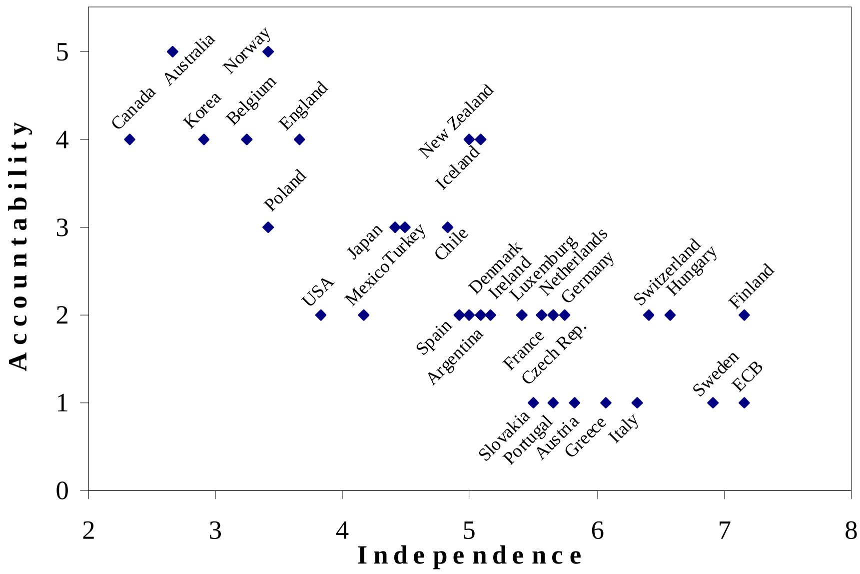

Figure 4. Central bank accountability (the 'final responsibility' component) vs independence using the Sousa (2002) indices, see his paper for details on the criteria and scores. The correlation coefficient equals -0.78 (the t-value is 6.94).

The latter finding has been viewed as undesirable since the bottom right hand corner countries feature a 'democratic deficit'.[28] The explanation derived in our model,

[28]If we only use the 'focus on price stability' criterion of the independence index that is arguable a closer proxy for conservatism α the finding remains unchanged. The same is true in the comprehensive dataset by Fry et al. (2000); both target-independence and the length of term in office are negatively correlated with punishment procedures (that apply if targets are missed or must be changed) in both industrial and transition countries.

Proposition 1(ii), is in line with the result of Schaling and Nolan (1998) and the hypothesis of Briault, Haldane and King (1997): '*The negative correlation ... suggests that accountability and transparency may have served as (partial) substitutes for independence...'*. For welfare consequences and implications for optimal timing of reform see Hughes Hallett and Libich (2006) in which a comparable result is derived through a different avenue.[29]

7. Robustness and Extensions

In order to show that our theoretical results are fairly robust, let us examine several alternative specifications and assumptions.

Anchored Expectations vs Anchored Wages. While our analysis explicitly modelled anchorness of wages, it is straightforward to show that all the results analogously obtain for expectations as well. This is intuitive – wages and expectations enter the model (the economy as well as the public's preferences) in the same way.

To demonstrate, let us make the cost of updating expectations positive $C_e > 0$. It is again natural to assume it to be decreasing in the frequency of updating, $\frac{\triangle C_e}{\triangle r_e^p} < 0, \forall r_w^p$, which reflects the cost of processing information (see eg the discussion in Mankiw and Reis (2002)). In line with this, we can consider any $\gamma \in (0,1)$ and/or $\kappa > 0$. It is evident that if the cost is sufficiently high, $C_e \geq \tilde{C}_e$, where the threshold $\tilde{C}_e$ is an increasing function of β in (5), then $r_e^{p*} > 1$, ie the public will find it optimal to update expectations infrequently. This is consistent with the models of rational inattention (Sims (2003) and Reis (2006)) and those featuring 'economically rational expectations' (Feige and Pearce (1976)) - in both streams of literature agents' expectation formation is a result of cost-benefit calculations.[30]

Under a range of reasonable circumstances the public will choose to update expectations in line with wage negotiations, $r_e^{p*} = r_w^{p*}$. Specifically, in Cournot periods expectations will be updated to make the contemporaneous wage bargaining more efficient, whereas in Stackelberg periods expectation will not get updated to minimize the cost. Moreover, even if $r_e^{p*} \neq r_w^{p*}$, under certain values of $\{C_e, c_w, c_\pi, \beta, \sigma_u^2\}$ (analogous to those of Propositions 2 and 6) we will have the anchoring effect in both expectations and wages, $\frac{\triangle r_m^{p*}}{\triangle r_T^g} > 0, \forall m$.

Timeless Perspective Commitment. In terms of $r_i^{g*} = 1$ reported in Proposition 4, it should be noted that the same result would obtain in the standard New Keynesian setting with both forward and backward looking expectations – it is optimal for the policymaker to be able to respond to shocks the period they occur. Nevertheless, this

[29]Hughes Hallett and Libich (2006) further present evidence that (goal) transparency, too, is negatively correlated to *goal*-independence. For example, it is shown that the correlation between transparency in Eijffinger and Geraats (2006) and goal-independence in Briault, Haldane and King (1997) is *-0.86 (t=-4.46)*. However, the Debelle and Fischer (1994) distinction between goal and instrument independence is crucial. Since the latter has come hand in hand with IT its correlation with transparency and accountability in most indices is positive rather than negative (for more details see Hughes Hallett and Libich (2006)).

[30]There is a growing body of literature in this spirit that examines some sort of inertia/stickiness/rigidity in updating/forming expectations (see eg Ball (2000), Mankiw and Reis (2002), Carroll (2003), Carroll and Slacalek (2006), Morris and Shin (2006)).

does not prescribe the exact form of the targeting rule the policymaker should follow, ie it is compatible with both discretionary and the *pre-commitment* solution ('timeless perspective' as popularized by Woodford (1999)). Under the latter, the targeting rule in (15) would be altered to also include past output gap, but $r_i^{g*} = 1$ would still apply.

Put differently, under our commitment the restriction relates to *when* the policymaker can move, whereas under the timeless perspective commitment it relates to *how* he can move. It is however interesting to note that both commitment concepts impact macroeconomic outcomes in the same direction – they both anchor wages/expectations to change less than it would be the case under 'discretion' (note that this term, too, means different things in the two settings). Therefore both types of commitment improve the SR variability tradeoff and reduce the volatility of interest rates.

Players' Impatience. The analysis was conducted under the assumption of *fully* patient players, $\delta_j = 1, \forall j$. Libich and Stehlík (2007a) examine discounting in this framework and show that all the LR results still obtain under a *sufficiently* patient policymaker, $\delta_g \geq \tilde{\delta}_g > 0$, and regardless of the public's discount rate, $\delta_p \in [0, 1]$. This is still true but with one interesting insight. The public's higher rate of discounting would lead to a heavier reaction of wages to current shocks, which would result in a greater misalignment of inflation and wage inflation in Stackelberg periods. This implies the following:

Remark 3. *The public's impatience reduces the anchoring effect and hence worsens the stabilization outcomes. This highlights the importance of communication and transparency of the central bank.*

Arguably, more clarity about monetary policy is likely to lead to the private agents' taking a long-term view, which strengthens the anchoring effect and reduces the variability of both inflation and output. This seems to have been the case over the past decade.

Backward-looking Agents. It is shown in Libich (2007) that all the conclusions of the LR game hold under backward-looking agents (or a combination of forward and backward agents).

Deterministic vs. Probabilistic r_m^j. It is important to realize that our deterministic commitment/anchorness can be reinterpreted as a probabilistic ones in the spirit of Calvo (1983). The reader may think of there being a certain probability (independent across time), $\theta_m^j = [0, 1)$, that instrument m cannot be reconsidered in a given period. Then the *average/expected* length of time between each reconsideration is $\frac{1}{(1-\theta_m^j)}$, which is equivalent to our r_m^j. In a companion paper Libich and Stehlík (2007c) we examine this probabilistic version explicitly.

Non-discrete and/or Non-constant r_m^j. In Libich and Stehlík (2007b) we examine the LR game in continuous time as well as using time scales calculus (a novel mathematical tool that nests both discrete and continuous time as special cases, see eg Bohner and Peterson (2001)). Comparable results are derived in these environments. Using time scales also enables us to generalize the framework by considering heterogeneous time intervals between players' moves (ie time-varying anchorness/explicitness).

Horizon of IT. Instead of assuming the IT horizon to be indefinite, it could be specified as the medium-run, MR (interpretable as the business cycle which is the case in some countries such as New Zealand and Australia). All our findings would still hold under the (reasonable) assumption that the supply shock has a zero mean over the MR. Due to the 'nullified' average effect of the shocks the two policy instruments would still be mutually consistent. In contrast, a targeting horizon shorter than the MR may lead to a conflict between the inflation target objective and the dual mandate - the commitment to the inflation target will then lead to a lower α and may inhibit output stabilization as argued by IT sceptics.[31]

Heterogeneous Agents. While assuming homogenous public may be justified on the basis of centralized wage bargaining (for references see eg Olivei and Tenreiro (2006)), examining the existence of differing players within the public may offer interesting insights. Libich (2007) generalizes the LR game analysis by introducing heterogeneous (atomistic) public – various Unions of potentially varying sizes and wage bargaining frequencies – and implies that all our conclusions still obtain.

Consumption Smoothing. This is commonly represented by an expected output term of the form $E_t x_{t+1}$ in the IS equation. It is apparent that the policy objectives are again best achieved if these expectations are anchored at the LR level, $\bar{x} = 0$. If it is not the case then after a cost push shock in t we will observe $E_t x_{t+1} < 0$ (which follows from the fact that $x_t < 0$ from equation (19)). This will tend to further decrease the current output gap, x_t, and therefore lead to Pareto inferior outcomes.

8. Summary and Conclusions

The paper provides a new tool to examine the impact of a commitment to an explicit long-run inflation target on the policymaker's short-run flexibility, and the resulting stabilization outcomes. In contrast to the widespread belief - one that Woodford coined '*traditional prejudice of central bankers*' - we find that a legislated numerical target may *increase* (rather than decrease) stabilization flexibility, and hence improve the variability tradeoff through its anchoring effect on the public's behaviour.

This is because under an explicit long-term inflation target the public adjusts wages and expectations less frequently in order to minimize the cost associated with their revision/adjustment/updating. Put differently, the public finds it optimal to look through shocks, and such anchored wage and expectations (to the target level) then enable the policymaker to more effectively fine-tune the economy (and with smaller changes in the interest rate instrument). This reduces the volatility of both inflation and output.[32]

[31] This is true of both inflation targeters from transition and developing countries, whose inflation targets are often specified over a one year period, and the inflation forecast targeting of the Bank of England type, see Svensson (1997), with its two year horizon. For example, Mishkin (2004) argues that this short targeting horizon has not been binding only due to absence of supply shocks. The real world experience suggests that the inflation target may have to start off as a rather SR goal to gain credibility, and can later be reformulated as a MR or LR objective allowing more flexibility. This is especially true if IT is used as a disinflation device.

[32] The following quote by the central banker who 'taught' IT to the world, ex-governor of the Reserve Bank of New Zealand Donald Brash (2002), summarizes our findings in several respects – it stresses the desirability of (i) agents' looking through shocks, (ii) anchorness of wages/expectations, and the resulting (iii) improved stabilization, and (iv) lower interest rate volatility: *'To put it bluntly, if the Reserve Bank is to be able to 'look through' the impact of things like the increase in petrol and cigarette prices in implementing monetary policy, we New Zealanders also need to 'look through' the impact of those things on the CPI. To the extent that we don't, and instead seek compensation for the impact of*

Our analysis thus formalizes the informal arguments of many recent papers on the effects of explicit inflation targets, eg Bernanke (2003), Goodfriend (2003), McCallum (2003), Mishkin (2004), or Lacker (2005), and similarly implies that the Federal Reserve and the European Central Bank should more explicitly commit to a (long-run) inflation target.

We show that while the empirical evidence is not conclusive, there exists fair support for all our findings.

9. References

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those things on the CPI, the Bank will need to tighten monetary policy to a greater extent... In recent years, the Reserve Bank has been happy to report that inflationary expectations are now well anchored at a low level. We have been able to say that, as a result, we expect that smaller adjustments in interest rates will be required...'

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Appendix A. Proof of Proposition 1

Proof. Let us throughout focus on the case of interest, $r_T^g > r_w^p$, and realize that, due to the assumed $r_T^g = nr_w^p$, the length/horizon of the unrepeated extensive LR game is $M(r_T^g, r_w^p, r_e^p) = r_T^g$ periods. Further, in this horizon, $\bar{\pi}^T$ gets only reconsidered once (in period 1) whereas $\bar{w}$ gets reconsidered n times (every r_w^p periods), and π^e gets reconsidered r_T^g times (every period due to $r_e^p = 1$).

Solving backwards, the public's optimal wage between its last move (that occurs in period $t = r_T^g - r_w^p + 1$) and its second move (that occurs in period $t = r_w^p + 1$) will be the best response to the policymaker's initial and observable move. Denoting b to be the best response, this implies $\bar{w}^*_{t\in[r_w^p+1, r_T^g]} \in b(\bar{\pi}_1^T)$. Further, from (5) and $r_e^p = 1$ we know that $\pi_t^e = \pi_t, \forall t$, which the public uses to perfectly predict the policymaker's initial move and set wages accordingly, $\bar{w}^*_{t\in[1, r_w^p)} \in b(\bar{\pi}_1^{T*})$. We therefore need to determine the policymaker's optimal play in period 1, $\bar{\pi}_1^{T*}$, which will then obtain for the rest of the game, $\bar{\pi}_t^T = \bar{\pi}_1^{T*}, \forall t$.[33]

The starting point is to note that in period 1 optimal wages are always set equal to inflation expectations, $w_1^* = \pi_1^e, \forall r_w^p$. For the optimal inflation target to be *time consistent* (and for a Ramsey SPNE to exist), it is required that $\bar{\pi}^O$ be the best response to optimal wages, $\bar{\pi}_1^O \in b(\bar{w}_1^O)$. This is guaranteed by the following condition

$$ar_T^g \geq cr_w^p + d(r_T^g - r_w^p). \tag{16}$$

Both the left-hand side (LHS) and the right-hand side (RHS) are derived assuming that the public plays $\bar{w}_1^O$. The LHS expresses the fact that if the policymaker plays $\bar{\pi}_1^O$ then it will achieve the payoff a in all $M = r_T^g$ periods. In contrast, the RHS describes

[33] This is because (i) in the rest of the unrepeated extensive LR game it cannot be changed, and (ii) in periods $t = nr_T^g + 1$ in which it can be changed, the decision is made under the same circumstances, so the same level will be selected as discussed above.

the scenario of the policymaker playing $\bar{\pi}_1^S$ and initially gaining the desired output x^T through an inflation surprise, and the c payoff. This however only lasts for r_w^p periods - then in period $t = r^p + 1$ the public switches to $\bar{w}^S$ which punishes the policymaker (with a d payoff) for the rest of the unrepeated game, $(r_T^g - r_w^p)$ periods. Substituting in the respective values $\{a, c, d\}$ from Figure 2 yields

$$r_T^g \geq \alpha r_w^p.$$

For *credibility* of the O level inflation target it is however required that *any* SPNE is Ramsey (otherwise S level wages and/or expectations could occur as $\bar{\pi}^S$ may also be played in equilibrium). For this to be the case $\bar{\pi}_1^O$ must be a strictly dominant strategy, thus in addition to $\bar{\pi}_1^O \in b(\bar{w}_1^O)$ from (16) (with strict inequality) it is required that $\bar{\pi}_1^O$ is the *unique* best response to $\bar{w}^S$, ie $b(\bar{w}_1^S) = \{\bar{\pi}_1^O\}$. The following condition, derived in the same way as (16) but assuming that the public plays $\bar{w}_1^S$, ensures this

$$br_w^p + a(r_T^g - r_w^p) > dr_T^g. \tag{17}$$

If satisfied, the policymaker prefers to select the O level even if he knows that $\bar{w}_1^S$ will be played and hence he will suffer some temporary output cost b due to lack of credibility. He does so knowing that he will be 'rewarded' by the public's switching to $\bar{w}^O$ when it first gets a chance, ie after r_w^p periods. Rearranging (17) yields (12) which, combined with the fact that $\tilde{r}_T^g$ is a function of α with the desired sign, completes the proof.[34] □

Appendix B. Proof of Proposition 2

Proof. The proof of Proposition 1 derived the players optimal choices and equilibrium outcomes for given values of r_T^g and r_w^p. Using these and moving backward, let us examine the public's optimal r_w^p choice made in period 0, observing r_T^g. This r_w^p choice entails a tradeoff between the inflation and the wage bargaining cost. If the public selects sufficiently short wage contracts, $r_w^p \leq \tilde{r}_w^p$, where $\tilde{r}_w^p = \frac{r_T^g}{3\alpha}$ follows from (12), then it will uniquely ensure the Ramsey SPNE. While its inflation cost will then be zero, $C_\pi = 0$ (due to $\bar{\pi}^{O*}$), its wage bargaining cost will be higher (due to more frequent bargaining - recall that $C_w = \frac{c_w}{r_w^p}$). Alternatively, if the public selects $r_w^p > \tilde{r}_w^p$ then the sub-optimal inflation level obtains, $\bar{\pi}^{S*}$, and the public will suffer a positive inflation cost, $c_\pi > 0$, accompanied by a lower wage bargaining cost C_w. Whichever the public chooses depends on the relative magnitudes of the c_w and c_π costs.

Due to the specification of C_w it is apparent that to minimize the wage bargaining cost the public would choose the upper thresholds in each of these two intervals, ie either $r_w^p = \tilde{r}_w^p = \frac{r_T^g}{3\alpha}$ or $r_w^p \to \infty$. Using the public's utility function (4) with the results of Proposition 1 implies that, under $c_w < c_\pi$, we have $U_t^p(r_w^p = \tilde{r}_w^p) > U_t^p(r_w^p \to \infty), \forall \tilde{r}_w^p, t$, ie the public will choose the former scenario. Specifically, it will select the level stated in (13), $r_w^{p*} = \tilde{r}_w^p = \frac{r_T^g}{3\alpha}$ (or, due to the assumed $r_T^g = nr_w^p$, if $\frac{r_T^{g*}}{3\alpha} \notin \mathbb{N}$ the public will

[34] It should be noted that if (12)-(17) are satisfied then there exists a unique Ramsey SPNE. This is because the policymaker's equilibrium path play is uniquely $\bar{\pi}_1^O$, to which the unique best response of the public is $\bar{w}_t^O, \forall t$. Off the equilibrium path, ie under $\bar{\pi}_1^S$, the public's optimal play is uniquely $\bar{w}_t^S, \forall t$.

select the highest integer below $\tilde{r}_w^p$). The fact that r_w^{p*} is an increasing function of r_T^g completes the proof.[35] □

Appendix C. Proof of Proposition 4

Proof. To show that under $r_i^g > 1$ there exist circumstances that lead to (π, x) deviating from (15), take for example $r_w^p > 1$, focus on the first two periods of the game, and consider a sole supply shock in period 1, ie $\hat{u}_1 \neq \hat{u}_2 = \hat{g}_1 = \hat{g}_2 = 0$. The optimal outcomes according to (15) are π_1^*, x_1^*, $\pi_2^* = \rho\pi_1^*$, and $x_2^* = \rho x_1^*$. However, under $r_i^g > 1$ the policymaker cannot adjust the interest rate in period 2, $i_2 = i_1$. Therefore, if the policymaker chooses outcomes according to (15) in period 1, π_1^* and x_1^*, then in period 2 the IS curve yields, using $w_2 = w_1$ (implied by $r_w^p > 1$), $x_2 = x_1^* \neq x_2^*$, ie the second period output is not optimal, which completes the proof. All these statements can be seen formally in (19). □

Appendix D. Proof of Proposition 5

Proof. Let us first realize that in the SR game it is still true that $\pi_t^e = \pi_t, \forall t$ (which follows from $r_e^p = 1$ and complete information). Despite this the (real) wage can now be, under $r_w^p > 1$, at a disequilibrium level due to shocks, ie $w_t \neq \pi_t$ is possible. We need to examine separately wage inflation in periods in which wages *cannot* be adjusted (which we refer to as *Stackelberg periods* and denote them by upper '*frown*', eg $\frown{\pi}_t$) and those in which they *can* be adjusted (*Cournot periods* that will have no extra notation).

The effect of r_w^p on stabilization outcomes will be examined in four steps. We will first show that the variability of both target variables in Cournot periods is decreasing in r_w^p. Second, we show the same for Stackelberg periods. Third, as the Stackelberg variance may be higher than Cournot, the same will be demonstrated for *average* variance (with the weight being the relative occurrence of Cournot vs Stackelberg periods). This will prove the result for all $r_w^p \geq 2$. Fourth, this average variance will be shown to be less than variance under $r_w^p = 1$, which will extend the proof to all $r_w^p \geq 1$.

Step 1. It follows from (5) that in Cournot periods optimal wages are set as an average of expected inflation over the whole duration of the contract

$$w_t^* = \frac{1}{r_w^p} \sum_{s=0}^{r_w^p - 1} E_t \pi_{t+s} = \frac{\pi_t}{r_w^p} \sum_{s=0}^{r^p - 1} \rho^s, \tag{18}$$

where the second element uses the fact that the public rationally expects $E_t\pi_{t+1} = \rho\pi_t$. Substituting (15)-(18) into the Phillips curve implies the reduced form expressions for equilibrium inflation and the output gap in Cournot periods

$$\pi_t^* = \frac{1}{\left(\frac{\lambda^2}{\alpha} + 1\right) - \frac{1}{r_w^p} \sum\limits_{s=0}^{r_w^p - 1} \rho^s} u_t \text{ and } x_t^* = -\frac{\lambda}{\alpha}\pi_t^*. \tag{19}$$

[35] Also note that the policymaker could choose the optimal inflation level (due to the multiple SPNE) even if $\frac{r_T^g}{r_w^p} \in [\alpha, 3\alpha)$, but since it may not be credible we assume it not to be the case. We therefore report sufficient rather then necessary conditions for the existence of the Ramsey SPNE. Finally, realize that if the sufficient conditions of Proposition 2 are not satisfied then there may be no anchoring effect, ie our result obtains weakly but is never reversed.

It is straightforward to see in (19) that the stabilization tradeoff in Cournot periods improves in wage anchorness. Focusing on the last element of the denominator, it is required that $\triangle\left(\frac{1}{r_w^p}\sum_{s=0}^{r_w^p-1}\rho^s\right)/\triangle r_w^p < 0$. This, using the formula for a finite sum and rearranging, yields

$$\rho^{r_w^p}[r_w^p(1-\rho)+1] < 1,$$

which holds for all assumed values of r_w^p and ρ. Denoting the variances of Cournot inflation and the output gap (conditional only on the fact that they occur in Cournot periods) by σ_π^2 and σ_x^2 we therefore have

$$\frac{\triangle\sigma_\pi^2}{\triangle r_w^p} < 0 \text{ and } \frac{\triangle\sigma_x^2}{\triangle r_w^p} = \left(\frac{\lambda}{\alpha}\right)^2\frac{\triangle\sigma_\pi^2}{\triangle r_w^p} < 0,$$

ie the variability of both inflation and output in Cournot periods is decreasing in r_w^p.

Step 2. In Stackelberg periods wage inflation is still at the level set at the nearest preceding Cournot period, $\widehat{w}_t = w_{t-1-s}$, where $s = 0, 1, ., r^p - 1$. Using this together with (15)-(18) and the Phillips curve yields the expressions for Stackelberg inflation and the output gap

$$\widehat{\pi}_{t+1+s} = \frac{\alpha}{\alpha+\lambda^2}\left(\frac{1}{r_w^p}\pi_t\sum_{s=0}^{r_w^p-1}\rho^s + u_{t+1+s}\right) \text{ and } \widehat{x}_{t+1+s} = -\frac{\lambda}{\alpha}\widehat{\pi}_{t+1+s},$$

which implies the variance of Stackelberg inflation and the output gap conditional on the type of period and the time after the Cournot period s (denoted by $\widehat{\sigma}_{\pi_s}^2$ and $\widehat{\sigma}_{x_s}^2$)

$$\begin{aligned}\widehat{\sigma}_{\pi_s}^2 &= \left[\left(\frac{\alpha}{(\alpha+\lambda^2)r^p}\sum_{s=0}^{r_w^p-1}\rho^s\right)^2 + \left(\frac{\alpha}{\alpha+\lambda^2}\right)^2 + \sum_{s=0}^{r_w^p-1}\rho^s\frac{2\alpha^2}{(\alpha+\lambda^2)(r_w^p+1)}\rho^{s+1}\right]\sigma_u^2 \\ \widehat{\sigma}_{x_s}^2 &= \left(\frac{\lambda}{\alpha}\right)^2\widehat{\sigma}_{\pi_s}^2\end{aligned} \tag{20}$$

Note that the variability of inflation and output in both types of periods only differs by a constant factor of $(\frac{\lambda}{\alpha})^2$. Therefore, we will show all the results for the output gap only, which will prove the claims for inflation as well. Using $\frac{\triangle\sigma_\pi^2}{\triangle r_w^p} < 0$, equation (20) implies that the variability in any one Stackelberg period is also decreasing in r_w^p, namely $\frac{\triangle\widehat{\sigma}_{x_s,\pi_s}^2}{\triangle r_w^p} < 0$.[36]

Step 3. Let us now show the same to hold for the *average* (per period) output variance in Stackelberg periods, denoted by $\bar{\widehat{\sigma}}_x^2$, which is the following weighted average

$$\bar{\widehat{\sigma}}_x^2 = \frac{1}{r_w^p - 1}\sum_{s=1}^{r_w^p-1}\widehat{\sigma}_{x_s}^2 \tag{21}$$

As the covariance between various periods' shocks is increasing in ρ, if $\frac{\triangle\bar{\widehat{\sigma}}_x^2}{\triangle r_w^p} < 0$ holds for ρ arbitrarily close to 1, then it is implied to hold for all $\rho = [0, 1)$. Using (20) and

[36] Intuitively, the fact that $\widehat{w}_{t+1+s}$ is *not* a function of $\hat{u}_{t+1+s}$ can be exploited by the policymaker in stabilization.

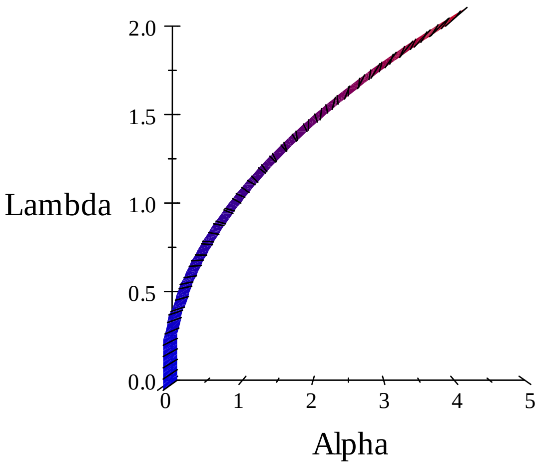

FIGURE 5. Plot of the solution to (22) in the (α, λ) parameter space. The curve depicts the threshold and all points to the right of it satisfy (22).

(21) with $\rho = 1$ and taking the first difference with respect to r_w^p yields

$$\frac{\triangle \bar{\sigma}_x^{2}}{\triangle r_w^p} = -2 \frac{\lambda^2}{(\alpha + \lambda^2)^2 (r_w^p - 1)^2} < 0$$

Combining this with $\frac{\triangle \sigma_x^2}{\triangle r_w^p} < 0$ implies that the average *overall* output variance under $r_w^p \geq 2$, denoted $\bar{\sigma}_x^2$, is decreasing in r_w^p.

Step 4. This step shows that the conclusion of step 3 extends to the case of $r_w^p = 1$, ie our result in Proposition 5 applies for $\forall r_w^p$. Therefore, we need to show that $\bar{\sigma}_x^2(r_w^p) < \sigma_x^2(r_w^p = 1), \forall r_w^p$. To do so we can focus on the *sufficient* condition, and hence the worst case scenario with $\rho \to 1$ and $r^p = 2$.[37] Using these values with all the above information yields the following

$$\sigma_x^2(r_w^p = 1) - \bar{\sigma}_x^2(r_w^p = 2) = \frac{1}{\lambda^2} - \frac{1}{2}\lambda^2 \left(\frac{6}{(\alpha + \lambda^2)^2} + \frac{1}{(\frac{\alpha}{2} + \lambda^2)^2} \right) > 0 \tag{22}$$

This inequality can be simplified into $4\alpha^4 + 24\alpha^3\lambda^3 + 39\alpha^2\lambda^4 + 12\alpha\lambda^6 - 12\lambda^8 > 0$, which makes it transparent that there exists some threshold value $\tilde{\alpha}$ above which it is satisfied (see Figure 5 for a demonstration).

[37] The result $\frac{\Delta \bar{\sigma}_x^2}{\Delta r^p} < 0$ implies that $\bar{\sigma}_x^2$ has it maximum in $r^p = 2$ (in the region for which it is defined, $r^p \geq 2$).

Since the real world value of λ is very small, it can be claimed that (22), and hence Proposition 5 (given that the expression for inflation is analogous), holds for all 'reasonable' parameter values.[38] Steps 2-4 also imply that the policy frontier of Figure 3 is qualitatively unchanged if we replace the Cournot variances, σ_π and σ_x, with the average variances, $\bar{\sigma}_\pi$ and $\bar{\sigma}_x$. This completes the proof. □

Appendix E. Proof of Proposition 6

Proof. The public's *average* one-period expected utility is, using (5), the negative of the sum of the wage bargaining cost and the average variance of the inflation-wage gap, denoted $\bar{\sigma}_p^2$

$$E\bar{U}^p = -\frac{c_w}{r_w^p} - \bar{\sigma}_p^2$$

Substituting in the above derived expressions and rearranging yields

$$E\bar{U}^p = -\frac{c_w + 1}{r_w^p}\left(\frac{\alpha\left(1 - \frac{\sum_{s=0}^{r_w^p-1}\rho^s}{r_w^p}\right)^2\sigma_u^2}{\left(\alpha + \lambda^2 - \frac{\alpha}{r_w^p}\right)^2} + \sum_{s=1}^{r_w^p-1}\left(\begin{array}{l}\frac{\alpha^2\sigma_u^2}{\left(\alpha+\lambda^2-\frac{\alpha}{r_w^p}\right)^2}\left(\frac{-\lambda^2\sum_{s=0}^{r_w^p-1}\rho^s}{(\alpha+\lambda^2)r_w^p}\right)^2 + \left(\frac{\alpha\sigma_u}{\alpha+\lambda^2}\right)^2 \\ +\frac{2\alpha^2\rho^s\sigma_u^2}{(\alpha+\lambda^2)(\alpha+\lambda^2-\frac{\alpha}{r_w^p})}\left(\frac{-\lambda^2\sum_{s=0}^{r_w^p-1}\rho^s}{(\alpha+\lambda^2)r^p}\right)\end{array}\right)\right)$$

We aim to derive a *sufficient* condition for the level of $\tilde{c}_w$, above which the public's expected utility is *monotonously* increasing in $r_w^p, \forall r_w^p \geq 1$. Therefore, we will focus on the worst case scenario. Realizing that $\frac{\triangle\bar{\sigma}_p^2}{\triangle r_w^p} < 0$ and $\frac{\partial\bar{\sigma}_p^2}{\partial\rho} < 0$ means depicting the case $r_w^p = 2$ and $\rho = 0$. This yields, after some manipulations

$$\tilde{c}_w \leq \frac{2\alpha^2(\alpha^2 + 3\alpha\lambda^2 + 3\lambda^4)}{(\alpha^2 + 3\alpha\lambda^2 + 2\lambda^4)^2}\sigma_u^2 \tag{23}$$

It is straightforward to verify that the RHS has a global maximum at the level of $\lambda = 0$. Using (23) with $\lambda = 0$ one then obtains the sufficient condition

$$\tilde{c}_w \leq 2\sigma_u^2.$$

These calculations however imply that (i) this sufficient condition is not tight, eg under $\lambda = 0.13, \rho = 0.2, r_w^p = 12$ and any $\alpha \leq 2$, the sufficient condition becomes $c_w \geq \tilde{c}_w = 1.07\sigma_u^2$; and (ii) necessary and sufficient condition is yet weaker. □

Appendix F. Proof of Proposition 8

Proof. The effect of r_T^g on $var(x^*)$ and $var(\pi^*)$ is implied by combining the fact that sufficiently explicit IT anchors wages (Proposition 6), and wage anchorness reduces the variability of both inflation and output (Proposition 5). It therefore suffices to focus on the effect of r_T^g on $var(i^*)$. The fact that the variability of equilibrium wages, inflation and output is decreasing in r_w^p implies, using the IS curve, that the same is true for

[38] For example, if $\lambda = 0.13$ (as estimated by Rudebusch (2002)), then the sufficient condition in (22) is satisfied for $\alpha \geq \tilde{\alpha} = 0.017$. The necessary condition is yet weaker; under $\lambda = 0.13, \rho = 0.2, r_w^p = 12$ we have $\tilde{\alpha} \cong 0.0008$.

the equilibrium interest rate, $\frac{\triangle var(i^*)}{\triangle r_w^p} < 0$, and hence $\frac{\triangle var(i^*)}{\triangle r_T^g} < 0$. Put differently, the improved stabilization in (19) will be achieved by a less aggressive interest rate response in both Cournot and Stackelberg periods. This is because in the former wages respond less than fully to the current shock, and in the latter they do not respond to the current shock at all. □