Inflation Nutters?
Modelling the Flexibility of Inflation Targeting

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Abstract

Opponents of explicit inflation targeting (including ex-Chairman Greenspan) have argued that a commitment to a numerical inflation target reduces monetary policy's flexibility, and is hence likely to increase output volatility. Our paper demonstrates that this claim may fail to account for the anchoring effect of explicit targets on expectations and wages - found in the data by a number of empirical studies. This is done in a novel, dynamic game theoretic framework with asynchronous moves. It incorporates the concept of 'economically rational expectations' by *endogenizing the frequency* of the private sector's and the central bank's actions. We derive the conditions under which a sufficiently explicit long-term inflation target makes the behaviour of private agents rationally inattentive and anchored. This is because it enhances monetary policy credibility, which leads private agents to reconsider expectations and wages only *infrequently* to minimize the cost of processing information and/or wage negotiations. Such anchorness makes the policymaker's interest rate instrument more effective in stabilization, giving it greater leverage over the real rate. The implication is that unless supply shocks are excessive, an explicit inflation target improves the variability tradeoff, ie it shifts the policy frontier inwards. It can therefore make *both* inflation and output less variable in equilibrium, unlike what inflation targeting sceptics argue. 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. We conclude by showing that our results are consistent with existing empirical evidence.

Keywords: explicit inflation targeting, stabilization flexibility, output volatility, nominal anchor, commitment, dynamic games, asynchronous moves, rule, discretion, wage rigidity, central bank independence.
JEL classification: E42, E61, C72

[1]I would also like to thank Don Brash, Chris Carroll, Viv Hall, Peter Howitt, Andrew Hughes Hallett, Jonathan Kearns, Michele Lenza, Martin Melecky, Ben McCallum, Glenn Otto, Jeff Sheen, Daniel Thornton, Carl Walsh, John Williams, the participants of the 2008 American Economic Association meeting, the 11th Australasian Macroeconomics Workshop, the 24th Australasian Economic Theory Workshop, the 35th Australian Conference of Economists, the ZEI Summer School on Monetary Theory and Policy, and seminars at Victoria University of Wellington, the Reserve Bank of New Zealand, Deutsche Bundesbank, Dutch National Bank and Czech National Bank for their comments and suggestions. All remaining errors are mine. Please address correspondence to Jan Libich, La Trobe University, School of Business, Melbourne, Victoria, 3086, Australia. Phone: +61 3 24792754. Email: j.libich@latrobe.edu.au. This is a modified version of a paper circulated as Inflexibility of Inflation Targeting Revisited: Modelling the 'Anchoring' Effect.

'The extent to which inflation targeting regimes impair central bank flexibility is a matter of professional dispute. There is probably no way that this disagreement can be settled in the present state of economic knowledge.' McCallum (2003)

'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)

'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)

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 associated with the regime's defining feature - an *explicit* commitment to a numerical inflation target.

On one hand, it has been argued that legislated numerical targets are beneficial in stabilization as they better *anchor* inflation expectations and wages (eg Mishkin (2004) above, or Bernanke (2003), Goodfriend (2003), McCallum (2003), Mishkin (2004), Lacker (2005). On the other hand, it has been believed that such a commitment constrains the policymaker's *stabilization flexibility* (eg Rudebusch and Walsh (1998) above, or Greenspan (2003), Kohn (2003), Friedman (2004)), which may lead to higher output volatility and interfere 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 link between them that may be crucial in assessing the regime's desirability.

In summary, our analysis demonstrates that the inflexibility concerns of IT sceptics indeed seem what Woodford coined '*traditional prejudice of central bankers*'. It is shown that explicit long-run targets are not inflexible in output stabilization per se, ie inflation targeters are not necessarily 'inflation nutters' (King (1997)). The model in fact shows the opposite: under reasonable circumstances explicit inflation targets *decrease* rather than increase the variability of output. This is due to their anchoring effect on expectations and wages that leads to a more effective policy leverage over the real interest rate and hence greater flexibility and control of monetary policy. Therefore, while the short-run tradeoff between stabilizing inflation and output arising from the Phillips curve is still present, it is improved and hence the desired reduction in variability can be achieved for both these variables.

[2]For extensive treatments of IT see Bernanke et al. (1999), Svensson (1999), Blejer et al. (2000), Mishkin and Schmidt-Hebbel (2001), Truman (2003), or Bernanke and Woodford (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.

This mechanism is shown in a novel asynchronous game theoretic framework developed by Libich and Stehlík (2010). The framework is a generalization of both simultaneously repeated games and alternating move games (Maskin and Tirole (1988)) in the direction of more dynamics. Specifically, the players take actions at a certain *frequency.* While the frequency is constant, it may: (i) differ across the players and their instruments, and (ii) be endogenous.[4]

Formally, after a simultaneous initial move in period 1, each player can adjust each of his instruments m every $r_m \in \mathbb{N}$ periods. While both the public and the policymaker are forward looking, they may rationally choose to move infrequently - a high r_m. This is either to commit to their actions, or minimize the cost $C_m(r_m)$ associated with their actions.

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 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. Second, unlike these standard setups in which gathering/processing information, updating expectations, or renegotiating wages is commonly costless, our framework incorporates some costs of these activities. Third, the frequency of the players' decisions can be made endogenous, ie optimally selected based on cost-benefit calculations in line with the increasingly popular concepts of 'economically rational expectations' (Feige and Pearce (1976)) and 'rational inattention' (Sims (2003) and Reis (2006)).

The inflexibility view of IT sceptics seems to be grounded in the following intuition. Let the policy objective function be as follows: $U = -\alpha var(x) - var(\pi)$, 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 (1985) coined a conservative central banker. It is straightforward to show that in the presence of aggregate supply shocks output volatility is indeed decreasing in α.

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, since this would imply an inflation nutter with $\alpha = 0$. In contrast, a number of academics and central bankers 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)).[5] This is because shocks have a zero mean so they do not affect the steady-state (average) levels of inflation and output. It then follows that such explicit

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[4] Such generalization seems overdue as it was already called for by Tobin (1982): *'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'.*

[5] To document, Svensson (2009) notes that: *'Previously, flexible inflation targeting has often been described as having a fixed horizon, such as two years, at which the inflation target should be achieved. However, as is now generally understood, under optimal stabilization of inflation and the real economy there is no such fixed horizon at which inflation goes to target or resource utilization goes to normal.'*

long-run IT does not imply stricter IT, ie it does not necessarily affect the parameter α, the stabilization flexibility, and the volatility of the targeted variables.[6]

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 Gürkaynak et al. (2009) and (2005), Beechey et al. (2008), Levin et al. (2004) or Kuttner and Posen (1999). It then shows that, due to this effect, the policy's flexibility may in fact increase (and output volatility decrease) under explicit IT, contrary to what IT opponents conjecture.

This parallels the findings of Adam (2008) and Orphanides and Williams (2005), and echoes the arguments of Bernanke (2003), Goodfriend (2003), and Mishkin (2004) that the extra credibility gained by IT enables central banks to reduce the interest rate more aggressively in response to shocks without 'upsetting' inflation expectations. Our finding is similar in that: (i) a sufficiently explicit long-run inflation target better anchors the public's behaviour (unless the variance of the supply shock is very high), and (ii) this makes the policymaker's interest rate instrument more effective in stabilization. We however show that such anchoring leads to an improved variability tradeoff - an inward shift of the policy frontier. Therefore, a *less* aggressive interest rate response is required in equilibrium to achieve lower volatility of both output and inflation. Since interest rate volatility is disliked (see eg Woodford (1999)), this constitutes an additional advantage of explicit long-run IT.

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 endogenously infrequent. Section 4 examines the LR (trend) outcomes whereas Section 5 considers the SR (stabilization) outcomes. Section 6 summarizes and concludes.

2. The Model

We use the New Keynesian setup of Clarida et al. (1999), but extend it in terms of (i) the number of the players' instruments, (ii) the timing of the players' actions, and (iii) the costs associated with the frequency of actions. The latter two extensions (discussed in detail in the next section) utilize a novel asynchronous game theoretic framework developed in Libich and Stehlík (2010).

Let us mention that merging a stochastic macro model (albeit reduced-form) into a dynamic asynchronous game framework (primarily designed for deterministic situations) has not been a trivial task and presented some modelling challenges. Therefore, in order for this merger to be feasible some simplifying assumptions and shortcuts need to be made to both the setting of Clarida et al. (1999) and the asynchronous framework. It is our belief that the benefit of deriving closed-form analytical solutions provides a justification for the taken approach. Given that the anchoring effect has been repeatedly identified in empirical studies, and its welfare consequences are far-reaching, it seems highly desirable to capture it theoretically and assess its macroeconomic effects.

[6] The policy responses to the global financial crisis demonstrate this also. Explicit inflation targeters responded vigorously to the situation willing to deviate from their inflation targets in order to stabilize the financial sector and the real economy.

In terms of the player's 'instruments', each has two distinct ones. The public, player p, forms inflation expectations, π^e, and sets wage inflation, w. The monetary 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 as implied by Svensson's (2009) quote above). In addition, each player has two other choice variables regarding the frequencies with which the levels of these instruments can be reconsidered throughout the game: we discuss this timing in the next section.

Throughout, both the public and the policymaker are assumed to be rational, have common knowledge of rationality, and complete information about the economy and the structure of the game. We will further abstract from the players' discounting for simplicity. These assumptions are made in order to better focus on the costs associated with the frequency of the players' actions, $C_m(r_m)$. It will become clear that the intuition of our results does not depend on any of these assumptions.

In the standard New Keynesian model of Clarida et al. (1999) the economy is described by two equations, namely a Phillips curve and an IS curve.[7] We extend both to feature w, the rate of change of nominal wages (wage inflation) as in Rogoff (1985). Using the above notation 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 discrete time, and $\lambda > 0$, $\gamma = [0,1]$, $\kappa \geq 0$, $\varphi \geq 0$ are parameters.[8] The disturbances follow the usual AR1 processes

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

where $\rho \in [0,1)\,, \mu \in [0,1)\,, \hat{u} \sim \text{iid}(0, \sigma_u^2)$ and $\hat{q} \sim \text{iid}(0, \sigma_q^2)$. The policymaker's period preferences are

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

where the inflation target is at the socially optimal level (which we throughout normalize to zero, $\pi^O = 0$). The output gap target can however be positive, negative or zero, $x^T \in \mathbb{R}$.[9] As discussed above, α expresses the reciprocal of the degree of *conservatism/strictness of IT* (the literature building on Rogoff (1985) interprets it as a measure of central bank independence). Further, C_T is an *IT implementation cost* and

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

[8] The timing of π_t^e will be specified (endogeneously) in Section 3.2. It will nevertheless be discussed in Appendix H that the intuition of our findings holds for various specifications of expectations π_t^e including the common $E_t\pi_{t+1}$.

[9] A number of reasons for $x_T \neq 0$ have been identified in the literature, such as mismeasurement of potential output (eg Orphanides (2001)), market imperfections (eg Kydland and Prescott (1977), Barro and Gordon (1983)), political economy reasons (eg Faust and Svensson (2001)), a shortcut way to reflect asymmetry in the policymaker's preferences (as in eg Cukierman and Gerlach (2003), Ruge-Murcia (2004)), or to represent spillovers from excessive fiscal policy (in the spirit of Sargent and Wallace (1981)).

C_i is a monetary policy committee *meeting cost* (both will be discussed below). The public's period utility function is the following

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

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 conventional, 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. The additional C_w and C_e 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', in which the players' frequency of 'moves' 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 adjusted *simultaneously* at *each* period t, ie $r_m = 1, \forall m \in \{\pi^e, w, \pi^T, i\}$. The same is implicitly assumed in conventional rational expectations models.

Under this special case our model yields outcomes analogous to Clarida et al. (1999). To see this, set up the Lagrangian, disregard the costs C in (4)-(5), and impose rational expectations to obtain the familiar targeting rule under discretion

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

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

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

As is standard, the supply shock in (7) does not affect the steady-state values due to its zero mean. This implies independence of LR levels from SR disturbances, ie the mutual consistency of the two instruments of the policymaker, π^T and i. Formally, denoting all LR variables by a bar and using $\bar{u} = 0$ with (7) yields the following LR equilibrium levels

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

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, π^O, but choose, through i_t, a different level of inflation, $\pi_t^* \neq \pi^O$, that maximizes its objective function according to (6)-(7) in a discretionary fashion.[10] This fact that LR commitment is consistent with SR discretion is obviously not specific to our model; it is present in most settings used in monetary analysis including Clarida et al. (1999). For that reason, IT has been referred to 'constrained discretion'.

[10]Responses of IT central banks to the global financial crisis provide a good demonstration of this point.

3.2. **Generalized Timing: Possibly Infrequent and Asynchronous Moves.** Our framework allows for $r_m \geq 1, \forall m \in \{\pi^e, w, \pi^T, i\}$, and thus generalizes the simultaneously repeated game with $r_m = 1, \forall m$, and the asynchronous (alternating) move setups of Maskin and Tirole (1988) and Lagunoff and Matsui (1997) with $r_m = 2, \forall m$. 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...'*. In doing so the framework draws on the intuition of games with endogenous timing, eg Bhaskar (2002).

Interpretation of r_m's. We will refer to r_e as *expectations anchorness* and to r_w as *wage anchorness (or rigidity).* The interpretation is as follows: the less frequently expectations and wages can be altered the more anchored (rigid) they are. Further, r_T can be interpreted as a measure of the degree of monetary policy's *LR commitment* due to its role in tying the policymaker's hands in regards to average inflation.[11] We will also refer to r_T as the degree of *explicitness of IT*. This is because arguably the more explicitly a long-run inflation target is stated in the central banking legislation or Statutes, the less frequently/likely the target can be altered, which increases the LR policy commitment.

As a real world example of r_T, the 1989 Reserve Bank of New Zealand Act states that the inflation target may only be changed in a Policy Target Agreement (PTA) between the Minister of Finance and the Governor, and this can only be done on pre-specified regular occasions (eg when a new Governor is appointed). Such explicit arrangement implies a high value of r_T - since December 1990 the PTA was only 'reconsidered' five times, ie roughly every three years (and on two of these occasions the target was slightly altered). In contrast, central banks without a legislated numerical target can arguably alter their inflation objective π^T more readily as it cannot easily be monitored by the public.[12] Allowing IT explicitness to have various degrees, $r_T \in \mathbb{N}$, rather than only distinguishing targeters vs non-targeters, addresses Gertler's (2003) criticism of the existing literature.

Game Theoretic Assumptions. The version of the framework used here adopts all the main features of a standard repeated game for comparability. Time is discrete, the game starts with a simultaneous move of all actions, and all r_m's as well as the opponent's preceding periods' moves can be observed (ie perfect monitoring). We postulate the following timing that we find most realistic in the monetary policy context: for an example see Figure 1.

(1) The policymaker selects r_T and r_i. Observing these, the public chooses r_e and r_w. All these choices apply throughout the whole game, ie all r_m's are constant.
(2) At the beginning of every period t there is a realization of shocks, u_t and q_t.

[11] 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 et al. (1999) in which $r_T = r_i = 1$ is implicitly assumed. We discuss the links between the two concepts in Appendix H.

[12] Nevertheless, an absence of a legislated inflation target does not necessarily imply $r_T = 1$. A central bank pursuing an inflation target *implicitly* (see eg Goodfriend (2003) for the US, and Bernanke et al. (1999) for the Bundesbank and the Swiss National Bank in the 1980s) can be described by some $r_T > 1$.

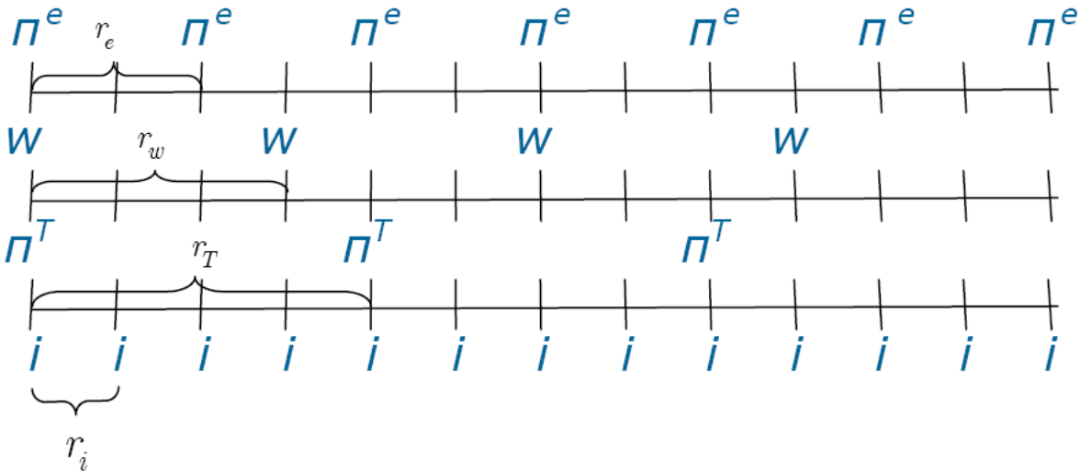

FIGURE 1. An asynchronous game: an example of the timing with $r_e = 2, r_w = 3, r_T = 4, r_i = 1$.

(3) In period 1 observing all r_m as well as u_1 and q_1, the players simultaneously set the levels of $\{\pi^e, w, \pi^T, i\}$.
(4) After period 1, the $\{\pi^e, w, \pi^T, i\}$ levels can then be reset every $\{r_e, r_w, r_T, r_i\}$ periods respectively, observing current and past shocks.[13]

Macroeconomic Assumptions. In terms of $C_i(r_i)$ the literature has not put forward any reasons for a non-zero value – this is because the cost of more frequent monetary policy committee meetings seems trivial relative to the macroeconomic consequences. Therefore, we will assume $C_i(r_i) = 0, \forall r_i$. Similarly, we will set $C_T(r_T) = 0, \forall r_T$. 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 relative to the stabilization outcomes.[14]

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)).

[13]Such full information is often assumed in the New Keynesian framework. It will make it possible to attribute the public's inattention to not-processing the available information rather than to not-possessing 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).

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

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, $\frac{\triangle C_w}{\triangle r_w} < 0, \forall r_w$.[15] In order to make the game theoretic analysis more transparent and enable us to derive analytical solutions several simplifying assumptions will be made. First, we use the following functional form for the wage bargaining cost

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

where $c_w > 0$. Second, as a matter of experimental control we will separate the effects of anchored (rigid) wages and anchored (sticky) expectations. This is because π^e is used in setting w and these two actions are therefore interconnected. We will focus on wages for two reasons. First, wage rigidity is an established concept with substantial empirical support. Second, Levin et al. (2005) find that the performance of optimal policy is closely matched by a simple wage stabilization rule and stress *'the importance of additional research regarding the structure of labor markets and wage determination'*.

In focusing on wage anchorness we will assume $C_e(r_e) = 0, \forall r_e$, and in line with this $\kappa = \gamma = 0$. This eliminates the direct expectational effect, but expectations still feature indirectly as they form the basis for wage setting. It then follows from (5), in combination with $\beta > 0$ and (7), that the public will choose to update expectations every period, $r_e^* = 1, \forall r_T, r_i, r_w$. Intuitively, the supply shock may occur every t, and it affects π_t^* (see (7)), which the public attempts to correctly expect (see (5)). This in turn, combined with the assumed full information, implies $\pi_t^{e*} = \pi_t, \forall t$, and has two advantages. It coincides with the assumption underlying the standard rational expectation solution. Further, the analysis will be simplified as the public will be setting wages using the 'correct' inflation expectations. Nevertheless, we will in Appendix H also discuss the cases $C_e, \kappa, \gamma > 0$ (and hence $r_e^* > 1$), which will imply that the intuition and impacts of anchorness in wages and expectations are analogous.

Two Stage Analysis. Due to the same expositional considerations, it is beneficial to present the results in two separate (but interconnected) parts: the 'LR game' and the 'SR game'. The LR game will focus on trend outcomes, primarily on setting the inflation target and trend wage growth, and will therefore consider the game under the assumption of no shocks. This part will derive the LR conditions for the inflation target to be credible, and for it to have an anchoring effect. In doing so it will communicate the intuition of the asynchronous game and its solution.

The SR game will then feature the full model including shocks and study the resulting deviations from the reported LR outcomes. This part will derive an additional SR condition for anchoring, and show its stabilization effects. The interplay of the LR and SR perspectives is important - while the anchoring effect is a LR phenomenon, its macroeconomic impact extends to SR stabilization as well.

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

4. The LR Game

Shocks do not affect the LR (average) levels of the variables, see (7), and can therefore be disregarded in this section (as well as the related r_i choice) by imposing $u_t = q_t = 0, \forall t$. In the absence of shocks the asynchronous LR game has a *stage game* that: (i) is itself a dynamic game, and (ii) lasts M periods where $M \in \mathbb{N}$ is the 'least common multiple' of all r_m. To give an example, in Figure 1 where $r_T = 4, r_w = 3, r_e = 2$ we have the least common multiple $M = 12$.

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 π^T and w: one optimal, O, and one sub-optimal, S. Specifically, we select the inflation level and the output gap target level:[16]

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

Using this with (1), (4), and (5) we can derive the following payoff matrix of the standard *static* (one period) stage game, where the first payoff $\{a, b, c, d\}$ refers to the row player g and the second payoff to the column player p.[17]

(12)

		Public	
		w^O	w^S
Policymaker	π^O	$a = -\alpha; 0$	$b = -4\alpha; -1$
	π^S	$c = -\lambda^2; -(c_\pi + 1)$	$d = -\left(\alpha + \lambda^2\right); -c_\pi$

Due to the truncation of the LR action sets in (11), we make three technical assumptions. 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 $\pi^S = \lambda x^T \neq \pi^O$. Note however, that π^S can still be greater or less than π^O.

Second, in order to preserve the time inconsistency feature in our truncated game, ie for $c > a$ to hold, we only consider the cases $\alpha > \lambda^2$. This is however not very restrictive since the real world value of λ is small; for example, Rudebusch (2002) estimates it to be 0.13. Therefore, this assumption effectively only excludes strict inflation targeting.[18]

It is apparent in (12) that the static normal form game with $r_m = 1$ has a unique Nash equilibrium, (π^S, w^S). The 'problem' identified by Kydland and Prescott (1977) is that the Nash is Pareto inferior to the efficient outcome (π^O, w^O). We will show that allowing for asynchronous moves, $r_T > 1$ and $r_w > 1$, may alter the outcomes of the game. This is because it allows for the possibility of policy commitment.

Third, we will throughout focus on the policy commitment case, $r_T > r_w$. The equilibrium r_T^* will later be shown to satisfy this condition. In this region let us restrict our attention to the intuitive special case of $r_T = nr_w$, where $n \in \mathbb{N}$. This assumption reduces the degree of asynchrony, and the length of the dynamic stage game to

[16]The output target in (11) is normalized by λ to simplify the payoff functions. Under different O and S values the results of the LR game may differ quantitatively, but their qualitative nature would be intact, see Libich (2009) for a different truncation of the action sets.

[17]For illustration we set $c_w \to 0$ and $\left(x^T\right)^2 = 1$ in (12).

[18]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) are not strict inflation targeters in practice, and attempt to stabilize output: see eg Cecchetti and Ehrmann (1999) or Kuttner (2004).

$M(r_T, r_w, r_e) = r_T$ periods (one move of the policymaker and n wage moves of the public). Nevertheless, Libich and Stehlík (2010) demonstrate that this special case $n \in \mathbb{N}$ is representative of the more asynchronous cases $n \notin \mathbb{N}$ in which the dynamic stage game can be up to $M(r_T, r_w, r_e) = r_T r_w r_e$ long, and both players act as Stackelberg leaders for some parts of the game. We will refer to the periods in which wages can be renegotiated as *bargaining* periods and those in which wages cannot be adjusted as *non-bargaining* periods.

Credibility. Let us define the following concept drawing upon the intuition of the literature, eg Faust and Svensson (2001) and Demertzis et al. (2008).

Definition 1. *An inflation target π^O will be called* ***credible*** *if the public (i) expects this inflation level on average in equilibrium, $\bar{\pi}^{e*} = \pi^O$, and therefore, (ii) optimally sets trend wage growth at this level, $\bar{w}^* = w^O = \pi^O$. If either (i) and/or (ii) are not satisfied, ie if expectations and/or wages differ from the inflation target on average, the target will be called to* ***lack credibility****.*

Note that as the inflation target is a LR objective, its credibility depends on expectations of average inflation and average wages.

Repetition, Strategies, and Equilibria. Throughout the LR game, we will be interested in conditions under which the sole *Pareto-efficient* outcome (π^O, w^O) *uniquely* obtains on the equilibrium path. This is because such outcome has obtained in developed countries for several decades now. Due to such interest we can, without loss of generality, focus on the dynamic stage game knowing that repeating it and allowing for reputation building of some form would not affect the reported equilibrium.[19] In doing so 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.

Definition 2. *Any SPNE that has, throughout its equilibrium path, both players in the LR game playing the optimal O levels will be called* ***Ramsey****.*

Results. We can now propose two sets of results for the LR game. Their order is implied by the backwards induction solution of the game used. The first proposition reports findings about the effect of r_T on average inflation, wages, and the inflation target's credibility (treating both r_T and r_w as exogenous). The second focuses on the relationship between r_T and r_w and reports the anchoring effect (treating r_T as exogenous and r_w as endogenous). Section 5 will show that all these results obtain even in the SR game in the presence of stochastic disturbances. It will then report results relating to the policymaker's optimal IT explicitness decision (treating both r_T and r_w as endogenous).

Proposition 1. *(i)* ***IT Credibility****: The π^O level of the inflation target is credible if and only if the target is sufficiently explicit. Only then a policymaker with $x^T \neq 0$*

[19] Intuitively, if the dynamic stage game has a unique SPNE that is efficient, then the effective minimax values of the repeated game will be equivalent to those of the dynamic stage game - since these cannot be improved upon. Put differently, since the outcome lies on the Pareto frontier the set of Pareto superior payoffs is empty. For the fact that the Folk theorem may not apply in asynchronous games, which is the case here, see eg Takahashi and Wen (2003).

behaves 'as if' he targets the natural rate of output, and such behaviour is credible.
(ii) ***IT Substitutability****: Explicitness of IT and strictness of IT (conservatism/goal-independence) are partial substitutes in achieving the target's credibility.*

Proof. The proposition states that (i) iff the target's explicitness is above some threshold, then the O levels will obtain throughout the LR game on average: $w_t^{O*} = \pi_t^{e*} = \pi_t^{O*}, \forall t, \alpha, x^T$. Put differently, the LR game has a unique SPNE that is of the Ramsey type. Appendix A derives a *necessary* credibility condition

$$r_T \geq \frac{\alpha}{\lambda^2} r_w, \tag{13}$$

as well as a *sufficient* credibility condition

$$r_T > \tilde{r}_T = \frac{3\alpha}{\lambda^2} r_w. \tag{14}$$

These conditions also prove claim (ii) by showing that the threshold levels are a decreasing function of the policy's strictness/conservatism/goal-independence (increasing in α). □

Unlike in the standard repeated game of the Barro and Gordon (1983) type, in the asynchronous game the optimal inflation target π^O may be time consistent and credible even if $\alpha > 0$ and $x^T \neq 0$; and this is true even in the worst case scenario of a finite game without reputation building. To achieve this, the policymaker must be sufficiently strongly committed, ie his inflation target must be sufficiently explicit. Intuitively, under $r_T > r_w$ the public gets to re-adjust wages *after* it has observed the level of inflation. Therefore, if the policymaker plays the S level then the public will get to 'punish' him with S level wages and the inefficient Nash.[20]

The proof in Appendix A shows that if $r_T > \tilde{r}_T$, 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 without fear of being surprised, and π^O then 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.

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 formally show how such behaviour will be achieved in equilibrium, and under what circumstances it will be credible in the eyes of the public. Our analysis fills this gap by deriving a sufficient degree of IT's explicitness, $\tilde{r}_T$, that ensures credibility throughout even for $x^T \neq 0$.

The results imply that a mere announcement of a preferred average inflation level, without it being legislated, may be an insufficient to achieve credibility, $r_T < \tilde{r}_T$. This is because it is easier to be reneged upon in the future than a formally legislated target.

Proposition 1 implies two auxiliary results of interest. First, it offers an explanation for the differences in IT explicitness across countries (due to its substitutability with other

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

institutional characteristics). Second, it implies a greater need for explicit commitment after an inflationary or deflationary experience (in order to escape inefficient equilibria). To maintain the focus of the paper we relegate the discussion of the latter point to Appendix B.

The next proposition examines the relationship between explicit IT and the equilibrium frequency of wage negotiations.

Proposition 2. ***Anchoring Effect (LR)****: If the wage bargaining cost is sufficiently low relative to the inflation cost, $c_w < \tilde{c}_w(c_\pi)$, then a sufficiently explicit inflation target, $r_T > \tilde{r}_T$, anchors wages. Specifically, wage anchorness is increasing in the degree of IT's explicitness.*

Proof. The proposition claims that $\frac{\triangle r_w^*}{\triangle r_T} > 0$, for all $r_T > \tilde{r}_T$ and $c_w < \tilde{c}_w(c_\pi)$. Appendix C first derives the latter threshold and then shows equilibrium wage anchorness to be, under the stated conditions,

$$r_w^* = \frac{\lambda^2 r_T}{3\alpha}. \tag{15}$$

The fact that r_w^* is an increasing function of r_T proves the claim. □

Intuitively, in its r_w choice the public faces a tradeoff between minimizing two costs: the wage bargaining cost (by selecting long contracts, high r_w) and the inflation cost (by selecting sufficiently short contracts and ensuring π^{O*}). If $c_w < \tilde{c}_w(c_\pi)$ then the public is more willing to incur a higher wage bargaining cost in order to ensure the optimal average inflation level π^O. This means choosing the r_w^* level from (15).[21]

5. The SR Game

In this section we use the full model including shocks as specified in (1)-(3). Let us first note that our results of the LR game carry over to this stochastic environment. In terms of Proposition 1, both claims still obtain under shocks since these have a zero mean and do not affect the LR inflation level (see (8)). It then follows that they affect neither LR expectations and wages, nor the credibility of the LR inflation target. 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.

To be able to focus on the SR deviations in this section we will start off by simply assuming that the sufficient credibility condition in (14), $r_T^* > \tilde{r}_T$, is satisfied and prove it ex-post. Our first SR game result relates to the policymaker's optimal choice of r_i, the frequency of the policy meetings (ie potential interest rate decisions).

Proposition 3. ***Frequency of Policy Decisions:*** *The policymaker will find it optimal to have the ability to adjust the interest rate (and hence inflation and output) every period, $r_i^* = 1$.*

[21]Note that since there exist Ramsey type SPNE in the multiple region $\frac{r_T}{r_w} \in \left[\frac{\alpha}{\lambda^2}, \frac{3\alpha}{\lambda^2}\right)$, the public could perhaps choose a somewhat longer contract. But since the policymaker may still be tempted to surprise inflation, we pay attention to the sufficient rather than necessary conditions for credibility. Let us also mention 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.

Proof. Under $r_T > \tilde{r}_T$ the optimal LR levels obtain, so the game is played 'as if' $x^T = 0$ - see Proposition 1(i). Therefore, the optimal targeting rule in (6) effectively becomes, $\forall x^T$

$$\pi_t = -\frac{\alpha}{\lambda} x_t. \tag{16}$$

The simplest way to prove that $r_i^* = 1$ is to note that under $r_w = 1$ the (π^*, x^*) combination is consistent with the optimal targeting rule in (16) in every period and under any circumstances, and show that under $r_i > 1$ there exist circumstances that lead to (π^*, x^*) deviating from (16), which we do in Appendix D. □

This result is intuitive. Since shocks occur every period, being able to respond to them promptly (the period they occur) clearly enhances the effectiveness of policy stabilization. The result seems consistent with the real world practice whereby central bankers commonly have regular monthly meetings. Their frequency coincides with major data releases, and can hence be interpreted as $r_i = 1$. The next proposition reports the macroeconomic effect of anchored wages.

Proposition 4. ***Effect of Anchorness:*** *Assume that $\alpha \geq \tilde{\alpha}$, where $\tilde{\alpha}$ is some positive threshold level. Then for any persistence of supply shocks ρ, wage anchorness r_w is beneficial in stabilization by increasing policy flexibility, and hence decreasing the variability of both inflation and output in equilibrium. The persistence ρ has, for any r_w, the opposite effect.*

Proof. The proposition claims that if $\alpha \geq \tilde{\alpha} > 0$ then $\frac{\triangle var(\pi^*, x^*)}{\triangle r_w} < 0, \forall r_w, \alpha, \rho$ and $\frac{\partial var(\pi^*, x^*)}{\partial \rho} > 0, \forall \rho$. Appendix E 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 et al. (1999) and demonstrate the policy tradeoff by constructing the efficient policy frontier – the so-called Taylor curve. Figure 2 depicts the locus of points that characterize how in bargaining periods equilibrium standard deviations of inflation and output, σ_π and σ_x, vary with r_w. It shows that the policy tradeoff improves (the frontier shifts in) with a higher value of wage anchorness r_w and lower persistence of supply shocks ρ. Recall that our definition of stabilization flexibility follows Bernanke (2003): it is the ability 'to choose the best policies in the future'. We interpreted it to refer to inflation and output variability, since these are the two objectives in the policymaker's utility function.

Let us now specify the conditions under which the anchoring affect, established in Proposition 2, will be present even in a stochastic economy.

Proposition 5. ***Anchoring Effect (SR):*** *Assume that the wage bargaining cost is sufficiently small relative to the inflation cost, but sufficiently large relative to the magnitude of supply shocks, $\hat{c}_w(\sigma_u^2) \geq c_w > \tilde{c}_w(c_\pi)$, where $\frac{\partial \hat{c}_w}{\partial \sigma_u^2} > 0$. Then, for all $\alpha \geq \tilde{\alpha}$, a sufficiently explicit inflation target, $r_T > \tilde{r}_T$, anchors wages.*

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

Intuitively, the public's choice of r_w under shocks features the same tradeoff as in the LR game. A short wage contract, low r_w, is costly (implies higher C_w), but ensures better alignment of wages with inflation, which is even more important in the SR game

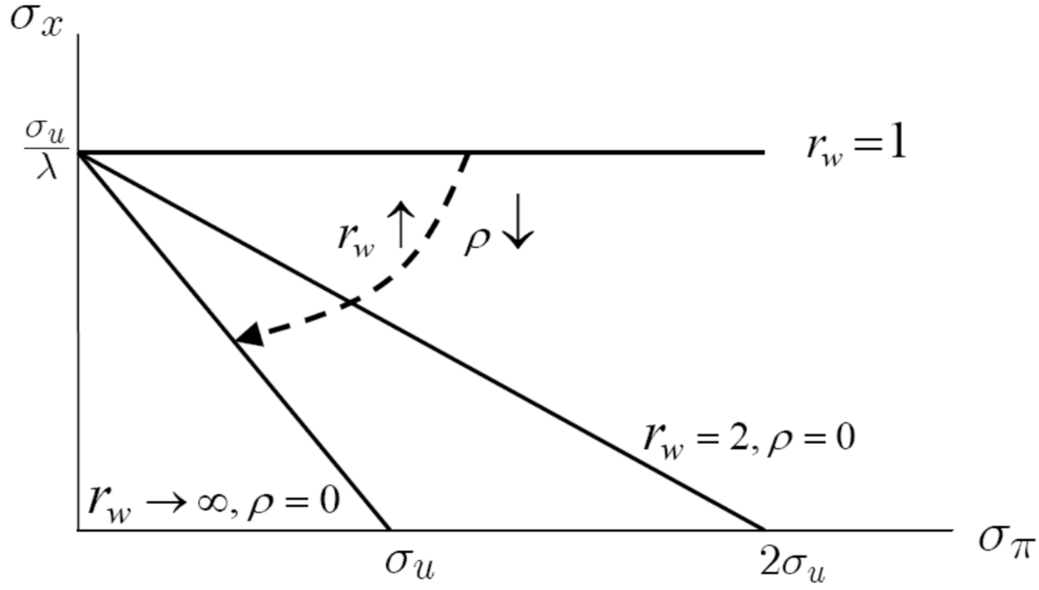

Figure 2. A schematic demonstration of the efficient policy frontier (Taylor curve) in bargaining periods. Higher r_w and lower ρ shift the frontier inwards.

due to shocks. Clearly, under very large supply shocks, high σ_u^2, the public will choose to have fully flexible wages to respond to the shock promptly, $r_w^* = 1$. In such 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 the anchoring effect occurs even in the presence of shocks, ie r_w^* is a monotonically increasing function of r_T.

Proposition 6. ***Optimal IT Explicitness:*** *If $\hat{c}_w(\sigma_u^2) \geq c_w > \tilde{c}_w(c_\pi)$ then it is optimal for the policymaker to make its LR inflation target sufficiently explicit.*

Proof. The proposition claims that $r_T^* > \tilde{r}_T$ for all $\sigma_u^2 \geq 0$. Recall from the LR game 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 the credibility motive the policymaker wants to ensure the beneficial anchoring effect (Proposition 4). This, together with $C_T = 0$ and (14), implies $r_T^* > \tilde{r}_T$. □

The analysis implies that, under the stated circumstances, the policymaker should commit as explicitly as possible, $r_T^* \to \infty$, to maximize the size of the anchoring effect. We can now combine the above findings to formulate the main result of the paper.

Proposition 7. ***Effect of IT Explicitness:*** *Assume $\hat{c}_w(\sigma_u^2) \geq c_w > \tilde{c}_w(c_\pi)$ and $\alpha \geq \tilde{\alpha}$. Then a sufficiently explicit IT, $r_T > \tilde{r}_T$, increases the policymaker's stabilization flexibility, and hence reduces the volatility of output, inflation and the interest rate.*

Proof. It is shown in Appendix G that under the reported circumstances it is true that $\frac{\triangle var(x^*, \pi^*, i^*)}{\triangle r_T} < 0, \forall r_T$. □

Let us summarize the intuition of this proposition. A sufficiently explicit IT cannot be easily reneged upon, which makes the target credible. The public is therefore more inclined to disregard shocks to reduce the cost associated with processing information and wage negotiation. As such, agents are rationally inattentive and look through shocks (unless these are very large relative to the wage bargaining cost). In particular, in the wage bargaining periods wages respond less than fully to the current shock, and in the non-bargaining periods (the proportion of which increases) wages do not respond to the current shock at all.

Such anchored behaviour of the public makes it easier for the central bank to affect the real interest rate and the demand side of the economy. We have shown formally that this leads to an improvement in the variability tradeoff the policymaker is facing (depicted in Figure 2). Because of that, a less aggressive interest rate response is required in both bargaining and non-bargaining periods to better fine-tune the economy.

Note that if the conditions of the proposition hold then social welfare increases unambiguously with a more explicit IT, because the utility of both the policymaker and the public increases. In addition to improved macroeconomic outcomes that benefit both players, the public's wage bargaining cost is lower under a higher r_T.

6. Summary and Conclusions

The paper provides a new, game theoretic tool to examine the impact of commitment to an explicit long-run inflation target on the policymaker's short-run flexibility, and the resulting stabilization and credibility outcomes. We show formally that a legislated numerical target may increase rather than decrease stabilization flexibility. As such, it can improve the variability tradeoff through its anchoring effect on the public's behaviour.

This is shown in two steps. The first step focuses on long-term (average) outcomes. It shows that a long-term inflation target ensures policy credibility if and only if it is sufficiently explicit. It is because a more visible and accountable target is more difficult for the policymaker to renege upon. As private agents know this, they adjust wages and expectations less frequently in order to minimize the cost associated with their revision without fear of being surprised by inflation. Their behaviour is hence better anchored and less responsive (attentive) to shocks - unless the variance of the supply shock is very high relative to the information processing and wage bargaining cost.

It however needs to be stressed that a legislated inflation target does not imply credibility per se, it works through current and future performance. By providing the right incentives to the central bank along the lines of Walsh (1995), it ensures that inflation is (on average) on target, and this is why credibility is enhanced. In this sense it can therefore be argued that credibility cannot be legislated, it must be earned.

The second step focuses on the short-run implications of the public's anchored behaviour for stabilization efforts of monetary policy. It is shown that anchored wages and expectations give the central bank a greater leverage over the real interest rate, and hence a more effective control over stochastic disturbances. Because of that, the bank can better fine-tune the economy and reduce the volatility of both inflation and output. Furthermore, it can do so with smaller changes in the interest rate instrument.[22]

[22] 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

Our analysis thus formalizes the arguments on the effects of explicit inflation targets, eg Bernanke (2003), Goodfriend (2003), McCallum (2003), Mishkin (2004), or Lacker (2005), and offers an alternative channel to that of Adam (2009) and Orphanides and Williams (2005). Similarly to these contributions, it implies that the Federal Reserve, the European Central Bank, and the Bank of Japan should more explicitly commit to a long-run inflation target.[23]

There exists fair empirical support for all our findings. First, explicit inflation targets have been shown to anchor expectations by eg Gürkaynak et al. (2009) and (2005), Horvath et al. (2009), Beechey et al. (2008), Adam (2008), Levin et al. (2004) or Kuttner and Posen (1999)). Second, several papers demonstrated that explicit targets have reduced the nominal interest rate and its volatility to a larger extent than non-IT countries, eg Siklos (2004), Neumann and von Hagen (2002). Third, they we shown to lead to either no change or a decrease in output volatility, eg Corbo, Landerretche and Schmidt-Hebbel (2001), Arestis, Caporale and Cipollini (2002), and Fatas, Mihov and Rose (2004).[24]

Our paper implies two explanations for why some of the empirical evidence, especially on the latter point, may be inconclusive. First, the above described beneficial effects of explicit IT are shown to occur under most - but not all - circumstances. For example, under very large supply shocks the public will prefer to pay the updating/bargaining cost and have full flexibility to respond to the shock promptly. In such case expectations and wages are not anchored. Second, explicit inflation targets work in conjunction with the conventional channels of improved monetary policy such as reputation, solid past performance, central bank independence, and effective communication. Therefore, explicit IT is not a panacea; some conditions need to be satisfied for it to work effectively, and it does not work alone. We have derived the conditions under which it anchors expectations and wages, and improves the variability tradeoff in a reduced-form New Keynesian model. While the conditions may be refined in a richer model, the intuition of our main results is not dependent on the particular details of the used framework.

In Appendix H we discuss several extensions of our analysis and argue that the main results are robust. The main issue the analysis is unable to incorporate is the exact specification of the inflation objective. The build up of the global financial crisis showed that focusing solely on consumer prices, which is what real world IT countries have

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 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...'*

[23]Whether this should happen only after the downturn caused by the global financial crisis is over, or earlier, is a matter of debate. A number of economists such as Greg Mankiw or Jim Hamilton have argued that a numerical target would be beneficial to reduce the threat of deflation, as well as help the Fed's 'exit strategy'.

[24]The working paper version of this article discusses these and other related empirical papers in more detail.

commonly done, may be problematic under some circumstances. More research is needed to deepen our understanding of whether various asset prices should play a role in setting monetary policy. Nevertheless, the above analysis demonstrated that regardless of the adopted specification of the target, it should be made sufficiently explicit in order to deliver anchored expectations and wages, and hence help the policymaker gain better control over the economy and improve stabilization outcomes.

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Appendix A. Proof of Proposition 1

Proof. Let us start by realizing that under $r_T \leq r_w$ there will be no change in the outcomes of the static game. The inefficient Nash equilibrium (π^S, w^S) will still obtain since the public cannot punish the policymaker for deviating from the O inflation level.

In fact, the incentive to deviate is even stronger because a surprise would last for more periods.

Therefore, we can focus on the case $r_T > r_w$. Solving backwards, the public's optimal trend wages between its last move in the dynamic stage game (that occurs in period $t = r_T - r_w + 1$) and its second move (that occurs in period $t = r_w + 1$) will be the best response to the policymaker's initial observable move. Denoting BR to be the best response, this implies $w^*_{t\in[r_w+1,r_T]} \in BR(\pi_1^T)$, which (12) implies to be w^S to π^S and w^O to π^O. The same is true for the public's initial move that is however made under imperfect information, and therefore expectations about it need to be formed. From (5) and $r_e = 1$ 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, $w^*_{t\in[1,r_w)} \in BR(\pi_1^{T*})$. We therefore need to determine the policymaker's optimal play in period 1, π_1^{T*}, which will then obtain for the rest of the dynamic stage game.

The starting point is to note that in period 1 optimal wages are always set equal to inflation expectations, $w_1^* = \pi_1^e, \forall r_w$. For the optimal inflation target to be *time consistent* (ie for a Ramsey SPNE to exist), it is required that π^O be the best response to optimal wages, $\pi_1^O \in BR(w_1^O)$. This is guaranteed by the following necessary credibility condition

(17)
$$\underbrace{ar_T}_{(\pi^O,w^O)} \geq \underbrace{cr_w}_{(\pi^S,w^O)} + \underbrace{d(r_T - r_w)}_{(\pi^S,w^S)}.$$

Both the left-hand side (LHS) and the right-hand side (RHS) are derived under the public playing w_1^O. The LHS expresses the fact that if the policymaker plays π_1^O then he will achieve the payoff a in all $M = r_T$ periods. In contrast, the RHS describes the scenario of the policymaker playing π_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 periods. Then in period $t = r_w + 1$ the public switches to w^S which punishes the policymaker with a d payoff for the rest of the dynamic stage game, $(r_T - r_w)$ periods. Substituting in the respective values $\{a, c, d\}$ from the payoff matrix in (12) yields the necessary credibility condition (13).

However, this condition is not sufficient. To achieve credibility of the O inflation target level with certainty it is required that *any* SPNE be Ramsey, otherwise S level wages and/or expectations could occur as π^S may also be played in equilibrium. Therefore, π_1^O must be a strictly dominant strategy, thus in addition to $\pi_1^O \in BR(w_1^O)$ from (17) it is required that π_1^O is the *unique* best response to w^S, ie $BR(w_1^S) = \{\pi_1^O\}$. The following condition, derived in the same way as (17) but under the public playing w_1^S, ensures this

(18)
$$\underbrace{br_w}_{(\pi^O,w^S)} + \underbrace{a(r_T - r_w)}_{(\pi^O,w^O)} > \underbrace{dr_T}_{(\pi^S,w^S)}.$$

If this sufficient condition is satisfied, the policymaker prefers to play π_1^O even if he knows with certainty that 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 w^O when it first gets a chance, ie after r_w periods. Rearranging

(18) yields the sufficient credibility condition (14) which, combined with the fact that $\tilde{r}_T$ is a function of α with the desired positive sign, completes the proof. □

Appendix B. Implications 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.*

Combining the necessary and sufficient conditions (13) and (14) implies that under $\frac{r_T}{r_w} \in [\frac{\alpha}{\lambda^2}, \frac{3\alpha}{\lambda^2}]$ there exist multiple SPNE, including both Ramsey and non-Ramsey SPNE.[25] The selected outcome is then likely to depend on the past, ie players will continue playing the previous SPNE. Therefore, certain degrees of IT's explicitness and strictness that may have been sufficient for credibility in a stable price level environment, may 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 perhaps helps explain why institutional arrangements such as explicit IT and central bank independence may not have been needed before the 1970s, but were imperative for credibility afterwards. Further, 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 inflation targeter. Perhaps most importantly, the result can also be related to the global financial crisis of 2007-9. It supports the argument of a number of economists that a more explicit inflation objective would be beneficial in avoiding fears of deflation in the short-term as a consequence of the crisis, and the fears of LR higher inflation as a consequence of the extraordinary monetary measures during the crisis. It would arguably make the 'exit strategy' of the Fed more credible.

Appendix C. Proof of Proposition 2

Proof. The proof of Proposition 1 derived the players' optimal choices and equilibrium outcomes for given values of r_T and r_w. Using these and moving backwards, let us examine the public's optimal r_w choice made in period 1, observing r_T. This choice entails a tradeoff between the inflation and the wage bargaining cost. If the public selects sufficiently short wage contracts, $r_w \leq \tilde{r}_w$, where $\tilde{r}_w = \frac{\lambda^2 r_T}{3\alpha}$ follows from (14), then it will uniquely ensure the Ramsey type SPNE. While its inflation cost will then be zero, $C_\pi = 0$ (due to π^{O*}), its wage bargaining cost will be higher due to more frequent bargaining - recall that $C_w = \frac{c_w}{r_w}$. Alternatively, if the public selects $r_w > \tilde{r}_w$ then the sub-optimal inflation level obtains, π^{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.

[25]This implies that equilibrium credibility in our framework is a jump function of the explicitness of the target. If equation (14) is satisfied then expectations and wages are always at the O level, and hence the target is always fully credible as per Definition 1. If $\frac{r_T}{r_w} \in [\frac{\alpha}{\lambda^2}, \frac{3\alpha}{\lambda^2}]$ then the target may or may not be credible, since expectations and wages may be at the O or S levels. If $r_T < \frac{\alpha r_w}{\lambda^2}$ then the target is never credible, since expectations and wages are surely at the S level in some periods. So it is often - but not always - true in our model that a more explicit target leads to an increase in credibility.

Due to the monotonocity 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 $r_w = \tilde{r}_w = \frac{\lambda^2 r_T}{3\alpha}$ or $r_w \to \infty$. Using the public's utility function (5) with the results of Proposition 1 implies that $U_t^p(r_w = \tilde{r}_w) > U_t^p(r_w \to \infty)$ holds, $\forall r_w, r_T, t$, iff

$$c_w < \tilde{c}_w = \frac{\lambda^2 r_T}{3\alpha} c_\pi. \tag{19}$$

Note that there exist paramter values under which $\tilde{c}_\pi > c_w$, as well as those under which $\tilde{c}_\pi < c_w$ or $\tilde{c}_\pi = c_w$. If (19) is satisfied, the public will choose the former scenario with the level stated in (15), $r_w^* = \tilde{r}_w = \frac{\lambda^2 r_T}{3\alpha}$. The fact that r_w^* is an increasing function of r_T completes the proof.[26] □

Appendix D. Proof of Proposition 3

Proof. We need to show that under $r_i > 1$ there exist circumstances that lead to (π^*, x^*) deviating from (16). Take for example some $r_w > 1$, focus on the first two periods of the game, and consider a sole supply shock in period 1 and no shock in period 2, ie $\hat{u}_1 \neq \hat{u}_2 = \hat{g}_1 = \hat{g}_2 = 0$. The optimal outcomes according to (16) are π_1^*, x_1^*, $\pi_2^* = \rho\pi_1^*$, and $x_2^* = \rho x_1^*$. However, under $r_i > 1$ the policymaker cannot adjust the interest rate in period 2, $i_2 = i_1$. Therefore, if the policymaker chooses outcomes according to (16) in period 1, π_1^* and x_1^*, then in period 2 the IS curve yields, using $w_2 = w_1$ (implied by $r_w > 1$), $x_2 = x_1^* \neq x_2^*$. In words, the second period output is not optimal, which completes the proof. All these statements can be seen formally in (21). □

Appendix E. Proof of Proposition 4

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 $r_e = 1$ and complete information. Despite this the wage can now be, under $r_w > 1$, at a disequilibrium level, $w_t \neq \pi_t$, due to shocks. We will denote the non-bargaining periods in which wage inflation cannot be adjusted by upper 'frown', eg $\widehat{\pi}_t$ (the remaining bargaining periods will have no extra notation).

The effect of r_w on stabilization outcomes will be examined in four steps. We will first show that the variability of inflation and output in bargaining periods is decreasing in r_w. Second, we show the same for non-bargaining periods. Third, as the non-bargaining variance may be higher than bargaining, the same will be demonstrated for average variance with the weight being the relative occurrence of bargaining vs non-bargaining periods. This will prove the result for all $r_w \geq 2$. Fourth, this average variance will be shown to be less than variance under $r_w = 1$, which will extend the proof to all $r_w \geq 1$.

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

$$w_t^* = \frac{1}{r_w} \sum_{s=0}^{r_w - 1} E_t \pi_{t+s} = \frac{\pi_t}{r_w} \sum_{s=0}^{r_w - 1} \rho^s, \tag{20}$$

[26]The assumed $n \in \mathbb{N}$ implies that if $\frac{\lambda^2}{3\alpha} \notin \mathbb{N}$ the public will select the highest integer below the reported r_w^*.

where the second element uses the fact that the public rationally expects $E_t\pi_{t+1} = \rho\pi_t$. Substituting (16)-(20) into the Phillips curve implies the reduced form expressions for equilibrium inflation and the output gap in bargaining periods

$$\pi_t^* = \frac{1}{\left(\frac{\lambda^2}{\alpha}+1\right) - \frac{1}{r_w}\sum_{s=0}^{r_w-1}\rho^s} u_t \quad \text{and} \quad x_t^* = -\frac{\lambda}{\alpha}\pi_t^*. \tag{21}$$

It is straightforward to see in (21) that the stabilization tradeoff in bargaining periods improves in wage anchorness. Focusing on the last element of the denominator, it is required that

$$\frac{\triangle\left(\frac{1}{r_w}\sum_{s=0}^{r_w-1}\rho^s\right)}{\triangle r_w} < 0. \tag{22}$$

This, using the formula for a finite sum and rearranging, yields

$$\rho^{r_w}[r_w(1-\rho)+1] < 1, \tag{23}$$

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

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

ie the variability of both inflation and output in bargaining periods is decreasing in r_w.

Step 2. In non-bargaining periods wage inflation is still at the level set at the preceding bargaining period, $\widehat{w}_t = w_{t-1-s}$, where $s = 0, 1, ..., r_w - 1$. Using this together with (16)-(20) and the Phillips curve yields the expressions for non-bargaining inflation and the output gap

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

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

$$\begin{aligned}\widehat{\sigma}_{\pi_s}^2 &= \left[\left(\frac{\alpha}{(\alpha+\lambda^2)r_w}\sum_{s=0}^{r_w-1}\rho^s\right)^2 + \left(\frac{\alpha}{\alpha+\lambda^2}\right)^2 + \sum_{s=0}^{r_w-1}\rho^s\frac{2\alpha^2}{(\alpha+\lambda^2)(r_w+1)}\rho^{s+1}\right]\sigma_u^2,\\ \widehat{\sigma}_{x_s}^2 &= \left(\frac{\lambda}{\alpha}\right)^2\left[\left(\frac{\alpha}{(\alpha+\lambda^2)r_w}\sum_{s=0}^{r_w-1}\rho^s\right)^2 + \left(\frac{\alpha}{\alpha+\lambda^2}\right)^2 + \sum_{s=0}^{r_w-1}\rho^s\frac{2\alpha^2}{(\alpha+\lambda^2)(r_w+1)}\rho^{s+1}\right]\sigma_u^2.\end{aligned} \tag{24}$$

Using (22)-(23) from Step 1, equation (24) implies that the variability in any one non-bargaining period is also decreasing in r_w, namely $\frac{\triangle\widehat{\sigma}_{x_s,\pi_s}^2}{\triangle r_w} < 0$.

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

$$\bar{\widehat{\sigma}}_x^2 = \frac{1}{r_w - 1} \sum_{s=1}^{r_w - 1} \widehat{\sigma}_{x_s}^2. \tag{25}$$

The fact that the covariance between various periods' shocks is increasing in ρ implies that if $\frac{\triangle \bar{\widehat{\sigma}}_x^2}{\triangle r_w} < 0$ holds for ρ arbitrarily close to 1, then it holds for all $\rho = [0, 1)$. Using therefore (24) and (25) with $\rho = 1$ and taking the first difference with respect to r_w yields

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

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

Step 4. This step shows that the conclusion of Step 3 extends to the case of $r_w = 1$, ie our result in Proposition 4 applies for $\forall r_w$. We need to show that $\bar{\sigma}_x^2(r_w) < \sigma_x^2(r_w = 1), \forall r_w$. To do so we will focus on deriving a sufficient condition, and hence use the worst case scenario with $\rho \to 1$ and $r_w = 2$ (the result $\frac{\Delta \bar{\sigma}_x^2}{\Delta r_w} < 0$ implies that $\bar{\sigma}_x^2$ has its maximum in $r_w = 2$ in the region for which it is defined, $r_w \geq 2$). Using these values with all the above information yields the following

$$\sigma_x^2(r_w = 1) - \bar{\sigma}_x^2(r_w = 2) = \frac{1}{\lambda^2} - \frac{1}{2}\lambda^2 \left(\frac{6}{(\alpha + \lambda^2)^2} + \frac{1}{(\frac{\alpha}{2} + \lambda^2)^2} \right) > 0. \tag{26}$$

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 3 for a graphical depiction).

Since the real world value of λ is very small, it can be claimed that (26), and hence Proposition 4 (given that the expression for inflation is analogous), holds for all 'reasonable' parameter values.[27] Steps 2-4 also imply that the policy frontier of Figure 2 is qualitatively unchanged if we replace the bargaining variances, σ_π and σ_x, with the average variances, $\bar{\sigma}_\pi$ and $\bar{\sigma}_x$. This completes the proof. □

Appendix F. Proof of Proposition 5

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 $\bar{\sigma}_p^2$

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

[27] For example, if $\lambda = 0.13$ as estimated by Rudebusch (2002), then the sufficient condition in (26) is satisfied for $\alpha \geq \tilde{\alpha} = 0.017$. The necessary and sufficient condition is yet weaker; under $\lambda = 0.13, \rho = 0.2, r_w = 12$ we have $\tilde{\alpha} \cong 0.0008$.

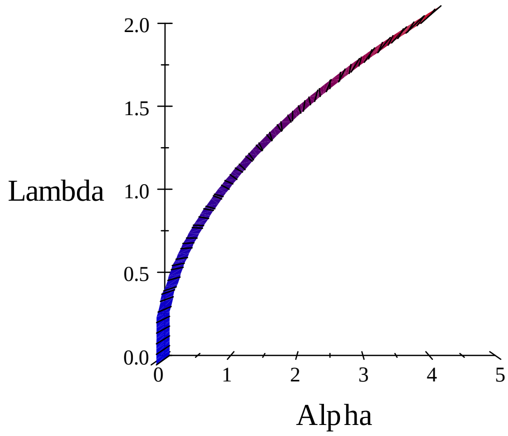

FIGURE 3. Plot of the solution to (26) in the (α, λ) parameter space. All points to the right of the curve satisfy the condition.

Substituting in the above derived expressions and rearranging yields

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

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

$$c_w \geq \hat{c}_w = \frac{2\alpha^2(\alpha^2+3\alpha\lambda^2+3\lambda^4)}{(\alpha^2+3\alpha\lambda^2+2\lambda^4)^2}\sigma_u^2. \tag{27}$$

It is straightforward to verify that the RHS of (27) has a global maximum at the level of $\lambda = 0$. Using (27) with $\lambda = 0$ one obtains the following sufficient condition

$$c_w \geq \hat{c}_w = 2\sigma_u^2.$$

These calculations however imply that this sufficient condition is not tight, eg under $\lambda = 0.13, \rho = 0.2, r_w = 12$ and any $\alpha \leq 2$, a tighter sufficient (but still not necessary) condition becomes $c_w \geq \hat{c}_w = 1.07\sigma_u^2$. □

Appendix G. Proof of Proposition 7

Proof. The claimed effect of r_T on $var(x^*)$ and $var(\pi^*)$ is implied by combining the fact that sufficiently explicit IT anchors wages (Proposition 5), and wage anchorness reduces the variability of both inflation and output (Proposition 4). In terms of the effect of r_T on $var(i^*)$, recall that the variability of equilibrium wages, inflation and output is decreasing in r_w. This implies, using the IS curve, that the same is true for the equilibrium interest rate, $\frac{\triangle var(i^*)}{\triangle r_w} < 0$. It then follows that $\frac{\triangle var(i^*)}{\triangle r_T} < 0$. □

Appendix H. Robustness and Extensions

In order to investigate the robustness of the findings, the working paper version of this article discusses a number of alternative specifications and assumptions, for example (i) the players' impatience, (ii) backward-looking expectations, (iii) heterogeneous private agents (or Unions), (iv) consumption smoothing, (v) the horizon of IT, (vi) non-discrete r_m, (vii) probabilistic r_m, and (viii) non-constant (time-varying) r_m. It is argued that the main results would be unaffected in such modified settings. Let us here briefly discuss three other issues.

Specification of Expectations. It should be noted that the specification π_t^e can encompass various forms of expectations. Recall that the private agents are forward looking and rationally choose the frequency of adjusting expectations. The latter is why we do not formally adopt the standard specification $E_t\pi_{t+1}$ in the Phillips curve - but the outcomes are analogous. This can be seen in equation (7), in which the equilibrium outcomes are identical to Clarida et al. (1999).

The reason this timing does not play a qualitative role is that if the inflation target is sufficiently explicit, $r_T > \tilde{r}_T$, then the policymaker is no longer tempted to surprise inflate/deflate. The public then expects optimal inflation to be played throughout, ie in all periods. Since it has full information, various specifications of expectations will be equivalent in the absence of shocks, and in their presence only different quantitative, not qualitatively. Therefore, our analysis preserves the forward looking nature of the Clarida et al. (1999) model.

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 anchorness of 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, $\frac{\triangle C_e}{\triangle r_e} < 0$, 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 updating 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 $r_e^* > 1$, ie the public will find it optimal to update expectations infrequently and leave them anchored at the target level to minimize the cost.

This is shown formally in Libich (2009), and is consistent with the models of (i) rational inattention (Sims (2003) and Reis (2006)), (ii) 'economically rational expectations' (Feige and Pearce (1976)), as well as models that examine some sort of inertia/stickiness/rigidity in updating/forming expectations (see eg Ball (2000), Mankiw and Reis (2002), Carroll and Slačálek (2006), Morris and Shin (2006)). In these papers agents' expectation formation is an (explicit or implicit) result of cost-benefit calculations.

It is straightforward to see that for a relatively small β the public will choose to update expectations only in the wage negotiation periods, $r_e^* = r_w^*$. This is because under a small β expectations are updated primarily to set wages accurately, and hence agents would not waste resources in non-bargaining periods in which wages cannot be adjusted.

Timeless Perspective Commitment. In terms of the $r_i^* = 1$ result reported in Proposition 3, it should be noted that the same 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 does not prescribe the exact form of the targeting rule the policymaker should follow, ie it is compatible with both discretionary and *pre-commitment* solutions ('timeless perspective' as popularized by Woodford (1999) or quasi-commitment of Schaumburg and Tambalotti (2007)). Under the pre-commitment solutions, the targeting rule in (16) would be altered to also include past output gap, but $r_i^* = 1$ would still apply. Put differently, under our explicit commitment the restriction relates to *when* the policymaker can move, whereas under the pre-commitment solutions 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 would otherwise be the case. Therefore both types of commitment improve the SR variability tradeoff and reduce the volatility of interest rates.