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An explicit inflation target as a commitment device

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Abstract

This paper shows an avenue through which a numerical long-run inflation target ensures low inflation and high credibility; one that is independent of the usual Walsh incentive contract. Our novel game theoretic framework – a generalization of alternating move games – formalizes the fact that since the target is explicit (legislated), it cannot be frequently reconsidered. This 'explicitness' therefore serves as a commitment device. There are two key results. First, it is shown that if the inflation target is sufficiently rigid/explicit relative to the public's wages, low inflation is time consistent and hence credible even if the policymaker's output target is above potential. Second, it is found that the central banker's optimal explicitness level is decreasing in the degree of his patience/independence (due to their substitutability in achieving credibility). Our analysis therefore offers an explanation for the 'inflation and credibility convergence' over the past two decades as well as the fact that inflation targets were legislated primarily by countries that had lacked central bank independence like New Zealand, Canada, and the UK rather than the US, Germany, or Switzerland. We show that there exists fair empirical support for all the predictions of our analysis.

JEL classification: E42; E61; C70; C72

Keywords: Explicit target; Inflation targeting; Commitment; Rigidity; Central bank independence; Alternating move games

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1. Introduction

The paper attempts to contribute to the inflation targeting debate (that is heated especially in regards to the US – see e.g. Bernanke and Woodford, 2005, McCallum, 2003, Friedman, 2004, Mishkin, 2004) by proposing novel explanations to the following two questions: (i) what has driven the widespread adoption of explicit inflation targets (ITs) over the past two decades? and (ii) why have some countries been more explicit than others in targeting low inflation?

The effect of an explicit IT has commonly been modeled through a Walsh (1995b) type incentive contract with the central banker. The offered example has been the accountability arrangement in New Zealand where the Governor is personally responsible for achieving the target and can lose his job if he fails to do so (see e.g. Walsh, 1995a). While this certainly captures a part of the story it has been criticized since other IT countries have not adopted such a dismissal procedure and still achieved desirable inflation and credibility outcomes.

We propose an alternative channel through which inflation targeting works. It has been spelled out on numerous occasions (e.g. Bernanke et al., 1999, Svensson, 1999) that one of the key features of the regime is the fact that the inflation target is explicit, i.e. transparently grounded in the central banking legislation. The main innovation of our paper is incorporating this 'explicitness' of the IT in the *timing structure* of the monetary policy game. This takes note of the fact that a legislated target is rigid, i.e. it may not be reconsidered every period. Such inability introduces some asynchronicity in the game and means that an explicit IT effectively acts as a commitment device.

Our game theoretic framework is a generalization of alternating move games by Maskin and Tirole (1988) and Lagunoff and Matsui (1997) that 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*...'.[1] Let us demonstrate the framework using an example of a timeline in Fig. 1.

The public, player p, will form expectations every period but will only be able to reconsider the wage – its instrument similarly to Rogoff (1985) – every $r^p \geqslant 1$ periods. Following Taylor (1979) we will refer to r^p as *wage rigidity*. The policymaker, player g, can adjust inflation every $r^g \geqslant 1$ to which we refer as (*long-run*) *commitment*.[2]

Since our paper focuses on trend/average monetary policy outcomes our economy will be deterministic. This implies that the policymaker's instrument represents setting *average* inflation or a certain level of a *long-run* inflation target. Long-run means that the legislated horizon of the target is the business cycle or longer (indefinite) – as is common in industrial countries, see Mishkin and Schmidt-Hebbel (2001). It then follows that r^g can be interpreted as the degree of the target's 'explicitness' – the more explicitly the inflation target is stated in the central banking legislation the less frequently it can be altered (in the

[1] Our companion papers Libich and Stehlik (2006, 2007) postulate this framework also in continuous time and in time scale calculus (a recent general mathematical environment that nests both discrete and continuous time as special cases, see e.g. Bohner and Peterson, 2001). Further, the papers apply the framework to other classes of games (e.g. the Battle of Sexes or the Coordination game).

[2] The setup makes it apparent that our commitment concept is very different from the standard pre-commitment solution popularized by Woodford (1999) and Clarida et al. (1999) in which $r^g = 1$. The links between the two concepts are discussed in Libich (2006).

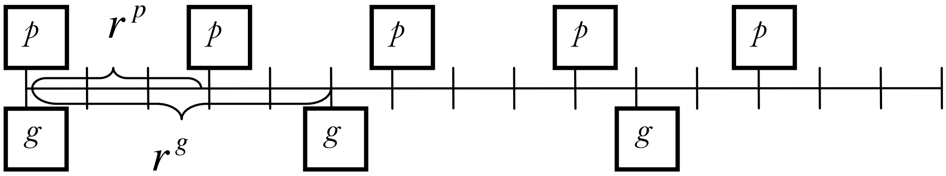

Fig. 1. An example of timing with $r^p = 3$, $r^g = 5$.

Taylor, 1979 deterministic sense) or the less likely it is (in the Calvo, 1983 probabilistic sense).[3]

Attempting to understand the developments over the past two decades we use this framework to revisit the Kydland and Prescott (1977) and Barro and Gordon (1983) environment. This does not mean that we necessarily accept the time inconsistency story to be true – we only intend to show that *even if* it were true low inflation could still be credible – under sufficiently explicit ITs.

We first treat r^g and r^p as exogenous and derive the exact degree of the IT's explicitness, $\bar{r}^g$, that is required to make low inflation policy time consistent and eliminate the inflation bias caused by an excessive output target. Put differently, we show how explicit the low inflation target must be in order to be credible. In game theoretic terms, it is shown under what circumstances any subgame perfect Nash equilibrium (SPNE) of the game features optimally low inflation and expectations on its equilibrium path. We then propose a simple way to endogenize r^g and r^p as players' optimal choices and show under what circumstances the policymaker will find it optimal to select this level, $(r^g)^* \geqslant \bar{r}^g$.

This necessary degree of explicitness is found to be *increasing* in (i) the public's wage rigidity, $\bar{r}^g = f(\overset{+}{r}{}^p)$ and (ii) the policymaker's impatience (rate of discounting). In terms of the latter, we then discuss how more patient monetary policy has been achieved in the real world drawing a link to the observed trend towards central bank independence (CBI). Since independent central bankers have been granted longer term in office (see Fry et al., 2000) they are likely to be more patient (see e.g. Eggertsson and Le Borgne, 2003).[4]

The analysis has therefore two main findings. First, it sheds new light on the popularity of explicit ITs (owing to their commitment effect on reducing inflation and enhancing credibility). Second, the derived substitutability of an explicit IT and CBI helps explain why the low inflation objective has been more explicitly legislated in countries whose central banks had lacked independence in the late 80s/early 90s such as New Zealand, the UK, and Canada, rather than those with a patient (conservative/independent) central bank like the US, Germany, or Switzerland.

[3] As a real world example of deterministic r^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). It should further be noted that the absence of a legislated numerical target may not necessarily imply $r^g = 1$; it has been argued that many countries pursue an inflation target *implicitly* (including the US, see e.g. Goodfriend, 2003, or the Bundesbank and the Swiss National Bank in the 1980s, see Bernanke et al., 1999). In such cases, we have $r^g > 1$.

[4] Throughout the paper CBI refers to goal independence rather than instrument independence (for the distinction see Debelle and Fischer, 1994 and for its non-trivial implications see Hughes Hallett and Libich, 2006b). This is because it will be related to a parameter in the policymaker's objective function.

These findings offer an explanation for 'convergence' to low inflation and high credibility in industrial countries over the past two decades. While the contribution of CBI and ITs to price stability have been shown before (see the references in Section 5), the novelty of our explanation lies in the fact that it is independent of the three common channels in the literature, namely the Walsh (1995b) incentive contract, the Rogoff (1985) conservative central banker, and the Barro and Gordon (1983) reputation building. Specifically, credibly low inflation may result in equilibrium even under (i) an unaccountable policymaker with (ii) an over-ambitious output target and (iii) without anti-inflation reputation.

Our model has three testable implications, namely that there exist *inverse* relationships between the level of inflation, the degree of CBI and the degree of the IT's explicitness. We survey below the related empirical literature and find support for our theory in all three respects. We further consider several extensions such as probabilistic commitment in the spirit of Calvo (1983), adaptive expectations, atomistic public, changes in the timing and presence of stochastic disturbances and show that our results are robust to these modifications.

The rest of the paper is structured as follows. Section 2 presents the model and the standard monetary policy game. Section 3 introduces the explicitness of the IT and wage rigidity into the timing structure of this game. Section 4 reports our results and Section 5 brings empirical support for them. Section 6 endogenizes r^{g} and r^{p}. Section 7 examines the robustness of our findings and Section 8 concludes.

2. Model

We denote $I = \{\mathrm{p}, \mathrm{g}\}$ the set of players where p is the public and g is the policymaker (government or central banker).[5] We first treat the public as one player but in Section 7.2 generalize the model by introducing atomistic public – two or more differently sized Unions. While the intuition will be shown to remain unchanged several novel insights emerge in this generalization. Lucas surprise-supply relationship between inflation and output applies

$$y_t - y_e = \lambda(\pi_t - w_t) \tag{1}$$

where y is output, y_e is the potential rate of output, π is inflation, λ is a positive parameter and $t = 1, 2, \ldots$ denotes time (for simplicity we normalize $y_e = 0$ and $\lambda = 1$ throughout). We follow Backus and Driffill (1985) in interpreting w as the rate of change of nominal wages, i.e. wage inflation. The preferences are as follows

$$U^i = \sum_{t=1}^{\infty} u_t^i \delta_i^{t-1} \tag{2}$$

where $i \in I$, δ is the discount factor and u are the following one-period utility functions of players

[5] We do not explicitly model the delegation of monetary policy but later relate CBI to the policymaker's discount factor (patience). For analysis of the interaction of monetary and fiscal policy see Dixit and Lambertini (2003) or Hughes Hallett et al. (2007).

		Public	
		w^L	w^H
Policymaker	π^L	$a = 0, 0$	$b = -\alpha^2, -\alpha^2$
	π^H	$c = \alpha^2/2, -\alpha^2$	$d = -\alpha^2/2, 0$

Fig. 2. General payoff matrix.

$$u_t^g = \alpha y_t - \frac{1}{2}(\pi_t - \pi^L)^2 \tag{3}$$

$$u_t^p = -(\pi_t - w_t)^2 \tag{4}$$

where π^L denotes a low-inflation target and $\alpha > 0$.[6] The public cares about correctly anticipating the inflation rate in order to set wages at the market clearing real wage level (for justification based on Fischer-Gray contracts see Canzoneri, 1985).[7] The policymaker and the public are assumed to directly set the inflation rate and wage inflation, respectively (as explained above due to the absence of disturbances the latter can be interpreted as setting an average/long-run inflation target).

In the standard game (denoted by G) players' instruments do not feature any commitment/rigidity and inflation and wages are chosen *simultaneously* at *each* period t. Assuming players are rational and have common knowledge of rationality (which we maintain throughout with the exception of Section 7.1) and using (1)–(4) yields the Markov Perfect equilibrium levels (denoted by a star throughout)

$$\pi_t^* = w_t^* = \pi^L + \alpha \tag{5}$$

This is the influential 'inflation bias' result. For expositional purposes and following the game theoretic literature, e.g. Cho and Matsui (2005), we will restrict the action space to two levels, the optimal and the time consistent one, $\pi = w = \{\pi^L, \pi^L + \alpha\}$.[8] The stage game is summarized in Fig. 2 in which the higher level is denoted by superscript H and $\{a, b, c, d\}$ denote the policymaker's payoffs obtained from (2) and (3).

Note that the policymaker's payoffs have the following property regardless of the policy weight α

$$c = -b + d \quad \text{and} \quad d = \frac{b}{2} \tag{6}$$

Therefore, we can divide through by α^2 without loss of generality which yields the payoff matrix of Fig. 3. The Kydland–Prescott outcome, (π^H, w^H), is the unique Nash equilibrium

[6] Since there are no shocks in the model we can assume out the policymaker's aversion to output volatility (as in Barro and Gordon, 1983). Libich (2006) includes this element (using the standard quadratic utility and a richer macroeconomic setting of the New Keynesian type) to study the effect of an explicit IT on policy flexibility and output stabilization.

[7] The intuition of the public is standard (its inflation aversion could be included with no changes to our results) and in a rigidity-free environment this is analogous to 'rational inflation expectations' (see Backus and Driffill, 1985). In the rigid framework, however, w is not equivalent to expected inflation.

[8] A longer version of this paper (available on request) considers the unrestricted game in which players' action sets are $\pi = w = (-\infty, \infty)$ and shows that while our truncation of the choice set alters some of our quantitative results their qualitative nature is intact.

		Public	
		w^L	w^H
Policymaker	π^L	0, 0	-1, -1
	π^H	½, -1	-½, 0

Fig. 3. Specific payoff matrix.

of the game, however, it is Pareto inferior to the Non-Nash outcome of credibly low inflation, $(\pi^{\mathrm{L}}, w^{\mathrm{L}})$.[9]

3. Introducing the explicitness of the IT and wage rigidity

It has been argued that neither 'simultaneity' nor 'every-period-move flexibility' of the standard Barro–Gordon framework are realistic features.[10] In terms of simultaneity 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...*'. In terms of the flexibility assumption it is in stark contrast with the current macroeconomic literature in which various *rigidities* take central stage.[11] We find this an example of '*inappropriate mapping between a model and reality*' – see McCallum (1997).

Our proposed game theoretic framework is finite, dynamic and rigid. This framework allows us to incorporate (i) *various degrees* of players' commitment/rigidity and (ii) their endogenous determination – in the spirit of Bhaskar (2002).

Definition 1. Player *i*'s action *m*'s *commitment/rigidity* (denoted r^i_m) express the number of periods for which the respective action is fixed.[12]

Since each player has (unlike an extension in Libich, 2006) only one action in the game, we will drop the subscript. It is straightforward to see that our framework is a generalization of previous game theoretic approaches in which $r^i = 1$, $\forall i$ (repeated games) or $r^i = 2$, $\forall i$ (alternating move games). Nevertheless, we stick to all of the repeated games assumptions, namely we assume rigidity to be *deterministic*, *constant* throughout each game and *observable* by the players (as well as players' previous periods' actions).[13]

[9] The term credible is used in our paper similarly to the literature – expressing that the public does not expect high/surprise inflation and therefore optimally sets low wage inflation from (4).

[10] In addition, the utilized infinite horizon setup typically leads to multiple Nash equilibria.

[11] This literature builds on Fischer (1977), Taylor (1980), Calvo (1983); see also Mankiw and Reis (2002) and for a comprehensive treatment Woodford (2003). For recent surveys of the empirical literature on price and wage rigidity see Apel et al. (2005) and Bewley (2002), respectively. We would like to point out a fact that is commonly not mentioned, namely that the rational expectations solution also makes implicit (simultaneity and flexibility) timing assumptions, i.e. goes well beyond assuming rationality. This may seem hard to reconcile with the micro-level rigidity present in the very models to which the solution is applied.

[12] While for a game theorist r^i_m is always commitment (since the interest lies in its effect on the game), a macroeconomist may want to use the term that better reflects the particular circumstances – practice which we will follow. We will later discuss a possible distinction between commitment and rigidity with respect to the associated cost.

[13] The latter assumption means that the game belongs to the category of games with 'observable actions', alternatively called games of almost perfect information or games of perfect monitoring.

Definition 2. *A rigid* version of game G (denoted G_R) is a dynamic game that starts with a simultaneous move of all players after which each player moves every r^i periods – observing opponents' preceding periods' moves. The *unrepeated* version of the game finishes just before the second simultaneous move is made, i.e. after C periods, where C denotes the 'least common multiple' of r^i, $\forall i$.

Starting with the simultaneous move may be interpreted as reflecting some 'initial' uncertainty (and allows for comparison with the standard Barro–Gordon model). While this asynchronous game can be repeated we can restrict our attention to the unrepeated game (as depicted in Fig. 1).[14]

Notation. As our interest lies in the circumstances under which equilibrium inflation is low and credible we introduce the notation for the case $r^{\mathrm{g}} > r^{\mathrm{p}}$ (the opposite case is later discussed). Let us define $r^{\mathrm{gp}} = \frac{r^{\mathrm{g}}}{r^{\mathrm{p}}} > 1$ to be players' *relative rigidity*. Further, $\lfloor r^{\mathrm{gp}} \rfloor$ will be the *integer* value of relative rigidity (the floor) and $R = r^{\mathrm{gp}} - \lfloor r^{\mathrm{gp}} \rfloor$ denotes the *fractional* value of relative rigidity (the remainder) that takes the values of $R = [0, 1)$. We denote g_n^s and p_n^s players' moves where the superscript expresses the level of each action, $s \in S = \{L, H\}$, and n refers to the node number, $n = \{1, 2, \ldots, n, \ldots, N^i\}$. From Definition 2 it follows that players' *last* moves of the unrepeated game are $N^i = \frac{C}{r^i}$.

An 'arrow' will denote moves that are the closest to precede a certain move of the opponent. For example, $\overleftarrow{g}_{p_3}$ is the policymaker's closest move preceding the public's third move, p_3. Further, we denote $b(.)$ to be the best response. For example, $g_1^{\mathrm{L}} \in b(p_1^{\mathrm{L}})$ will express that g_1^{L} is the policymaker's best response to the public's first move of low wage inflation. If an action is, in a certain node, the *unique* best response to both L and H levels of opponent's (past or current) play, for example $b(\overleftarrow{p}_{g_2}^{\mathrm{L}}) = b(\overleftarrow{p}_{g_2}^{\mathrm{H}}) = \{g_2^{\mathrm{L}}\}$ or $b(p_1^{\mathrm{L}}) = b(p_1^{\mathrm{H}}) = \{g_1^{\mathrm{L}}\}$, we will call it 'history independent' and denote it by two stars in the superscript, $(g_2^{\mathrm{L}})^{**}$. Finally, let us refer to $\delta_i = 1$ as *full patience* and $\delta_i < 1$ as *impatience*. Further, using $\bar{\delta}_i = [0, 1]$ as a certain threshold (whose level is shown in each case), players with discount factors that are higher, $\delta_i > \bar{\delta}_i$ (lower, $\delta_i < \bar{\delta}_i$) will be called *sufficiently (insufficiently) patient*.

Timing. Let us summarize the timing of the game using this notation. In the rigid version of the game (denoted G_R) in period 1 players move simultaneously choosing g_1 and p_1 and then each player moves every r^{g} and r^{p} periods *observing* all $\overleftarrow{p}_{g_n}$ and $\overleftarrow{g}_{p_n}$, respectively.

Strategies and equilibria. A strategy for a certain player is a function that assigns a probability distribution to the player's action space for all histories. As common in macroeconomics, in this paper we will restrict our attention to pure strategies. 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 (one strategy for each player) that forms a Nash equilibrium after any history. Given the large number of nodes in the game reporting fully characterized SPNE would be cumbersome – we will therefore focus on the equilibrium path (actions that will actually get played).

[14] This is because we will be deriving conditions under which the efficient outcome uniquely obtains on the equilibrium path of the unrepeated game. If these conditions are satisfied repeating the game and allowing for reputation building of some form would not affect the derived equilibrium. In this sense, we can think of our analysis as the worst case scenario in which reputation cannot help cooperation.

Definition 3. *The Ramsey outcome* is a situation in which in all SPNE of the game both players play L in all their moves on the equilibrium path, $(i_n^{\mathrm{L}})^*$, $\forall n, i$.

4. Results

Let us propose our main result in a general form, two special cases of interest will be reported later as a part of the proof.

Proposition 1. *The Ramsey outcome obtains if and only if (i) the IT is sufficiently explicit relative to the public's wage rigidity,* $r^{\mathrm{g}} > \bar{r}^{\mathrm{g}}(r^{\mathrm{p}})$, *and (ii) the policymaker is sufficiently patient,* $\delta_{\mathrm{g}} > \bar{\delta}_{\mathrm{g}}$. *Then low inflation is the unique time consistent/credible policy of the game.*

To better expose the intuition of the rigid setting, we break up the proof into three main parts. In part A, both players are fully patient, $\delta_{\mathrm{g}} = \delta_{\mathrm{p}} = 1$. In part B, we consider the public's impatience and part C solves for the policymaker's impatience. In each part, we distinguish three cases. In case 1, relative rigidity is an integer, $r^{\mathrm{gp}} = \lfloor r^{\mathrm{gp}} \rfloor \iff R = 0$, so only one player, g, experiences the role of the Stackelberg leader in the game. In the remaining cases 2, $R = (0.5, 1)$, and 3, $R = (0, 0.5]$, players' rigid periods overlap so both players experience Stackelberg leadership.[15]

Proof. The aim of the proof is to derive the appropriate values of $\bar{r}^{\mathrm{g}}$ and $\bar{\delta}_{\mathrm{g}}$ in each case and its intuition is as follows. For low inflation to be time consistent/credible it is required that the policymaker is *never tempted* to surprise inflate. Formally, it must be true that $b(p_1^{\mathrm{L}}) = \{g_1^{\mathrm{L}}\}$ and $b(\overleftarrow{p}_{g_n}^{\mathrm{L}}) = \{g_{n\geqslant 2}^{\mathrm{L}}\}$. This will be the case if the public's 'punishment', i.e. the post-inflating period of high wage inflation is long enough to offset the possible output gain of the policymaker from surprise inflating.[16]

For the Ramsay outcome to obtain we need an additional condition, namely that the policymaker would uniquely choose low inflation even if wages were high (knowing that output loss would occur), i.e. $b(p_1^{\mathrm{H}}) = \{g_1^{\mathrm{L}}\}$ and $b(\overleftarrow{p}_{g_n}^{\mathrm{H}}) = \{g_{n\geqslant 2}^{\mathrm{L}}\}$. Combining these two sets of conditions implies that $(g_n^{\mathrm{L}})^{**}$, $\forall n$. Since $b(\pi^{\mathrm{L}}) = \{w^{\mathrm{L}}\}$ it follows that on the equilibrium path we also have p_n^{L}, $\forall n$.

A: Fully patient players

Case A1: R = 0 (e.g. Fig. 4)

In this case, we have $C = r^{\mathrm{g}}$ from which it follows that the policymaker only makes one move in the unrepeated game, $N^{\mathrm{g}} = 1$. In contrast, the public makes r^{gp} moves.

Since all the public's moves in the Stackelberg part are made under identical circumstances, the same action will be selected, i.e. $(p_2^s)^* = \ldots = (p_n^s)^* = \ldots = (p_N^s)^*$. This allows us to simplify the extensive form of the game by collapsing all $p_{n\geqslant 2}$ into one move (depicted in Fig. 5).

[15] Libich and Stehlik (2006) present a different – more compact – proof (without breaking it up into the three cases). Nevertheless, the proof presented here better illustrates the intuition of the players' behaviour in the rigid game.

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

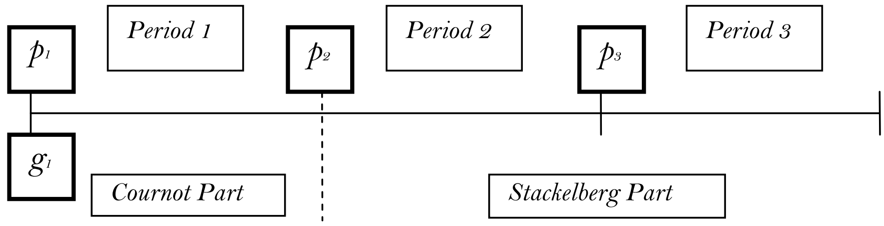

Fig. 4. Example of timing with $r^{\mathrm{g}} = 3$, $r^{\mathrm{p}} = 1$.

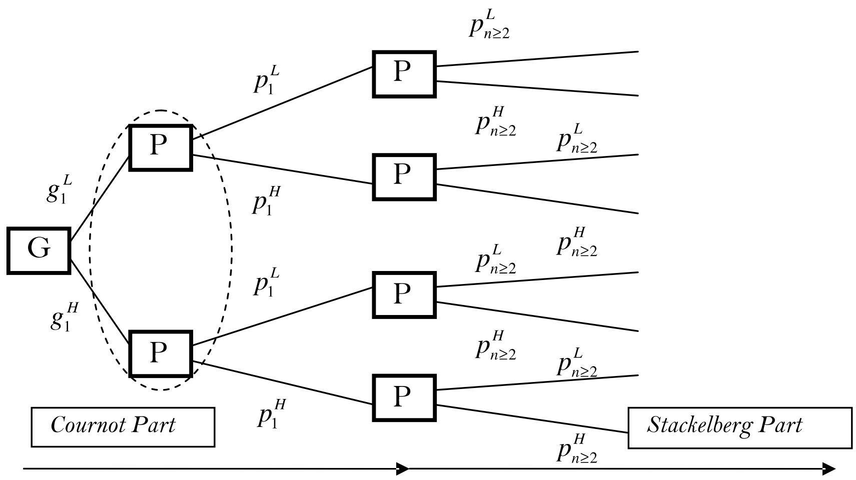

Fig. 5. Extensive form of case 1.

Solving backwards, the public's optimal wage throughout the Stackelberg part (in which there is perfect information) will be the best response to the policymaker's Cournot move, $(p^{s}_{n\geqslant 2})^{*} \in b(g_1)$. The two conditions that ensure $b(p^{\mathrm{L}}_1) = \{g^{\mathrm{L}}_1\}$ and $b(p^{\mathrm{H}}_1) = \{g^{\mathrm{L}}_1\}$ are, respectively, the following

$$ar^{\mathrm{g}} > cr^{\mathrm{p}} + d(r^{\mathrm{g}} - r^{\mathrm{p}}) \tag{7}$$

$$br^{\mathrm{p}} + a(r^{\mathrm{g}} - r^{\mathrm{p}}) > dr^{\mathrm{g}} \tag{8}$$

The left-hand sides (LHS) and the right-hand sides (RHS) report the policymaker's payoffs from playing g^{L}_1 and g^{H}_1 (assuming p^{L}_1 in (7) and p^{H}_1 in (8)). For example in (7), if the policymaker surprises the public (gaining a c payoff) then at the first opportunity, period $t = r^{\mathrm{p}} + 1$, the public switches to p^{H}_2 which punishes the policymaker (with a d payoff) for the rest of the unrepeated game, $(r^{\mathrm{g}} - r^{\mathrm{p}})$ periods. Substituting (6) into (7), (8) and rearranging yields

$$r^{\mathrm{g}} > \frac{c-d}{a-d} r^{\mathrm{p}} = 2r^{\mathrm{p}} \tag{9}$$

$$r^{\mathrm{g}} > \frac{a-b}{a-d} r^{\mathrm{p}} = 2r^{\mathrm{p}} \tag{10}$$

The equivalence of the two conditions ensuring $b(p^{\mathrm{L}}_1) = \{g^{\mathrm{L}}_1\}$ and $b(p^{\mathrm{H}}_1) = \{g^{\mathrm{L}}_1\}$ is a structural feature of this particular setup (linear-quadratic preferences). It is straightforward to show (see Appendix A for a proof) that the equivalence obtains, due to the first relationship in (6), at any g_n for all α, r^i, δ_i, and i. This simplifies the proof since we only need to show one of these conditions (we choose to focus on the latter). Therefore, for the Ramsey outcome to obtain it must hold that

$$r^{\mathrm{g}} > \bar{r}^{\mathrm{g}} = 2r^{\mathrm{p}} \tag{11}$$

which completes the proof for case A1.

Case A2: $R = (0.5, 1)$ (e.g. Fig. 1)

In this and the remaining case we have $C > r^{\mathrm{g}}$, i.e. the policymaker makes more than one move in the unrepeated game. Solving backwards, the condition for $(g_N^{\mathrm{L}})^{**}$ (in particular for $g_N^{\mathrm{L}} = b(\overleftarrow{p}_{g_N}^{\mathrm{H}})$) derived in the same way as (8) is as follows

$$br^{\mathrm{p}}R + a(r^{\mathrm{g}} - r^{\mathrm{p}}R) > dr^{\mathrm{g}} \tag{12}$$

Using (6) and rearranging yields

$$r^{\mathrm{gp}} > 2R \tag{13}$$

Combining (13) with $r^{\mathrm{gp}} = \lfloor r^{\mathrm{gp}} \rfloor + R$ leads to

$$\lfloor r^{\mathrm{gp}} \rfloor > R \tag{14}$$

which always holds since $\lfloor r^{\mathrm{gp}} \rfloor \geqslant 1$ and $R < 1$. It then follows that $(g_N^{\mathrm{L}})^{**}$. Further, combining this with $R > 1/2$ and $\delta_{\mathrm{p}} = 1$, we know that $(\overleftarrow{p}_{g_N}^{\mathrm{L}})^{**}$ since $(\overleftarrow{p}_{g_N}^{s})^{*} = b(g_N^s)$, $\forall s \in S$ (thereafter, we will drop the superscript s for notational parsimony). This affects the policymaker's preceding move, g_{N-1}, and causes the condition for $(g_{N-1}^{\mathrm{L}})^{**}$ to be equivalent to (14) and therefore satisfied. This is true for all $g_{n > \lfloor N^{\mathrm{g}}/2 \rfloor}$, i.e. the same condition as in (14) obtains.

Moving forward, for $g_{2 \leqslant n \geqslant \lfloor N^{\mathrm{g}}/2 \rfloor}$ (if any) the conditions are *weaker* than (14) and therefore satisfied. This is because such moves determine one extra move of the public.[17] We can, therefore, conclude that $(g_{n \geqslant 2}^{\mathrm{L}})^{**}$. The condition for $(g_1^{\mathrm{L}})^{**}$ is the strongest of all n (in the weak sense) since the length of the inflation surprise and output gain would be the full length of r^{p} periods (i.e. more than after any $g_{n \geqslant 2}$). It will become evident that this it true in all four cases, i.e. for all R (see Libich and Stehlik (2006) for a formal proof). This is an additional convenient feature of the framework since only one condition – regarding players' first moves – needs to be derived to solve a game such as in Fig. 1. Using $(g_2^{\mathrm{L}})^{**}$ and $\overleftarrow{p}_{g_2}^{*} \in b(g_1)$ (which follows from $R > 1/2$ and $\delta_{\mathrm{p}} = 1$) yields the following inequality analogous to (8)

$$br^{\mathrm{p}} + a(r^{\mathrm{g}} - r^{\mathrm{p}}) + a(1 - R)r^{\mathrm{p}} > r^{\mathrm{g}}d + b(1 - R)r^{\mathrm{p}} \tag{15}$$

and after rearranging

$$r^{\mathrm{g}} > \bar{r}^{\mathrm{g}} = \frac{R(a - b)}{a - d} r^{\mathrm{p}} = 2Rr^{\mathrm{p}} \tag{16}$$

which completes the proof for case A2 as all $r^{\mathrm{g}} > r^{\mathrm{p}}$ satisfy (16).

Case A3: $R = (0, 0.5]$ (e.g. Fig. 6)

Since the proof is similar to case A2 we leave the details to Appendix B. It shows that the appropriate condition for $(g_n^{\mathrm{L}})^{**}$, $\forall n$ is

[17] In particular, $\lfloor r^{\mathrm{gp}} \rfloor + 1$ of the public's moves are the best response to any $g_{2 \leqslant n \geqslant \lfloor N^{\mathrm{g}}/2 \rfloor}$ (in contrast to $\lfloor r^{\mathrm{gp}} \rfloor$ for any $g_{n > \lfloor N^{\mathrm{g}}/2 \rfloor}$).

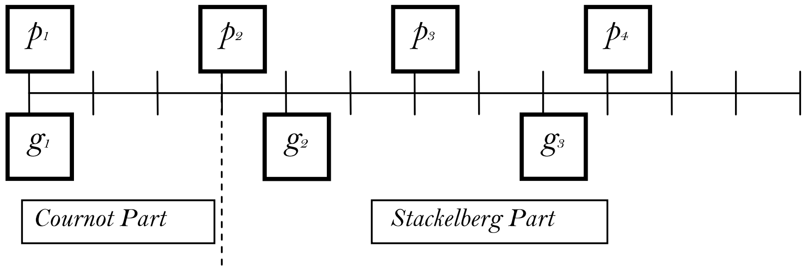

Fig. 6. Example of timing with $r^g = 4$, $r^p = 3$.

$$br^p + a(r^g - r^p) > dr^p + d(r^g - r^p - Rr^p) + cRr^p \tag{17}$$

Rearranging and combining with (6) yields

$$r^g > \bar{r}^g = \frac{R(c-d) + a - b}{a - d} r^p = 2(1+R)r^p \tag{18}$$

which completes the proof for case A3. It is illustrative to consider why some low r^{gp} values (in particular $r^{gp} = (1, 1.5] \cup (2, 2.5])$ fail to deliver the Ramsey outcome. It is because the relative length of the public's high wage punishment is insufficient to discourage the policymaker from inflating. For our example in Fig. 6 with $r^g = 4$ and $r^p = 3$ there would be no punishment whatsoever and the 'disinflation' would be costless for the policymaker. The forward looking public would, *if* surprised by g_1^H, find it optimal to 'forgive in advance' and play p_2^L knowing that $(g_2^L)^{**}$, i.e. disinflation will surely follow in the policymaker's next move.[18]

Summarizing cases A1-3 we have the following result.

Corollary 1. *If both the policymaker and the public are fully patient the sufficient condition for (i) low inflation to be the unique time consistent/credible policy of G_R and for (ii) the Ramsey outcome to obtain is $r^g > \bar{r}^g = 2.5r^p$.*

As we indicated, the required level of the IT's explicitness is rather low – even more so since the *necessary and sufficient* condition implied by the above proof is $r^{gp} \in (1.5, 2) \cup (2.5, \infty)$.

B: Public's impatience

Let us first continue the proof of Proposition 1 and then strengthen our claim (for a special case). Building on the discussion of part A, in case 1 the condition of (11) still applies in part B as it is independent of δ_p. While in case 2 the public's impatience plays a role, namely alters the conditions for some g_n, the crucial (strongest) condition for $(g_1^L)^{**}$ is unaffected. This is also true in case 3 if the public's discount factor is above a certain threshold, $\delta_p > \bar{\delta}_p$ (that is a function of r^g and r^p).

However, under insufficiently patient public, $\delta_p < \bar{\delta}_p$, the public will disregard the policymaker's future periods' play and set wages that maximize the payoff of the current period t. The condition for $(g_1^L)^{**}$ in case 3 is then *weakened*, since we have $(\overleftarrow{p}_{g_2})^* \in b(g_1)$ (unlike in part A where $(\overleftarrow{p}_{g_2})^* \in b(g_2)$). Intuitively, inflating that was insufficiently pun-

[18] The reader can easily verify that the equilibrium under $r^g = 4$, $r^p = 3$ is $(g_1^H)^*$, $(p_1^H)^*$, $(p_{n=\{2,3,4\}}^L)^*$, and $(g_{n=\{2,3\}}^L)^*$.

ished under patient public will be punished enough which offsets the policymaker's temptation. Specifically, (17) will be replaced by (15) and the condition for $(g_1^{\mathrm{L}})^{**}$ for case 3 becomes the same as for the case 1, namely $r^{\mathrm{g}} > 2Rr^{\mathrm{p}}$. Since this is satisfied for all $r^{\mathrm{g}} > r^{\mathrm{p}}$, we have the following.

Corollary 2. *If the policymaker is fully patient and the public is insufficiently patient,* $\delta_{\mathrm{p}} < \bar{\delta}_{\mathrm{p}}$, *low inflation is time consistent/credible in* G_R *for any* $r^{\mathrm{g}} > r^{\mathrm{p}}$.

The Corollary claims that under some circumstances $\bar{r}^{\mathrm{g}} = r^{\mathrm{p}}$. Therefore, an IT that is *marginally* more explicit/rigid than wages ensures credibly low inflation as a possible equilibrium.[19] We explicitly formulate this result since it shows that credibly low inflation can obtain in equilibrium in a setting that approaches the standard Barro–Gordon game in the limit, namely $r^{\mathrm{g}} \to 1$, $r^{\mathrm{p}} = 1$.

C: Policymaker's impatience

In this part we show that if the policymaker is less than fully patient, the necessary conditions from parts A-B *strengthen* ($\bar{r}^{\mathrm{g}}$ increases) i.e. he needs to commit more explicitly to avoid the inflation bias. The solution and proofs are equivalent to the above and hence the strongest condition is still the one required for $(g_1^{\mathrm{L}})^{**}$. Therefore, we show the proof for case 1 only (which is independent of the public's patience), cases 2–3 are analogous.

Case C1: R = 0

Allowing δ_{g} to differ from unity in (2) qualifies (8) into

$$\sum_{t=1}^{r^{\mathrm{p}}} b\delta_{\mathrm{g}}^{t-1} + \sum_{t=r^{\mathrm{p}}+1}^{r^{\mathrm{g}}} a\delta_{\mathrm{g}}^{t-1} > \sum_{t=1}^{r^{\mathrm{g}}} d\delta_{\mathrm{g}}^{t-1} \tag{19}$$

As in (8) the payoffs are derived under p_1^{H}; the LHS expresses the payoff from g_1^{L} (in which case the output loss – payoff b – will only accrue for r^{p} until the public has switched to p_2^{L} in period $r^{\mathrm{p}}+1$) and the RHS expresses the payoff from g_1^{H}. After rearranging and using (6) we obtain

$$\frac{\sum_{t=r^{\mathrm{p}}+1}^{r^{\mathrm{g}}} \delta_{\mathrm{g}}^{t-1}}{\sum_{t=1}^{r^{\mathrm{p}}} \delta_{\mathrm{g}}^{t-1}} > \frac{d-b}{a-d} = 1 \tag{20}$$

In order to derive the values of $\bar{r}^{\mathrm{g}}$ and $\bar{\delta}_{\mathrm{g}}$ this can be, after some manipulations, rewritten as

$$r^{\mathrm{g}} > \bar{r}^{\mathrm{g}} = \log_{\delta_{\mathrm{g}}}\left(\frac{a-b}{a-d}\delta_{\mathrm{g}}^{r^{\mathrm{p}}} - \frac{d-b}{a-d}\right) = \log_{\delta_{\mathrm{g}}}(2\delta_{\mathrm{g}}^{r^{\mathrm{p}}} - 1) \tag{21}$$

It follows from the domain of logarithms that $\bar{\delta}_{\mathrm{g}} = \sqrt[r^{\mathrm{p}}]{0.5}$. This means that under insufficiently patient policymaker, $\delta_{\mathrm{g}} \leqslant \bar{\delta}_{\mathrm{g}} = \sqrt[r^{\mathrm{p}}]{0.5}$, the Ramsey outcome cannot obtain. In contrast, if $\delta_{\mathrm{g}} > \bar{\delta}_{\mathrm{g}} = \sqrt[r^{\mathrm{p}}]{0.5}$ the low inflation target can be time consistent/credible, i.e. there exists an r^{g} level that will satisfy (21) for any finite r^{p}. This completes the proof of Proposition 1 – by inspection of (21) $\bar{r}^{\mathrm{g}}$ is increasing in r^{p}. □

[19] Note, however, that unlike Proposition 1 Corollary 2 does not state that the Ramsey outcome obtains. This is because under $r^{\mathrm{g}} = 2r^{\mathrm{p}}$ the policymaker is indifferent between high and low inflation in its initial move, i.e. there exist at least one SPNE that features H on the equilibrium path.

Corollary 3. *Under a sufficiently explicit IT the equilibrium inflation and credibility outcomes are independent of the degree of the policymaker's conservatism* α.

Proposition 1 showed that a sufficiently explicit IT level achieves inflation and wage inflation on target in every t, regardless of how conservative the policymaker is. This is an *observational equivalence* result: credibly low inflation may be a result of either a fully conservative central banker, $\alpha = 0$, or a sufficiently explicit IT, $r^g \geqslant \bar{r}^g(r^p, \delta_g, \delta_p)$. This suggests that caution should be exercised in concluding that a track record of credibly low inflation necessarily indicates a conservative policymaker without any temptation to over-stimulate output.

Further, a number of authors, e.g. McCallum (1997) and Blinder (1997), argued that a simple recognition of the fact that $\alpha > 0$ leads to undesirable outcomes is sufficient to constrain the policymaker's behaviour, i.e. he then acts 'as if' $\alpha = 0$. The question left unanswered was under what circumstances such behaviour would be credible in the eyes of a forward-looking public. Our analysis offers an answer by showing the required *explicitness level*, $\bar{r}^g$, that ensures credibility in such cases. The following claim summarizes our findings with respect to standard Barro–Gordon type setups.

Corollary 4. *If explicitness of the IT is equal to* (*or lower than*) *the public's wage rigidity*, *the low inflation target is time inconsistent* (*lacks credibility*) *even under a fully patient policymaker.*

It follows from the above proofs that even full patience of the policymaker is not sufficient under $r^g \leqslant r^p$; a more explicit commitment to low inflation is required. Eq. (21) implies an additional result that offers a testable hypothesis.

Proposition 2. *The policymaker's patience and an explicit IT are substitutes in achieving the Ramsey outcome*, *i.e. the time-consistency and credibility of low inflation.*

Proof. See Appendix C for a formal proof using (21) that $\bar{r}^g$ is decreasing in δ_g. This implies that the less patient the policymaker is the more explicit IT she needs to pursue for the target to be credible. □

5. Empirical support

In the real world the policymaker's discount factor has been arguably increased by granting the central banker with a longer term in office; this is because a longer optimizing horizon translates into more *patient* behaviour (see e.g. Eggertsson and Le Borgne, 2003).[20] This has come as a part of the trend towards CBI (see for example Waller and Walsh, 1996).

Such interpretation implies, combined with Proposition 2, that there exists substitutability between an explicit IT and CBI in ensuring low inflation and high credibility. This has three main testable predictions, namely that there exist inverse relationships between

[20] On the length in office for 93 countries see Mahadeva and Sterne (2000). While the norm of 5–7 years is only marginally longer than the government term, in the majority of cases (in industrial countries) the Governor gets reappointed which makes the *expected* term in office significantly longer. The US offers itself as a good example.

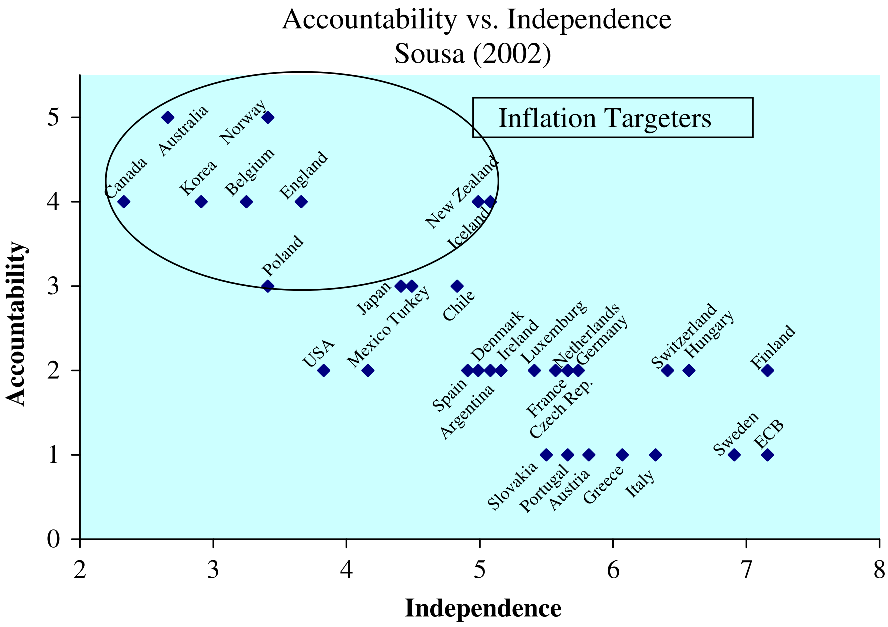

Fig. 7. Source: Sousa (2002), see Appendices D, E, and F for details on the criteria, countries, and scores. The correlation coefficient equals −0.78 ($t = -6.94$).

the level of inflation, the degree of CBI and the explicitness of the IT (for which the degree of the policy's goal-transparency and/or accountability can be used as a proxy).

All three predictions seem to be consistent with real world observations. First, a number of empirical studies found inflation to be decreasing in CBI, e.g. Grilli et al. (1991), Cukierman et al. (1992), Alesina and Summers (1993), Eijffinger et al. (1998) and Fry et al. (2000).

Second, Briault et al. (1997) find accountability to lower inflation and Chortareas et al. (2002) and Fry et al. (2000) find transparency to lower inflation. Corbo et al. (2001), Wu (2004) and Hyvonen (2004) find inflation targeting to reduce inflation.[21] See also Debelle (1997) who finds inflation targeting to increase the policy's credibility.

Third and perhaps most surprisingly, Fig. 7 presents the accountability vs. independence relationship using recent indices by Sousa (2002) and the correlation is clearly negative. This result seems robust as it replicates previous findings of Briault et al. (1997) and de Haan et al. (1999) who use differently constructed indices for earlier periods.[22]

If we plot Sousa (2002) accountability against the length of term in office (which is one of the criteria in his independence index) the picture remains roughly the same. Furthermore, in a comprehensive dataset of Fry et al. (2000) the length of term in office is negatively correlated to accountability procedures (that apply when targets are missed or must be changed) in both industrial and transition countries.

[21] These findings are however not universally accepted, see e.g. Ball and Sheridan (2003) and Willard (2006).

[22] Briault et al. (1997) refer to the bottom right corner countries in Fig. 7 as featuring a 'democratic deficit'; an undesirable situation of an independent institution lacking democratic accountability. For a welfare analysis of these institutional features see Hughes Hallett and Libich (2006a) in which comparable results are derived through an entirely different avenue (by explicitly incorporating independence, accountability and transparency in the Barro–Gordon model).

Finally, Hughes Hallett and Libich (2006a) 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 et al. (1997) is -0.86 ($t = -4.46$).[23]

6. Endogenizing the IT's explicitness and wage rigidity

Drawing upon the discussion of the real world institutional developments our objective in this Section is to briefly discuss players' r^i's as optimal choices. We will first consider the various scenarios and then elaborate one simple example. In an endogenous version of the game the players choose the levels of r^i which may be associated with some '*investment cost*', c_i.[24] The equilibrium outcome of the game will then depend on a number of specifications, among other (i) the timing of the 'investment' moves, (ii) players' information, (iii) and the cost functions.

In terms of the timing and information, all r^i may be chosen simultaneously or observing (completely or incompletely) opponent's play. As these are long-term decisions they will commonly be known in period 1. With regards to the investment cost, it may be fixed and/or ongoing, presumably (at least for some values of the parameter space) decreasing in the selected level of rigidity and increasing in the level of commitment.[25]

It is evident that our public will optimally choose some 'minimum-cost' level of rigidity (i.e. long-term contracts) in order to minimize the cost of wage renegotiation. Our policymaker has an incentive to invest into *increasing* its r^{g} to eliminate the costly inflation bias. Whether or not the policymaker commits (makes the IT sufficiently explicit) depends on the associated cost.[26] If the cost is too high the policymaker will not commit and the inflation bias will not be fully eliminated.

Corollary 5. *Under a sufficiently patient policymaker,* $\delta_{\mathrm{g}} > \bar{\delta}_{\mathrm{g}}$, *with an insufficiently explicit IT,* $r^{\mathrm{g}} < \bar{r}^{\mathrm{g}}(r^{\mathrm{p}})$ *such that* $R = (0, 1)$, *equilibrium inflation and wages will follow cycles and inflation variability is higher than under* $r^{\mathrm{g}} > \bar{r}^{\mathrm{g}}(r^{\mathrm{p}})$.

It was shown in the proof of Proposition 1 for cases 2–3 that under $r^{\mathrm{g}} < \bar{r}^{\mathrm{g}}$ we have $(g_1^{\mathrm{H}})^* = (p_1^{\mathrm{H}})^*$ but also (under $\delta_{\mathrm{g}} > \bar{\delta}_{\mathrm{g}}$) we have $(g_N^{\mathrm{L}})^* = (p_N^{\mathrm{L}})^*$, i.e. disinflation eventually follows.

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[23] As we mentioned above the Debelle and Fischer (1994) distinction between goal and instrument independence is crucial. Since the latter has come hand in hand with ITs its correlation with transparency and accountability in most indices is positive rather than negative (for more details see Hughes Hallett and Libich (2006a)).

[24] This is similar to an interesting attempt in the literature to endogenize price-rigidity, see Hahn (2006).

[25] It may seem natural to differentiate rigidity and commitment on the basis of the associated cost. Since rigidity in macroeconomics is commonly due to costly updating/revising/switching an investment must be made to *reduce* r^i (i.e. $c_i'(r^i) < 0$). Such cost underlies both sticky-price models, e.g. Taylor (1980) and Calvo (1983), and the sticky-information model of Mankiw and Reis (2002). The game theoretic literature has also studied the effect of a switching cost, see e.g. Lipman and Wang (2000). In contrast, as commitment constrains the players an investment must be made to *increase* r^i (i.e. $c_i'(r^i) > 0$).

[26] Our companion papers study alternative sources of this cost in detail. Hughes Hallett and Libich (2006b) consider the policymaker's aversion to accountability (the threat of punishment/criticism) whereas Libich (2006) studies the impact of commitment to explicit ITs on the flexibility to stabilize output in the presence of supply shocks.

However, if the investment cost of explicit IT is sufficiently small the policymaker will invest and commit sufficiently. To demonstrate, let us consider circumstances that we believe reflect the real world monetary policy game. The timing is as follows:

(1) The policymaker chooses r^{g}.
(2) Observing r^{g} the public chooses r^{p} and p_1.
(3) Observing r^{p} but unable to observe p_1 the policymaker selects g_1.
(4) Observing all previous periods' moves each player i moves every r^i periods.

In terms of the investment costs, we postulate c_i to be a *per period* cost with the following properties similar to Hahn (2006). With regards to the policymaker we have a cost of increasing the IT's explicitness (such as an implementation cost or accountability cost for missing the target), $c'_{\mathrm{g}}(r^{\mathrm{g}}) > 0$, $c_{\mathrm{g}}(1) = 0$. In terms of the public we believe it realistic to assume the cost to be non-monotonous in r^{p} with global minimum at some $\hat{r}^{\mathrm{p}} > 1$. Formally, we have $c'_{\mathrm{p}}(r^{\mathrm{p}}) < 0$ if $r^{\mathrm{p}} + 1 \leqslant \hat{r}^{\mathrm{p}}$ and $c'_{\mathrm{p}}(r^{\mathrm{p}}) > 0$ if $r^{\mathrm{p}} + 1 > \hat{r}^{\mathrm{p}}$.[27]

Proposition 3. *If and only if the investment cost of explicit ITs is sufficiently small,* $c_{\mathrm{g}} \leqslant \bar{c}_{\mathrm{g}}$, *the policymaker will optimally choose the explicitness level* $\bar{r}^{\mathrm{g}}$ *derived in Section 4 and the Ramsey outcome obtains.*

Proof. It is claimed that if $c_{\mathrm{g}} \leqslant \bar{c}_{\mathrm{g}}$ then $(r^{\mathrm{g}})^* = \bar{r}^{\mathrm{g}}$ where both thresholds $\bar{c}_{\mathrm{g}}$ and $\bar{r}^{\mathrm{g}}$ will be a function of r^{p}, δ_{g}, δ_{p}. This implies that the results derived in Section 4 under exogenous r^i will obtain under endogenous r^i as well. As we have shown above in the proof of Proposition 1 that the simple case A1 ($R = 0, \delta_{\mathrm{p}} = \delta_{\mathrm{g}} = 1$) is representative of the whole framework we will only prove the proposition for this special case – all other scenarios are analogous.

Solving backwards, from Eq. (11) it follows that if $r^{\mathrm{g}} > \bar{r}^{\mathrm{g}} = 2r^{\mathrm{p}}$ then $g_t^* = p_t^* = 0$, $\forall t$ (and hence $\pi_t^* = w_t^* = 0, \forall t$) whereas if $r^{\mathrm{g}} < \bar{r}^{\mathrm{g}} = 2r^{\mathrm{p}}$ then $g_t^* = p_t^* = \alpha$, $\forall t$. Moving forward, the public will use this information to derive its optimal (least costly) wage rigidity, $(r^{\mathrm{p}})^* = \hat{r}^{\mathrm{p}}$. The policymaker will then use this to maximize his utility and obtain the following

$$\frac{\partial u^{\mathrm{g}}}{\partial r^{\mathrm{g}}} = \alpha - \frac{\partial c_{\mathrm{g}}}{\partial r^{\mathrm{g}}} \tag{22}$$

This (interpreted in the discrete sense) implies that if $c'_{\mathrm{g}}(\bar{r}^{\mathrm{g}}) \leqslant \bar{c}_{\mathrm{g}} = \alpha$ then $(r^{\mathrm{g}})^* = \bar{r}^{\mathrm{g}} = 2\hat{r}^{\mathrm{p}}$ which concludes the proof. □

Two issues are worth noting. First, under the policymaker's impatience $(r^{\mathrm{g}})^*$ will also be a decreasing function of δ_{g} (see Proposition 2), i.e. impatient/non-independent policymakers will optimally choose a more explicit IT. Second, if the cost is above the threshold $\bar{c}_{\mathrm{g}}$ we get $(r^{\mathrm{g}})^* = 1$ and the low inflation target is time-inconsistent (lacks credibility) from Corollary 4.

[27] The latter expresses the fact that circumstances such as labour productivity may change over time so extremely long wage contracts may be costly.

Proposition 3 offers an explanation for why explicit ITs had not been adopted prior to the 1990s – the cost of explicit commitment may have been too high. This cost has arguably been *decreasing* over time with the growing ability of central banks to control inflation. This was due to a number of factors, namely more efficient forecasting methods, more effective monetary policy procedures, more forward looking private agents, less volatile economic variables, as well as the realization that explicit ITs specified as a *long-term* objective do *not* constrain the policymaker's flexibility to stabilize shocks and hence do not increase the variability of output (see e.g. Mishkin, 2004; Bernanke, 2003; Orphanides, 2003; Libich, 2006).[28] This implies that a greater number of countries would tend to satisfy the condition in Proposition 3 and make their low inflation goal more explicit.

7. Robustness

This section shows that our results are robust to a number of alternative specifications and assumptions. We consider eight modifications two of which, backward looking expectations and heterogeneous public are examined in detail.

(1) We assumed the public to be indifferent to inflation. In the more realistic case in which the public is, like the policymaker, inflation averse it will have an incentive to invest into *reducing* its wage rigidity, i.e. more frequently renegotiate wages. This would reduce $\bar{r}^{g}$ but it would not alter the fact that $\bar{r}^{g}$ is increasing in r^{p}.
(2) In terms of the timing of the investment moves (Section 6) if r^{g} and r^{p} are chosen simultaneously rather then sequentially, i.e. the public is unaware of the IT's explicitness, Proposition 3 still holds as $(r^{p})^{*} = \hat{r}^{p}$.
(3) While the analysis studies rigid wage setting the *insights* will also apply to the public's (infrequent) updating of *expectations* – due to the associated cost of acquiring and processing information. 'Rigid expectations' can be modeled explicitly in our framework by relaxing the full information assumption – see Libich (2006) for an analysis.
(4) Deterministic commitment/explicitness of Taylor (1980) they can be reinterpreted to a probabilistic one in the spirit of the Calvo (1983) staggered price-setting mechanism. The reader may think of there being a certain probability (independent across time), $\theta = [0, 1)$, that the inflation target cannot be reconsidered in any given period. Then the *average/expected* length of time between each reconsideration is $1/(1-\theta)$, which is equivalent to our r^{g}. In a companion paper Libich and Stehlik (2007), we examine this probabilistic version explicitly.
(5) As the paper takes the long-run view it is imperative to consider whether the findings are qualified in the presence of shocks. Some IT skeptics (see e.g. Kohn, 2003, Friedman, 2004) have expressed concerns that an explicit commitment to an IT may reduce the policymaker's flexibility to react to shocks and stabilize output. Our companion paper Libich (2006) uses the asynchronous framework to examine a 'stochastic' New Keynesian type environment and a standard quadratic utility $U = -\alpha(y_t - y^{T})^2 - (\pi_t - \pi^{L})^2$ where y^{T} is the output target. It shows that allowing for disturbances does not alter the conclusions of the presented paper, i.e. since the

[28] The latter paper provides a formal analysis of the impact of explicit ITs on output stabilization.

inflation target is specified as a long-run objective (achievable on average over the business cycle) it does not reduce the policymaker's flexibility in output stabilization.[29]

(6) In such setting the necessary explicitness level is further related to the policymaker's *conservatism*, in particular $\bar{r}^g$ is increasing in α. Since independent central bankers are, in the spirit of Rogoff (1985), commonly considered more conservative this further strengthens the case for our CBI interpretation of Proposition 2.

7.1. Adaptive expectations

There is a large body of empirical research that shows that backward looking expectations are important, if not predominant (see e.g. Fuhrer, 1997). Let us for simplicity consider the simplest case of *adaptive/static* expectations in which the public uses a simple rule of thumb to form inflation expectations, namely $E_{t-1}\pi_t = \pi_{t-1}$. It is apparent that in the rigid world the Stackelberg part outcomes of such static behaviour are equivalent to those under *insufficiently patient* public studied in Section 4. In both cases, the public will disregard the policymaker's future periods' play. This is because in the Stackelberg part the players never move simultaneously so the inflation level of the $t-1$ period will remain to be played in some t in which the public plays, $\pi_t = \pi_{t-1}$, which implies $p^*_{n\geqslant 2} = b(\overleftarrow{g}_{p_n})$ and $w^*_t = \pi_{t-1}$. It then follows that Corollary 2 holds under adaptive (as well as a combination of forward and backward looking) expectations.[30] This further suggests that the public's 'myopic' behaviour (of the 'tit for tat' variety) may be *optimal* in the rigid world serving as a credible threat.[31]

7.2. Heterogeneous public

While assuming homogenous public may be justified on the basis of centralized wage bargaining (for some references see e.g. Olivei and Tenreiro, 2007) examining the existence of differing players within the public may offer interesting insights.

Let us generalize the above analysis and extend the set of players to $I = \{g, p^j\}$ where p^j denotes various Unions, each with a certain degree of wage rigidity r^{p}_j. There will be $J \geqslant 1$ Unions and their relative size, i.e. the proportion of (homogenous) individuals in each Union will be denoted by P_j such that $\sum_{j=1}^{J} P_j = 1$. We can now generalize the result in Proposition 1.[32]

[29] The paper in fact finds the opposite, the policymaker's flexibility under inflation targeting will increase which will reduce the volatility of both inflation and output in equilibrium. This is due to the 'anchoring' effect of explicit ITs that is explicitly modeled.

[30] To be able to make conclusions about the validity of all our remaining propositions and corollaries we would have to specify how backward-looking agents act in the first period, p_1 (to which there exists no $\overleftarrow{g}_{p_1}$).

[31] Interestingly, that is the case even if acquiring relevant information is costless. Public's costly monitoring (of the policymaker's preferences, see e.g. Hughes Hallett and Libich, 2007) would constitute an *additional* reason for the public to follow a simple rule of thumb (similarly to the concept of near-rational expectations, e.g. Ball, 2000).

[32] We report the result for the case of a fully patient policymaker to save space but it is straightforward to extend it under policymaker's impatience.

Proposition 4. *If the policymaker is fully patient the sufficient condition for low inflation to be the unique time consistent/credible policy of* G_R *is* $r^g > \bar{r}^g = 2.5\sum_{j=1}^{J} P_j r_j^p$.

Proof. Let us start with case A1 which is under heterogeneous public re-defined to be $r^{gp^j} = \lfloor r^{gp^j} \rfloor, \forall j \in I$. The inequality in (8) under heterogeneous public becomes

$$b\sum_{j=1}^{J} P_j r_j^p + a\sum_{j=1}^{J}(r^g - P_j r_j^p) > dr^g \tag{23}$$

Substituting in the payoffs and rearranging yields the equivalent of condition (11)

$$r^g > \bar{r}^g = 2\sum_{j=1}^{J} P_j r_j^p \tag{24}$$

Analogously to Section 4, the condition for case A2 is $r^g > \bar{r}^g = 2R\sum_{j=1}^{J} P_j r_j^p$ and case A3 $r^g > \bar{r}^g = 2(1+R)\sum_{j=1}^{J} P_j r_j^p$. The same applies under sufficiently patient public. Under insufficiently patient public the conditions are again weakened to become $r^g > \bar{r}^g = 2R\sum_{j=1}^{J} P_j r_j^p$ for cases B2-3 while condition (24) applies to case B1. This completes the proof. □

Let us discuss two special scenarios which convey the intuition of the result. First, if each Union has the same size (number of individuals) then $P_j = 1/J, \forall j$. The sufficient condition in Proposition 4 therefore becomes $r^g > \bar{r}^g = \frac{2.5}{J}\sum_{j=1}^{J} r_j^p$, e.g. with two equally sized Unions under case A1 we get $r^g > \bar{r}^g = r_1^p + r_2^p$.

Second, consider two Unions such that $r_1^p < r_2^p = r^g$. This approaches the Barro–Gordon setup and can be interpreted as the existence of a 'normal public' (individuals), p^2, and a 'flexible public' (financial markets), p^1, that respond relatively quickly.

Proposition 5. *The Ramsey outcome obtains if and only if the flexible public's relative size and relative speed are sufficient, i.e.* $P_1 > \overline{P}_1$ and $r_1^p > \bar{r}_1^p$.

Proof. The sufficient condition from Proposition 4 becomes here $r^g > \bar{r}^g = \frac{3r_1^p P_1}{3P_1 - 2}$ from which it follows that $P_1 > \bar{P}_1 = 2/3$. Using $r_2^p = r^g$ the equation can be rearranged into

$$\frac{r_1^p}{r_2^p} < 1 - \frac{3}{5P_1} \tag{25}$$

This implies the necessary level of relative speed, $r_1^p < \bar{r}_1^p = 0.4 r_2^p$, and completes the proof. It is interesting to note that the speed and size of the flexible public are substitutes in achieving credibly low inflation. □

8. Summary and conclusions

This paper models a new channel – an alternative to the Walsh (1995b) incentive contract – through which an explicit IT affects the outcomes of monetary policy. It formalizes the fact that since the target is legislated it is more rigid, i.e. it can be less frequently reconsidered. Our proposed game theoretic framework generalizes the alternating move games of Maskin and Tirole (1988) and Lagunoff and Matsui (1997) and allows us to study the effect of various degrees of the IT's explicitness and the policymaker's optimal choice of this degree.

The analysis explains the widespread adoption of explicit ITs in the 1990s – as an attempt to 'lock in' low inflation and build its credibility. Further, it offers an explanation to the fact that numerical inflation targets have been adopted primarily by countries with low degree of CBI such as New Zealand, Canada, and the UK, rather than the relatively independent central banks in the US, Germany, and Switzerland. This is by showing that an explicit IT may *substitute* the policymaker's patience (conservatism/independence) in securing credibly low inflation.

Using established indices we show that all our predictions are supported by the data, most interestingly the substitutability of explicit inflation targeting and CBI. This confirms the hypothesis of Briault et al. (1997) that '[*t*]*he negative correlation in Chart [7] ... suggests that accountability and transparency may have served as (partial) substitutes for independence ...*'.

It is important to note that our paper implies convergence to low inflation and high credibility that is independent of the three most common solutions in the literature, i.e. (i) the Walsh (1995b) incentive contract, (iii) the Rogoff (1985) conservative central banker, and (iii) the Barro and Gordon (1983) reputation building. Put differently, credibly low inflation may be achieved in equilibrium even by a policymaker with an over-ambitious output target, without anti-inflation reputation, and without a dismissal procedure.

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Appendix A. Equivalence proof

We want to show equivalence of the conditions implied by $b(p_n^{\mathrm{L}}) = \{g_n^{\mathrm{L}}\}$ and $b(p_n^{\mathrm{H}}) = \{g_n^{\mathrm{L}}\}$, for all n, α, r^i, δ_i and i. To see this let us rewrite (7) and (8) by breaking up each side into two components

$$ar^{\mathrm{p}} + a(r^{\mathrm{g}} - r^{\mathrm{p}}) > cr^{\mathrm{p}} + d(r^{\mathrm{g}} - r^{\mathrm{p}})$$
$$br^{\mathrm{p}} + a(r^{\mathrm{g}} - r^{\mathrm{p}}) > dr^{\mathrm{p}} + d(r^{\mathrm{g}} - r^{\mathrm{p}})$$

The above equations make transparent the intuition of the proof; the corresponding conditions for every g_n only differ in the 'initial stage' (lasting up to r^{p} periods – the length varying with the node n). This is due to the fact that the current play of the public to which the policymakers responds differs, w^{L} and w^{H}, respectively. After the public's first reconsidering the payoffs become the same – the public reacts to the observed play of g (which is the same across the two conditions) taking the future into account (which is again equivalent for each pair of conditions).

During the initial stage and under $\delta_g = 1$ the per-period benefit of inflating, π^H, as opposed to low inflation, π^L, is then $c - a$ given w^L and $d - b$ given w^H. From (6) it follows that for every α we have $c - a = d - b$. Note that for $\delta_g < 1$ these payoffs are discounted but since they accrue over the same period of time the effect of discounting will again be equivalent in both equations. Noting that other cases are analogous completes the proof.

Appendix B. Proof of case A3

Solving backwards, for $(g_N^L)^{**}$ it is required that (14) be satisfied which we showed to always be the case. Due to $R < 1/2$ and $\delta_p = 1$, we know that $(\overleftarrow{p}_{g_N})^* = b(g_{N-1})$. This causes the condition for $(g_{N-1}^L)^{**}$ to again be equivalent to (14) and therefore satisfied. Moving forward, this is true for all $g_{n>\lfloor N^g/2 \rfloor}$, the same condition obtains. While for $g_{2\leqslant n \geqslant \lfloor N^g/2 \rfloor}$ (if any) this may not be so and the conditions may be stronger, the strongest possible condition of all g_n is for $(g_1^L)^{**}$ *given* the condition for $(g_2^L)^{**}$ is satisfied (note that $(\overleftarrow{p}_{g_2})^* = b(g_2)$, i.e. it is now the best response to g_2, not g_1). The appropriate condition, knowing that $(g_2^L)^{**}$ and $(\overleftarrow{p}_{g_2}^L)^{**}$ is then equation (17) in the text.

Appendix C. Proof of Proposition 2

Take (21) and rewrite it into

$$\bar{r}^g = \frac{\ln(2\delta_g^{r^p} - 1)}{\ln \delta_g}$$

Our task is to show that $\bar{r}^g$ is decreasing in δ_g (i.e. $\bar{r}^{g\prime}(\delta_g) < 0$) on the considered domain $D := \left(\sqrt[r^p]{0.5}, 1\right)$. Taking the derivative we obtain

$$\bar{r}^{g\prime}(\delta_g) = \frac{\frac{2r^p\delta_g^{r^p-1}}{2\delta_g^{r^p}-1}\ln \delta_g - \frac{1}{\delta_g}\ln(2\delta_g^{r^p} - 1)}{\ln^2 \delta_g} = \frac{2r^p\delta_g^{r^p}\ln \delta_g - (2\delta_g^{r^p} - 1)\ln(2\delta_g^{r^p} - 1)}{\delta_g(2\delta_g^{r^p} - 1)\ln^2 \delta_g}$$

Since the denominator is always positive, it suffices to show that

$$2r^p\delta_g^{r^p}\ln \delta_g - (2\delta_g^{r^p} - 1)\ln(2\delta_g^{r^p} - 1) < 0$$

or equivalently

$$\phi(\delta_g) := 2r^p\delta_g^{r^p}\ln \delta_g < (2\delta_g^{r^p} - 1)\ln(2\delta_g^{r^p} - 1) := \psi(\delta_g)$$

on the considered domain D. We observe that $\phi(1) = 0 = \psi(1)$. Therefore, it suffices to show that $\phi'(\delta_g) > \psi'(\delta_g)$ for all $\delta_g \in D$. But this is satisfied since:

$$\phi'(\delta_g) > \psi'(\delta_g)$$

$$2r^{p2}x^{r^p-1}\ln \delta_g + 2r^px^{r^p-1} > 2r^px^{r^p-1}\ln(2\delta_g^{r^p} - 1) + 2r^px^{r^p-1}$$

$$r^p\ln \delta_g > \ln(2\delta_g^{r^p} - 1)$$

$$\delta_g^{r^p} > 2\delta_g^{r^p} - 1$$

$$1 > \delta_g^{r^p}$$

where the last inequality is trivially satisfied since $\delta_g < 1$ and $r^p \geqslant 1$.

Appendix D. Central bank independence index (Sousa, 2002)

Criteria	Points
Personal independence	
1. Appointment of the central bank board members	1.00
2. Mandate duration of more than half of the central bank board members.	1.00
3. Policymaker (or other fiscal branches representatives) participation at central bank meetings, where monetary decisions are taken.	1.00
Political independence	
4. Ultimate responsibility and authority on monetary policy decisions.	1.00
5. Price stability	1.00
6. Banking supervision	1.00
7. Monetary policy instruments	1.00
Economic and financial independence	
8. Policymaker financing	1.00
9. Ownership of the central bank's (equity) capital	1.00

Appendix E. Central bank accountability index (Sousa, 2002)

Criteria and methodology are adopted from de Haan et al. (1998). We only use the 'final responsibility' component that best proxies the policymaker's LR commitment (explicitness of the IT).

Criteria	Points
Final responsibility	
1. Is the central bank subject of monitoring by Parliament?	1.00
2. Has the policymaker (or Parliament) the right to give instruction?	1.00
3. Is there some kind of review in the procedure to apply the override mechanism?	1.00
4. Has central bank possibility for an appeal in case of an instruction?	1.00
5. Can the central bank law be changed by a simple majority in Parliament?	1.00
6. Is past performance a ground for dismissal of a central bank governor?	1.00

Appendix F. Evaluation table

Index		Independence Sousa (2002)[a]				Accountability Sousa (2002)[a]
Country		Personal	Political	Economic/Financial	Total[b]	Final responsibility
1	Argentina	1.25	2.83	1.00	5.08	2
2	Australia	0.50	2.16	0.00	2.66	5
3	Austria	1.66	3.16	1.00	5.82	1
4	Belgium	1.75	1.50	0.00	3.25	4
5	Canada	0.50	1.83	0.00	2.33	4
6	Chile	2.00	1.83	1.00	4.83	3
7	Czech Republic	1.58	3.16	1.00	5.74	2
8	Denmark	2.16	2.83	0.00	4.99	2
9	EMU-ECB	2.50	3.66	1.00	7.16	1
10	England	1.00	2.66	0.00	3.66	4
11	Finland	2.50	3.66	1.00	7.16	2
12	France	1.50	3.16	1.00	5.66	2
13	Germany	1.50	3.16	1.00	5.66	2
14	Greece	1.91	3.16	1.00	6.07	1
15	Hungary	1.91	3.66	1.00	6.57	2
16	Iceland	1.75	3.33	0.00	5.08	4
17	Ireland	1.00	3.16	1.00	5.16	2
18	Italy	2.16	3.16	1.00	6.32	1
19	Japan	0.75	3.66	0.00	4.41	3
20	Korea	0.75	2.16	0.00	2.91	4
21	Luxemburg	1.25	3.16	1.00	5.41	2
22	Mexico	1.83	2.33	0.00	4.16	2
23	Netherlands	2.41	3.16	0.00	5.57	2
24	New Zealand	1.83	2.16	1.00	4.99	4
25	Norway	1.58	1.83	0.00	3.41	5
26	Poland	1.25	2.16	0.00	3.41	3
27	Portugal	1.50	3.16	1.00	5.66	1
28	Slovakia	1.00	3.50	1.00	5.50	1
29	Spain	0.75	3.16	1.00	4.91	2
30	Sweden	2.75	3.16	1.00	6.91	1
31	Switzerland	2.08	3.33	1.00	6.41	2
32	Turkey	1.66	2.83	0.00	4.49	3
33	USA	2.00	1.83	0.00	3.83	2

[a] Assessment is based on situation in January 2002.
[b] Excludes aspect 9 due to missing observations.

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