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Centralized Wage Setting and Monetary Policy in a Reputational Equilibrium

IN ALL INDUSTRIAL COUNTRIES, MACROECONOMIC POLICIES are implemented sequentially, as an ongoing process. At each stage of the process, the policymakers can deviate at their discretion from previous announcements and take unexpected actions. Some implications of this institutional feature have been recently analyzed in a number of models in which the policymakers play a dynamic or a repeated game against the private sector or among themselves.[1]

This paper analyzes a repeated game between the central bank (CB) and a centralized trade union (TU). The real wage set by the TU is above what would be optimal for the CB. Thus, the CB has an incentive to reduce the real wage by creating unexpected inflation. The fact that the CB cannot commit to a noninflationary strategy gives rise to a noncooperative equilibrium in which, from the point of view of the CB, inflation is too high and output is too low. If, however, the TU is incompletely informed about the nature of its opponent, reputational effects provide an incentive for the CB to choose a noninflationary monetary policy. For some parameter values, this incentive is shown to be large enough to sustain an equilibrium with no inflation until the last period of the game.

One central feature distinguishes the present model from those already ana-

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[1]These models are surveyed in Cukierman (1986), Fischer (1986), and Rogoff (1987).

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lyzed on this topic. In the existing literature the private sector is described by an expectation formation mechanism; this description may be appropriate for a setting of competitive labor markets (like the United States), but it certainly lacks realism for many European economies where wages are controlled by powerful and coordinated trade unions.[2] This paper analyzes a wage formation process that incorporates this institutional feature. Wages are set by a centralized TU, who takes into account the effect of its actions on government incentives. Perhaps surprisingly, this richer strategic interaction makes the reputational equilibria with low inflation easier to sustain than in equivalent models with decentralized labor markets. Specifically, the presence of the TU (i) enlarges the set of parameter values for which an equilibrium with low inflation can occur, and (ii) allows the equilibrium to be defined exclusively on pure strategies (rather than on mixed strategies as in the existing literature).

Section 1 of this paper presents the basic model; section 2 computes the equilibrium with precommitments; section 3 derives the discretionary equilibrium under the hypothesis of complete information and finite horizon. Section 4 characterizes the reputational equilibrium under the hypothesis that the TU is incompletely informed about a parameter in the CB objective function (i.e., it characterizes the perfect Bayesian equilibrium of the game). Section 5 contains some concluding remarks.

1. THE MODEL

The macroeconomy is described by two simple equations; an aggregate demand function:

$$m_t = p_t + x_t \tag{1}$$

where m_t = log of the money supply, p_t = log of the price level, and x_t = log of real output; and an aggregate supply function:

$$x_t = \alpha(p_t - w_t) , \qquad \alpha > 0 \tag{2}$$

where w_t = log of the nominal wage.

The CB sets m_t so as to minimize:

$$V_t^M = \frac{1}{2} \sum_{k=t}^{T} [\pi_k^2 + \tau x_k^2]\, \beta^k, \qquad 1 > \beta > 0, \qquad \tau > 0 \tag{3}$$

[2]Countries where large unions figure prominently in the wage formation process include Argentina, Australia, Austria, Belgium, Britain, Denmark, Finland, France, Italy, Norway, and Sweden. In many of these countries the monetary authorities announce in advance their monetary targets. The credibility of these announcements is affected by the reputational incentives analyzed in this paper.

where $\pi_k = p_k - p_{k-1}$ is the rate of inflation in period k. The TU sets w_t so as to minimize:

$$V_t^U = \frac{1}{2} \sum_{k=t}^{T} (w_k - p_k - v)^2)\ \rho^k, \qquad v > 0, \qquad 1 > \rho > 0 \ . \tag{4}$$

Equation (3) says that the CB wants to keep output and inflation close to some desired values, taken to be zero for notational convenience. The parameter τ indicates the relative weight assigned by the CB to the output objective. Equation (4) says that the TU has a desired target for real wages, $v > 0$. Implicitly, therefore, it is assumed that firms take nominal wages as given and that they set employment (and output) according to equation (2). This assumption, together with the specification of preferences for the two players, is standard in the literature.[3]

The conflict between the two players is generated by the hypothesis that $v > 0$ in (4). The real wage targeted by the TU causes output to be below the level desired by the CB. Hence, the CB has an incentive to inflate away the high real wages, so as to increase output. If the TU realizes this, it will set nominal wages even higher. This strategic interaction between the two players is analyzed throughout the paper under different hypotheses about the information available to them.

2. RULES

This section computes the equilibrium in which the CB can precommit to a monetary policy rule before nominal wages are set by the TU. This equilibrium serves as a benchmark against which to evaluate the outcomes that arise with discretionary monetary policy.

The game here proceeds as follows. At the beginning of each period, the CB sets the money supply, taking into account the TU response. Then the TU sets nominal wages, after having observed the CB action. Output, inflation, and real wages are then determined according to (1) and (2).

From (4), it follows immediately that the nominal wage rate minimizing the TU loss function is (time subscripts will be omitted when superfluous)

$$w = p + v \ . \tag{5}$$

Substituting (5) into (2), we get that in each period output is unaffected by monetary policy:

[3]See, for instance Calmfors (1984), McDonald and Solow (1981), Oswald (1985, 1982). The real wage target, v, is presumably related to the elasticity of labor demand, and thus can be taken to be independent of monetary policy. Adding a quadratic function of output to the TU loss function would complicate the notation but it would not affect any of the results.

$$x = -\alpha v \,. \tag{6}$$

Finally, substituting (6) into the CB loss function, (4), we obtain that the optimal monetary policy rule is always to set inflation at zero: $\pi = 0$.

We thus obtain that, in the equilibrium with monetary policy precommitments,

$$\pi^C = 0, \qquad x^C = -\alpha v, \qquad w^C - p^C = v \tag{7}$$

where the C superscripts stand for "commitment."

The intuition behind this result is exactly as in Barro and Gordon (1983): with binding commitments, the CB takes into account that nominal wages respond one for one to any change in prices. Hence, monetary policy is neutral. The best thing that the CB can do, here, is to set inflation to zero and let output be determined by the TU.

3. DISCRETION

Under the institutional setting currently prevailing in all industrial countries, the monetary authority cannot enter into binding commitments and enjoys a large degree of flexibility. Nominal wages, on the other hand, are generally either partially or completely predetermined by binding labor contracts lasting some specific interval of time. This setup is best captured by a noncooperative repeated game in which the TU has the first move in each period. The subgame perfect equilibrium of such a game can be derived by working backwards from the last period. Since there is no dynamic state variable and since the model is linear-quadratic, it is easy to show that the "one-shot" Stackelberg equilibrium is the unique subgame perfect equilibrium of the repeated game.

The "one shot" Stackelberg equilibrium can be computed as follows. The CB minimizes its loss function, subject to (1) and (2). Since it moves after the TU, the CB is forced to take nominal wages as given. Hence, its first-order condition yields:

$$\pi = -\alpha\tau x \,. \tag{8}$$

The TU minimizes its loss function, subject to (1) and (2) and to the CB reaction function, equation (8). Its first-order condition is given again by (5) in the previous section. The discretionary equilibrium is obtained by combining (5), (8), and (2) (the D superscript standing for "discretion"):

$$\pi^D = \alpha^2\tau v > 0, \qquad x^D = -\alpha v < 0, \qquad w^D - p^D = v \,. \tag{9}$$

Comparing (9) with (7), the only difference between the discretionary equilibrium and the equilibrium with policy precommitments concerns the rate of inflation, which is positive under discretion but zero with precommitments. Real output and real wages are identical in the two equilibria. Hence, the CB is better off with precommitments, whereas the TU is indifferent between the two regimes since it does not care about nominal variables. This is the well-known result that rules are better than discretion, obtained by Kydland and Prescott (1977) and Barro and Gordon (1983b) with competitive labor markets. The intuition here is similar to the models with competitive labor markets. Once nominal wages have been set, the CB might be tempted to reduce the real wage by means of unexpected inflation, so as to increase output. The TU realizes this, and sets nominal wages high enough so that the marginal benefit to the CB of some unexpected inflation is fully offset by the marginal cost of that higher inflation. Hence, in equilibrium real wages are at the level targeted by the TU and inflation is positive.

4. REPUTATION

Even though in the current monetary regime policy precommitments are not feasible, in many countries the monetary authorities announce in advance their intermediate monetary targets. This section analyzes the issue of the credibility of such announcements and the extent to which they influence the behavior of the TU and of the CB itself.

Since the discretionary equilibrium computed in section 4 is the unique subgame perfect equilibrium, under the assumptions of complete information and finite horizon no announcement will ever be believed unless it coincides with the CB first-order condition given by equation (8) above. If either of the two assumptions is dropped, however, announcements may become an effective policy instrument.

Here the game is solved for a finite horizon and under the hypothesis that the TU has incomplete information about the parameter τ in the CB objective function. The setting is as in Kreps and Wilson (1982), Barro (1986), Backus and Driffill (1985a,b), and Tabellini (1985): this element of incomplete information now gives the CB an incentive to maintain its reputation in the early stages of the game by not deviating from the announcements. If this incentive is large enough, the announcements may become perfect credible. Unlike in Backus and Driffill (1985a) or in Barro (1986), however, here the private sector has an active strategic role, since it is a large player who has the first move in each period; this turns out to make a difference in the qualitative features of the solution.

The game proceeds as follows: when the game is started the CB announces that it will follow a noninflationary policy rule. Then both players choose their actions. At the beginning of each period the TU sets nominal wages so as to minimize its expected loss, on the basis of its prior beliefs about the nature of its opponent. Then the CB moves and the TU, having observed the actual behavior of the

CB, revises its beliefs according to Bayes rule. The resulting equilibrium is a perfect Bayesian equilibrium.[4]

Some Preliminary Results

For simplicity it is assumed that, when the game begins, the TU assigns a prior probability $\bar{P}$ to the event that $\tau = 0$, and a probability $(1-\bar{P})$ to the event that $\tau = \bar{\tau} > 0$. These prior beliefs are common knowledge. A CB with $\tau = 0$ will be called "tough," and a CB with $\tau = \bar{\tau} > 0$ will be called "weak."[5] If the CB actually is tough, its optimal behavior is simply to set m_t so as to have $\pi_t = 0$ in any period. If the CB is weak, its optimal strategy is more sophisticated: as will be shown below, the equilibrium nominal wage is a function of the TU prior beliefs about the CB preferences. This creates an incentive for a weak CB to choose a noninflationary monetary policy in the early stages of the game, so as to influence the TU beliefs in later stages. The optimal strategy for a weak CB is characterized in the next two subsections. Before then, we need some investments in notation.

Let $P_t = prob(\tau{=}0)$ be the TU prior beliefs at time t, and let $Q_t = prob(\pi_t{=}0)$, $P_t^* = prob(\pi_t{=}0/\tau{=}\bar{\tau})$. Thus, Q_t is the unconditional probability that there will be no inflation at time t, and P_t^* is the conditional probability of zero inflation, given that the CB is weak. As will be shown below, P_t^* is chosen by a weak CB. It then follows from these definitions that

$$Q_t = P_t + (1-P_t)\, P_t^* \,. \tag{10}$$

The hypothesis that P_t is revised according to Bayes rule implies that

$$P_{t+1} = 0 \qquad \text{if } \pi_t \neq 0 \,; \tag{11}$$

$$P_{t+1} = \frac{P_t}{P_t+(1-P_t)P_t^*} = \frac{P_t}{Q_t} \text{ if } \pi_t = 0 \,. \tag{12}$$

P_t is a sufficient statistic for the history of the game up to time t, and is a natural measure of the CB reputation. If a positive rate of inflation is observed in period t, then the CB reputation of being tough is destroyed, and $P_{t+1} = 0$. If instead zero inflation is observed, the CB could be truly tough (i.e., $\tau = 0$); or it could simply pretend to be so, in order to maintain or enhance its reputation. The relevant posterior probability, then, depends on P_t^*, the probability that a weak CB will tolerate zero inflation. In equilibrium, P_t^* must be consistent with the

[4]See Kreps and Wilson (1982), Fudenberg and Tirole (1983).

[5]As Rogoff (1987) points out, this specification of the TU prior beliefs can also be interpreted as uncertainty about the political costs faced by the CB if it reneges on a previous announcement. In a related setting with decentralized labor markets, Vickers (1986) and Driffill (1986) point out that, if the "tough" CB type also cares about output, there would exist signaling equilibria in which the reputation mechanism can break down.

optimal behavior of a weak CB. In the following subsections the optimal P_t^* will be deduced from the solution of the CB strategic problem.

The Last Period

In the last period of the game, the weak CB will always inflate, since destroying its reputation can have no future adverse consequences. The optimal inflationary strategy is still given by the first-order condition in (8): $\pi_T = -\alpha\bar{\tau}\, x_T$. As a result, the TU expects the rate of inflation to be $\pi_T = 0$ with probability P_T, and $\pi_T = -\alpha\tau\, x_T$ with probability $1-P_T$, P_T being the CB reputation at the beginning of period T. After some substitutions, and expressing the nominal wage in deviation from the price level in the equilibrium with commitments, p^C, the TU expected loss in period T can be written as

$$\hat{H}_T^U = \frac{1}{2}\, P_T(w_T - v)^2 + \frac{1}{2}\,(1-P_T)\left(\frac{w_T}{1+\alpha^2\bar{\tau}} - v\right)^2 . \tag{13}$$

The first-order condition with respect to w_T, taking P_T as given, yields (the B superscript standing for Bayesian equilibrium)

$$w_T = w^C\,\phi(P_T) + w^D(1-\phi(P_T)) \equiv w^B(P_T) \tag{14}$$

where w^C and w^D, $w^C < w^D$, are the nominal wage in the precommitments and discretionary equilibrium with complete information respectively,[6] and where

$$0 \leqslant \phi(P_T) = \frac{P_T}{P_T + (1-P_T)/(1+\alpha^2\bar{\tau})^2} \leqslant 1 \tag{15}$$

with $\phi'(P_T) > 0$, $\phi(0) = 0$, $\phi(1) = 1$.

Thus, in the last period of the game the nominal wage set by the TU is a weighted average of the nominal wages in the precommitments and discretionary equilibria of the game with complete information. The weight on w^C is an increasing function of the CB reputation, P_T. Therefore, the higher is the CB reputation, the lower is the nominal wage in the last period of the game. This inverse relationship between nominal wages and its reputation provides the CB with an incentive not to inflate in the earlier stages, so as to maintain or enhance its reputation.

The Central Bank Behavior

In any period other than the last one, the weak CB chooses monetary policy by weighting the short-term gains of unexpected inflation against the long-term

[6]Recall that nominal wages are expressed in deviations from p^C. Using the results of sections 3 and 4, it can be shown that: $w^D = (1+\alpha^2\bar{\tau})v$, $w^C = v$.

costs of losing its reputation. Suppose that the CB has not inflated up to and including period $T-2$, and let w_{T-1} denote the nominal wage set by the TU in period $T-1$, in deviation from the price level in the equilibrium with commitments, p^C. With probability P^*_{T-1} the CB will set $\pi_{T-1} = 0$; from (3) and (2), if $\pi_{T-1} = 0$ is realized, its loss in period $T-1$ will be $\alpha^2 \bar{\tau} w^2_{T-1}/2$. With probability $(1-P^*_{T-1})$ the CB will play the optimal inflationary strategy, $\pi_{T-1} = -\alpha\bar{\tau}x_{T-1}$; in this case, using (2) and (3), its loss is given by $\bar{\tau}\alpha^2 w^2_{T-1}/[2(1+\alpha^2\bar{\tau})]$. Hence, the CB expected loss in period $T-1$ is

$$\hat{H}^M_{T-1} = \frac{1}{2}\alpha^2\bar{\tau}\left[P^*_{T-1}w^2_{T-1} + (1-P^*_{T-1})\frac{1}{1+\alpha^2\bar{\tau}}w^2_{T-1}\right]. \tag{16}$$

If in period $T-1$ the CB inflates, then, as stated in (11), $P_T = 0$. As a consequence, in the last period nominal wages would be like in the discretionary equilibrium of the game with complete information: from (14) and (15), $w^B(P_T) = w^D$ if $P_T = 0$. If instead in period $T-1$ the CB sticks to the noninflationary strategy, then P_T is formed according to (12), and from (14) and (15) it follows that $w^B(P_T) < w^D$.

Denoting by $V^M_{T-1}(P_{T-1})$ the CB indirect loss function from period $T-1$ up to the end of the game, conditional on having played the non-inflationary strategy up to and including period $T-2$, we then have

$$V^M_{T-1}(P_{T-1}) = \underset{P^*_{T-1}}{\text{Min}}\left\{\hat{H}^M_{T-1} + \beta\frac{1}{2}\frac{\alpha^2\bar{\tau}}{1+\alpha^2\bar{\tau}}\left[P^*_{T-1}(w^B(P_T))^2 + (1-P^*_{T-1})(w^D)^2\right]\right\} \tag{17}$$

where $\hat{H}^M_{T-1}$ is defined in (16). For a given nominal wage in period $T-1$, $V^M_{T-1}(P_{T-1})$ is linear in P^*_{T-1}. But w_{T-1} has to be taken as given, since wages are predetermined when the CB chooses monetary policy in period $T-1$. Moreover, $1 \geqslant P^*_{T-1} \geqslant 0$. Hence, there are three cases to consider:

(i) $\partial V^M_{T-1}(P_{T-1})/\partial P^*_{T-1} < 0$, which implies $P^*_{T-1} = 1$ (recall that $V^M_{T-1}(P_{T-1})$ is a *loss* function). That is, the optimal CB strategy in period $T-1$ is the pure strategy of no inflation. Hereafter, an equilibrium in which the CB plays such a strategy will be called *pooling*.

(ii) $\partial V^M_{T-1}(P_{T-1})/\partial P^*_{T-1} > 0$, implying $P^*_{T-1} = 0$; here, the optimal strategy is the pure inflationary strategy: $\pi_{T-1} = -\alpha\bar{\tau}x_{T-1}$. In this case, the equilibrium will be called *separating*.

(iii) $\partial V^M_{T-1}(P_{T-1})/\partial P^*_{T-1} = 0$, in which case the CB chooses a mixed strategy (it plays $\pi_{T-1} = 0$ with probability $P^*_{T-1} > 0$, and $\pi_{T-1} = -\alpha\bar{\tau}x_{T-1}$ with probability $(1-P^*_{T-1}) > 0$.)

Differentiating the right-hand side of (17) with respect to P^*_{T-1}, using (16) and then simplifying, we obtain that $\partial V^M_{T-1}(P_{T-1})/\partial P^*_{T-1} \gtreqless 0$ as:

$$w^2_{T-1} \gtreqless \frac{\beta}{\bar{\tau}\alpha^2}[(w^D)^2 - (w^B(P_T))^2] \ . \tag{18}$$

Using (16), the left-hand side of (18) can be shown to be proportional to the net gain for the CB of creating unexpected inflation today, i.e., it is the "temptation to cheat" of Barro and Gordon (1983a), Barro (1986). The right-hand side of (18) can be shown to be proportional to the net cost for the CB of creating unexpected inflation *today rather than tomorrow* (since it is proportional to next period loss if the CB inflates today less next period loss if it unexpectedly inflates tomorrow). Thus, the right-hand side of (18) is the incentive that sustains a noninflationary monetary policy today for a weak CB. When the two sides of (18) are equal, the CB chooses a mixed strategy (i.e., $1 > P^*_{T-1} > 0$), since it is indifferent between creating unexpected inflation today rather than tomorrow. If (18) holds with a $>$ sign, then the net gain of inflating today exceeds the corresponding net cost, and the CB chooses a pure inflationary strategy right away (i.e., $P^*_{T-1} = 0$). Conversely, if (18) holds with a $<$ sign, the net gain from creating unexpected inflation is smaller than the cost of losing its reputation, and the CB resists the temptation to inflate (i.e., $P^*_{T-1} = 1$).

Condition (18) is illustrated in Figure 1. The downward sloping line corresponds to the case in which (18) holds with an equal sign. Any point below the downward sloping line has the CB playing the noninflationary strategy with certainty ($P^*_{T-1} = 1$), any point above it has the CB playing inflation with certainty ($P^*_{T-1} = 0$), and any point on the line, has the CB playing a mixed strategy, ($1 > P^*_{T-1} > 0$).

If in period $T-1$ the weak CB inflates with certainty ($P^*_{T-1} = 0$), and if in that period zero inflation is observed by the TU, then according to (12) $P_T = 1$ (i.e., the TU infers from that the CB is tough). In the subsequent period the TU will then set the nominal wage at w^C—cf. (14) and (15). Condition (18) then implies that, given this future behavior on the part of the TU, the weak CB does indeed find it optimal to play the inflationary strategy in period $T-1$, $P^*_{T-1} = 0$, if

$$w^2_{T-1} > \frac{\beta}{\bar{\tau}\alpha^2}[(w^D)^2 - (w^C)^2] \equiv (w^S)^2 \ . \tag{19}$$

Thus w^S is the minimum wage rate compatible with a separating equilibrium in period $T-1$. In terms of Figure 1: if in period $T-1$ the nominal wage rate is set above the horizontal dotted line labeled $(w^S)^2$, then the weak CB inflates in that period, since at that wage the temptation to cheat exceeds the cost of losing its reputation. This result identically applies to all earlier periods. Specifically, define w^S_t as the minimum wage rate compatible with a separating equilibrium in period t. Then:

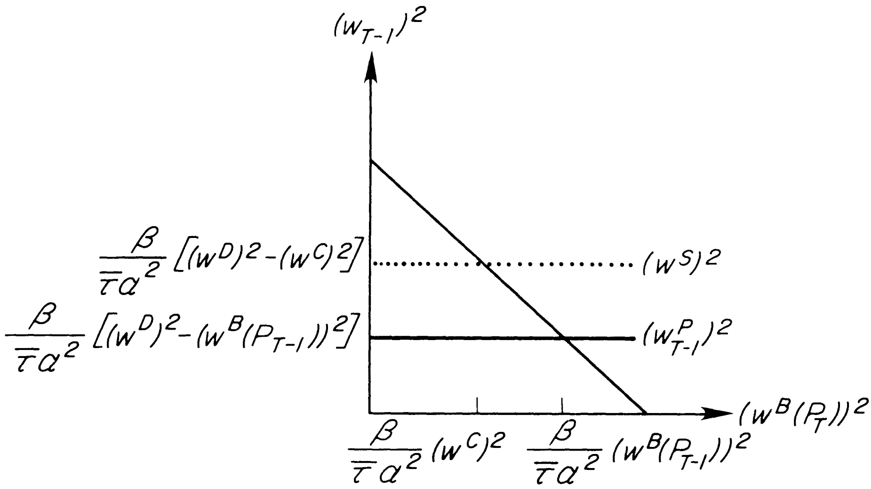

FIG. 1. Separating and Pooling Wage Rates

LEMMA 1: $w^S_t = w^S$ *for all t such that the equilibrium is separating from t+1 onwards.*

A formal proof is available from the author. The proof exploits the fact that, if the equilibrium is separating at $t+1$ and onwards, then there is no relevant distinction between period t and period $T-1$, as far as the CB incentives are concerned: in period t, just like in $T-1$, the reputational gains associated with a noninflationary monetary policy only last for one period (since by hypothesis the CB inflates in period $t+1$). Hence, w^S_t is defined by the right-hand side of (19), just like w^S_{T-1}.

Conversely, if in period $T-1$ the CB plays $\pi_{T-1} = 0$ with certainty ($P^*_{T-1} = 1$), then according to (12) its reputation at the beginning of the last period is the same as in period $T-1$: $P_T = P_{T-1}$. From (18) it then follows that in the last period the nominal wage will be $w^B(P_{T-1})$, as defined in (14). Condition (18) then implies that the weak CB will indeed find it optimal not to inflate in period $T-1$ if

$$(w_{T-1})^2 < \frac{\beta}{\bar{\tau}\alpha^2}[(w^D)^2 - (w^B(P_{T-1}))^2] \equiv (w^P_{T-1})^2 . \tag{20}$$

Thus w^P_{T-1} denotes the maximum wage rate compatible with a pooling equilibrium in period $T-1$. Condition (20) is illustrated in Figure 1 as the horizontal solid line. If the wage rate in period $T-1$ is set below such a line, the CB will find it optimal not to inflate, since the value of its reputation exceeds the temptation to cheat. Here, too, the result can be generalized to all earlier periods. Specifically, define w^P_t as the maximum wage rate compatible with a pooling equilibrium in period t. Then:

LEMMA 2: *$w_t^P > w_{T-1}^P$ for all $t < T-1$ such that the equilibrium is pooling from $t+1$ until $T-1$. If $\beta \leqslant \bar{\tau}\alpha^2$, then $w_t^P = w_{T-1}^P$ for all $t < T-1$ such that the equilibrium is separating from $t+1$ until T.*

The proof, also available from the author upon request, is based on the following two insights. If the equilibrium from $t+1$ onwards is separating, then period t is just like period $T-1$, and consequently $w_t^P = w_{T-1}^P$. If instead the equilibrium in future periods is pooling, then the CB temptation to deviate from a pooling equilibrium by creating unexpected inflation is always stronger at $T-1$ than in any earlier period. Intuitively, in this case it is more costly to inflate in period t than at $T-1$: by inflating earlier, the CB foregoes a longer stream of the benefits accruing to its previous reputational investments. Hence, the reputational incentives that sustain a pooling equilibrium are stronger in the early stages of the game.

The next section exploits these two Lemmas and completes the characterization of the equilibrium by describing how the TU sets nominal wages in any period other than the last one.

Characterization of the Perfect Bayesian Equilibrium

Since by hypothesis the TU is indifferent about nominal magnitudes, its only concern is to correctly forecast the CB action. As such, in setting the nominal wage in any period $t < T$, the TU might seek to make the CB behavior more predictable. In this respect the TU faces an intertemporal trade-off: in a separating equilibrium the TU faces some uncertainty in the current period, but the CB action reveals its type, so that the uncertainty will be resolved as of next period. On the other hand, in a pooling equilibrium the TU faces no uncertainty in the current period, but it does not learn by observing the CB action. If, as assumed, the TU discounts the future (if $\rho < 1$), then it prefers the pooling to the separating equilibrium. This reasoning provides the basic intuition for the following:

PROPOSITION 1: *If the following condition holds,*

$$1 < \beta\phi(\bar{P})\,[2(1+\alpha^2\bar{\tau}) - \alpha^2\bar{\tau}\phi(\bar{P})] \tag{P.1}$$

where $\bar{P}$ is the CB reputation at the start of the game, then the only perfect Bayesian equilibrium is pooling, with the TU playing

$$w_t = w^C, \qquad t < T, \qquad w_T = w^B(\bar{P})$$

and the weak CB playing

$$\pi_t = 0, \qquad t < T, \qquad \pi_T = \alpha^2\bar{\tau}\nu\ .$$

PROOF: Consider period $T-1$ first, and suppose that $P_{T-1} = \bar{P}$. If (P.1) holds, then it can be shown that $w^C < w_{t-1}^P$. Hence (20) is satisfied and the CB finds it optimal to play $\pi_{T-1} = 0$, given that the TU has played $w_{T-1} = w^C$—cf. Figure 1.

In order to show that the TU is also playing optimally, note first that in periods $T-1$ and T the TU is playing its optimal response to the CB strategy—cf. equations (14) and (15). We want to show that the TU cannot be made better off by the CB playing any other strategy. Let $\hat{H}^U(Q_{T-1})$ be the TU indirect expected loss function in period $T-1$, given that the CB plays $\pi_{T-1} = 0$ with probability Q_{T-1} and $\pi_{T-1} = -\alpha\bar{\tau}x_{T-1}$ with probability $(1-Q_{T-1})$, and given that the TU plays optimally in period $T-1$. Substituting (14) in (13) and simplifying, we have

$$\hat{H}^U(Q_{T-1}) = \begin{cases} \dfrac{1}{2} v^2 \left(\dfrac{\alpha^2\bar{\tau}}{1+\alpha^2\bar{\tau}} \right)^2 \phi(Q_{T-1})(1-Q_{T-1}) > 0 & \text{if } 1 > Q_{T-1} > 0 \\ = 0 & \text{otherwise.} \end{cases} \tag{21}$$

Next, consider the TU indirect expected loss function in the last two periods of the game, $V^U_{T-1}(\bar{P})$, given that $\bar{P}$ is the CB reputation at the beginning of period $T-1$, and given that the CB is playing $1 \geqslant P^*_{T-1} \geqslant 0$, $P^*_T = 0$. From (10)–(12) we have[7]

$$V^U_{T-1}(\bar{P}) = \hat{H}^U(Q_{T-1}) + \rho Q_{T-1} \hat{H}^U\left(\frac{\bar{P}}{Q_{T-1}}\right). \tag{22}$$

Going through some tedious algebra, it can be shown that the right-hand side of (22) reaches a minimum at $Q_{T-1} = 1$ (i.e., at $P^*_{T-1} = 1$), which corresponds to the pooling equilibrium of this proposition.

Having established that the equilibrium is pooling at $T-1$, consider now period $T-2$. By Lemma 2, $w^P_{T-1} > w^P_{T-1} > w^C$. Hence, the CB still finds it optimal to pool and play $\pi_{T-2} = 0$, given that the TU plays its best response to the CB noninflationary strategy: $w_{T-2} = w^C$. Going through the same argument presented above, it can be shown that the TU is better off if the CB pools in $T-2$ and in $T-1$ than if the CB plays any other strategy. Hence, the TU does indeed play $w_{T-2} = w^C$, and the equilibrium is pooling in $T-2$. The same steps can then be repeated for any arbitrary number of periods up to the start of the game, by showing that the equilibrium is pooling at t, given that it is pooling at $t+1$. Finally, if the equilibrium is pooling for all $t \leqslant T-1$, then nothing is learned by the TU about the nature of its opponent. Equation (12) accordingly implies that $P_t = \bar{P}$, $t \leqslant T$, where $\bar{P}$ is the CB reputation at the start of the game.

Q.E.D.

[7]Equation (22) has been derived by noting that, if the CB inflates in period $T-1$ (which happens with probability $(1-Q_{T-1})$), then the TU loss in period T is zero.

If condition (P.1) in the text of Proposition 1 is violated, then the wage rate that would prevail with precommitments, w^C, is not low enough to sustain a pooling equilibrium. In terms of Figure 1, $(w^C)^2$ is above the horizontal line labeled $(w^P_{T-1})^2$, so that at that wage rate the CB incentives to maintain a reputation are too weak.

The TU then has to choose between the following alternatives: (a) to accept a lower real wage in the current period, by setting the nominal wage just below w^P_t, so as to sustain the pooling equilibrium. The gain from doing so is to delay by one period the uncertainty about the inflation rate. Or (b) to set a nominal wage higher than w^S_t—cf. Figure 1. This would induce the CB to separate and reveal its type, so that as of next period there would be no uncertainty. Or else (c) to set the wage in between w^P_t and w^S_t, at a level which makes the CB just indifferent between inflating and not inflating. In this case in equilibrium the CB would play a mixed strategy and the wage chosen by the TU would be the optimal response to the CB strategy. In the remainder of this section I will further describe the TU choice between the pooling and the separating equilibrium, neglecting the possibility of a mixed strategy equilibrium. Even though such an equilibrium is subgame perfect and could be preferred by the TU for some parameter values, it is nonetheless a less appealing solution concept: the CB has no clear incentive to choose that unique probability assignment for its randomized strategy which is consistent with equilibrium. A detailed description of the mixed strategy equilibrium for the whole game is contained in a previous version of this paper, available upon request. The main qualitative feature of such an equilibrium is that wages and output generally exhibit oscillations. Barro (1986), Section 5, briefly describes a very similar equilibrium.

In order to describe the TU choice between the pooling and the separating equilibrium, we first need to show that, when condition (P.1) in Proposition 1 is violated, the minimum wage rate compatible with a separating equilibrium at time t, w^S_t, is constant over time. More precisely:

LEMMA 3: *If (P.1) is violated, then* $w^S_t = w^S$ *for all* $t \leqslant T-1$*, where* w^S *is defined in (19).*

The proof, available from the author upon request, is based on the following argument. If the CB unilaterally deviates from a separating equilibrium in period t, by playing $\pi_t = 0$, then the TU would interpret this deviation as revealing that the CB is tough with certainty (i.e., $P_{t+1} = 1$). In the next period, therefore, the TU would play its best response to a tough CB: $w_{t+1} = w^C$. But if P.1 is violated, then $w^C > w^P_{t+1}$, so that in period $t+1$ the CB will find it optimal to separate and play $\pi_{t+1} > 0$. The proof is then completed by appealing to Lemma 1.

We are now ready to describe the equilibrium in the case where (P.1) in Proposition 1 is violated.

PROPOSITION 2: *If* $\beta \leqslant \bar{\tau}\alpha^2$ *and if (P.1) is violated, the unique perfect Bayesian equilibrium is pooling if*

$$w^P > v\left[1 - \frac{\alpha^2\bar{\tau}}{1+\alpha^2\bar{\tau}}\sqrt{\frac{(1-\rho)\phi(\bar{P})(1-\bar{P})}{2}}\right] \qquad \text{(P.2)}$$

where w^P is defined in (20) by replacing P_{T-1} with $\bar{P}$; and it is separating otherwise. If the equilibrium is pooling, the TU plays $w_t = \mathrm{Min}(w_t^P, w^C)$ up to period T–1 and the CB does not inflate. In period T the TU plays $w^B(\bar{P})$ and the weak CB inflates. If the equilibrium is separating, then the TU plays $w^B(\bar{P})$ in the first period, and the weak CB inflates. From then on, the equilibrium is as in the game with complete information.

PROOF: Consider period $T-1$ first, and suppose that $P_{T-1} = \bar{P}$. If $\beta \leqslant \bar{\tau}\alpha^2$ and if (P.1) is violated, then it can be shown that $w^B(\bar{P}) > w^S_{T-1} = w_S$. *That is, if in period* $T-1$ the TU plays its optimal response to the CB inflationary strategy, $w^B(\bar{P})$, the weak CB indeed finds it optimal to separate and play such a strategy. In this case, the TU indirect loss function from period $T-1$ up to the end of the game is $\hat{H}^U(\bar{P})$, with $\hat{H}^U(\cdot)$ defined in (21).

If instead in period $T-1$ the TU plays the maximum wage rate consistent with a pooling equilibrium, $w^P_{T-1} = w^P$, its indirect loss function from $T-1$ up to the end of the game is

$$V^U_{T-1}(\bar{P}) = (w^P - v)^2 + \rho\hat{H}^U(\bar{P}) \ . \qquad (23)$$

Hence, in period $T-1$ the TU is just indifferent between the pooling and the separating equilibrium if

$$(v - w^P)^2 = \hat{H}^U(\bar{P})(1-\rho) \ . \qquad (24)$$

If the left-hand side of (24) is smaller than the right-hand side, then the TU prefers the pooling equilibrium. If it is larger, the separating equilibrium is preferred. Condition (P.2) in the text of this proposition is derived by substituting (21) in the right-hand side of (24). Hence, if (P.2) holds, then the TU prefers the pooling equilibrium at $T-1$. Otherwise, it prefers the separating equilibrium.

Consider now period T–2. Applying Lemmas 2 and 3, it can be shown that if (P.2) is violated, so that the equilibrium at $T-1$ is separating, then the equilibrium at $T-2$ is also separating. This happens because, according to Lemmas 2 and 3, if $T-1$ is separating, there is no relevant distinction between periods $T-1$ and $T-2$. Similarly, applying Lemmas 2 and 3, it can be shown that if (P.2) holds, so that the equilibrium at $T-1$ is pooling, then the equilibrium at $T-2$ is also pooling. Here this happens because, according to Lemmas 2 and 3, $w^S_{T-2} = w^S{}_{T-1}$ but $w^P_{T-2} > w^P_{T-1}$. Hence the pooling equilibrium is easier to sustain in $T-2$ then in $T-1$, given that the equilibrium at $T-1$ is also pooling. The rest of the proof can be completed by repeating the same steps for all earlier periods, and by noting that according to (13) $P_t = \bar{P}$ if the equilibrium is pooling up to period t.

Q.E.D.

Finally, if (P.1) in Proposition 1 is violated but $\beta > \bar{\tau}\alpha^2$, then the TU cannot play $w^B(\bar{P})$ and still bring about the separating equilibrium for all parameter values. The equilibrium in this case is analogous to the one described in Proposition 2, with two exceptions: the condition for the existence of the pooling equilibrium is weaker than (P.2), since the separating equilibrium may now be more costly for the TU. And in the first period of the separating equilibrium the TU plays w_t^S rather than $w^B(\bar{P})$. The formal proof is very similar to that of Proposition 2.

Proposition 2 underscores the importance of having nominal wages set by a single union rather than by decentralized labor markets. Nominal wages here do not just reflect inflationary expectations as in Backus and Driffill (1985a) and Barro (1986). Instead, they are determined strategically by the union so as to influence monetary policy. In particular, the TU is willing to tolerate some reduction in real wages so as to provide the CB with adequate incentives to pursue a noninflationary monetary policy. This happens despite the fact that the TU does not care about nominal magnitudes. It is the TU risk aversion, and the fact that nominal wages are predetermined when monetary policy is chosen, that induces the TU to accept lower real wages in exchange for less uncertainty in the current period.

This difference between the present model and the existing literature on reputation with decentralized labor markets is reflected in the equilibrium time path of output. In the pooling equilibrium of Proposition 2, nominal and real wages tend to fall over time (since, according to Lemma 2, w_t^P tends to fall as the end of the game is approached). As a result, output tends to rise towards the end of the game, even though actual and expected inflation remain equal to zero. Intuitively, since the CB reputational incentives tend to weaken towards the end of the game, the TU is willing to accept lower wages so as to sustain a noninflationary monetary policy. In the existing models with decentralized labor markets, instead, as the reputational incentives weaken, the equilibrium goes through a phase in which the CB plays a mixed strategy. Hence, expected inflation is positive and, while actual inflation is zero, output is lower than in the earlier stages of the game.

Finally, on the basis of the results presented so far, it is possible to assess the consequences of changes in the underlying parameters. Most notably: increasing the CB reputation at the start of the game, $\bar{P}$, and increasing its rate of time preference, β, have the effect of raising w^P. As such, the pooling equilibrium is more likely to occur. The intuition is simply that increasing $\bar{P}$ and β tends to strengthen the CB reputational incentives. Moreover, decreasing the TU rate of time preference, ρ, has the same final effect of making the pooling equilibrium more likely, though for a different reason. If the TU assigns a lower weight to the future, it is prepared to accept a lower real wage now in order to delay the consequences of its uncertainty about the CB type. Hence, if ρ is reduced, a pooling equilibrium with lower real wages, higher output and zero inflation is more likely to arise—cf. equation (24) in the proof of Proposition 2.

5. CONCLUDING REMARKS

Under the institutional setting currently prevailing in most industrial countries, monetary policy precommitments are not feasible. Nonetheless, the monetary authorities in these countries often announce their intermediate policy targets well in advance. This paper has investigated the issue of whether reputational incentives can be strong enough to induce the authorities to abide by their announcements and hence refrain from creating unexpected inflation. Unlike in recent papers by Barro and Backus and Driffill, the private sector here has an active strategic role, similar to that played by a centralized trade union in many European countries.

The main novel implication of the preceding analysis is that the existence of a trade union strengthens the reputational effects of monetary policy announcements and makes the pooling equilibrium with no inflation more likely to occur than in a model with competitive labor markets. This happens for two reasons. First of all, in a model with decentralized labor markets who take monetary policy as given, multiple equilibria can exist. Specifically, if in the model of this paper nominal wages are set by decentralized players, then for some parameter values a pooling, a separating, and a mixed strategy equilibrium can simultaneously coexist.[8] If, however, wages are set by a trade union who discounts the future and takes into account how monetary policy is influenced by nominal wages, this multiplicity disappears. As shown in Proposition 1, the trade union is always better off in the pooling equilibrium, provided that it can play its best response to the noninflationary monetary policy. Hence, whenever a pooling equilibrium exists with decentralized labor markets, it would also exist, but be unique, with a centralized trade union.

Secondly, as shown in Proposition 2, the trade union intertemporal preferences can make it willing to accept a lower real wage so as to induce the central bank to play the noninflationary policy with certainty in the current period. Hence, the range of parameter values for which a pooling equilibrium exists is larger than in an equivalent model with decentralized labor markets that take monetary policy as given, and the equilibrium time path of output has different qualitative properties than in such a model.

Finally, the pooling equilibrium described in the previous section never goes through any phase during which the central bank plays a randomized strategy. This appealing feature of the equilibrium was absent from most of the other models of reputation with competitive labor markets.

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[8]In terms of the formal discussion of section 4, this can happen if $\beta \geqslant \bar{\tau}\alpha^2$, for then it is possible that $w^B(\bar{P}) > w^S$ (in which case the TU optimal response to the CB separating strategy sustains a separating equilibrium) and at the same time $w^C < w^P_{T-1}$ (in which case the TU optimal response to the CB pooling strategy sustains the pooling equilibrium).

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[Footnotes]

[3] **Wage Bargaining and Employment**
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[4] **Sequential Bargaining with Incomplete Information**
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