CAN CENTRAL BANK SCREENING SOLVE THE INFLATIONARY BIAS?[*]

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Abstract

We analyze the optimal incentive scheme for central banks when there exists an inflationary bias and the monetary authorities' preferences are private information. In the mechanism proposed the government designs a menu of contracts so that the central bank's choice reveals its type. Therefore, this arrangement removes the extraneous noise that asymmetric information introduces into monetary policy. We conclude that the inflationary bias is eliminated for the type of central bank with the high valuation of the financial reward. However, if this valuation is low this bias is reduced only partially unless the transfer is not costly for the government.

Keywords: Walsh contract, inflationary bias, discretionary monetary policy, independent central bank, credibility, asymmetric information

JEL classification: E58, E52, D80

1 Introduction

Kydland and Prescott (1977) and Barro and Gordon (1983a) pointed out that discretionary monetary policy tends to generate an inefficiently high level of inflation with no gain in terms of output. The key element that originates this "inflationary bias" is the policymaker's inability to credibly commit to the socially optimal inflation rate. In this respect, an active line of investigation has focused on the search of credible commitment technologies that make it more costly for the central bank to generate inflation. This literature has followed two different routes which can be labelled as the "reputation" approach and the "institutional design" approach[1].

The reputation approach was pioneered by Barro and Gordon (1983b). They considered a dynamic context where a central bank who carries out a monetary surprise signals that it is prone to inflation. As a result it is "punished" by the private sector since they respond to such behavior by rising their expectations on inflation[2]. By contrast, the institutional design approach aims at proposing monetary institutions that provide the central bank with the right incentives to deal with the inflationary bias. Within this approach Rogoff (1985), Walsh (1995a) and Svensson (1997) put forward different mechanisms which mitigate or even eliminate this bias[3]. Each of these three institutions can be interpreted as a contract that the government (the principal) designs and offers to the central bank (the agent) whose preferences are common knowledge[4]. On that score, however, Obstfeld and Rogoff (1996, p. 644) remarked that "a problem with the optimal contract scheme is that there may be uncertainty about the relative weight the banker places on public welfare versus personal financial remuneration. If so, uncertainty about say, the central banker's financial needs may lead to uncertainty over inflation and introduces extraneous noise into inflation policy".

The existence of this private information problem about the central bank's objective function

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[1] Such a classification can be found, for intance, in Persson and Tabellini (2000) and in Walsh (2003).

[2] For other papers belonging to this approach see Walsh [2003, pp. 385-393] and the references therein.

[3] The elimination of the inflationary bias is only partial in Rogoff's proposal and complete in Walsh's and in Svensson's.

[4] The interpretation of Rogoff's arrangement as a "quadratic contract" appears in Walsh (1995a), Beetsma and Jensen (1998) and Jensen (2000). The interpretation of Svensson's institution as a contract appears in Persson and Tabellini (2000).

has been considered by Chortareas and Miller (2003a). They study the performance of a single contract to be offered to a central banker randomly selected from society when the valuation of the contract is private information by the central banker. In this sense, they follow Beetsma and Jensen (1998, 2003), Muscatelli (1998a,b), Nolan and Schaling (1998) and Eijffinger *et al* (2000, 2003) who considered the performance of a single contract when there is uncertainty about the preferences of the central banker about output and inflation stabilization. A common feature shared by these proposals is that they do not remove the inflationary since they cannot eliminate the uncertainty about the monetary authorities' type.

The aim of our paper is to put forward a new mechanism for dealing with the inflationary bias in a context in which the central bank's objective function is private information. We show that the government's optimal strategy consists of designing a menu of contracts to be offered to the central bank so that the latter's choice represents a credible signal that reveals its true type to the private sector. In this sense, our study draws on the institutional design approach since the performance of the central banker (the agent) is influenced by an incentive scheme designed by the government (the principal). However, our mechanism includes features which are absent in the proposals within this line of research. First, our arrangement achieves the complete elimination of the uncertainty about the monetary authorities' preferences, removing the extraneous noise that asymmetric information introduces into monetary policy[5]. Second, in our institution the central bank is offered not just one contract but a menu of them, which yields a superior outcome in terms of social welfare[6].

We begin by analyzing the benchmark scenario in which information is symmetric. We consider two types of central banks that differ in their valuation of the transfer payments (associated to the contract) relative to social welfare (determined by inflation and output stabilization). In

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[5] Stiglitz (1999) discusses the importance of transparency in a democracy from a normative point of view. In his view, if society delegates tasks to independent institutions, people should know the preferences of these institutions. In this respect, we show that society can design mechanisms that imply the revelation of such preferences.

[6] Note that we work within a more general framework, since we admit the possibility that the central bank could be offered just a single contract if that option were optimal to the government. However, we show that this case is not the principal's best response.

this context, we study the optimal contract for each type of agent when the financial reward is costly to the government. Then, we compare this set of contracts with the menu that is optimal under asymmetric information about the monetary authorities' objective function. The transfer scheme analyzed in this setup maximizes the expected utility of the government subject to participation and incentive constraints of the central banker.

The reason why the principal finds it optimal that revelation of the central bank's type occurs is that mimicking would be too costly for the government in terms of the financial reward to be paid. In our separating equilibrium, the central bank of high type (i.e., the one with the highest valuation of the transfer payment) selects a contract that induces the complete elimination of the inflationary bias. On the other hand, if the monetary authorities have a low type they choose a contract which reduces the inflationary bias as well. However, this bias is not eliminated unless the government does not attach any value to the transfer that it pays to the central bank.

Our incentive scheme has the desirable property that the financial reward is not contingent on the realizations of the shocks. In the real world it is not feasible in practice to commit to a policy rule that is dependent on the state of the world. The reason is that it is prohibitively costly to specify all possible contingencies in advance, let alone to enforce such a hypothetical arrangement.

It is worthwhile to emphazise that our scenario differs from the typical adverse selection setup in that, in addition to the principal (government) and the agent (central bank), a third player is considered, namely, the private sector. It is precisely the incorporation of such a third actor which makes it possible for us to design the signalling game in which is based the instituion proposed in our paper. In fact, since we depart from this literature by allowing the government to offer not just one contract but a menu of them[7], this leaves room for designing such a (revealing) signalling process, which proves to be an effective device to eliminate the undesirable noise that asymmetric information introduces into monetary policy.

The rest of the paper is organized as follows. Section 2 presents the model. Sections 3 and 4 are devoted, respectively, to analyze the equilibrium contracts under symmetric and asymmetric

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[7]Observe that the space of admissible signals is restricted by the government to the set of contracts that it designs.

information. The final section concludes. Computations not included in the text are gathered in the Appendix.

2   The model

We consider a version of the simple stochastic model which have been widely used in the literature on credibility in monetary policy (see, for instance, Walsh [2003, chapter 8]). The working of the economy is summarized by the following equations:

$$y = \overline{y} + \alpha(\pi - \pi^e) - \varepsilon. \tag{1}$$

$$U^G = -\delta\left(A - b\pi\right) - \left(\lambda\pi^2 + (y - y^*)^2\right). \tag{2}$$

$$U_i^B = \theta_i\left(A - b\pi\right) - \left(\lambda\pi^2 + (y - y^*)^2\right). \tag{3}$$

where α, λ, $\theta_i > 0$ and $\delta \geq 0$. Equation (1) shows that the economy possesses a Lucas supply function, so that the difference between output (y) and the natural level $(\overline{y})$ depends: (a) on the deviations of inflation (π) from the value of this variable expected by the (rational) private sector (π^e); and (b) a shock (ε) with zero mean and finite variance $\left(\sigma_\epsilon^2\right)$.

We adopt a principal-agent framework augmented to include the private sector as a third player. Expressions (2) and (3) are closely related. They represent, respectively, the utility functions that the principal (government) and the agent (the central banker) aim to maximize in expected value. The first term of equation (2) shows that the government values negatively the transfer that it pays to the central banker[8]. Parameter δ is the weight the government puts on the banker's remuneration relative to the social loss. In this respect, our framework is more general than the ones adopted in other studies (Beestma and Jensen [1998], Muscatelli [1998a,b, 1999], Nolan and Schaling (1998), Eijffinger *et al* (2000) and Chortareas and Miller [2003a]) which implicitly assume that $\delta = 0$. However, our results can be evaluated in this particular case. The transfer scheme, defined by parameters A and b, is a performance contract that relates

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[8]The assumption that the transfer is costly to the government has also been considered in Walsh (1995a). In this sense, Chortareas and Miller (2003b) state that if this payment is financed by distortionary taxes its social cost exceeds the transfer.

the central banker's income (or his budget) to the inflation rate that he is assumed to perfectly control[9].

The second term of the government's objective function states that the government dislikes deviations of inflation and output from optimal levels. Now, we define:

$$k \equiv y^* - \overline{y} > 0$$

The positive sign of k implies that, for a given inflation rate, a monetary surprise involves a gain in terms of output for the government.

The main difference between the central banker's utility function (expression (3)) and the government's is that the former values positively the transfer payment. This valuation (relative to output and inflation variability) depends on the type of central banker, which is represented by the parameter θ_i. Without any loss of generality, we assume that there are two such types. Namely, θ_i can take two values: θ_L and θ_H, where $0 < \theta_L < \theta_H$.

The sequence of events is as follows:

1) Nature selects the type of central banker;

2) the government designs and offers the central banker a set of contracts (which can be a singleton);

3) the central banker chooses one contract (or rejects all of them);

4) the private sector forms its expectations on inflation;

5) the realization of the output shock is known;

6) the central banker determines the inflation rate.

Two scenarios are analyzed and compared. In the first one (considered in section 3) information is symmetric in the sense that, once nature selects the type of central banker it becomes public information. By contrast, in the second scenario (dealt with in section 4) no one but the agent observes his own type, although the prior probability distribution across types is

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[9] As explained in Persson and Tabellini (1993) and Walsh (1995a), the penalization can either be interpreted as a pecuniary penalty on the central banker through performance-related salaries or as a non-pecuniary reputation penalty. Walsh (1995a) describes this mechanism as a useful fiction for deriving the optimal incentive structure. Besides, Walsh (1995b, 2002) shows how the properties of a linear inflation contract can be mimicked by a dismissal rule under which the central banker is fired if inflation ever rises above a critical level.

common knowledge. However, in equilibrium this characteristic is revealed when the central banker chooses a specific contract (the one intended for his type). This revelation is taken into account by the private sector when forming its (rational) expectations on inflation. Finally, the whole process is taken into consideration by the (expected) utility maximizing government when designing the optimal menu of contracts.

3   Symmetric information

This section analyzes the optimal contract scheme in the benchmark scenario in which the government can perfectly observe the central banker's type prior to the contract offer. Now, we proceed to solve by backward induction the game outlined in Section 2.

In the last stage of the game, once the private sector has set up its expectations on inflation a central banker of type θ_i observes the realization of the shock (ε) and then selects the value for π that solves:

$$\max_{\{\pi\}} \quad \theta_i \left(A_i - b_i \pi \right) - \lambda \pi^2 - (y - y^*)^2$$

$$s.t. \qquad y = \overline{y} + \alpha(\pi - \pi^e) - \varepsilon.$$

The solution to this problem yields the optimal response of the monetary authorities of type θ_i, i.e., their reaction function:

$$\pi(\theta_i, b_i, \pi^e, \varepsilon) = \frac{-\theta_i b_i}{2(\alpha^2 + \lambda)} + \frac{\alpha k}{\alpha^2 + \lambda} + \frac{\alpha^2}{\alpha^2 + \lambda}\pi^e + \frac{\alpha}{\alpha^2 + \lambda}\varepsilon. \tag{4}$$

This behavior is anticipated by the private sector, who take rational expectations on inflation without having observed the realization of the shock but bearing in mind the central banker's type. Therefore, it computes the expected rate of inflation by solving for π^e the equation $\pi^e = E(\pi(\theta_i, b_i, \pi^e, \varepsilon))$, which yields:

$$\pi^e(\theta_i, b_i) = \frac{-\theta_i b_i}{2\lambda} + \frac{\alpha k}{\lambda}. \tag{5}$$

Plugging this value for the expected inflation into equation (4) and solving for π, we obtain:

$$\pi(\theta_i, b_i, \varepsilon) = \frac{-\theta_i b_i}{2\lambda} + \frac{\alpha k}{\lambda} + \frac{\alpha}{\alpha^2 + \lambda}\varepsilon. \tag{6}$$

Remark 1 *The inflationary bias is eliminated if and only if the penalty related to inflation is:*

$$b_i(\theta_i) = \frac{2\alpha k}{\theta_i}.$$

Proof. substituting this value into (6) yields the following expression for the inflation level:

$$\pi(\varepsilon) = \frac{\alpha}{\alpha^2 + \lambda}\varepsilon.$$

whose expected value is zero. ∎

It must be emphasized that the condition appearing in Remark 1 for the type-dependent penalization on inflation is crucial to the analysis developed in the rest of the paper. Besides, it must be mentioned, as will be apparent in what follows, that the only role of the fixed part of the transfer, A_i, is just to guarantee that a central banker of type θ_i willingly accepts the contract. Notice that, as shown in equation (6), the value for A_i has no influence on the central bank's choice of the inflation level.

Now we proceed to characterize the government's best response to the sequence of events just described. In order to do so, first, we need to express the expected utilities for both the government and the central banker in terms of the variables which shape the contract, namely, A_i and b_i. With this aim, first we substitute (1) into (2) and (3). Then, we plug the values for π^e and π (appearing in equations (5) and (6)) into the resulting two expressions for U_i^B and U_i^G. After doing so, taking expectations yields:

$$E(U_i^B) = \theta_i A_i + \frac{\theta_i^2}{4\lambda}b_i^2 - K, \tag{7}$$

$$E(U_i^G) = -\delta A_i - \frac{(\theta_i + 2\delta)\,\theta_i}{4\lambda}b_i^2 + \frac{\alpha k(\theta_i + \delta)}{\lambda}b_i - K, \tag{8}$$

where

$$K = \frac{k^2}{\lambda}(\alpha^2 + \lambda) + \frac{\lambda\sigma_\varepsilon^2}{\alpha^2 + \lambda}. \tag{9}$$

When designing the contract, the government takes account of the incentives that the monetary authorities have when they decide whether or not to enter into the agreement. These incentives are embedded within the participation constraint which states that the expected utility obtained by the central banker when signing the contract must be greater or equal to a given reservation expected utility level.

Therefore, normalizing the reservation expected utility to zero[10], the government faces the following problem:

$$\underset{\{A_i, b_i\}}{Max} \quad E\left(U_i^G\right)$$

$$s.t. \quad E(U_i^B) \geq 0,$$

where the expressions for $E\left(U_i^G\right)$ and $E(U_i^B)$ appear in (8) and (7). The solution to this problem yields the following result:

Proposition 1 *When information is symmetric the inflationary bias is always eliminated, i.e.,* $b_i^s(\theta_i) = \frac{2\alpha k}{\theta_i}$.

Proof. see Appendix 1. ∎

Figure 1 below helps explain in more detail the equilibria corresponding to the two types of central banks. To begin with, it is worth commenting on the relevant features of the respective maps of indifference (expressed in terms of expected utility) of the central banker and the government. The former's (the latter's) indifference curves are concave, reach their maximum when $b_i = 0$ ($b_i > 0$) and represent a greater expected utility when we move upward (downward)[11].

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[10]This normalization has been made with the only aim of simplifying the algebra and does not affect the results of the paper.

[11]More specifically, an indifference curve of the central bank has a slope $\frac{\partial A_i}{\partial b_i} = -\frac{\theta_i b_i}{2\lambda} < 0$ and reaches its maximum at $b_i = 0$. On the other hand, in the case of the government, any such curve has a slope:

$$\frac{\partial A_i}{\partial b_i} = \frac{1}{2}\frac{2\alpha k\left(\theta_i + \delta\right) - \left(\theta_i + 2\delta\right)\theta_i b_i}{\delta\lambda},$$

and achieves its maximum when:

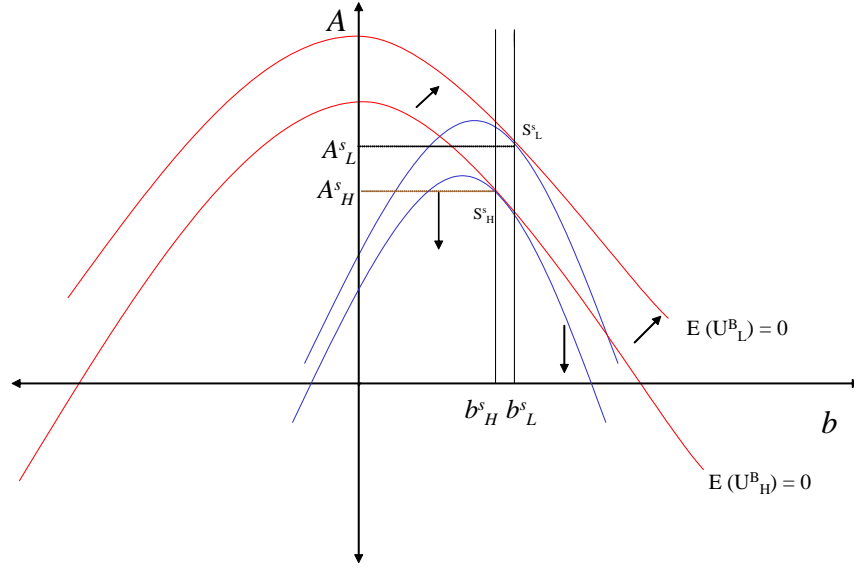$$b_i = 2\alpha k \frac{\theta_i + \delta}{\left(\theta_i + 2\delta\right)\theta_i} > 0.$$

Figure 1

Now, we explain why points S_L^s and S_H^s are the solutions to the government's problem when the types of the central banker are θ_L and θ_H (where $\theta_L < \theta_H$), respectively. Since the participation constraint must hold with equality (see Appendix 1), the equilibrium point for each type belongs to the indifference curve in which he achieves just the reservation (expected) utility level. But which points on those curves will be chosen? The answer is that, because the government's expected utility increases when its indifferent curves move downward, both equilibria must be points in which the indifference curves of the principal and the (corresponding type of) agent are tangent. Notice that since the indifference curves are not identical for both types, tangency occurs at differents point. In fact, type low's tangency point has greater coordinates than type high's. Appendix 1 also shows that the design of the optimal contract can be seen as a two step process:

(i) In a first step, the penalty related to inflation (b_i) is determined with the only aim of getting rid of the inflationary bias and taking no account of the participation constraint. It can be checked (see Appendix 1) that the value of this penalization is found with the only concurrence of the (just referred) tangency condition . In fact, the left (right) vertical line in Figure 1 corresponds the set of (all) the tangency points when the type is θ_H (θ_L). This feature

will help understand, in the following section, the difference between the optimal contracts under asymmetric and symmetric information.

(ii) And, in a second step, once this bias has been removed, the part of the transfer that is not related to the central bank's performance (A_i) has a rather residual role, since its value is designed with the only purpose of guaranteeing that the central banker does not reject the contract, i.e. the participation constraint holds with equality.

Note that, comparing the indifference curves in which both types achieve the common reservation expected utility level, the one which applies to the banker with a high valuation of the transfer payment (θ_H) is located further to the south. Therefore, we have:

Remark 2 *A central banker of type θ_H (θ_L) would increase (decrease) his expected utility if offered the contract designated for the other type.*

In other words, only type θ_H would try to masquerade as the other type if offered the pair of contracts (taylored to the two types). Therefore, it must be enphasized that since the government achieves a greater expected utility when its indifferent curves move downward:

Remark 3 *This mimicking behavior of central bank θ_H is costly to the government who, therefore, will try to prevent it.*

This result is important to understand the asymmetric information scenario that we take up in the following section.

4 Asymmetric information

This section is devoted to the study of the optimal contracts when the government and the private sector cannot observe the central banker's type. In principle, it could be thought that the government's best response could consist of a single contract that took into account the probability distribution across types and were accepted by both types of agents. However, as it will become apparent in what follows, the principal can do better by offering the agent a menu of contracts. This set of transfer schemes is designed with the aim of obtaining a separating

equilibrium. That is, in this scenario each type of central banker will select the contract that the government designated for him. This tailor-made contracts are designed by the government to maximize its expected utility. Besides, the monetary authority's equilibrium choice becomes a signal that reveals his type to the private sector who, therefore, sets up its expectations on inflation accordingly. Equilibrium beliefs must be consistent in the sense that the private sector is right to believe that a central banker whose type is θ_i will always select the contract intended for him (i.e., (A_i, b_i)) since he cannot derive a greater expected utility from the alternative choice (i.e. the contract (A_j, b_j), where $j \neq i$).

To help understand the differences that this adverse selection setup presents in relation to the symmetric information scenario, it is worth addressing the following question. When the type is private information, will the principal offer the symmetric information menu of contracts (i.e., the set $\{(A_L^s, b_L^s), (A_H^s, b_H^s)\}$) analyzed in section 3) to induce a separating equilibrium? As shown in Appendix 2, the answer to this question is negative. The intuition of this outcome can be expressed with the help of Remark 2. To wit, if this set of contracts were offered, even though type θ_L selects the contract the intended for him (A_L^s, b_L^s), type θ_H would select the contract (A_L^s, b_L^s) as well. Therefore, separation would not occur.

The previous discussion implies that when the type is private information the optimal contract must satisfy not only the participation constraints (required in the symmetric information case), but also an additional pair of conditions. Namely the so-called incentive compatibility constraints, implying that each type of agent willingly chooses the contract tailored to him (i.e. they do not mimic the other type).

In order to formulate the problem to be solved by the government in this environment we denote by: (a) (A_i, b_i) the contract designated for type θ_i; (b) p_L the prior probability of being type θ_L; (c) $E\left[U_i^G(A_i, b_i)\right]$ the government's expected utility when type is θ_i (and chooses the contract intended for him); (d) $E\left[U_i^B(A_i, b_i)\right]$ the expected utility that type θ_i would obtain if he selected the contract tailored to him; (e) $E\left[U_{ij}^B(A_j, b_j)\right]$ the expected utility of type θ_i if he mimicked type θ_j $(i \neq j)$. Observe that the functional form of $E\left[U_{ij}^B\right]$ is different from $E\left[U_i^B\right]$ because the former is computed in the hypothetical scenario in which the private sector forms its expectations on inflation in the (false) belief that the type is θ_j, whereas the latter refers to

the case where these belief are correct.

Now, the principal maximizes its expected utility (across types and realizations of the supply shock) subject to the two kinds of constraints just mentioned. Formally, the problem faced by the government is:

$$\underset{\{A_L, b_L, A_H, b_H\}}{Max} \quad p_L E\left[U_L^G(A_L, b_L)\right] + (1 - p_L) E\left[U_H^G(A_H, b_H)\right]$$

$$s.t. \quad \begin{cases} E\left[U_L^B(A_L, b_L)\right] \geq 0, \\ E\left[U_H^B(A_H, b_H)\right] \geq 0, \\ E\left[U_L^B(A_L, b_L)\right] \geq E\left[U_{LH}^B(A_H, b_H)\right], \\ E\left[U_H^B(A_H, b_H)\right] \geq E\left[U_{HL}^B(A_L, b_L)\right]. \end{cases}$$

The solution to this problem yields the following result:

Proposition 2 *Under asymmetric information the optimal menu of contracts generates a separating equilibrium in which: (a) the inflationary bias is eliminated when the type is θ_H; (b) but if the type is θ_L and the government values (does not value) the transfer payment then the penalization on inflation is smaller than (equal to) the one needed to remove this bias. Formally, $b_H^a = \frac{2\alpha k}{\theta_H}$; but $0 < b_L^a < \frac{2\alpha k}{\theta_L}$ if $\delta > 0$ and $b_L^a = \frac{2\alpha k}{\theta_L}$ if $\delta = 0$.*

Proof. see Appendix 3. ■

Notice that this proposition states that the mechanism analyzed in this paper removes completely the inflationary bias (even for type θ_H) in the case in which the transfer payment does not reduce the government's expected utility ($\delta = 0$). Now, it should be emphasized that this case, particular though it is in our framework, is the standard scenario considered in this literature.

Figures 2a and 2b below help understand how the optimal contracts under asymmetric information are modified with respect to the ones designed when information is symmetric. This two diagrams apply to the case in which the government values the transfer ($\delta > 0$) and refer, respectively, to the contracts designated for types θ_H and θ_L.

Figure 2a shows that the penalty related to inflation for the high type is the same no matter whether information is symmetric or asymmetric ($b_H^a = b_H^s$). Therefore, in both scenarios the inflationary bias is eliminated. That is, the indifference curves of the government and the central

bank are tangent. Recall that this tangency condition is satisfied along the vertical line appearing also in Figure 1. Notice that, as far as the contract for type θ_H is concerned, the only difference between those two scenarios has to do with the fixed part of the financial reward. To wit, this component is greater when information is asymmetric, which means that the central bank of high type obtains an information rent $(R > 0)$ in excess of the reservation level.
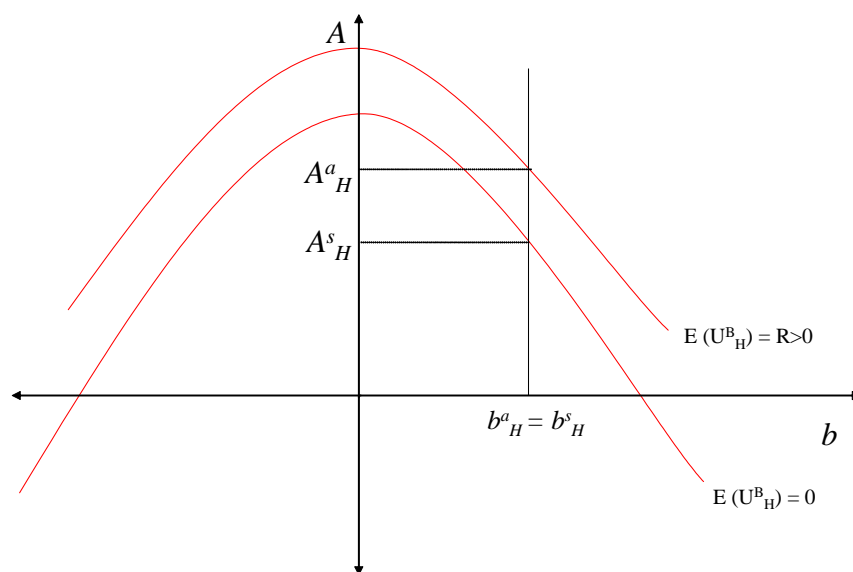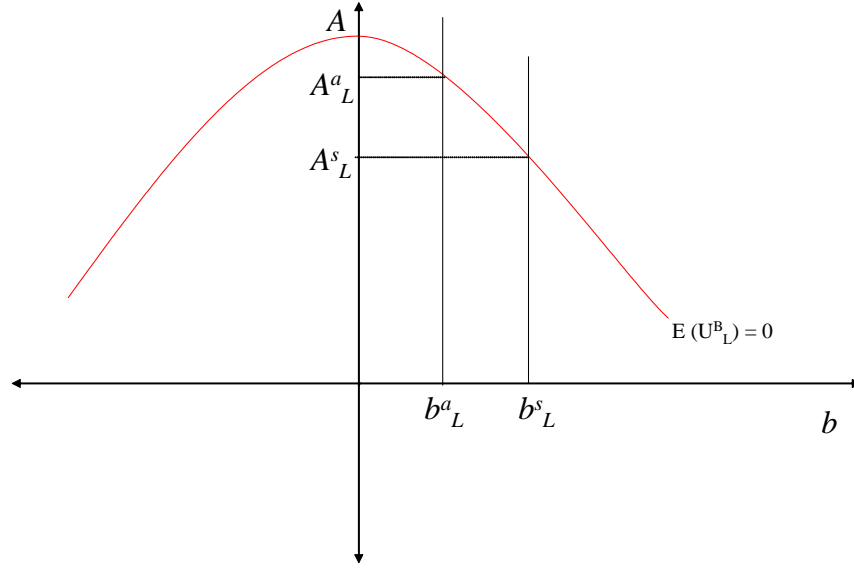

Figure 2a

Figure 2b

Figure 2b shows that, for type θ_L, both components of the equilibrium contract under asymmetric information are modified with respect to the ones designed when the type is common knowledge. That is, in the former scenario the fixed part of the transfer is greater $(A_L^a > A_L^s)$ and the penalty related to inflation lower $(b_L^a < b_L^s)$, which implies that the inflationary bias is not reduced completely.

We now explain the intuition behind why if the government cares about the transfer payment the inflationary bias is not removed when the central banker is type θ_L. Suppose that the government offered the menu of contracts that was optimal under symmetric information. In this case, as shown in the previous section (see Remark 2), both types would choose the contract intended for the low type. Now, the following two alternatives would prevent this mimicking behavior: (a) a rise in the fixed part of the transfer intended for the high type who therefore would increase his information rent at the government's expense; and (b) reducing the penalty related to inflation for the low type at the cost of fueling the inflationary bias. Therefore, the principal has to compromise and apply, to a certain extent, both amendments to the menu of contracts that was optimal under symmetric information. In this sense, it is no surprise that the optimal distortion on the penalty related to inflation created by the principal increases with the

probability of type θ_H (check in Appendix 3 that $\frac{db_L^a}{d(1-p_L)} < 0$), since the greater this probability, the greater the risk of this type extracting an information rent from the principal.

Following a similar argument it can be explained that, if the government does not care about the transfer, the inflationary bias is completely eliminated when the type is θ_L. The reason is that in this scenario, no compromise needs to be reached between minimizing the information rent of the banker of high type (which now is not costly to the government) and doing the same with the inflationary bias created by the low type.

This proposition can also be understood by making use of the intuition behind the classical approach of Tinbergen (1952) relating objectives and instruments. With symmetric information, in the case where the government values the transfer payment, it has two objectives: minimizing the inflationary bias and the transfer paid to the central bank; and the same number of instruments: the components "b_i" and "A_i" that shape the contract. In this case, the first instrument can be used to completely eliminate the inflation bias and the second one to make the participation constraint to hold just with equality. However, in the asymmetric information scenario if the transfer reduces the government's expected utility there is an additional objective. Namely, to prevent the high type of central banker from masquerading as a the other type. In this context the fact that there are more objectives than instruments implies that not all the objectives can be achieved: the inflationary bias cannot be eliminated when the central banker has a low valuation of the transfer and the government has to pay an information rent to the other type of agent. Finally, the better outcome obtained by the principal in the case in which he does not care about the transfer is due to the fact that, again (as in symmetric information setup), the number of objectives coincides with the number of instruments.

5 Conclusions

A recent literature on monetary policy has stressed the importance of institutional arrangements as a way out of the classic time-inconsistency problem. Namely, the inflationary bias to discretionary monetary policy resulting from the central banker's futile attempt to stimulate output above the natural level.

The aim of our paper has been to analyze the incentives that a central bank should face in order to deal with this bias, in a context in which the monetary authorities' objective function is private information. In our setup the information advantage refers to the central bank's valuation of the financial reward (that it receives from the government) relative to inflation and output stabilization. Since it is not feasible in practice to commit to a state-contingent policy rule, we have looked for a incentive scheme which it not contingent on the realizations of the shocks hitting the economy. We have proposed a mechanism which consists of the government designing a menu of contracts to be offered to the central bank. In equilibrium each type of central banker selects the contract tailored to him. Therefore, in contrast with the other studies within the institution design approach our arrangement achieves the complete elimination of the uncertainty about the monetary authorities's type, removing the extraneous noise that asymmetric information introduces into monetary policy.

We conclude that the inflationary bias is completely eliminated when the monetary authorities have a high valuation of the transfer scheme paid by the government. However, if this valuation turns out to be low this bias is reduced only partially. In this case, the presence of imperfect information involves a cost in terms of efficiency relative to the symmetric information benchmark. The reason is that the penalty related to inflation included in the contract designated for the low type must be distorted in order to achieve a separating equilibrium. We also find that this distortion need not be introduced and the inflation bias is eliminated even for the low type when the transfer does not represent a cost to the government.

6   Appendix 1

Firstly, note that the participation constraint must hold with equality since, otherwise, the principal would not be maximizing its expected utility. Namely, it could be better-off by lowering A_i (in such a "small" amount that the central bank still found optimal to sign the contract).

Then, the problem to be solved by the government can be restated as:

$$\underset{\{A_i, b_i\}}{Max} \quad E\left(U_i^G\right)$$
$$s.t. \quad E\left(U_i^B\right) = 0,$$

which results in the following Lagrangian function:

$$\pounds = E\left(U_i^G\right) + \mu E\left(U_i^B\right).$$

Therefore, the first order conditions are:

$$\frac{\partial \pounds}{\partial A_i} = \frac{\partial E\left(U_i^G\right)}{\partial A_i} + \mu \frac{\partial E\left(U_i^B\right)}{\partial A_i} = 0, \tag{10}$$

$$\frac{\partial \pounds}{\partial b_i} = \frac{\partial E\left(U_i^G\right)}{\partial b_i} + \mu \frac{\partial E\left(U_i^B\right)}{\partial b_i} = 0, \tag{11}$$

$$\frac{\partial \pounds}{\partial \mu} = E\left(U_i^B\right) = 0. \tag{12}$$

Solving for μ equations (10) and (11), equating the resulting two expressions and rearranging one obtains that the marginal rates of substitution of the government and the central banker must be equal:

$$-\frac{\frac{\partial E\left(U_i^G\right)}{\partial b_i}}{\frac{\partial E\left(U_i^G\right)}{\partial A_i}} = -\frac{\frac{\partial E\left(U_i^B\right)}{\partial b_i}}{\frac{\partial E\left(U_i^B\right)}{\partial A_i}}. \tag{13}$$

This condition implies that the indifference curves of the principal and the agent must be tangent. Namely, contracts must be efficient. Now, plugging the values of $E(U_i^B)$ and $E(U_i^G)$ (appearing in (7) and (8)) into (13) this tangency or efficiency condition can be restated as:

$$b_i^s(\theta_i) = \frac{2\alpha k}{\theta_i}. \tag{14}$$

Notice that this expression for the optimal penalization on inflation coincides with the necessary and sufficient condition for the elimination of the inflationary bias (see Remark 1) and has not been obtained with the concurrence of the last first order condition, i.e., the participation constraint.

7 Appendix 2

First we need to introduce a piece of notation. It is referred to the scenario in which: (a) the principal offers the pair of contracts that were optimal for him under symmetric information, i.e., the set $\{(A_L^s, b_L^s), (A_H^s, b_H^s)\}$; and (b) the type is only observed by the agent; but (c) the private sector believes that by choosing (A_i^s, b_i^s) the central banker reveals that he is of type θ_i.

In this setup, denoting by $E\left[U_i^B(A_i^s, b_i^s)\right]$ the expected utility that type θ_i would obtain if he choose the contract (A_i^s, b_i^s); and by $E\left[U_{ij}^B(A_j^s, b_j^s)\right]$ the expected utility of type θ_i if he mimicked type θ_j we can state:

Result 1: *Let us consider the scenario in which the central banker is offered the pair of symmetric information contracts and his type is private information but expectations on inflation are formed in the belief that the contract (A_i^s, b_i^s) is chosen if and only if the banker is of type θ_i. In this case, both types would always select the contract (A_L^s, b_L^s). The reason is that $E\left[U_{HL}^B(A_L^s, b_L^s)\right] > E\left[U_H^B(A_H^s, b_H^s)\right]$ and $E\left[U_{LH}^B(A_H^s, b_H^s)\right] < E\left[U_L^B(A_L^s, b_L^s)\right]$.*

Proof.

First we show that $E\left[U_{HL}^B(A_L^s, b_L^s)\right] > E\left[U_H^B(A_H^s, b_H^s)\right]$. On the one hand, the value of $E\left[U_{HL}^B(A_L^s, b_L^s)\right]$ is obtained as follows. If type θ_H chose (A_L^s, b_L^s) he would solve:

$$\max_{\{\pi\}} \quad \theta_H \left(A_L^s - b_L^s \pi\right) - \lambda \pi^2 - (y - y^*)^2$$

$$s.t. \qquad y = \overline{y} + \alpha(\pi - \pi^e) - \varepsilon.$$

The first order condition yields the following reaction function:

$$\pi(\theta_H, b_L^s, \pi^e, \varepsilon) = \frac{-\theta_H b_L^s}{2(\alpha^2 + \lambda)} + \frac{\alpha k}{\alpha^2 + \lambda} + \frac{\alpha^2}{\alpha^2 + \lambda}\pi^e + \frac{\alpha}{\alpha^2 + \lambda}\varepsilon. \qquad (15)$$

If the private sector's expectations are formed in the belief that by choosing the contract (A_L^s, b_L^s) the central banker signals that his type is θ_L, the expected inflation is

$$\pi^e(\theta_L, b_L^s) = \frac{\alpha k}{\lambda} - \frac{\theta_L b_L^s}{2\lambda}.$$

Substituting the previous expression into (15) yields:

$$\pi(\theta_H, \theta_L, b_L^s, \varepsilon) = \frac{\alpha k}{\lambda} - \frac{\left(\theta_H \lambda + \alpha^2 \theta_L\right)}{2\lambda\left(\alpha^2 + \lambda\right)}b_L^s - \frac{\alpha}{(\alpha^2 + \lambda)}\varepsilon.$$

Now, the expected utility that type θ_H would obtain if he masqueraded as type θ_L (and fooled the public into believing that he was of type θ_L) expressed as a function of the components of the contract is obtained by: (i) substituting the previous two expressions into the objective function appearing in (3); and (ii) taking expectations:

$$E\left[U_{HL}^B(A_L^s, b_L^s)\right] = \theta_H A_L^s + \frac{2\alpha^2 \theta_H \theta_L - \alpha^2 \theta_L^2 + \theta_H^2 \lambda}{4\lambda\left(\alpha^2 + \lambda\right)}(b_L^s)^2 - \frac{(\theta_H - \theta_L)\alpha k}{\lambda}b_L^s - K. \qquad (16)$$

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Observe that the functional form of $E\left[U_{HL}^B(.)\right]$ is different from $E\left[U_H^B(.)\right]$ since in each case the private sector sets up its expectations on inflation in a different way.

Taking account of the values of b_L^s (appearing in (14)) and A_L^s (obtained by plugging (14) into (12)), this expression can be reformulated as:

$$E\left[U_{HL}^B(A_L^s, b_L^s)\right] = \frac{(\theta_H - \theta_L)}{\theta_L\left(\alpha^2 + \lambda\right)}\left(\frac{\alpha^2 k^2 \theta_H}{\theta_L} + \lambda\left(k^2 + \sigma_\varepsilon^2\right)\right).$$

This expected utility is positive (since all the parameters are positive and $\theta_H > \theta_L$) and, therefore, greater than the reservation level (equal to zero) that type θ_H would obtain if he chose he contract (A_H^s, b_H^s). Namely, $E\left[U_{HL}^B(A_L^s, b_L^s)\right] > E\left[U_H^B(A_H^s, b_H^s)\right] = 0$. Thus, in this scenario type θ_H would select (A_L^s, b_L^s).

Now we show that type θ_L would also choose the same contract (A_L^s, b_L^s). Making use of an analogous reasoning, it can be checked that by selecting the alternative contract (i.e. (A_H^s, b_H^s)) he would end up having the following level of expected utility:

$$E\left[U_{LH}^B(A_H^s, b_H^s)\right] = \frac{(\theta_L - \theta_H)}{\theta_H\left(\alpha^2 + \lambda\right)}\left(\frac{\alpha^2 k^2 \theta_L}{\theta_H} + \lambda\left(k^2 + \sigma_\varepsilon^2\right)\right).$$

Since this expression is negative, it is lesser than his null reservation level (that he would obtain if he chose (A_L^s, b_L^s)). That is, $E\left[U_{LH}^B(A_H^s, b_H^s)\right] < E\left[U_L^B(A_L^s, b_L^s)\right] = 0$. ∎

8   Appendix 3

First we show that the participation constraint holds with equality for θ_L. The participation constraint must hold with equality for at least one type of central banker, since otherwise the principal would not be maximizing its expected utility: it could increase it by just lowering A_H and A_L in such a way that both conditions still held. Now, if in addition to that, we take account of the fact that the agent of type θ_H always achieves a greater expected utility out of any contract (since from (7) we have that $\frac{\partial E(U_i^B)}{\partial \theta_i} > 0$), we conclude that type θ_L is the one whose participation constraint is binding.

Next we prove that the incentive compatibility constraint is binding for type θ_H. Imagine that this statement were false. In this case, by a similar argument, since (again) type θ_H obtains

a greater expected utility than type θ_L, the government could be made better off by decreasing A_H so that the central banker would be indifferent between the two contracts.

To sum up, we have established that the two binding constraints are:

$$
\begin{aligned}
E\left[U_L^B(A_L, b_L)\right] &= 0, \\
E\left[U_H^B(A_H, b_H)\right] &= E\left[U_{HL}^B(A_L, b_L)\right],
\end{aligned}
$$

which can be rewritten in the following way (making use of (7) and (16)):

$$
\begin{aligned}
\theta_L A_L + \frac{\theta_L^2}{4\lambda} b_L^2 - K &= 0, \\
\theta_H A_H + \frac{\theta_H^2}{4\lambda} b_H^2 - K &= \theta_H A_L + \frac{2\alpha^2 \theta_H \theta_L - \alpha^2 \theta_L^2 + \theta_H^2 \lambda}{4\lambda\left(\alpha^2 + \lambda\right)} b_L^2 - \frac{\left(\theta_H - \theta_L\right)\alpha k}{\lambda} b_L - K.
\end{aligned}
$$

Therefore, the Lagrangian associated to the problem is

$$
\mathcal{L} = p_L E\left(U_L^G\right) + (1 - p_L) E\left(U_H^G\right) + \mu_1 E\left(U_L^B\right) + \mu_2\left[E\left(U_H^B\right) - E\left(U_{HL}^B\right)\right].
$$

The first order conditions are:

$$
\frac{\partial \mathcal{L}}{\partial A_i} = 0, \quad i = H, L \tag{17}
$$

$$
\frac{\partial \mathcal{L}}{\partial b_i} = 0, \quad i = H, L \tag{18}
$$

$$
\frac{\partial \mathcal{L}}{\partial \mu_j} = 0, \quad j = 1, 2. \tag{19}
$$

The solution to this system of equations yields:

$$
b_H^a = \frac{2\alpha k}{\theta_H}, \tag{20}
$$

$$
b_L^a = \xi \frac{2\alpha k}{\theta_L}, \tag{21}
$$

where

$$
\xi = \frac{Z + \lambda\delta\left[\theta_H - (1 - p_L)\theta_L\right]}{Z + \lambda\delta\left[(2p_L - 1)\theta_H + \left(\frac{\theta_H}{\theta_L}\right)^2 (1 - p_L)\theta_L\right]}, \tag{22}
$$

and

$$
Z = \left(\alpha^2 + \lambda\right) p_L \theta_H \theta_L + \delta\alpha^2 \theta_H - \delta(1 - p_L)\theta_L \alpha^2. \tag{23}
$$

From an inspection of $(20) - (23)$ and taking into account Remark 1 we know that:

(a) The inflationary bias is eliminated when the type is θ_H.

(b) If $\delta > 0$ ($\delta = 0$) then $\xi < 1$ ($\xi = 1$), which implies that $b_L < \frac{2\alpha k}{\theta_L}$ ($b_L = \frac{2\alpha k}{\theta_L}$). Namely, the expected value of inflation is positive (zero).

Moreover, to find the lower and upper bounds of b_L^a note that (using expressions (21) to (23)): (i) b_L^a is strictly increasing in p_L, namely:

$$\frac{\partial b_L^a}{\partial p_L} = \frac{2\alpha k \left(\alpha^2 + \lambda\right) \delta \theta_H \lambda \left((\theta_L + \delta)(\theta_H - \theta_L)^2\right)}{\left[\theta_L p_L \theta_H \left(2\delta\lambda + \theta_L \alpha^2 + \theta_L \lambda\right) + \delta \left(\theta_L \theta_H \left(\alpha^2 - \lambda\right) + \theta_L^2 \alpha^2 \left(p_L - 1\right) - \theta_H^2 \lambda \left(p_L - 1\right)\right)\right]^2} > 0;$$

(ii) when the probability of the central banker being of type θ_L goes to one, the penalty related to inflation under asymmetric information converges to the one that eliminates the inflationary bias:

$$\lim_{p_L \to 1} \left(b_L^a\right) = \frac{2\alpha k}{\theta_L} = b_L^s;$$

and that (iii) the distortion in this penalization with respect to the symmetric information case achieves its maximum when this probability goes to zero since:

$$\lim_{p_L \to 0} \left(b_L^a\right) = \left(\frac{\alpha^2 + \lambda}{\alpha^2 + \lambda \frac{\theta_H}{\theta_L}}\right) \frac{2\alpha k}{\theta_L} > 0.$$

Therefore, (i) to (iii) imply that when information is asymmetric (i.e. $p_L \in (0,1)$) then $0 < \left(\frac{\alpha^2 + \lambda}{\alpha^2 + \lambda \frac{\theta_H}{\theta_L}}\right) \frac{2\alpha k}{\theta_L} < b_L^a < \frac{2\alpha k}{\theta_L}$.

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