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Efthimiadis, Tilemahos and Tsintzos, Panagiotis

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Tilemahos Efthimiadis*,
Joint Research Centre, European Commission Post Office box 2, 1755 ZG, Petten, Netherlands
e-mail: tilemahos.efthimiadis@ec.europa.eu

Panagiotis Tsintzos
Democritus University of Thrace, Department of Economics, University Campus, 69100 Komotini, Greece, e-mail: ptsintzo@econ.duth.gr

Abstract

In this paper we examine the case of partial central bank transparency and the interaction between public debt management and the design of monetary institutions. In particular, we establish a relationship between central bank transparency and nominal debt and find that it depends on whether the public has (ex-ante) under or overestimated the preferences of the central banker. Furthermore, we analytically examine the relationship between central bank transparency and central bank conservativeness and find it positive.

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1. Introduction

The literature on central banking today is mainly focused on the private sector's inflation expectations. The main issue is that the private sector consistently forms low inflation expectations which is a self-fulfilling prophecy. Woodford (2005, p.3) has even claimed that "For not only do expectations about policy matter, but, at least under current conditions, very little *else* matters" (emphasis in original). This mainly explains the increasing interest on the subject of central bank transparency.[1] The intent of this paper is to examine the monetary authority's incentive to reveal (or

* Corresponding author. European Commission, Post Office box 2, 1755 ZG, Petten, NL
Email address: tilemahos.efthimiadis@ec.europa.eu

[1] In a survey, Fry et al. (2000) found that 74% of central bankers consider transparency a "... vital or very important component of their monetary policy framework" .

not) her preferences and how this affects expectations. Furthermore, we examine the relationships between central bank transparency, independence and nominal debt.

Regarding central bank transparency, there does not yet exist a consensus amongst academics as to an exact definition, as this has proved to be a tedious task due to the many definitions that transparency can have.[2] For the purposes of this paper we will use Winkler's (2000) definition who argues that transparency is: "the degree of genuine understanding of the monetary policy process and policy decisions by the public."

Most authors conclude that optimality is achieved through full transparency (Demertzis and Hughes Hallet, 2002; Freedman, 2002; Muscatelli, 1998). In particular, Demertzis and Hughes Hallet (2002) argue that: "if the central banker can correctly anticipate what the public thinks, then an increase in political transparency reduces the variability of inflation and output but does not affect their average levels". An increase in central bank transparency is always beneficial for society as it reduces the problem of central bank accountability and the inflationary bias that arises in a Barro-Gordon (1983) framework. Furthermore, increased central bank transparency results in a reduction of the private sector's (perhaps even the government's) uncertainty over the preferences of the central banker,[3] which in turn enables better coordination between the private sector and the monetary authority and reduces what Haslag (2002) calls "the costs of fed watching."[4]

However, there is a strand of literature that challenges the proposition that transparency is always beneficial. An example on the potential shortcomings of full transparency comes from Posen (2002) who provides a practical example where he states that televising central bank internal meetings could be considered as a way of increasing transparency. However, he provides arguments against such an idea on the basis that the public will be rather more confused than enlightened by viewing such meetings as they are carried out using extremely specific technical vocabulary. In this example, although the central bank and the public share exactly the same information, the central bank once again retains superior knowledge. Furthermore, transparency, as defined by Winkler

[2] In example, Geraats (2001) lists five different aspects of transparency while many more are mentioned in the relevant literature.

[3] There could be other sources of uncertainty i.e. the central bank could retain superior information as to the state of the economy.

[4] Haslag (2002) argues that "following and guessing the future actions of the central bank brings about uncertainty of monetary policy."

(2000), might in effect be reduced due to the (potential if not certain) arising confusion of the viewers.[5]

In the relevant literature, it has been shown that the inflation bias that arises in a Barro-Gordon (1983) game-theoretical model of monetary policy, can be reduced if monetary policy is delegated to an independent and conservative central banker (Rogoff, 1985).[6] Taking these divergent preferences of the central banker as granted, various authors examine the case where these preferences are not known to the public, therefore, the central banker is fully opaque. In these models, as noted, most authors show that it is optimal for the central banker to fully reveal her preferences. However, this is examined in a framework where the central banker functions under either full opacity or full transparency, whereas the case of partial transparency is usually ignored.

In analytical terms, as the public has no information as to the central banker's preferences, when forming its inflation expectations it zeros the central banker's extra weight on inflation, as it treats it as a white noise (*iid*) shock, and therefore it forms its expectations based on the (quasi) hypothesis that the central banker does not have an extra weight on inflation (i.e. Beetsma and Bovenberg, 1997; Muscatelli, 1998). Even if the government (or the central banker) announces that there does exist an extra weight on inflation, with the existing modelling this could not be taken into account and therefore is is not possible to characterize a conservative central banker in these models.[7]

Our framework differs as it captures the effects of greater or less central bank transparency, where transparency is a mechanism that reveals the central banker's preferences. The private sector's expectations as to the central banker's preferences, and thus inflation expectations, depend on the level of transparency. We proceed to show how central bank transparency can be used as a policy device by the central bank in order to manipulate expectations and therefore achieve real policy outcomes.

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[5] Posen (2002) also argues that after a few episodes the viewing audience will have decreased dramatically as "I do not think we would compete very successfully with daytime television!".

[6] By conservative we shall refer to a central banker that shares the same preferences with society but places a greater weight on inflation. Other proposals for the reduction of the inflation bias include the use of inflation contracts (Walsh, 1995) and/or inflation targets (Svensson, 1997). For an in-depth discussion as to the distinction between central bank independence and central bank conservativeness see Berger *et at.* (2001).

[7] However, Sibert (2002) develops a framework where she examines partial transparency with a conservative central banker. There are many similarities between this paper and Sibert's (2002) as to the research questions and the achieved results but the modeling differs drastically and thus our papers are distinguishable and can be viewed separately.

Another point of interest is the role of the fiscal authorities in this framework. The actions of the central banker have real effects on output, and thus the tax base, the real value of the debt and deficits. In particular, changes in prices resulting from the central banker's actions could necessitate debt restructuring (Calvo and Guidotti, 1990; Lucas and Stokey, 1983; Persson et al., 1987), i.e. a change in the proportion of debt issued in nominal terms.

As for nominal debt, Bohn (1988) has shown that it is optimal to have (at least) some nominal debt as it functions as a good hedging device to offset shocks. In the context of monetary policy, Blanchard and Missale (1994) argue that by decreasing the maturity of nominal debt, the government signals to the private sector that it will keep an anti-inflationary stance and therefore the credibility of its monetary policy is significantly increased. Furthermore, Falcetti and Missale (2002) find a positive relationship between nominal debt and central bank conservativeness.[8] Ciccarone et al. (2004) examine the relationship between central bank transparency and fiscal policy in terms of deficit spending.

Our paper follows this strand of literature by linking central bank transparency with public debt issuing policy. We analytically show that it is optimal for the central banker to appear as conservative as possible, regardless of her actual preferences, that is, even to "mislead" the public into thinking that she is more conservative than she actually is, by not revealing her true preferences. In other words, the central banker will always want the private sector to believe that she is at least as conservative as she is and, if possible, even more conservative than she actually is. The central banker achieves this result through optimally setting her degree of transparency. The intuition behind this result is that the more inflation averse (the more conservative) the private sector believes that the central banker is, the lower inflation expectations are. If the private sector believes that the central banker is more inflation averse than she actually is, then its expectation of inflation will be too low and the central banker may create a positive inflation surprise which would lead to increased output. However, this “cheating” solution is not sustainable. As agents are rational they recognize the incentive of the central banker set their expectations accordingly. In equilibrium the central banker fully reveals her preferences.

[8] In a different context Mourmouras and Su (1995) also examine central bank independence under a public debt stabilization framework. Their main findings are that appointing a conservative central banker creates a larger burden on the government, which forces it to stick to its policy reforms and not rely on the easy option, which in this model is inflationary finance. Therefore, the appointment of an independent monetary authority can be beneficial to both the outcome of the stabilization program and to an optimizing government as well.

We also proceed to examine the relation between central bank transparency and debt issuing policy, in terms of the optimal share of nominal debt issued. Furthermore, we analytically derive the relationship between central bank conservativeness and central bank transparency.

The paper is organized as follows: Section 2 describes the analytical model and provides the framework on how the government and the private sector form expectations as to the central banker's preferences. Section 3 explains in detail the sequence of events. Section 4 examines the central banker's optimal choice of inflation, the government's optimal choice of the share of nominal debt and the central banker's choice of the level of transparency. Section 5 concludes.

2. The Model

We develop a standard game-theoretical framework of monetary policy. For simplicity and to be able to conduct comparative statics, we use a variant of Falcetti and Missale (2002). Output is given by an expectations augmented Phillips curve:[9]

$$y = \overline{y} + b\left(\pi - \pi^{e}\right) - \varepsilon \tag{1}$$

where y is the rate of unemployment, $\overline{y}$ is the natural rate of output, b is output sensitivity to unexpected inflation, π is the inflation rate, π^{e} are inflation expectations and ε is a white noise (*iid*) productivity shock [$\varepsilon \sim N(0, \sigma_{\varepsilon}^{2})$].

Following Missale (1999) we consider a government that has to raise taxes to pay for its spending and service of the outstanding public debt. The government has two financial instruments available, conventional nominal bonds and bonds indexed to the price level. We assume that all bonds mature after one period. Making the standard assumption that investors are risk-neutral ensures that expected returns be equal across all types of bonds, although the realized returns on nominal debt depend on the price level. We denote the nominal interest rate as i and then the realized gross return on nominal bonds is given by $(1+i)/(1+\pi)$, and the real return on price-indexed bonds is equal to its expected return $(1+r)$, where r is the real interest rate which is assumed to be constant.[10] The government faces the following budget constraint:

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[9] All variables are in logs and time scripts have been ignored to reduce clutter.

[10] In example, the interest rate (r) could be set in international markets or one could assume that there is a flat

$$tY = G + (1+r)(1-m)D + \frac{(1+i)}{(1+\pi)}mD \tag{2}$$

where m is the share of nominal debt, t is the tax rate, G is real public spending, Y is real output and D the real value of debt. Using a standard linearisation and the Fisher equation $[(1+i) = (1+r)(1+\pi^e)]$ the constraint can be written as:

$$t = (1+r)\left[1 - m(\pi - \pi^e)\right]d + g \tag{3}$$

Where g and d are percentages of GDP. The government's loss function is given by:

$$L^G = \chi\pi^2 + (y - y^T)^2 + ct \tag{4}$$

where χ is the weight that society places on inflation (i.e. the marginal cost of inflation), y^T is society's output target and c is society's weight on taxes which is a positive constant. We assume that the government aims at a level of output, $y^T = \bar{y} + kt$, which is greater than the natural rate ($\bar{y}$).[11] The last term (kt) is the cost that society incurs from taxation and it includes the aforementioned tax smoothing implication. It is clear that deviation from optimal policies will have real effects on real output, thus the tax base, and increasing the value of the debt resulting in increasing taxes which increases social costs.

The central bank's loss function is described by the following equation:

$$L^{CB} = (\chi + \xi^*)\pi^2 + (y - y^T)^2 \tag{5}$$

where $\chi + \xi^*$ is the central banker's inflation weight and ξ^* is her extra weight on inflation (vis-á-vis the government). We assume that the central banker shares the same output target with the

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demand for government bonds.

[11] For an in-depth discussion as to the social loss function see Falcetti and Missale (2002).

government. In the spirit of Rogoff (1985), the main difference between the government and the central banker are their preferences over inflation. In particular, the central banker is conservative and we assume that the public is aware of this fact. In terms of modelling, the conservativeness of the central banker shows up as a (strictly) positive extra weight on inflation ($\xi^* > 0$). Unlike Rogoff (1985), we assume that the weight itself (ξ^*) is exogenous to the model.[12]

The central banker (ex-ante) chooses how transparent she will be regarding her preferences through an optimization process. This level of transparency is captured by the parameter *trans*, which takes the value of one for full transparency and zero for full opacity and is continuous ($trans \in [0,1]$).The central banker can reveal her preferences (be more transparent) by providing more information to the private sector in the form of explicit policy goals, forecasts, data etc. We assume that this information is credible and believable by the public.

The existing literature on central bank transparency examines the case where the preferences of the central banker are either exactly known or fully unknown. However, the empirical literature shows that almost all central banks are between these two extremes.[13] The framework below aims to fill the gap between the two extremes. In particular, we assume that the private sector has some information about the central banker's extra weight on inflation (ξ^*) which is in the form of transparency ($trans$) and this allows the central banker to function under partial transparency.

In order to identify how agents form expectations about the central banker's preferences (ξ^*) we define two distinct regions in our framework. At first we have region A which is the region of all possible values for the extra weight on inflation ξ^* which is $A \equiv (0, N] \in \Re$ (therefore $\xi^* \in (0,N]$), where N is a very large number. Every point in region A characterizes a unique, and different from the rest, central banker (all points have the same probability). This region is continuous and open from the left as is positive since the central banker is assumed to be conservative. Furthermore, we assume that the central banker is not an "inflation-nutter" (King, 1997) and therefore the upper bound for ξ^* is a very large number (N) and not infinity. This region (A) is

[12] This is a standard assumption in the relevant central bank transparency literature so as to focus only on issues of transparency (Muscatelli, 1998; Sibert, 2002). Furthermore, a series of empirical papers show that most central banks today are independent (Berger *et al,* 2001) and many are considered conservative in the Rogoff (1985) sense (eg. ECB, FED, Bank of New Zealand).

[13] I.e. Geraats, 2002; Eijffinger and Geraats, 2002; de Haan and Amtenbrink, 2002.

known by all agents. The government randomly chooses central banker with preferences $\xi^* \in (0,N]$ from this pool of infinite central bankers, while neither the government nor the private sector know the value of ξ^*.

Next, we proceed to characterize region B which is used by the private sector and the government to derive their expectations for ξ^*. In particular, region B practically describes the information set which agents use to form conditional rational expectations for ξ^*, which we denote with ξ^e ($E(\xi^*) = \xi^e$). This information set is provided by the central banker in the form of transparency (*trans*). In particular, region B is a subset of region A and its size depends on how much information the central banker provides about ξ^*, that is, on how transparent she is (*trans*). Under conditional rational expectations agents will always take the average of region B as their expectation.

If the central banker is fully transparent ($trans = 1$) then all agents know the exact value of ξ^* and therefore region B collapses to ξ^* ($E(\xi^*) = \xi^e = \xi^*$, $E(\xi^*)^2 = 0$, and $B \equiv [\xi^*, \xi^*]$).

If the central banker is fully opaque ($trans = 0$) then there is no information as to the value of ξ^* and agents take the whole of region A as possible values for ξ^*. Therefore $E(\xi^*) = \xi^e \neq \xi^*$ and $E(\xi^*)^2 = \sigma^2_{\xi^e}$. In this case, $A = B \equiv (0,N]$ and agents take the average of region A (which is $N/2$) as their expectation of ξ^* ($\xi^e = N/2$).[14]

If the central banker is partially transparent ($0 < trans < 1$) then region B is a true subset of region A ($B \subset A$). As transparency increases, region B decreases in size and ξ^e is now more accurate (closer to the real value ξ^*). That is, the left end of region B moves away from the origin towards ξ^* and the right end moves away from N towards ξ^*. Therefore, the average of region B (ξ^e) moves away from the average of region A (its value under zero transparency) towards the actual value of ξ^*. As always, agents take the average of region B as their expectation for ξ^*. Under partial transparency agents form the following expectations:

[14] As there is no relative empirical evidence to suggest otherwise, we assume that all points on region A are identical and therefore the agents' best guess is the average of this region. Even if there is a bias for over or under-conservativeness, this would just shift our initial starting point when the central banker is fully opaque without affecting the framework or the achieved results.

$$E\left(\chi+\xi^{*}\left|trans\right.\right)=\chi+E\left(\xi^{*}\left|trans\right.\right) \tag{6}$$

$$E\left(\xi^{*}\left|trans\right.\right)=\xi^{e}=f\left(trans\right) \tag{7}$$

where $f\left(trans\right)$ is a function of $trans$ which returns the agents expectation of ξ^{*}.

In general, the left end of region B will be the distance $trans\xi^{*}$ from the origin (its coordinate will be $trans\xi^{*}$) and therefore the right end will be at $\left(1-trans\right)\xi^{*}$. After some simple geometry we arrive at an analytical expression for region B:

$$B\equiv\left[trans\xi^{*},\left(1-trans\right)\left(N-\xi^{*}\right)+\xi^{*}\right] \tag{8}$$

Therefore the average of region B is:

$$\begin{aligned}E\left(\xi^{*}\right)=\xi^{e}&=\frac{\int\xi d\xi}{\left(1-trans\right)\left(N-\xi^{*}\right)+\xi^{*}-trans\xi^{*}}\\&=\frac{1}{2}\left[N-Ntrans+2trans\xi^{*}\right]\end{aligned} \tag{9}$$

The variance ($\sigma^{2}_{\xi^{e}}$) is given by the following equation:

$$\sigma^{2}_{\xi^{e}}=\frac{\int\left(\xi-\xi^{e}\right)^{2}d\xi}{\left(1-trans\right)\left(N-\xi^{*}\right)+\xi^{*}-trans\xi^{*}} \tag{10}$$

The degree of the conservativeness of the central banker (ξ^{*}) can be (equally) larger or smaller than the average of A ($N/2$) and is assumed exogenous. If $\xi^{e}\prec\xi^{*}$ then ex-ante[15] the private sector would *underestimate* the real value of ξ^{*}. Increasing transparency moves ξ^{e} towards ξ^{*}

[15] Before $trans$ is (optimally) set, its perceived value is zero and therefore central banker is fully opaque.

from the left side. For the remainder of the paper, when referring to under and overestimation we shall always imply the ex-ante (full opacity) case as described above.

If $\xi^e > \xi^*$ the private sector would *overestimate* the real value of ξ^*, and by increasing transparency ξ^e approaches ξ^* from the right side. In general, as transparency increases, the possible region of values for ξ^* and $\sigma^2_{\xi^e}$ will be reduced and therefore ξ^e gradually converges to ξ^*. Under full transparency this region collapses to the real value of ξ^*. We can easily derive this analytically from equation (9):

$$\lim_{trans \to 1} \xi^e = \xi^* \tag{11}$$

$$\lim_{trans \to 0} \xi^e = \frac{N}{2} \tag{12}$$

$$\frac{\partial \xi}{\partial trans} = \xi^* - \frac{N}{2} \tag{13}$$

with the second derivative of equation (13) being zero. Depending on whether ξ^* is to the right or left of the average of region A (which is $N/2$) the above derivative (eq. 13) is positive or negative.

In both cases as *trans* increases, ξ^e converges (and finally collapses) to ξ^* in a monotonically fashion. In the extreme case where ξ^* is at the exact middle of region A, then ξ^e is equal to ξ^* and it is independent of the value of *trans*. However, the variance will be non-negative ($\sigma^2_{\xi^e} \neq 0$) for less than full transparency (*trans* < 1). Therefore, for *trans* $\neq 1$, even though the private sector has (by pure chance) correctly anticipated the central banker's preferences, it will still either underestimate or overestimate the actual value of ξ^* due to the existence of the variance.

The expectation of ξ^* (ξ^e) will directly affect inflation expectations (π^e) which in turn affects inflation, unemployment etc. Therefore, the central banker can manipulate these parameters directly through inflation and indirectly through the level of transparency.

3. Timing of Events

The timing of events is as follows: First, the government randomly chooses a central banker from a pool of conservative central bankers (region A) which is known by all agents. The exact preferences (ξ^*) of the central banker remain unknown to the private sector and the government.[16] Second, the central banker optimally sets her degree of transparency ($trans$) which is used by the government and the public to form expectations as to the preferences of the central banker (ξ^e). Third, taking $trans$ as given, the government optimally sets the percentage of nominal debt (m) so as to minimize its expected loss. Fourth, the private sector forms its inflation expectations (π^e) after observing m and $trans$. Fifth, the productivity shock (ε) is realized. Sixth, taking all the relevant information into account, the central banker optimally sets inflation (π).

We derive the optimal strategies of each player by solving the model recursively, beginning with the central banker's optimal choice of inflation.

4. Equilibrium and Main Results

4.1 The Central Banker's Choice of Inflation

At first, we solve the central banker's optimization problem for inflation. This is achieved by substituting y (eq. 1) and t (eq. 3) into L^{CB} (eq. 5), minimizing and solving for π. We then take expectations (π^e) and find:

$$\pi^e = \frac{k(d+g+dr)(b+dkm(1+r))}{\xi^e+\chi} \tag{14}$$

$$\pi = \frac{(b+dkm(1+r))\dfrac{k(d+g+dr)(\xi^e+(b+dkm(1+r)^2+\chi)}{\xi^e+\chi}}{(\mathrm{b+dkm(1+r)})^2+\chi+\xi^*} + \frac{b+dkm(1+r)}{(\mathrm{b+dkm(1+r)})^2+\chi+\xi^*}\varepsilon \tag{15}$$

[16] Following the relevant literature (i.e. Muscatelli, 1988; Sibert, 2002) we assume that a new central banker is appointed yearly. This avoids reputation building and similar punishment strategies.

where ξ^e is characterized by equation (9). When forming expectations, the private sector knows the value of *trans* and utilizes this information to form expectations about the particular value of ξ^*. Note that ξ^* and ξ^e show up as separate arguments in the first term of equation (15), and we can clearly see that inflation (π) depends on the public's' expectation of the central banker's conservativeness (ξ^e), which in turn (from eq. 9) is determined by the level of central bank transparency (*trans*). The second term in equation (15) reflects the central banker's efforts to offset any output shocks.

From equation (14) we can see that the higher ξ^e is, that is, the more conservative the private sector believes that the central banker is (regardless of the actual preferences), the lower are inflation expectations (π^e), which shows the incentive on behalf of the central banker to manipulate these expectations. Therefore, transparency (*trans*) can be an important policy instrument as it (indirectly but effectively) affects both inflation expectations and actual inflation.

Furthermore, with full transparency ($trans = 1$) we have $\xi^e = \xi^*$ and equation (15) reduces to: $\pi = \pi^e +$ the output shock stabilizing parameter (second term of eq.15) and therefore, although an inflation bias exists, the central banker does not try to create surprise inflation and any discrepancy between anticipated and actual inflation is due to output stabilization efforts, which leads us to the standard Rogoff (1985) model.

4.2 The Government's Choice for the Share of Nominal Debt

At this stage, the government optimally sets it's choice of the share of nominal debt (m^*) by taking into account all the relevant information. As aforementioned, there are many incentives for the existence of (at least some level of) nominal debt, i.e. as a hedge against adverse supply shocks (Bohn, 1988).

As the government and the private sector share the same information about the central banker's preferences, that is, they both know *trans*, both their inflation expectations are described by (14). The rate of inflation (π) affects the government's decision in two ways: i) the government dislikes inflation and ii) the central banker can inflate away the level of debt.

We now turn to the government's minimization problem. The government is aware that the appointed central banker is conservative and observes $trans$. Utilizing this information, the government optimally chooses the share of nominal debt (m^*). To find this value, we solve the government's expected loss by substituting y (eq. 1), t (eq. 3), π^e (eq. 14), π (eq. 15), into L^G (eq. 4), minimize and solve for m and arrive at:[17]

$$m^* = m\left(\xi^e\left(trans\right), \sigma^2_{\xi^e}\left(trans\right)\right) \tag{16}$$

where the optimal level of nominal debt (m^*) is a function of the average (ξ^e) and variance ($\sigma^2_{\xi^\varepsilon}$) of the private sector's expectations of the central banker's preferences (ξ^*), which depend on the level of central bank transparency ($trans$).

4.3 The Central Banker's Choice of Transparency

At the beginning of the period the central banker optimally sets her degree of transparency and therefore $trans$ is an endogenous parameter which we derive in this particular sub-section. The central banker does not have any *per se* incentive to be transparent; she will be more or less transparent according to what minimizes her loss.[18] After taking into account all the relevant information from the previous subsections, we re-solve the central banker's optimization problem for $trans$ by substituting y (eq. 1), t (eq. 3), π^e (eq. 14), π (eq. 15), ξ^e (eq. 9) into L^{CB} (eq. 5), minimize and solve for $trans$, and find:[19]

$$trans = \frac{\mathrm{k(d+g+dr)(N+2(b+dkm(1+r))^2+2\chi)+(N+2\chi)\varepsilon}}{\left[\mathrm{k(d+g+dr)+\varepsilon}\right]\left(N-2\xi^*\right)} \tag{17}$$

From (17) it follows easily that it is optimal for the central banker to be fully transparent ($trans = 1$) if the public underestimates its extra weight on inflation (ξ^*). In contrast, it is optimal for the

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[17] Due to non-linearities the expression for m^* is too long and complicated to be included in the paper. This is why we show m^* as a function instead of providing an exact expression.

[18] In effect we ignore issues of central bank accountability, democratic deficits etc.

[19] We intentionally do not substitute m with its optimal value (eq. 16) so as to have a clear image on the interactions between m and $trans$.

central banker to be fully opaque ($trans = 0$) if the public has overestimated this weight. In particular, the optimal degree of transparency depends of the share of nominal debt (m^*) and whether the public had overestimated or underestimated the true value of ξ^*, The latter is captured by the term $N - 2\xi^*$ in the denominator of (17).[20]

As aforementioned, if ξ^* is above the average of the region A (which is $N/2$) then under less than full transparency the public would have underestimated the true value of ξ^* ($\xi^e < \xi^*$, $N/2 < \xi^*$) and $N - 2\xi^*$ is negative. In this case, it is optimal for the central banker to be fully transparent. Otherwise, the public would believe that the central banker is less conservative than she actually is resulting in inflation expectations being larger than inflation (negative inflation surprise, $(\pi - \pi^e) < 0$), which has a magnitude of adverse effects. In general, if the public will underestimate the preferences of the central banker ($\xi^e < \xi^*$) then it is optimal for the central banker to be fully transparent ($trans = 1$, $\xi^e = \xi^*$) which would lead us to Rogoff's (1985) solution where an inflation bias exists but not an inflation surprise.

On the other hand, in strict analytical terms, if ξ^* is below the average of region A, then under less than full transparency the public would have overestimated the true value of ξ^* and the term $N - 2\xi^*$ is positive ($N/2 > \xi^*$). In this case, it is optimal for the central banker to be fully opaque.[21] Therefore, the central banker tricks the public into believing that she is more conservative than she actually is, and this leads to reduced inflation expectations which in turn result in reduced (actual) inflation.[22] In effect this is a "cheating" solution. Sibert (2002) finds similar results.

However, the above achieved analytical result is challenged on the basis that agents are rational. By not being transparent a central banker would convey the information that her inflation aversion is lower than expected and this would lead the public to revise its expectations. Upon this revision the central banker must re-examine whether the private sector has under or overestimated its

[20] The nominator is always positive.

[21] The optimal values of $trans$ actually occur at points outside the feasible region which is between zero and one.

[22] To be exact, the central banker finds it optimal to not provide additional information that would correct the publics' misconception as to her preferences. This could provide a formal explanation as to the (mostly anecdotal) evidence that as head of the FED Greenspan would consistently state that he is tough and only interested on fighting inflation while the actual policies implemented would also accommodate output shocks through demand management policies.

preferences. As before, if we have an underestimation the central banker will be fully transparent otherwise she will be fully opaque which leads to a recurrence of this process.

By applying this argument sequentially it is evident that the only equilibrium is one where any type of central banker chooses full transparency and reveals her preferences. In other words, the private sector will continue to revise its expectations until its expectation is less than the actual preference ($\xi^e < \xi^*$) in which the central banker will opt to be fully transparent. Indeed, as signaling has no cost, the equilibrium must be a separating equilibrium with full revelation of preferences.

In terms of the model presented, under full opacity the private sector will acknowledge that the actual preferences of the central banker are in the first half of region A, that is, $\xi^* \in (0, N/2)$. Therefore, from equation (8) region B is now $B \equiv \left[trans\xi^*, (1-trans)\left(N/2 - \xi^*\right) + \xi^* \right]$. From equation (9) and taking into account that $trans = 0$, we have $\xi^e = N/4$. In other words, agents once again take the average of the plausible values of ξ^*, that is, the average of the (revised) region B. If again we have an overestimation of the preferences, the central banker will be fully opaque, the process is repeated which leads us to a new expectation of $\xi^e = N/8$ and so on. This continues until the central banker fully reveals her preferences.

In the one-shot model examined in this paper if the central banker is fully opaque the private sector will respond by setting a zero rate as their expectation for the preferences of the central banker. As this is recognized by the central banker she finds that it is optimal to always be fully transparent otherwise the economy will be faced with a negative inflation surprise. Therefore, due to the rationality of agents, the "cheating" equilibrium cannot be sustained which leads us to a unique full transparency solution.

As in equilibrium $trans = 1$ and $\xi^e = \xi^*$ the model is reduced to a standard Rogoff-type (1985) model where an inflation bias exists without any gains from the positive inflation as to output or unemployment (see eq. 1, 14 and 15).

Proceeding with the results of the model, we derive the relationship between the level of conservativeness of the central banker and the degree of central bank transparency by taking the partial derivative of $trans$ (eq. 17) for ξ^* which leads to:

$$\frac{\partial trans^*}{\partial \xi^*} = \frac{2\left(N + 2(\text{b+dkm(1+r)})^2 + 2\chi\right)}{\left(N - 2\xi^*\right)^2} > 0 \qquad (18)$$

From equation (18) we can clearly see:

Proposition 1. T*here exists a positive relationship between the level of conservativeness of the central banker (ξ^*) and the degree of central bank transparency (trans).*

As the level of central bank conservativeness is set ex-ante and exogenously this is a one-way relationship, that is, conservativeness affects transparency and not the other way around. As the above derivative is always positive, the more conservative the central banker is, the more transparent she will be. If the central banker is more conservative she would want the public to be aware of this fact as it shows a stronger anti-inflation stance and brings inflation expectations in compliance with the new (decreased) level of actual inflation. In other words, transparency is used as a signal device to coordinate the publics' inflation expectations.

Regarding the relationship between transparency and nominal debt it is easy to show that:

Proposition 2. *Whether the relationship between the share of nominal debt (m) and transparency ($trans^*$) is positive or negative depends on whether the public has ex-ante overestimated or underestimated the central banker's preferences.*

When setting the optimal share of nominal debt (m) the government takes the degree of central bank transparency as exogenously given. The relationship between the share of nominal debt (m) and transparency ($trans^*$) is given by equation (19) below.[23]

[23] It follows easily that $\partial m / \partial trans^* = [4dk^2(\text{1+r})(\text{d+g+dr})(\text{b+dkm(1+r)})]/(k(d+g+dr)+\varepsilon)(N-2\xi^*)$

$$sign\left(\frac{\partial m}{\partial trans^{*}}\right) = sign\left(N - 2\xi^{*}\right) \tag{19}$$

When setting the optimal share of nominal debt (m) the government takes the degree of central bank transparency as exogenously given. The relationship between the share of nominal debt (m) and transparency ($trans^{*}$) is given by equation (19) below.[24]

Through the combination of propositions 1 and 2 and taking into account equation (17), it follows easily that:

Proposition 3. *The degree of central bank conservativeness (ξ^{*}) affects the optimal level of nominal debt (m^{*}). If the public has underestimated the central banker's preferences, then the degree of central bank conservativeness (ξ^{*}) and the share of nominal debt (m) are positively related. If the public has overestimated these preferences then these variables are negatively related.*

As the level of conservativeness of the central banker (ξ^{*}) is positively related with the optimal degree of transparency (*trans*), it also (indirectly) affects the level of nominal debt. In particular, if the level of conservativeness is large[25] and therefore we have an underestimation of preferences, conservativeness is positively related with nominal debt and so a higher level of conservativeness would lead to more nominal debt. Falcetti and Missale (2002) also find this positive relationship. However, they treat the level of conservativeness as an endogenous variable and find that it is optimal for both variables (ξ^{*}, m^{*}) to be infinite.

The intuition behind this result is as follows. Let us take the case where the public has underestimated the central banker's extra weight on inflation (ξ^{*}), that is, it believes that the central banker is less conservative than she actually is, which in turn leads the public to expect a weaker (than actual) anti-inflation stance. Thus, inflation expectations are higher than the actual rate of inflation and there is a negative inflation surprise ($\pi - \pi^{e} < 0$) which leads to decreased output (see eq. 1). The negative inflation surprise increases the level of debt in real terms which leads the

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[24] It follows easily that $\partial m / \partial trans^{*} = [4dk^{2}(1+r)(d+g+dr)(b+dkm(1+r))]/(k(d+g+dr)+\varepsilon)(N-2\xi^{*})$

[25] By "larger" we mean larger than average, that is, ξ^{*} is in the upper half of region A ($\xi^{*} > N/2$).

government to prefer a lower share of nominal debt (m). In other words, the government has a lower incentive to issue nominal debt.[26] As transparency increases, ξ^e moves closer to ξ^* which leads to a smaller anti-inflation surprise and therefore the government's incentive to issue nominal debt (m) is increased. Therefore, under an underestimated regime, central bank transparency (*trans*) and the share of nominal debt (m) are positively related.

5. Conclusions

The main contribution of this paper is the result that a relationship between central bank transparency and nominal debt exists. The majority of the pre-existing literature examines an environment where the central banker functions either under full transparency or full opacity while we provide a framework to fill the gap between these two extremes. We find that although the central banker can function under full opacity, intermediate transparency or full transparency, due to the assumed rationality of the private sector, it will be optimal for the central banker to always function under full transparency.

Furthermore, whether transparency and nominal debt are positively or negatively related depends on whether the public has ex-ante overestimated or underestimated the true value of the central banker's extra weight on inflation. In particular, if the public underestimates the central banker's extra weight on inflation then there is a positive relationship between the level of conservativeness of the central banker and the degree of central bank transparency and the optimal degree of transparency and the share of nominal debt are positively related. Finally, we show an unambiguous analytical positive relationship between the level of conservativeness of the central banker and the optimal level of central bank transparency.

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[26] As stated before the government and the public share the same information regarding the central banker's preferences.

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