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1. Introduction

A modern trend in central banking is that more and more central banks are making monetary policy by committees. This fact suggests that committee decisions are perceived to be superior; also, there is an increasing literature highlighting several benefits of committee decision making in monetary policy: it allows the pooling of information and forecasts; it allows for diversity in methods for processing information; it reduces volatility since extreme positions are not adopted, which is presumably beneficial if agents are risk averse. Moreover, in the case of a monetary union, a committee is the natural way to reach a consensus on the best policy for the different regions which may prefer different courses of action.

It is also a well documented fact (Fry et al., 2000; Lybek and Morris, 2004; Maier, 2007) that there are differences in the organization among central banks, and indeed, optimal organization is subject to debate (Gerlach-Kristen, 2003, 2007; Blinder and Morgan, 2005, 2007; Fujiki, 2005). Also, authors argue that a central bank's internal organization influences the way the members of an MPC decide (Besley et al., 2008; Meade and Sheets, 2005; Gerlach-Kristen, 2007; Romer and Romer, 2008). One of the main issues in this discussion is the disclosure of information. The present paper contributes to this literature by introducing information disclosure in the context of committee decision making in a framework of time inconsistency in monetary policy à la Barro and Gordon (1983). In particular, we focus on the decision of an hypothetical central bank's constitution designer, who has to determine which is the optimal disclosure rule regarding voting records and individual proposals of the members of the MPC, and ask under which circumstances she will choose to mandate the committee to disclose individual votes or opinions (for example through the publication of minutes of the MPC meetings), or mandate the central bank not to disclose that information. As we will show below, decision to disclose such information is important when monetary policy is discretionary and signaling motives are present.

In order to explain why some countries choose to appoint transparent monetary committees while others appoint opaque committees, we consider a stylized model of discretionary monetary policy with asymmetric information. Each committee member has private information about her relative preferences concerning inflation cost and output expansion, which can be signaled to private agents through monetary policy decisions in order to reduce the inflation bias that appears when policymaking is discretionary. We examine social welfare under two alternative institutions: transparent monetary policy, in which individual proposals and MPC's choice are made public, and opaque monetary policy, in which only MPC's choice is published.

Usually, a plethora of equilibria exist in signaling games. To address this problem, we focus the analysis on separating equilibria, in which each MPC member reveals her type with her inflation proposal for the first period, and we refine the equilibrium concept assuming that MPC members do not play dominated strategies. We give sufficient conditions for the existence of a unique separating equilibrium in undominated strategies. In this equilibrium, the most inflation averse policymaker proposes the least costly inflation rate that allows her to separate from the least inflation averse policymaker, who proposes her preferred inflation rate in the absence of signaling motives.

Using this refinement, we evaluate society's expected welfare under both institutional frameworks. With costly signaling, we show that a strong policymaker proposes a lower inflation rate under transparency than under opacity, and in both cases, inflation proposals are lower than the strong policymaker's myopic inflation rate. We also show that under transparency, the inflation rate chosen by the strong policymaker is lower the higher the preference heterogeneity and patience of the MPC. For each discount factor, there is a threshold value for our measure of preference heterogeneity such that for higher values, the country will be better with an opaque regime, in order to avoid extremely low and below the target inflation rates, which are welfare reducing. This is argued for example by Blanchard et al. (2010), who suggest that low inflation rates limit monetary policy effects during deflationary and recessionary episodes. Although they propose a higher inflation target as a solution to this problem, there are many banks that have no explicit or legal inflation targets –the European Central Bank and the Federal Reserve being leading examples– so the choice of opacity may be an alternative to a raise of the target in order to prevent the policy limitations due to extremely low inflation rates.

To see why under a transparent regime, average inflation rate may be too low, note that under such regime, preferences of every committee member are revealed in a separating equilibrium. This implies that the difference between the inflation rate that the public will rationally expect for the second period after observing a signal of weakness, and the inflation rate that the public will expect after observing a signal of strength, is larger under transparency than under opacity. For example, consider the case of a monetary policy committee where both policymakers are strong. If under transparency, they play separating strategies, the public will know that both policymakers are strong after observing first period's inflation proposals, so they will accordingly learn that the inflation rate for the second period will surely be low.

Instead, under opacity, only the final decision is published, and it will signal that at least one policymaker is strong; however public will not rationally rule out the possibility that one of the policymakers is weak, so they will expect a higher inflation rate than under transparency. Consider now the opposite case, that is, a committee integrated by weak policymakers. Under transparency and in a separating equilibrium, public will know that both policymakers are weak after observing inflation proposals for the first period, so they will be sure that the inflation rate for the second period will be high, while with opacity they will assign a positive probability that one of the policymakers is strong, so they will expect a lower inflation rate than under transparency.

In other words, under opacity the public is never sure that the committee is conformed only by doves or only by hawks. This means that interim expected inflation rates for the second period are more extreme under transparency. Thus, for each policymaker the effect of signaling weakness instead of strength on public's inflation expectations, is larger under transparency. To avoid this (larger) increase on inflation expectations, which is costly, a strong policymaker under transparency has to choose a lower inflation rate than under opacity. The differential effect of signaling weakness instead of strength is larger, the larger the difference in the preferences of a strong and a weak policymaker, that is, the greater preference heterogeneity of the committee. Thus, to avoid such a low (and below the target) inflation rate, the constituents of the country or monetary union may prefer to appoint an opaque committee.

Frequently, appointment of MPC members needs approval of the legislature. In other cases, such as the European Central Bank, the organic chart explicitly states that regions within the monetary union have to be represented in the MPC. This also applies to the Federal Open Market Committee, which is partially constituted by representatives of the regional federal reserves. Thus, an assumption made in this paper is that through diverse political mechanisms, a greater preference heterogeneity and a greater patience in the country will be reflected in a greater preference heterogeneity and greater patience of the MPC –we believe that there is no reason to assume that in the long run, MPC's characteristics will persistently differ from those of the country. Thus, a prediction of the theoretical results introduced above is that we will observe opaque committees in heterogeneous and patient countries, and transparent committees in homogeneous and more impatient countries. We test this using a sample of 36 central banks. In particular, we test the significance of patience and heterogeneity as covariates of the probability that an MPC publishes its voting records or individual proposals. A Probit estimation allows us to confirm that higher heterogeneity is associated with a lower probability of publishing voting records. The sign of the proxy for patience is also the expected one in all of the specifications. However, it is not significant, so we cannot confirm that more patience is associated with more opacity.

The rest of the paper is organized as follows: we review the relevant literature in section two; the model is presented in section three; in section four we characterize separating equilibria in both frameworks, and we also characterize the least costly separating equilibrium (LCSE); in section five we characterize ex ante welfare under both disclosure rules and give conditions under which a country would choose opacity or transparency. In section six we present empirical support to the results of section five. We conclude in section seven. All proofs are provided in the appendix.

2. Literature review

The argument that some kind of opacity on behalf of the policymaker may be welfare enhancing is not new. Cukierman and Meltzer (1986) show that under imperfect control of the policy instruments, the link between current inflation and future expected inflation is looser, because wage setters assign a lower informational content to the observed inflation rate in their inference process. As a consequence, the policymaker benefits from his private information. Also, Sibert (2009) demonstrates that in a non-transparent regime, increased transparency need not improve the public's ability to infer a central bank's private information, but numerical results suggest that society and central banks prefer the transparent to the non-transparent regimes.

Another strand of literature incorporates monetary policymaking by committees to address informational issues. Sibert (2003) uses a model of overlapping generations and two types of policymakers (hawks and doves) to show that it may be profitable for doves to vote for a lower inflation rate, in order to appear as hawks. Under opacity, these incentives are lower. Hence, transparency increases incentives for doves to vote for low inflation in their first period, yielding a lower inflation bias. Sibert assumes that the average of the two proposals is adopted. Hahn (2002), commenting on a previous version of Sibert's paper, argues that given the average voting procedure and that there are dissenting interests in the MPC, it is not optimal for both central bankers to make the proposal that they individually estimate to be optimal. In the present paper we do not consider overlapping terms, and we assume a different voting procedure, which leads to the choice of the median proposal (instead of the average). In equilibrium, hawks, rather than doves, vote for a lower inflation rate than their preferred one. Thus, average inflation rate may be too low (deflation, or inflation below the target). Under these circumstances, opacity may be preferred.

Mihov and Sibert (2006) also consider a model with overlapping generations of policymakers. There are two possible types of policymakers: hawks, who mechanically vote for zero inflation, and doves, who are opportunistic and benevolent, wanting to maximize a social welfare function. They show that a transparent committee can deliver lower inflation rates (reducing the inflation bias due to dynamic inconsistency) without hindering its ability to react to stochastic shocks (that is, the committee keeps an activist role –flexible inflation targeting). The reason is that committee members are likely to opt for low inflation and building reputation when shocks are small, while if shocks are large, the incentive to react outweights the reputation motive. For a wide range of parameters, this institution dominates discretionary monetary policy conducted by a single opportunistic policymaker, and also dominates a zero-inflation rule (strict inflation targeting). As in Sibert (2003), a weighting rule is adopted in case of dissent, so the argument of Hahn (2002), also applies to this setting. A key parameter driving their results is the prior p that a policymaker is hawk. By increasing the ratio of hawks, society can attain lower inflation at the cost of less activism, which is in spirit of Rogoff's (1985) influential insight. This observation raises the normative issue of how to control the proportion of hawks. An alternative (positive) interpretation is that p is related to the probability that a policymaker is going to be captured by the financial sector (a highly inflation averse interest group). In societies with powerful financial sectors, a committee is a natural way to implement a flexible inflation targeting scheme, which dominates strict inflation targeting.

Other authors have stressed the importance of predictability on the effectiveness of monetary policy. (Blinder, 1999; Eggertsson and Woodford, 2003.) Furthermore, Gerlach-Kristen (2004) shows that publication of voting records enhances predictability, making it socially desirable. However, if there is a high degree of communication dispersion among committee members (high heterogeneity), ability of financial markets to anticipate future monetary policy decisions may suffer (Ehrmann and Fratzscher, 2009). Also, with bounded rationality, central bank may need to be careful not to confuse the public with extra information. This is shown in Weber (2010) in a model with time varying preferences, bounded rationality and perpetual learning on behalf of the private sector, and different institutional arrangements; however, voting is not strategic. It is also shown that greater heterogeneity makes decision making by majority rule more desirable, and also makes more likely that the publication of votes will be welfare enhancing.

On the contrary, in the present paper we assume strategic behavior. Moreover, strategic considerations drive our result that not disclosing voting records or individuals may be welfare enhancing if heterogeneity is high enough. Needless to say, strategical issues have also been at the core of the influential literature addressing time inconsistency, pioneered by Kydland and Prescott (1977) and Barro and Gordon (1983). These models correctly predict the inflation bias episodes of the seventies (high inflation and low growth). In spite of this, authors have recently challenged the strategic behavior assumption, arguing that modern central banks "just want to do the right thing" (Blinder, 1999; McCallum, 1995). However, institutional changes should not be left aside when explaining actual motivations of central bankers. In other words, modern central bankers may do the right thing only under institutional constraints such as mechanisms to grant more independence to central bankers, implicit contracts, and mechanisms leading to the appointment of more conservative central bankers. Because our paper is about optimal central banking institutions, we allow for strategic behavior and ask how is the time inconsistency problem solved when a committee decides policy under different information disclosure rules. For this, we use as benchmark a discretionary monetary policy model grounded on Kydland and Prescott (1977), Barro and Gordon (1983) and Vickers (1986).

Another important argument in favor of transparency is that it makes policymakers accountable, inducing them to be more competent. However, accountability may be problematic if an external interest group attempts to influence committee decisions (Felgenhauer and Grüner, 2008). A concern of Issing (1999), is that national authorities will put more pressure on the members of the European Central Bank governing council if voting records are published. Buiter (1999) disagrees, arguing that due to information leaks, authorities will know voting behavior even if votes are not disclosed. Also, while an increase in transparency can raise welfare by reducing the informational asymmetry, strategic behavior could potentially offset the welfare gain if policymakers withhold information during their deliberations in order to enhance their reputations. For example, Gersbach and Hahn (2009) show that the publication of voting records lowers welfare if members care more about being reappointed than about beneficial policy outcomes.

The present paper makes the following contributions to the literature reviewed above: even without accountability mechanisms or political pressure, a central bank may prefer opacity if public's preferences are very heterogeneous. Transparency may be different from opacity in a discretionary setting because signaling costs under each disclosure rule differ, leading to different average inflation rates for the first period. Hawks (and not doves) vote for a lower inflation rate then their preferred one. Thus, average inflation rate may be too low (deflation, or inflation below the target). Under these circumstances, opacity may be preferred.

3. THE MODEL

The model considers an economy that lasts for two periods, indexed by $t=1,2$. There are two sets of agents: the public and the members of a monetarypolicy committee (MPC). We assume the simplest form of committee: one comprising two members, designed A and B, who are elected for two periods. There is no reelection and members have no reputational concerns after their mandate. For simplicity, we assume that inflation is controlled without errors or lags, so we consider committee members as directly choosing the inflation rate for the period. we use P to indicate the public and $i \in \{A,B\}$ to indicate any committee member. We also refer to a committee member as a *policymaker*.

The voting mechanism is as follows: in each period, both policymakers propose simultaneously an inflation rate for the period. If proposals coincide, the proposed inflation rate is implemented. If they do not coincide, one of them is chosen with probability $1/2$. Under this procedure, each policymaker is pivotal with equal probability. There is no commitment technology to a rule, so in each period, MPC chooses monetary policy in a discretional way. We consider two possible information disclosure rules: under transparency, proposals are disclosed to the public; under opacity, proposals are not disclosed to the public. MPC's final decision is always disclosed to the public.

Instantaneous payoff for policymaker $i \in \{A,B\}$ is:

(1) $$W_t^i = -\frac{1}{2}(\pi_t)^2 + \omega_i\left(\pi_t - \pi_t^e\right),$$

where π_t is the chosen inflation rate for the period, π_t^e is rationally expected inflation rate for the period and ω_i is a preference parameter for policymaker i. The policymaker desires to stabilize inflation rate but also wants to boost output (proxied by the term $\pi_t - \pi_t^e$). ω_i is also the proposal that a policymaker would make absent signaling motives (i.e. in an economy lasting one period). The reason is that ω_i maximizes W_t^i given π_t^e. We henceforth refer to this proposal as policymaker's *myopic proposal*. In view of (1), committee members are better off if expectations are lower. Thus, both types have incentives to keep expectations low for the second period, in order to boost output.[1]

[1] A more general specification would be:

$$W_t^i = -\frac{1}{2}(\pi_t - \pi_T)^2 + w_i(\pi_t - \pi_t^e),$$

Intertemporal payoff is:

$$W_1^i + \beta W_2^i,$$

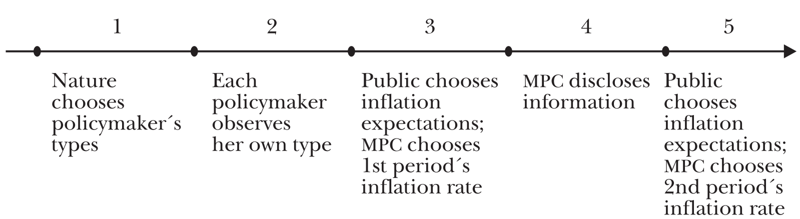
where β is a common discount factor. We assume that ω_i can take two values: $\omega_i \in \{\omega_S, \omega_W\}$ with $0 < \omega_S < \omega_W$. We refer to a policymaker with preference parameter ω_S as a strong policymaker (the most inflation averse) and to a policymaker with ω_W as a weak policymaker (the least inflation averse).

In each period, public chooses expected inflation rationally. That is, they use all available information to make a prediction of the inflation rate that will be chosen by the MPC.

Timing for period one is as follows: *i)* nature chooses each policymaker's type ω_i with prior $p \equiv \Pr(\omega_i = \omega_W)$, and each policymaker privately observes her type; *ii)* public chooses π_1^e and simultaneously each MPC member proposes an inflation rate for the period, π_1^i. One of the proposals is chosen by the procedure described above. Under transparency, public observes both proposals (π_1^A, π_1^B) and final decision π_1. Under opacity, public only observes final decision.

In period two, public form expectations π_2^e using available information (first period's proposals and policy decision under transparency or first period's policy decision under opacity), and simultaneously, each policymaker proposes an inflation rate for the period, π_2^i, $i = A, B$. One of the proposals is chosen by the procedure described above. First period's proposals and final decision (under transparency) or final decision (under opacity) are used for choosing expected inflation rate for the second period. We assume that in both institutions (transparency and opacity) votes are made public within the committee, so each MPC member at the beginning of period two knows first period's proposal of the other policymaker.

FIGURE 1. TIMING UNDER OPACITY AND TRANSPARENCY. IN STAGE 4, UNDER TRANSPARENCY, MPC DISCLOSES PROPOSALS AND SELECTED INFLATION RATE, WHILE UNDER OPACITY, MPC DISCLOSES ONLY SELECTED INFLATION RATE



To compare social welfare under opacity and transparency, we use the following function:

$$W_1 + \beta W_2,$$

where:

$$W_t = -\frac{1}{2}(\pi_t)^2 + \chi(\pi_t - \pi_t^e)$$

where π_T is an exogenous inflation target. Without loss in generality we consider this target to be 0. Indeed, every inflation proposal described below can be interpreted as a deviation from some target π_T.

and $\chi \geq 0$. The literature that proposes the appointment of a conservative central banker as a solution to the dynamic inconsistency problem in monetary policy assumes $\chi \geq \omega_W > 0$ (Rogoff, 1985).

3.13.1. Information structure

Let $I^{F,a}$ denote the information available for decision making at period two for agent a (public P or policymakers A or B) when institutional framework is $F \in \{T,O\}$ where T is an abbreviation for transparency and O is an abbreviation for opacity. Thus, $I^{T,P} = \{\pi_1^A, \pi_1^B, \pi_1\}$ and $I^{O,P} = \{\pi_1\}$. Note that (π_1^A, π_1^B) is a sufficient statistic for π_1 in $I^{T,P}$. (If (π_1^A, π_1^B) is known, π_1 does not add more information.) As in both institutions (transparency and opacity) votes are made public within the committee, the information available for each MPC member in period two is $I^{F,i} = \{w_1, \pi_1^{j}\}$. The information available for each MPC member in period one is her own type: w_i. In period one, public has no information. However, the prior p is common knowledge among all the agents in the economy.

4. EQUILIBRIUM

4.1 Equilibrium concept

The equilibrium concept used in this paper is that of perfect Bayesian equilibrium (PBE). This equilibrium entails strategies for the policymakers and for the public and beliefs for the policymakers and for the public such that each policymaker's strategy maximizes her welfare taking into account its effect on public's beliefs and on the other policymaker's beliefs, public and policymaker's beliefs are updated using Bayes rule whenever possible and use every information available and are formed using the correct conjecture about equilibrium strategies; this in turn implies that public's equilibrium expectations are rational. Formally:

Definition 1

A perfect Bayesian equilibrium (PBE) is given by:

i) strategies for committee members $\pi_1^i(\omega_i)$, $\pi_2^i(I_2^{F,i})$

ii) strategies for the public π_1^e, $\pi_2^e(I^{F,P})$

iii) beliefs for policymakers $i = A, B$

$$\mu_1^i \equiv \Pr(w_j = w_W)$$

$$\mu_2^i(I^{F,i}) \equiv \Pr(w_j = w_W \mid I^{F,i})$$

and

iv) beliefs for the public

$$\mu_1^P \equiv \Pr \textit{ (pivotal policymaker in period 1 is weak)}$$

$$\mu_2^P(I^{F,P}) \equiv \Pr \textit{ (pivotal policymaker in period 2 is weak} \mid I^{F,P}\textit{)}$$

such that

i) $\pi_2^i(I^{F,i})$ maximizes expected payoff in the second period, for each w_i, π_1^j, given beliefs of agents and of *j*,

ii) inflation expectations in the second period are rational *($I_2^{F,P}$ is used)* given the strategies $\pi_1^i(w_i)$, $\pi_2^i(I_2^{F,i})$, ,

iii) $\pi_1^i(w_i)$ maximizes expected present and discounted future payoff, taking into account the influence of π_1^i on second period's inflation expectations and on beliefs of agents and j,

iv) inflation expectations in the first period are rational given the strategies $\pi_1^i(w_i)$, $\pi_2^i(I^{F,i})$, and

v) beliefs are updated using Bayes' rule when it is possible.

If a reference to beliefs given a particular type of strategy profile σ is needed, we will use the following notation: $\mu_2^P(I_2^{F,P};\sigma)$.

4.2 Separating equilibria

We focus the analysis on separating equilibria, in which each type proposes a different inflation rate in each period. Later, we will also introduce a refinement, based on the assumption that it is known that a strong policymaker does the minimum necessary to convince the public that she is strong.

Let $\pi_1^{i,F}(\omega)$ denote inflation rate proposal for period 1 by policymaker i having type ω under institutional framework $F \in \{O,T\}$.

It follows from the definition of a PBE (condition 1) that for each ω_i and π_1^j, $\pi_2^i(\omega_i, \pi_1^j)$ maximizes (recall that the probability of being pivotal is $1/2$)

$$\frac{1}{2}\mathop{\mathrm{E}}_{\omega_j}\left[W\left(\pi_2^i, \omega_i, \pi_2^e\right) + W\left(\pi_2^j, \omega_i, \pi_2^e\right) \mid \omega_i, \pi_1^j\right]$$

given $\mu_2^A\left(\omega_A, \pi_1^B\right)$ and taking π_2^e as given. Note that

$$\begin{aligned} &\arg\max_{\pi_2^i} \frac{1}{2}\mathop{\mathrm{E}}_{\omega_B}\left[W\left(\pi_2^i, \omega_i, \pi_2^e\right) + W\left(\pi_2^j, \omega_i, \pi_2^e\right) \mid \omega_i, \pi_1^j\right] \\ &= \arg\max_{\pi_2^i} W\left(\pi_2^i, \omega_i, \pi_2^e\right) \end{aligned}$$

(uncertainty about type of j does not matter). Thus in both transparency and opacity cases, each type of MPC member has a dominating strategy for the second period: for every π_2^e, she proposes her myopic inflation rate:

$$\pi_2^{i,F}\left(\omega_S\right) = \omega_S < \omega_W = \pi_2^{i,F}\left(\omega_W\right).$$

Since in the second period a strong policymaker proposes a lower inflation rate than a weak policymaker, strong policymakers have an incentive to signal their type in the first period, perhaps proposing a lower inflation rate than the myopic one, while weak policymakers have an incentive to conceal their type (recall that $W\left(\pi_t, \omega, \pi_t^e\right)$ is decreasing in π_t^e). A separating equilibrium exists if there is a set S_F of values for π such that a strong type chooses to propose an inflation rate in S_F and a weak type chooses to propose an inflation rate out of S_F. The subindex makes explicit that the set S_F depends on the institutional framework.

Under transparency both proposals are made public, so two proposals in S_T signal to the the public that both policymakers in office are strong, while two proposals out of S_T signals that both policymakers in office are weak; if one proposal is in S_T and the other proposal is out of S_T, this signals that the committee is conformed by both types of policymakers.

In the first period, a strong policymaker is pivotal with probability $(1-p)$ and a weak policymaker is pivotal with probability p. That is, in any equilibrium,

$$\mu_1^P = p.$$

Let x, y be the proposals for the first period, so $I^{T,P} = (x, y)$. Denote with $\gamma_T(x, y)$ the probability (as assessed by the public) that a weak policymaker will be pivotal in the second period, given that proposals in the first period are $\pi_1^A = x$, and $\pi_1^B = y$, the institutional framework is transparency, and policymakers' separating strategy profile is σ_{sep}^T (with the set S_T being the separating set). That is, public beliefs for the second period are $\mu_2^P(I^{T,P}; \sigma_{sep}^T \equiv \gamma_T(x, y)$. Then

$$\gamma_T(x, y) = \begin{cases} 0 & \text{if both } x, y \in S_T \\ 1 & \text{if both } x, y \in S_T \\ 1/2 & \text{if only } x \text{ or only } y \in S_T \end{cases}$$

Accordingly, separating equilibrium's public expectations for the second period under transparency are

$$\begin{aligned} \pi_{2,T}^e(x, y) &= \gamma_T(x, y) w_W + [1 - \gamma_T(x, y)] w_S \\ &= \begin{cases} w_S & \text{if both } x, y \in S_T \\ w_W & \text{if both } x, y \notin S_T \\ (w_W + w_S)/2 \equiv \overline{w} & \text{if only } x \text{ or only } y \in S_T \end{cases} \end{aligned}$$

Under opacity, only the final decision is published. An inflation rate in set S_O, signals to the public that at least one committee member is strong, while an inflation rate outside S_O signals that at least one committee member is weak. Let x be the policy decision for the first period, so $I^{O,P} = \left(x\right)$. Denote with $\gamma_O(x)$ the probability (as assessed by the public) that the weak type will be pivotal in the second period, given that chosen inflation rate for the first period is $\pi_1 = x$ and policymakers' separating strategy profile is σ_{sep}^O; that is, public beliefs are $\mu_2^P(I^{O,P}; \sigma_{sep}^O) = \gamma_O\left(x\right)$. The following lemma gives an expression for $\gamma_O(x)$ (see Appendix A for the proof).

Lemma 1. $\gamma_O(x) = \begin{cases} \frac{1}{2}p & \text{if } x \in S_O \\ \frac{1}{2}(1+p) & \text{if } x \notin S_O \end{cases}$.

It follows from lemma 1 that expectations for the second period are

$$\pi_2^e(x) = \gamma_O(x)\omega_W + (1-\gamma_O(x))\omega_S$$
$$= \begin{cases} \frac{1}{2}p\omega_W + \left(1-\frac{1}{2}p\right)\omega_S & \text{if } x \in S_O \\ \frac{1}{2}(\omega_W+\omega_S+p\omega_W-p\omega_S) & \text{if } x \notin S_O \end{cases}.$$

Let $g[y(x_A), y(x_B), i, F]$ denote the public's expected inflation rate for the second period, when A proposes x_A which signals that A's type is $y(x_A)$, B proposes x_B which signals that B's type is $y(x_B)$, i is pivotal in the first period and institutional framework is $F \in \{T, O\}$.

Under transparency,

$$g[y(x_A), y(x_B), i, T] = \begin{cases} \omega_S & \text{if} \quad x_A, x_B \in S_T \\ \omega_W & \text{if} \quad x_A, x_B \notin S_T \\ \bar{\omega} & \text{if} \quad x_A \text{ or } x_B \in S_T \text{ (but not both)} \end{cases},$$

and under opacity,

$$g[y(x_A), y(x_B), i, O] = \begin{cases} \frac{1}{2}p\omega_W + \left(1-\frac{1}{2}p\right)\omega_S & \text{if} \quad x_A, x_B \in S_O \\ \frac{1}{2}(\omega_W+\omega_S+p\omega_W-p\omega_S) & \text{if} \quad x_A, x_B \notin S_O \\ \frac{1}{2}p\omega_W + \left(1-\frac{1}{2}p\right)\omega_S & \text{if only} \quad x_i \in S_O \text{ and } i \text{ is pivotal} \\ \frac{1}{2}(\omega_W+\omega_S+p\omega_W-p\omega_S) & \text{if only} \quad x_i \in S_O \text{ and } j \text{ is pivotal} \end{cases}.$$

To characterize the set S_F it is useful to define $V_i^F[x, y_i(x); \omega_i]$ as interim expected welfare (i.e. expected welfare after policymaker i knows her type w_i but before first period voting takes place) of policymaker i under institutional framework F, when she proposes inflation rate x for the first period, and this proposal is intended to signal that her type is $y_i(x)$, and j uses the equilibrium strategy. An expression for $V_i^F[x, y_i(x); w_i]$ is the following (see Appendix B for a detailed derivation):

(2) $$V_i^F[x, y_i(x); \omega_i] = -\frac{1}{2}x^2 + \omega_i\left[x - 2\beta\Pi_i^F(y_i(x))\right],$$

where

(3) $$\Pi_i^F(y_i(x)) \equiv \frac{1}{2}\left\{E_{\omega_j} g\left[y_i(x), \omega_j, i, F\right] + E_{\omega_j} g\left[y_i(x), \omega_j, j, F\right]\right\}.$$

The first term inside the brackets at the right hand side of (3) is policymaker i's expectation (taken over j's types) of the inflation rate that the public will expect for period two when i proposes x which signals $y_i(x)$, policymaker j uses the equilibrium strategy (and thus, she proposes $x_j(w_j)$ signaling her own type i.e. $y_j[x_j(w_j) = w_j]$, and i is pivotal in the first period under institutional framework F. Similarly for the second term but with policymaker j being pivotal in the first period. Hence, $\Pi_i^F[y_i(x)]$ is i's expectation (taken over j's types) of the inflation rate that the public will expect for period two when i proposes x which signals $y_i(x)$, and j plays a separating strategy, under framework F. Recall that $\frac{1}{2}$ is the probability of being pivotal.

The best a policymaker can do if the public is going to believe that she is weak is to propose her myopic inflation rate. Thus, an inflation proposal k for the strong type policymaker under framework F will be part of a separating equilibrium only if

$$(4) \qquad V_i^F(k, w_s; w_s) \geq V_S^F(w_s, w_W; w_s).$$

Similarly, an inflation proposal w_W for the weak type policymaker will be part of a separating equilibrium only if

$$(5) \qquad V_i^F\left(k', \omega_S; \omega_W\right) \leq V_W^F\left(\omega_W, \omega_W; \omega_W\right)$$

for any choice k' such that $y(k') = w_S$.

Let K_S^F and K_W^F be the lower values for k and k' that satisfy the above conditions (4) and (5) with equality. In view of (2) and (3), it can be shown (see Appendix D) that these values are

$$K_S^F = w_s - 2\sqrt{\beta w_s \Delta^F} \quad \text{and} \quad K_W^F = w_W - 2\sqrt{\beta w_W \Delta^F}$$

where $\Delta^F \equiv \Pi^F(w_W) - \Pi^F(w_S)$ is i's expected rise of the inflation rate that the public will expect for period two, if i signals weakness instead of strength, and j does not deviate from the separating strategy. In appendix C it is shown that in each institutional framework, Δ^F is

$$\Delta^T = \frac{1}{2}(w_W - w_S) > \Delta^O = \frac{1}{4}(w_W - w_S).$$

Thus, expected effect of signaling weakness instead of strength on public's inflation expectations for period two is higher under transparency than under opacity. Intuitively, signaling is more costly for a policymaker under transparency, because complete revelation of policymaker's types (in a separating equilibrium) results in more extreme values for interim expected inflation rate for the second period. An important consequence of the inequality above is that under transparency, a strong policymaker will choose a lower inflation rate than under opacity. We will show below that opacity may mitigate the need to propose recessionary policies in order to signal strength, thus making opacity socially desirable.

4.2.1 Existence of a separating equilibrium

For convenience, we define the following measure of preference heterogeneity: $\phi \equiv \Delta w / w_W$. Note that $0 < \varphi < 1$ and that φ rises with the difference $\Delta\omega$. The following lemma (which extends proposition 16.3 in Cukierman (1992) to our committee framework) states that under opacity a separating equilibrium always exists, and gives sufficient conditions for the existence of a separating equilibrium under transparency (see Appendix E for the proof).

Lemma 2. *i)* $K_W^O \geq K_S^O$; *ii)* Suppose that $\beta > 1/2$ and that $\varphi < \frac{8\beta}{(2\beta+1)^2}$; then $K_W^T \geq K_S^T$ for all $p \in (0,1)$.

Conditions of the previous lemma require a not too low discount factor and a not too high preference heterogeneity. It is clear that under these conditions the set

$$S_F \equiv \{\pi \in \mathbb{R} : K_S^F \leq \pi \leq K_W^F\}$$

is non empty.[2] Figure (2), which is adapted from figure 1 in Vickers (1986), illustrates the set S_F; indifference curves are of the form

$$-\frac{1}{2}(\pi_1)^2 + w_i(\pi_1 - 2\beta\pi_2^e) = \overline{V(w)},$$

where $w = w_S$ for the strong policymaker and $w = w_W$ for the weak policymaker. The constant $\overline{V(w)}$ satisfies

$$\overline{V(w)} = -\frac{1}{2}(w_W)^2 + w_W[w_W - 2\beta\Pi^F(w_W)]$$

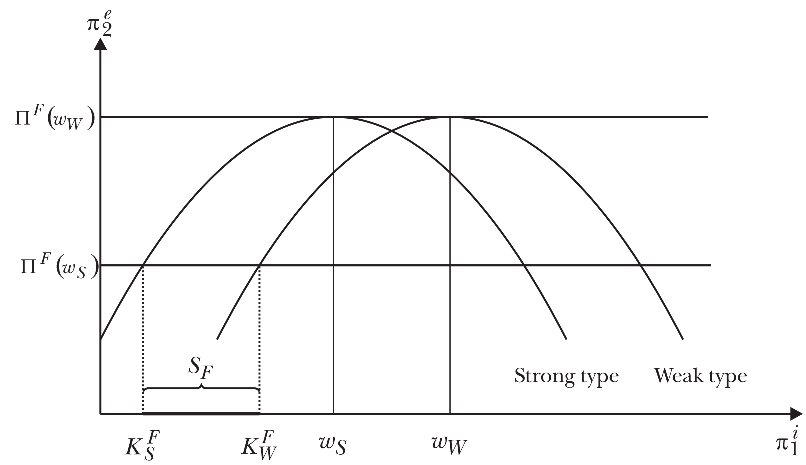
and

$$\overline{V(w)} = -\frac{1}{2}(w_S)^2 + w_S[w_S - 2\beta\Pi^F(w_S)]$$

That is, $\overline{VV(w)}$ is interim expected utility of policymaker i when she proposes w as the inflation for the first period, and public expects $\Pi^F(w_W)$ for the second period. The strong policymaker is indifferent between proposing K_S^F and expectations for the second period being $\Pi^F(w_S)$ (on an expected basis, because she does not know yet how the other policymaker is going to vote) or proposing her myopic inflation rate w_S and expectations for the second period being $\Pi^F(\omega_W)$. Similarly, the weak policymaker is indifferent between proposing K_W^F and expectations for the second period being $\Pi^F(\omega_S)$ (on an expected basis) or proposing her myopic inflation rate ω_W and expectations for the second period being $\Pi^F(\omega_W)$.

[2] If differences in relative preferences between types are too high, there are values of β such that it is too costly for a strong policymaker to signal his type, because signaling requires the choice of an inflation rate that is too low relative to the strong policymaker's myopic inflation rate.

FIGURE 2. THE SET S_F



Pick values $k_T \in S_T$ and $k_O \in S_O$ and consider the following public expectations for the second period inflation rate under transparency and under opacity:

$$\pi_2^{e,T}(\pi_1^A, \pi_1^B) = \begin{cases} w_S \text{ if } \pi_1^A \le k_T \text{ and } \pi_1^B \le k_T \\ \overline{w} \text{ if } \pi_1^A \le k_T \text{ and } \pi_1^B > k_T \\ \overline{w} \text{ if } \pi_1^A > k_T \text{ and } \pi_1^B \le k_T \\ w_W \text{ if } \pi_1^A > k_T \text{ and } \pi_1^B > k_T \end{cases}$$

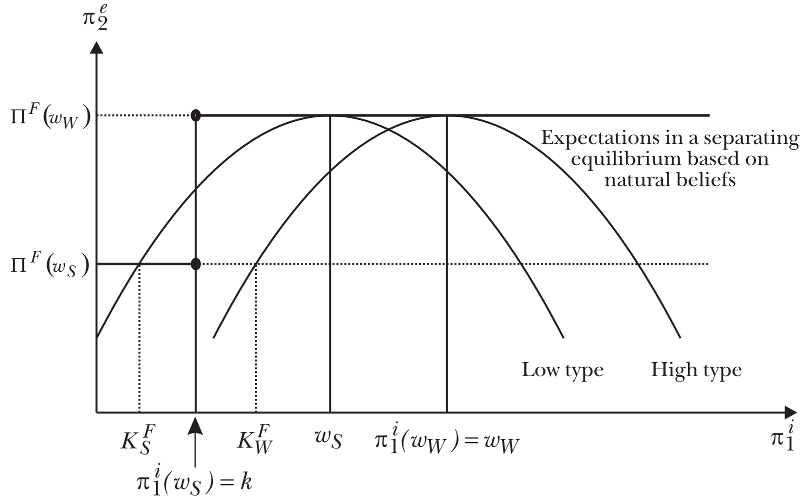
and

$$\pi_2^{e,O}(\pi_1) = \begin{cases} \frac{1}{2} p w_W + (1 - \tfrac{1}{2} p) w_S = w_S + p\Delta w / 2 \text{ if } \pi_1 \le k_O \\ \frac{1}{2}(w_W + w_S + p w_S) = \overline{w} + p\Delta w / 2 \text{ if } \pi_1 \le k_O \end{cases},$$

which is consistent with the expectations in lemma 1. These expectations are not the only one that support a separating equilibrium, but they are reasonable in the sense that expectations are weakly increasing in first period's proposals. We refer to these beliefs as *natural* beliefs.

Given these expectations, strong policymakers find it optimal to propose ω_W for the first period, and given these proposal strategies for the first period, beliefs are correct in equilibrium. This is stated formally in the following proposition. Figure (3) illustrates.

FIGURE 3. A SEPARATING EQUILIBRIUM. STRONG POLICYMAKER CHOOSES $\pi_1^i(w_S) = k \in S_F$ AND WEAK POLICYMAKER CHOOSES $\pi_1^i(w_W) = w_W$



Proposition 1. Assume that conditions (i) and (ii) of lemma 2 hold. Then,

i) for any $k_T \in S_T$ there exists a separating equilibrium under transparency in which

$$\pi_1^i(\omega_S) = k_T \quad i = A, B,$$
$$\pi_1^i(\omega_W) = \omega_W \quad i = A, B,$$
$$\pi_2^i(\omega, \pi) = \omega \quad \forall \pi \quad i = A, B \quad \omega = \omega_S, \omega_W,$$
$$\pi_1^e = (1-p)k_T + p\omega_W,$$

and

$$\pi_2^e(\pi_1^A, \pi_1^B) = \begin{cases} w_S \text{ if } \pi_1^A \le k_T \text{ and } \pi_1^B \le k_T \\ \overline{w} \text{ if } \pi_1^A \le k_T \text{ and } \pi_1^B > k_T \\ \overline{w} \text{ if } \pi_1^A > k_T \text{ and } \pi_1^B \le k_T \\ w_W \text{ if } \pi_1^A > k_T \text{ and } \pi_1^B > k_T \end{cases}$$

ii) for any $k_O \in S_O$ there exists a separating equilibrium under opacity in which

$$\pi_1^i(w_S) = k_O \quad i = A, B,$$
$$\pi_1^i(w_W) = w_W \quad i = A, B,$$
$$\pi_2^i(w, \pi) = w \quad \forall \pi \quad i = A, B \quad w = w_S, w_W,$$
$$\pi_1^e = (1-p)k_O + pw_W,$$

and

$$\pi_2^e(\pi_1) = \begin{cases} \frac{1}{2}pw_W + (1 - 1/2\, p)w_S = w_S + p\Delta w / 2 \text{ if } \pi_1 \le k_O \\ \frac{1}{2}(w_W + w_S + pw_W - pw_S) = \overline{w} + p\Delta w / 2 \text{ if } \pi_1 \le k_O \end{cases}.$$

4.3 Least costly separating equilibrium

The last proposition implies that there is a continuum of separating equilibria in each framework. Each of them correspond to a value $k_F \in S_F$. But note that the best beliefs from the strong policymaker's point of view are those stated above with $k_F = \min\{\omega_S, K_W^F\}$. The closer is k_F to this value, the smaller is the cost of separation for a strong policymaker (i.e. the closer is k_F to $\min\{\omega_S, K_W^F\}$, the higher is her first period's welfare, which achieves a maximum at ω_S). Under this refinement, a strong policymaker does not propose an inflation rate π if there exists another inflation rate π' that allows her to separate herself from a weak policymaker and gives her a higher expected welfare than π. Suppose that a strong policymaker proposes $k \in S_F$ and suppose that $k < K_W^F < w_S$. By choosing k' such that $k < k' < K_W^F$, her payoff increases, and public will still believe that she is strong, because a weak policymaker would never choose $k' \in S_F$ even if she could convince the public that she is strong. (By the construction of S_F.) If $w_S \in S_F$, a similar reasoning applies: by proposing $w_S \in S_F$ instead of $k' = w_S \in S_F$, her payoff increases and public will still believe in his strength because a weak policymaker would never choose that value even if she could convince the public that she is strong. This refinement is due to Cho and Kreps (1987) and is also used in Vicker's (1986) model of signaling in monetary policy with a single policymaker. We call this equilibrium Least Costly Separating Equilibrium (LCSE). Using proposition 1 and lemma 1 we can state:

Corollary 1

i) There exists a least costly separating equilibrium under opacity in which

$$\pi_1^i(\omega_S) = k_O^* \quad i = A, B,$$
$$\pi_1^i(\omega_W) = \omega_W \quad i = A, B,$$
$$\pi_2^i(\omega, \pi) = \omega \quad \forall \pi \quad i = A, B \quad \omega = \omega_S, \omega_W,$$
$$\pi_1^e = (1-p)k_O^* + p\omega_W,$$

and

$$\pi_2^e(\pi_1) = \begin{cases} \frac{1}{2} p w_W + (1 - \frac{1}{2} p) w_S = w_S + p\Delta w / 2 \text{ if } \pi_1 \le k_O^* \\ \frac{1}{2}(w_W + w_S + p w_W - p w_S) = \bar{w} + p\Delta w / 2 \text{ if } \pi_1 > k_O^* \end{cases}$$

ii) Assume that conditions of lemma 2 part (ii) hold, and let $k_F^* \equiv \min\{w_S, w_W - 2\sqrt{\beta w_W \Delta^F}\}$ with $\Delta^T = \frac{1}{2}(w_W - w_S)$ and $\Delta^O = \frac{1}{4}(w_W - w_S)$. Then, there exists a least costly separating equilibrium under transparency in which

$$\pi_1^i(\omega_S) = k_T^* \quad i = A, B,$$

$$\pi_1^i(\omega_W) = \omega_W \quad i = A, B,$$

$$\pi_2^i(\omega, \pi) = \omega \quad \forall \pi \quad i = A, B \quad \omega = \omega_S, \omega_W,$$

$$\pi_1^e = (1 - p) k_T^* + p\omega_W,$$

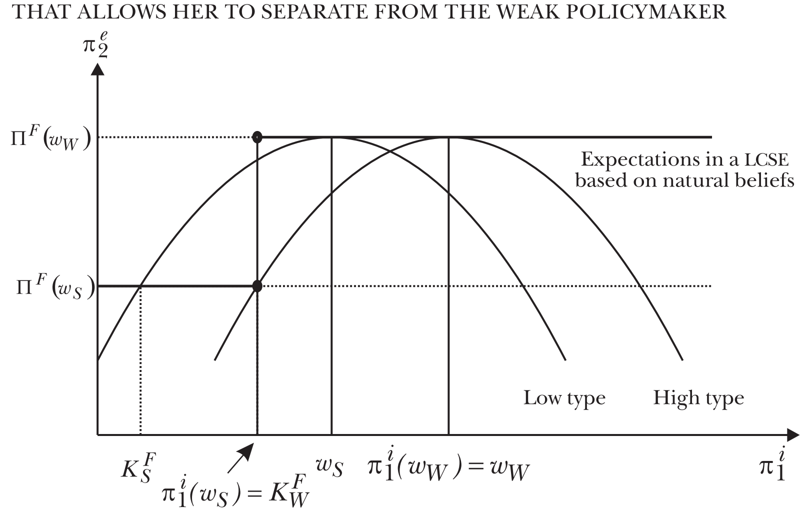
and

$$\pi_2^e(\pi_1^A, \pi_1^B) = \begin{cases} w_S \text{ if } \pi_1^A \le k_T^* \text{ and } \pi_1^B \le k_T^* \\ \bar{w} \text{ if } \pi_1^A \le k_T^* \text{ and } \pi_1^B > k_T^* \\ \bar{w} \text{ if } \pi_1^A > k_T^* \text{ and } \pi_1^B \le k_T^* \\ w_W \text{ if } \pi_1^A > k_T^* \text{ and } \pi_1^B > k_T^* \end{cases}$$

Figure (4) illustrates the proposition above.

Expected effect of signaling strength on public's inflation expectations for period two is higher under transparency than under opacity; thus, we have that in a LCSE, a strong policymaker proposes under transparency a lower inflation rate than under opacity in order to signal her type. This is stated in the following lemma (see Appendix F for the proof).

FIGURE 4. A LEAST COSTLY SEPARATING EQUILIBRIUM. STRONG POLICYMAKER CHOOSES $\pi_1^i(w_S) = K_W^F$, WHICH IS THE CLOSEST VALUE TO w_S THAT ALLOWS HER TO SEPARATE FROM THE WEAK POLICYMAKER



Lemma 3. $k_T^* < k_O^*$.

Recall that we placed a restriction on the discount factor and on ϕ (see lemma 2). In particular, we assumed $\beta > 1/2$ which in turn implies that

$$\omega_S > \omega_W - 2\sqrt{\beta\omega_W \Delta\omega / 2},$$

thus, we have

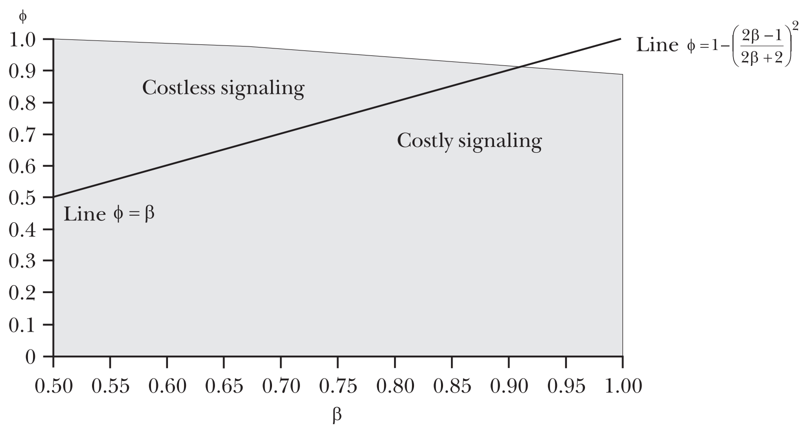
$$k_T^* = \omega_W - 2\sqrt{\beta \omega_W \Delta\omega / 2}.$$

Intuitively, a high enough discount factor allows separation under transparency, but only at a cost. (The strong policymaker cannot signal her strength proposing her myopic inflationrate ω_S .) However, under opacity there exist combinations of parameters such that a strong type policymaker does not need to propose a different (lower) inflation rate than ω_S , her myopic proposal.

Lemma 4. Let $\beta > 1/2$ and $\phi \leq 1 - \left(\frac{2\beta - 1}{2\beta + 1}\right)^2$. *i)* If $\beta > \phi$, then sig-

naling for a strong policymaker is costly under opacity, that is, a strong type proposes a different (lower) inflation rate than ω_S , her myopic inflation rate; *ii)* if $\beta < \phi$, , then signaling for a strong policymaker is costless under opacity; that is, a strong type proposes ω_S , which is her myopic inflation rate; *iii)* under transparency, signaling for the strong type is always costly; that is, a strong type policymaker proposes a different (lower) inflation rate than ω_S .

FIGURE 5. COSTLESS AND COSTLY SIGNALING UNDER OPACITY



This lemma is illustrated in figure (5). At the northwest of the line $\varphi = \beta$, signaling is costless under opacity. At the southeast, it is costly. Transparency is always costly. The area which is not shadowed (at the northeast of the line $\varphi = 1 - \left(\frac{2\beta - 1}{2\beta + 1}\right)^2$) shows the combination of parameters for which a separating equilibrium under transparency does not exist.

5. Welfare comparisons

In this section we characterize ex ante welfare under both disclosure rules and give conditions under which a country would choose opacity or transparency. In order to do this, we show (see appendix G) that there is no difference in expected welfare for the second period between opacity and transparency ($EW_2^O = EW_2^T$). The reason is that both types of policymakers have a dominant strategy for the second period, which entails proposing their myopic inflation rate, in both institutional frameworks, so on an expected basis, there is no difference between inflation expectations under transparency and under opacity. Then, we only need to examine first period's welfare under each framework, compare them, and give conditions under which each disclosure rule dominates the other.

Recall that in each period, policy is decided by a strong policymaker with probability

$$\left(1-p\right)^2+p\left(1-p\right)=1-p,$$

and by a weak policymaker with probability p. So in a LCSE, expected welfare for period 1 under institutional framework F is

$$EW_1^F = pW(w_W,\chi,\pi_1^{e,F})+(1-p)W(k_F^*,\chi,\pi_1^{e,F})$$
$$= -\frac{1}{2}[p(w_W)^2+(1-p)(k_F^*)^2].$$

In a LCSE only the strong type policymaker can propose a different inflation rate; a weak type proposes ω_W in both institutional frameworks; thus, difference in expected welfare between transparency and opacity is (see appendix F for a detailed derivation)

$$EW^O-EW^T=EW_1^O-EW_1^T=\frac{1}{2}\left(1-p\right)\left[\left(k_T^*\right)^2-\left(k_O^*\right)^2\right].$$

This difference depends on deviations from the target of strong type's proposals in opacity and in transparency. In this period there is no output boosting on an expected basis in either framework.

We consider two cases:

i) $\beta<\varphi$. In this case, signaling is costly under transparency but not under opacity. A strong type proposes $\omega_W-2\sqrt{\beta\omega_W\Delta^T}$ under transparency, and ω_S under opacity. Difference in expected welfare for the first period is

$$EW^O-EW^T=\frac{1}{2}\left(1-p\right)\left[\left(\omega_W-2\sqrt{\beta\omega_W\Delta^T}\right)^2-\left(\omega_S\right)^2\right].$$

ii) $\beta>\varphi$. At higher discount factors, signaling is costly in both frameworks, so a strong type proposes $\omega_W-2\sqrt{\beta\omega_W\Delta^F}$ under transparency ($F=T$) and opacity ($F=O$), so

$$EW^O-EW^T=\frac{1}{2}(1-p)[(\omega_W-2\sqrt{\beta\omega_W\Delta^T})^2-(\omega_W-2\sqrt{\beta\omega_W\Delta^O})^2].$$

Define $\beta_C\equiv 2(\sqrt{2}-1)(=0.8284)$ and $\Omega(\beta,\varphi)\equiv\frac{\varphi}{2}\left(1+\beta-\frac{\varphi}{2}\right)^2-\beta$.

Proposition 2. Let $\beta>1/2$ and $\varphi\leq 1-\left(\frac{2\beta-1}{2\beta+1}\right)^2$.

i) If $\beta<\beta_C$, then,

(6) $$EW^O \gtreqqless EW^T \Leftrightarrow \Omega(\beta,\varphi)\gtreqqless 0;$$

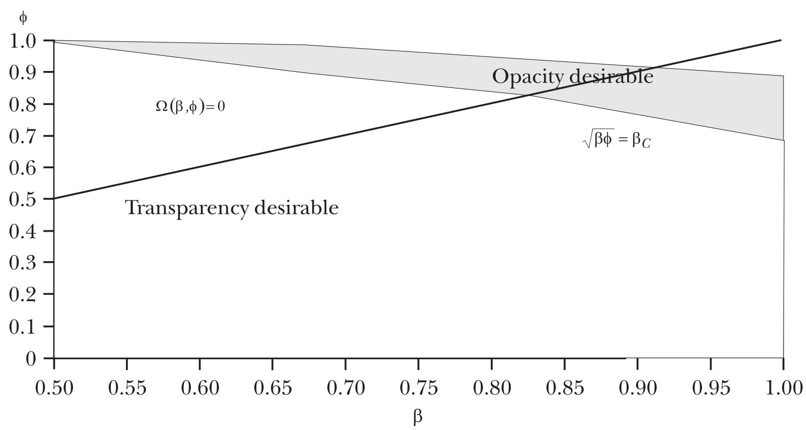
ii) If $\beta\geq\beta_C$, then

(7) $$EW^O \gtreqqless EW^T \Leftrightarrow \sqrt{\beta\varphi}\gtreqqless\beta_C.$$

The proof is provided in appendix H to this paper. The proposition states that the difference EW^O-EW^T has the same sign as $\Omega(\beta,\phi)$ when signaling is costless under opacity, and that it has the same sign as $\sqrt{\beta\varphi}-\beta_C$ when signaling is costly under opacity. Both equations $\Omega(\beta,\phi)=0$ and

$\sqrt{\beta\varphi} - \beta_C = 0$ have a negative slope. Moreover, at the northeast of each equation graph, the left hand side is positive, and at the southwest, the left hand side is negative, which means that opacity is desirable at high values of the discount factor and at high values of ϕ, which is a measure of preference heterogeneity. At low values of β or ϕ, transparency is desirable. Figure (6) illustrates. The prior p and the society's preference parameter χ do not affect desirability of each information disclosure rule, i.e. the sign of $EW^O - EW^T$ do not depend on p or χ.[3]

FIGURE 6. DESIRABILITY OF OPACITY AND TRANSPARENCY. RECALL THAT $\phi = \Delta w / w_W$ IS A MEASURE OF PREFERENCE HETEROGENEITY

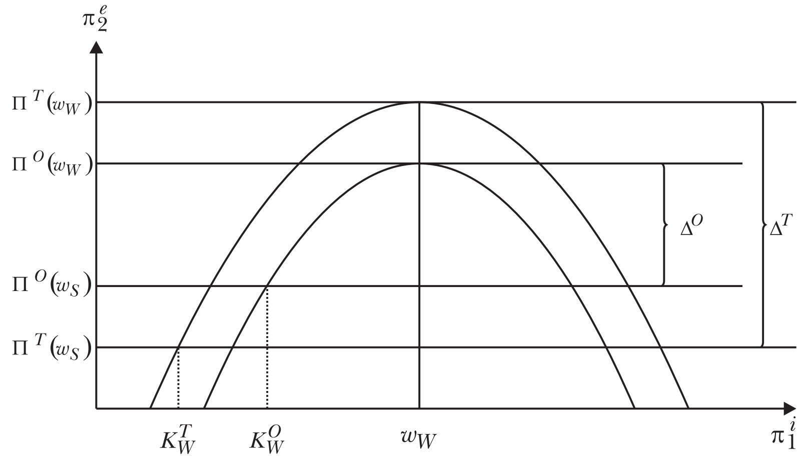


In both cases, difference in expected welfare between frameworks can be positive or negative depending on which term is closer to the inflation target. We have shown above that $\Delta^T > \Delta^O$, so $\omega_W - 2\sqrt{\beta\omega_W\Delta^T} < \omega_W - 2\sqrt{\beta\omega_W\Delta^O}$. That is, under transparency, a strong policymaker proposes a lower inflation rate than under opacity. This is illustrated in figure (7), where it can be seen that $K_W^T < K_W^O$ because complete revelation of policymaker's types results in more extreme values for expected inflation rate for the second period. Differences in expected inflation rates are $\Delta^F = \Pi^F(w_W) - \Pi^F(w_S)$. These values are $\Delta^T = \Delta w / 2$ under transparency and $\Delta^O = \Delta w / 4$ under opacity.

We have showed that desirability of opacity or transparency depends on patience and with heterogeneity among committee members. We already argued in the introduction that more heterogeneous and patient committees should be observed in more heterogeneous and patient countries. Thus, an empirical prediction of the model is that opaque monetary policy committees should be found in more heterogeneous or patient societies. We test this prediction in the following section.

[3] However, the value of $EW^O - EW^T$ does depend on p. In particular, the absolute value of this difference rises with the prior probability that a policymaker is of strong type. This means that at higher priors that a policymaker is strong, the issue of opacity vs transparency becomes more relevant.

FIGURE 7. EXPECTED INATION RATE UNDER OPACITY AND TRANSPARENCY



6. Empirical findings

6.1 Data and methodology

Our sample is composed by thirty six central banks making monetary policy decisions by committees, and it is the result of merging the data exhibited in Tuladhar (2005), Maier (2007) and Fujiki (2005).

In all of the banks of the sample except New Zealand, the committee expressly makes the decision, either through voting –28 central banks– or consensus –7 central banks. New Zealand's monetary policy committee convenes to advice the Governor on the setting of the monetary policy instrument, but decision-making responsibility rests solely with the Governor. Only 9 of these central banks (25%) publish minutes which include voting records or individual opinions regarding the appropriate value for the monetary policy instrument. The variable *vrec* captures this distinction. (vrec = 1 if voting records are published).

The dependent variable is the probability that the country's MPC publishes voting records or individual opinions. We employ a Probit method since *vrec* is binary. Thus, we estimate

$$P(vrec = 1 \mid \mathbf{x}) = \Phi(\beta_c + \beta_r r + \beta_h h), \quad (8)$$

where $\mathbf{x} = (r, h)$ is the vector of covariates. The first covariate is a measure of the degree of impatience of the monetary policy committee. For this proxy, we use the difference of the real interest rate of the country versus the average real interest rate of the group of similar countries included in the sample. The second covariate is a measure of the degree of heterogeneity of the monetary policy committees. We consider two groups of proxies for this variable: proxies of the political polarization of the country and proxies of the cultural diversity of the country. The following indices are an annual average of years 1994 to 2003. Annual values have been taken from Norri's (2009) political database.

6.1.1 Political polarization

We consider the following indices:

i) Number of seats largest party. The original source is Arthur Banks Cross-National Time-Series Database. We conjecture that a a higher number of seats of the largest party in the legislature is associated with a lower political polarization. Thus, we expect a positive marginal effect of this covariate.

ii) Years in office governing party, which measures how long has executive party been in office. It is taken from Norris political database but the original source is the DPI Database of Political Institutions (Beck et al., 2001). Based on the conjecture that political polarization is inversely related to the average period the executive party has been in office, we expect a positive marginal effect of this covariate, as a lower political polarization increases the probability that the voting records are published.

iii) Number of seats governing coalition. The original source is also the DPI Database of Political Institutions (Beck et al., 2001). A higher number of seats of governing coalition is presumably associated with a lower degree of political polarization. Thus, we also expect a positive marginal effect of this covariate.

6.1.2 Cultural diversity

As measures of cultural diversity, we consider the following indices:

i) Ethnical fractionalization. The original source is Alesina et al. (2003). This index measures the probability that any two members of the society belong to different ethnic groups. We conjecture that a higher ethnic diversity is associated with a higher cultural (and maybe political) diversity of the society, which is presumably related to a higher preference heterogeneity of the country's MPC. Thus, we expect a negative marginal effect of this covariate.

ii) Linguistic fractionalization. The original source is also [?]. This index measures the probability that any two members of the society speak different languages. We also conjecture that a higher linguistic diversity is associated with a higher cultural (and maybe political) diversity of the society, which is presumably related to a higher preference heterogeneity of the country's MPC. Thus, we expect a negative marginal effect of this covariate.

In the following subsection we provide results of estimation (8).

6.2 Results

Table 1 exhibits marginal effects of political heterogeneity covariates, which have the expected positive sign (recall that higher value of the indices are related to lower heterogeneity) and are significantly different from zero. These results suggest that greater political polarization is associated with a lower probability that a monetary policy committee makes public the voting records or the policy proposals of each member.

Table 2 shows marginal effects of cultural diversity covariates, which also have the (negative) expected signal and are significantly different from zero. These results indicate that the probability that a monetary policy committee makes public its voting records or individual policy proposals is lower in more culturally diverse countries. Differential real interest rate has the expected sign in all of the models but it is not significant. Thus, empirical results do not confirm that more patient societies prefer to appoint opaque committees.

. TABLE 1

PUBLICATION OF VOTING RECORDS AND POLITICAL HETEROGENEITY: MARGINAL EFFECTS OF PROBIT ESTIMATES

	mfx1 *b/p*	*mfx2* *b/p*	*mfx3* *b/p*
Differential real interest rate	−0.720	−0.806	−1.189
	(0.569)	(0.580)	(0.292)
Number of seats largest party	0.003[b]		
	(0.008)		
Years in office governing party		0.003[a]	
		(0.048)	
Number of seats governing coalition			0.002[a]
			(0.017)
Observations	36	36	36
Overall model significance (*p*-value)	0.006	0.082	0.033

NOTES: Dependent variable is the probability that the central bank's MPC makes public the voting records; and standard errors in parenthesis. [a] Denotes significance at 0.05 while. [b] Denotes significance at 0.01.

TABLE 2

PUBLICATION OF VOTING RECORDS AND CULTURAL DIVERSITY: MARGINAL EFFECTS OF PROBIT ESTIMATES

	mfx1 *b/p*	*mfx2* *b/p*
Differential real interest rate	−1.264	−0.759
	(0.376)	(0.360)
Ethnical fractionalization	−0.806[a]	
	(0.010)	
Linguistic fractionalization		−0.869[b]
		(0.002)
Observations	36	36
Overall model significance (p-value)	0.021	0.004

NOTES: Dependent variable is the probability that the central bank's MPC makes public the voting records; and standard errors in parenthesis. [a] Denotes significance at 0.05 while. [b] Denotes significance at 0.01.

European Central Bank (ECB) was not included in the sample, because polarization and diversity indices are not available for the European Union as a whole. However, it is worth noting that ECB's monetary policy committee does not publishes minutes of its meetings, and it is presumably a highly heterogeneous committee, with representatives of most of euro zone countries. We believe that the inclusion of ECB in the sample would not alter the empirical findings.

7. CONCLUDING REMARKS

In this paper we consider the signaling problem in discretionary monetary policy when decisions are made by a committee, and analyze the welfare properties of two alternative institutional frameworks, each characterized by a different information disclosure rule: transparency, in which proposals of each committee member are made public along with the policy decision, and opacity, in which only the policy decision is made public. After showing that many separating equilibria exist, we focus on one of them, the least costly separating equilibrium, in which the strong policymaker does the minimum necessary to separate from the weak policymaker. We also analyze the welfare properties of both disclosure rules. In particular, we find that opacity dominates transparency for high values of patience and heterogeneity among committee members. Thus, an empirical prediction of the model is that opaque monetary policy committees should be found in more heterogeneous or patient societies. (Who will presumably appoint more heterogeneous or patient committees?)

Using a sample of thirty six central banks in which a committee is directly or indirectly involved in setting the monetary policy instrument, we estimate a Probit specification for the probability that voting records are published, employing as covariates several measures of cultural and political heterogeneity, and a proxy for society's degree of impatience. The prediction that more heterogeneous societies are more prone to appoint opaque committees is confirmed by the data. However, we cannot confirm the hypothesis that more patient societies will appoint opaque committees.

8. APPENDIX

8.1 Proof of Lemma 1

Proof. Suppose that in a separating equilibrium under opacity, $x \in S_O$. Then, at least one policymaker is strong, because only strong types choose inflation rates in S_O. Then

$$\gamma_O(x) = \frac{1}{2}\Pr(\omega_A = \omega_W, \omega_B = \omega_S \mid x \in S_O) + \frac{1}{2}\Pr(\omega_A = \omega_S, \omega_B = \omega_W \mid x \in S_O)$$
$$= \frac{1}{2}\left[\frac{(1/2)p(1-p)}{\Pr(x \in S_O)} + \frac{(1/2)(1-p)p}{\Pr(x \in S_O)}\right] = \frac{1}{2}\frac{p(1-p)}{\Pr(x \in S_O)} = \frac{1}{2}p\frac{1-p}{1-p} = \frac{1}{2}p.$$

Now suppose that in a separating equilibrium under opacity, $x \notin S_O$. Then, at least one policymaker is weak, because only weak types choose inflation rates outside S_O. In what follows, $x \notin S_O$ denotes the event "at least one policymaker is weak". Recall that this probability is $\Pr(x \notin S_O) = p$. Then

$$\gamma_O(x) = \Pr(\omega_A = \omega_W, \omega_B = \omega_S \mid x \notin S_O)\Pr(A \text{ is pivotal})$$
$$+ \Pr(\omega_A = \omega_S, \omega_B = \omega_W \mid x \notin S_O)\Pr(B \text{ is pivotal})$$
$$+ \Pr(\omega_A = \omega_W, \omega_B = \omega_W \mid x \notin S_O)$$
$$= \frac{1}{2}\frac{p(1-p)}{\Pr(x \notin S_O)} + \frac{p^2}{\Pr(x \notin S_O)} = \frac{1}{2} + \frac{1}{2}p.$$

8.2 An expression for $V_i^F(x, y_i(x))$

Suppose that i proposes x signaling $y_i(x)$ and suppose that j plays a separating equilibrium, in which case her first period proposal is intended to signal her type: $y_j[\pi_1^j(w_j)] = w_j$. Public's expectations for the second period when $h \in \{i, j\}$ is pivotal under institutional framework F is $g[y_i(x_i), w_j, h, F]$ Then, interim expected utility (i.e. expected welfare after policymaker i knows her type w but before first period voting takes place) of policymaker i under institutional framework F, when she proposes inflation rate x for the first period, and this proposal is intended to signal that her type is $y_i(x)$, and j uses a separating equilibrium, is

$$\Lambda_i^F[x, y_i(x)]$$
$$= \frac{1}{4}\underset{w_j|w_i}{E}\left\{\begin{aligned} &W(x, w_i, \pi_1^e) + \beta W\{\pi_2^i[w_i, \pi_i^j(w_j)], w_i, g[y_i(x), w_j, i, F]\} \\ &+ W(x, w_i, \pi_1^e) + \beta W\{\pi_2^j(w_j, x), w_i, g[y_i(x), w_j, i, F]\} \\ &+ W[\pi_1^j(w_j), w_i, \pi_1^e] + \beta W\{\pi_2^i[w_i, \pi_1^j(wj)], w_i, g[y_i(x), w_j, j, F]\} \\ &+ W[\pi_1^j(w_j), w_i, \pi_1^e] + \beta W\{\pi_2^j(w_B, x), w_i, g[y_i, (x), w_j, j, F]\} \end{aligned}\right\}$$

The expression above can be simplified to

$$
\begin{aligned}
&= \frac{1}{2}\left[-\frac{1}{2}(x)^2 + w_i(x-\pi_1^e)\right] \\
&+ \frac{1}{2}\underset{w_j|w_i}{E}\left\{\begin{matrix}-\beta w_i g[y_i(x), w_j, i, F] - \beta w_i g[y_i(x), w_j, j, F] \\ -\frac{1}{2}\beta[\pi_2^j(w_j, x)]^2 + \beta w_i \pi_2^j(w_j, x)\end{matrix}\right\}
\end{aligned}
$$

where A_F does not depend on x. Note that in any equilibrium, j has a dominant strategy for the second period: $\pi_2^j\left(\omega_j, x\right) = \omega_j$ for every x. Thus,

$$
\begin{aligned}
&\Lambda_i^F\left(x, y_i(x)\right) = \frac{1}{2}\left[-\frac{1}{2}\left(x\right)^2 + \omega_i\left(x - \pi_1^e\right)\right] \\
&-\beta\omega_i \frac{1}{2}\underset{\omega_j|\omega_i}{\mathrm{E}}\left\{g\left[y_i\left(x\right), \omega_j, i, F\right] + g\left[y_i\left(x\right), \omega_j, j, F\right]\right\} \\
&+\frac{1}{2}\underset{\omega_j|\omega_i}{\mathrm{E}}\left\{-\frac{1}{2}\beta\left(\omega_j\right)^2 + \beta\omega_i\left(\omega_j\right)\right\} + A_F
\end{aligned}
$$

When choosing x, we can considering policymaker i as maximizing the following affine transformation of $\Lambda_i^F\left(x, y_i(x)\right)$, where we omit those summands where x is not present:

$$
\begin{aligned}
&V_i^F\left(x, y_i(x)\right) \\
&= -\frac{1}{2}\left(x\right)^2 + \omega_i\left(x\right) - \beta\omega_i \underset{\omega_j|\omega_i}{\mathrm{E}}\left\{g\left[y_i\left(x\right), \omega_j, i, F\right] + g\left[y_i\left(x\right), \omega_j, j, F\right]\right\}
\end{aligned}
$$

Letting

$$
\frac{1}{2}\underset{\omega_j|\omega_i}{\mathrm{E}}\{g\left[y_i\left(x\right), \omega_j, i, F\right] + g\left[y_i\left(x\right), \omega_j, j, F\right]\} \equiv \Pi_i^F\left(y_i\left(x\right)\right)
$$

we have

$$
V_i^F\left(x, y_i(x)\right) = -\frac{1}{2}\left(x\right)^2 + \omega_i\left[x - 2\beta\Pi_i^F\left(y_i\left(x\right)\right)\right]
$$

which is the expression in the main body of the paper.

8.3 Expressions for Δ^F

Under transparency we have the following expression for public's expectations when i proposes x_i signaling $y(x_i)$ and i is pivotal:

$$
g\left[y(x_A), y(x_B), i, T\right] = \begin{cases} \omega_S & \text{if} \quad x_A, x_B \in S_T \\ \omega_W & \text{if} \quad x_A, x_B \notin S_T \\ \overline{\omega} & \text{if} \quad x_A \text{ or } x_B \in S_T \text{ (but not both)} \end{cases},
$$

Similarly, under opacity, we have

$$g\left[y(x_A),y(x_B),i,O\right]=\begin{cases}\frac{1}{2}p\omega_W+\left(1-\frac{1}{2}p\right)\omega_S & \text{if} \qquad\qquad x_A,x_B\in S_O\\ \frac{1}{2}(\omega_W+\omega_S+p\omega_W-p\omega_S) & \text{if} \qquad\qquad x_A,x_B\notin S_O\\ \frac{1}{2}p\omega_W+\left(1-\frac{1}{2}p\right)\omega_S & \text{if} \quad \text{only} \quad x_i\in S_O \text{ and } i \text{ is pivotal}\\ \frac{1}{2}(\omega_W+\omega_S+p\omega_W-p\omega_S) & \text{if} \quad \text{only} \quad x_i\in S_O \text{ and } j \text{ is pivotal}\end{cases}.$$

Thus, i's expectation (taken over j's types) of the inflation rate that the public will expect for period two when i proposes $x\notin S_F$ (thus, signaling weakness), and j plays a separating strategy, under framework F, is

$$\Pi^F(\omega_W)=\frac{1}{2}\begin{Bmatrix} pg\left[\omega_W,\omega_W,i,F\right]+(1-p)g\left[\omega_W,\omega_S,i,F\right]\\ +pg\left[\omega_W,\omega_W,j,F\right]+(1-p)g\left[\omega_W,\omega_S,j,F\right]\end{Bmatrix}.$$

Similarly, i's expectation (taken over j's types) of the inflation rate that the public will expect for period two when i proposes $x\in S_F$ (thus, signaling strength), and j plays a separating strategy, under framework F, is

$$\Pi^F(\omega_S)=\frac{1}{2}\begin{Bmatrix} pg\left[\omega_S,\omega_W,i,F\right]+(1-p)g\left[\omega_S,\omega_S,i,F\right]\\ +pg\left[\omega_S,\omega_j,j,F\right]+(1-p)g\left[\omega_S,\omega_S,j,F\right]\end{Bmatrix}$$

We have $\Pi^T(\omega_W)=p\omega_W+(1-p)\bar{\omega}$ and $\Pi^T(\omega_S)=p\bar{\omega}+(1-p)\omega_S$, so under transparency, i's expected rise of the inflation rate that the public will expect for period two, if i signals weakness instead of strength, and j does not deviate from the separating strategy is $\Pi^T(\omega_W)-\Pi^T(\omega_S)=\frac{\Delta\omega}{2}$. Similarly, under opacity, using lemma 1 we have

$$\Pi^O(\omega_W)=\frac{1}{2}p\bar{\omega}+\frac{1}{2}\bar{\omega}+\frac{1}{2}p\Delta\omega+\frac{1}{2}\omega_S-\frac{1}{2}p\omega_S$$

and

$$\Pi^O(\omega_S)=-\frac{1}{2}p\omega_S+\frac{1}{2}p\Delta\omega+\frac{1}{2}p\bar{\omega}+\omega_S$$

so under opacity, i's expected rise of the inflation rate that the public will expect for period two, if i signals weakness instead of strength, and j does not deviate from the separating strategy is $\Pi^O(w_W)-\Pi^O(w_S)=\frac{\Delta w}{4}$, which is lower than $\Pi^T(w_W)-\Pi^T(w_S)$.

8.4 Derivation of k_i^F

Let k_i^F be the lowest value of x that satisfies the equation $V_i^F(x,w_S)=V_i^F(w_S,w_W)$. In view of the definition of V_i^F, we have the following quadratic equation:

$$-\frac{1}{2}x^2+w_i[x-2\beta\Pi^F(w_S)]=-\frac{1}{2}w_i^2+w_i[w_i-2\beta\Pi^F(w_W)]$$

Rearranging terms we have

$$\frac{1}{2}x^2 - w_i x + \frac{1}{2}w_i^2 - 2\beta w_i \Delta^F = 0,$$

were we used the notation $[\Pi^F(w_W) - \Pi^F(w_S)] \equiv \Delta^F$ that was defined in the main text. Solving for the lower root gives $k_i^F = w_i - 2\sqrt{\beta w_i \Delta^F}$.

8.5 Proof of Lemma 2

Proof. Recall that $S_F \equiv \{\pi \in \mathbb{R} : K_S^F \leq \pi \leq K_W^F\}$ with $K_S^F = \omega_S - 2\sqrt{\beta \omega_S \Delta^F}$ and $K_W^F = w_W - 2\sqrt{\beta w_W \Delta^F}$, so this set is not empty if $K_W^F \geq K_S^F$. That is, if $\frac{\Delta w}{2} \geq \sqrt{\beta w_W \Delta^F} - \sqrt{\beta w_S \Delta^F}$. Let $\Delta^F = \Delta w b_F / 2$ where $b_F = 1$ under transparency, and $b_F = 1/2$ under opacity, and define $R \equiv w_W / w_S$, which is higher than 1. Then, the above inequality becomes $R(2\beta b_F - 1) - 4\beta b_F \sqrt{R} + 1 + 2\beta b_F \leq 0$. We further define $a_F \equiv 2\beta b_F$ and $r \equiv \sqrt{R}$, so we get the following polinomial inequality:

$$P_F(r) \equiv r^2(a_F - 1) - 2a_F r + 1 + a_F \leq 0.$$

Under opacity, $a_O = \beta$ so the coefficient of the quadratic term is negative and polinomial $P_O(r)$ has a maximum. Roots are 1 and $-\left(\frac{1+\beta}{1-\beta}\right)$. Thus, under opacity, a sufficient condition for the set S_O to exist is $r > 1 \Leftrightarrow R > 1$ for every β. But $R > 1$ by construction, so S_O always exists. Under transparency, $a_T \equiv 2\beta$ so the coefficient of the quadratic term is positive if $\beta > 1/2$. In this case, polinomial $P_T(r)$ has a minimum. Roots are 1 and $\frac{2\beta+1}{2\beta-1}$. A sufficient condition for the set S_T to exist is $\beta > 1/2$ and $\phi < \frac{8\beta}{(2\beta+1)^2}$.

8.6 Proof of Lemma 3

Proof. First, note that $\Delta^T = \frac{1}{2}\Delta w > \Delta^O = \frac{1}{4}\Delta w$, which implies $K_W^T = w_W - 2\sqrt{\beta w_W \Delta^T} < w_W - 2\sqrt{\beta w_W \Delta^T} = K_W^O$. From the definition of k_F^* it follows that $k_T^* \leq k_O^*$. Now, note that $w_S > K_W^T$ if and only if $w_S > w_W - 2\sqrt{\beta_{w_W} \Delta^T}$, that is, in and only if $2\beta \geq \phi$,

and recall that $\phi < 1$. Thus, $\beta > 1/2$ which implies $2\beta > 1 > \phi$ which in turn implies $K_W^T < w_W$. Also, by definition, $k_T^* \equiv \min\{w_W, K_W^T\} = K_W^T$. We already know that it cannot be $k_T^* > k_O^*$, so it suffices to suppose that $k_T^* = k_O^*$ and look for a contradiction. If $k_O^* = k_T^*$, then, by definition of k_O^*, we have $K_W^T = k_T^* = k_O^* \equiv \min\{\omega_S, K_W^O\}$, that is, $K_W^T = \min\{\omega_S, K_W^O\}$. This is a contradiction because we already proved that $K_W^T < w_S$ and that $K_W^T < K_W^O$.

8.7 Expressions for welfare comparisons

In this appendix we give expressions for $EW_t^O - EW_t^T$ where EW_t^F is expected welfare for period t under framework F. In what follows $W_t^F(\omega_A, \omega_B)$ denotes period t's expected welfare for society, when types of policymakers are (w_A, w_B), institutional framework is F, and both policymakers plays the least costly separating strategy.

If both policymakers are strong, we have the following expressions for first period's welfare under a LCSE:

$$W_1^T(L,L) = -\frac{1}{2}\left(k_T^*\right)^2 + \chi p\left(k_T^* - \omega_W\right)$$

under transparency, and

$$W_1^O(L,L) = -\frac{1}{2}\left(k_O^*\right)^2 + \chi p\left(k_O^* - \omega_W\right)$$

under opacity. Thus, difference in first period's welfare between opacity and transparency, if both policymakers are strong, is

$$W_1^O(L,L) - W_1^T(L,L) = \frac{1}{2}\left(k_T^*\right)^2 - \frac{1}{2}\left(k_O^*\right)^2 + \chi p\left(k_O^* - k_T^*\right)$$

Similarly, if one policymaker is strong and the other is weak, we have

$$W_1^T(L,H) = \frac{1}{2}\left[-\frac{1}{2}\left(k_T^*\right)^2 + \chi\left(k_T^* - (1-p)k_T^* - p(\omega_W)\right)\right] + \frac{1}{2}\left[-\frac{1}{2}(\omega_W)^2 + \chi(1-p)\left(\omega_W - k_T^*\right)\right]$$

under transparency, and

$$W_1^O(L,H) = \frac{1}{2}\left[-\frac{1}{2}\left(k_O^*\right)^2 + \chi p\left(k_O^* - \omega_W\right)\right] + \frac{1}{2}\left[-\frac{1}{2}(\omega_W)^2 + \chi(1-p)\left(\omega_W - k_O^*\right)\right]$$

under opacity, so difference in first period's welfare between opacity and transparency, if one policymaker is strong and the other is weak, is

$$W_1^O(L,H) - W_1^T(L,H) = \frac{1}{2}\left[\frac{1}{2}\left(k_T^*\right)^2 - \frac{1}{2}\left(k_O^*\right)^2\right] + \frac{1}{2}\chi\left(k_O^* - k_T^*\right)(2p-1)$$

Finally, if both policymakers are weak, we have

$$W_1^T(H,H) = -\frac{1}{2}(w_W)^2 + \chi\left[w_W - (1-p)k_T^* - p(w_W)\right] - \frac{1}{2}(w_W)^2 + (1-p)\chi\left(w_W - k_T^*\right)$$

under transparency, and

$$W_1^O(H,H) = -\frac{1}{2}(w_W)^2 + (1-p)\chi\left(w_W - k_O^*\right)$$

under opacity, so difference in first period's welfare between opacity and transparency, if one policymaker is strong and the other is weak, is

$$W_1^O(H,H)_1^T - W_1^T(H,H) = (1-p)\chi\left(k_T^* - k_O^*\right)$$

Given that both policymakers are strong with probability $(1-p)^2$, both are weak with probability p^2, and one is strong and the other weak with probability $p(1-p)$, difference in expected welfare for the first period is

$$EW_1^O - EW_1^T = (1-p)\frac{1}{2}\left[\left(k_T^*\right)^2 - \left(k_O^*\right)^2\right].$$

Under transparency, we have the following expressions for second period's welfare under a LCSE:

$$W_2^T(L,L) = -\frac{1}{2}(w_S)^2 + \chi(w_S - w_S) = -\frac{1}{2}(w_S)^2,$$

if both policymakers are strong;

$$W_2^T(L,H) = -\frac{1}{2}\frac{1}{2}(w_S)^2 - \frac{1}{2}\frac{1}{2}(w_W)^2,$$

if one is strong and the other is weak; and

$$W_2^T(H,H) = -\frac{1}{2}(w_W)^2 + \chi(w_W - w_W) = -\frac{1}{2}(w_w)^2$$

if both are weak. Similarly, under opacity, we have the following expressions for second period's welfare under a LCSE:

$$W_2^O(L,L) = -\frac{1}{2}(w_S)^2 + \chi(w_S - \tilde{w}_W(p))$$

if both policymakers are strong;

$$W_2^O(L,H) = \frac{1}{2}\left[-\frac{1}{2}(w_S)^2 + \chi(w_S - \tilde{w}_S(p)) - \frac{1}{2}(w_W)^2 + \chi(w_W - \tilde{w}_W(p))\right]$$

if one is strong and the other is weak; and

$$W_2^O(H,H) = -\frac{1}{2}(\omega_W)^2 + \chi(\omega_W - \tilde{\omega}_W(p))$$

if both are weak. Thus, difference in expected welfare for period two is

$$EW_2^O - EW_2^T = \chi\left[-p(1-p)\Delta\omega/2 + p(1-p)\Delta\omega/2\right] = 0,$$

so on an expected basis, there is no difference in period two's welfare between transparency and opacity.

8.8 Proof of Proposition 3

Proof. If signaling under opacity is costless, then

$$EW^O \gtreqless EW^T$$

$$\Leftrightarrow (\omega_W + \omega_S)\Delta\omega - 4\omega_W\sqrt{\beta\omega_W\frac{\Delta\omega}{2}} + 4\beta\omega_W\frac{\Delta\omega}{2} 0 \text{ (using definition of } \Delta^T)$$

$$\Leftrightarrow \sqrt{\beta\varphi} - \beta_C \gtreqless 0.$$

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