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A Model of Reputation in Cheap Talk*

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Abstract

We study a dynamic game of advice where the sender's preferences are unknown to the receiver. The novel feature of the model is that there is more than one type of biased sender. We show that the more equal the proportions of different biases in the sender population, the greater the credibility of the information transmitted. Somewhat surprisingly, however, we also find that the receiver does not benefit from this equality. We discuss our results in the context of political lobbying and show that institutions that increase transparency lower lobbyists' incentives for truthtelling, but unambiguously promote the policymaker's welfare.

Keywords: Information transmission; reputation; unequal representation; lobbying; interest groups

JEL classification: *D*72; *D*78; *D*82

I. Introduction

In their seminal study on cheap talk, Crawford and Sobel (1982) demonstrated the difficulty for agents to share information when the veracity of the information is unverifiable. Even a small difference in preferences between sender and receiver casts doubt on the credibility of the sender's statement, which leads to informational losses. Sobel (1985) showed that the prospects for information transmission improve in a dynamic setting, as the sender may acquire a reputational concern for truthtelling. In this paper we extend Sobel's model by allowing for more than one type of

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biased sender, which enables us to address questions about the composition of interests in the sender population.

We couch our model in terms of a policymaker consulting a lobbyist. The game consists of two periods, and the same lobbyist is consulted in both periods. The lobbyist can be of three different types: one whose interests are aligned with the policymaker's, one who always (regardless of the state of the world) wants a left-wing policy, and one who always wants a right-wing policy. The policymaker does not know the lobbyist's type, but can infer whether or not the lobbyist was truthful in the first period. This is the feature of the model that creates an incentive for biased lobbyists to be honest in the first period, in order to enhance their reputation as the honest type. We do not incorporate more than a single lobbyist into the model. Nevertheless, due to the fact that the policymaker faces uncertainty about what type of lobbyist he is dealing with, we can use the prior distribution of lobbyists as a measure of the equality or inequality among different interests.

Our main result is that the more equal the composition of interests in the pool of lobbyists, the stronger the incentives of a (biased) lobbyist's to be truthful. This shows up in two ways. First, more equality weakens the requirement on the parameters that is needed for an equilibrium with some information transmission to exist. Second, within the subset of the parameter space where such an equilibrium does exist, the degree of information transmission increases with the degree of equality.

To see the intuition for this result, consider the incentive for, say, a rightist lobbyist to reveal his information honestly in the first period even though it indicates that the policymaker should adopt a leftist policy. The cost of this "investment in reputation" is determined by the extent to which the policymaker actually acts on this message, which in turn depends on the composition of lobbyists in the population. With a large number of leftists it is less costly to recommend a leftist policy, since the policymaker will then discount such a message more heavily. For the analogous reason, however, with many leftist lobbyists in the population, a message that suggests a rightist policy has a large impact on the decision, which increases the rightist's payoff from sending a dishonest message. These forces are symmetric, so that the incentives for truthtelling are maximized when leftists and rightists are equally represented.

We then show that, somewhat paradoxically, this does not imply that the policymaker benefits from greater equality. The reason is that greater equality implies greater uncertainty over the lobbyist's bias, which reduces the policymaker's ability to act on the advice. We conclude by considering the welfare effects of two institutions which both lead to greater transparency but which also lower the lobbyist's incentives for truthtelling.

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Our paper is related to the literature on cheap talk in general and in particular to the fairly small part of that literature that allows the sender and receiver to interact over more than one period. Sobel (1985) was the first to model this and to show that, in such an environment, the sender may care instrumentally about his reputation for truthtelling.[1] Sobel's model has been extended and further examined by Bénabou and Laroque (1992) and Morris (2001). In all three of these papers, however, the type space is binary; that is, the sender is assumed either to have preferences that are identical to the receiver's or to have preferences that differ from his in one particular way.

Our paper is also related to a strand of literature that models lobbying as an exercise in strategic information transmission; see, for example, Austen-Smith and Wright (1992), Potters and van Winden (1992), Lohmann (1995), Lagerlöf (1997), Grossman and Helpman (2001) and Bennedsen and Feldmann (2002). Although our model can be applied to various situations, we think the lobbying context is the most pertinent. Given this interpretation we show that, in a dynamic setting, more equal representation among interest groups facilitates information transmission. This argument is complementary to, but different from, an old and prominent idea that goes back at least to J. S. Mill's *On Liberty*: if any relevant piece of information favors at least one interest and if all interests have an opportunity to express their views, then all relevant pieces of information will be presented.[2]

The remainder of the paper is organized as follows. In the next section we describe our model, which is then analyzed in Section III. Section IV investigates the effects of a change in equality on the amount of information that is transmitted in equilibrium; it also considers the effects on expected welfare. In Section V we discuss the welfare effects of the two institutions mentioned above. Section VI concludes. An appendix contains some proofs that are omitted from the main text.

II. The Model

We model strategic advice as a game between a lobbyist and a policymaker, in which the lobbyist has private information about a policy-relevant state of the world and about his own type. There are two possible states of the world: in a "low state" the policymaker would—given that he knew the state—prefer a left-wing policy, whereas in a "high state" he would prefer a right-wing policy. The lobbyist's type refers to what kind of interest he

[1] Sobel's analysis in turn drew on the work by Kreps and Wilson (1982) and Milgrom and Roberts (1982).
[2] The idea has been studied in formal game-theoretic settings by, among others, Milgrom and Roberts (1986), Austen-Smith and Wright (1992), Dewatripont and Tirole (1999), Krishna and Morgan (2001) and Frisell (2005).

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represents.[3] Here there are three possibilities: the lobbyist may represent (i) a left-wing group that, regardless of the state, wants a policy that is as far left as possible, (ii) a right-wing group that, regardless of the state, wants a policy that is as far right as possible, or (iii) he may be an "honest" lobbyist whose interests coincide with those of the policymaker.

The game consists of two periods, and the same lobbyist is consulted in both periods.[4] In each period the events are the same: knowing the state for that period, the lobbyist first sends a cheap-talk message to the policymaker, whereupon the policymaker chooses a policy. The states in the two periods are independent. At the end of the first period the state is observed, which means that the policymaker can infer whether or not the lobbyist was truthful when sending his first-period message.

Formally, we denote the period t (for $t=1,2$) policy by $x_t \in [0,1]$, the period t state by $\theta_t \in \{0,1\}$, and the period t message by $m_t \in \{0,1\}$. In each period, the two possible states are drawn with equal probability: $\Pr(\theta_t = 1) = 1/2$, where θ_1 and θ_2 are independent. The lobbyist learns θ_t at the beginning of period t, whereas the policymaker knows only the distribution according to which the state is drawn. The policymaker's per-period payoff is given by

$$U_{PM}(x_t, \theta_t) = -(x_t - \theta_t)^2.$$

Only the lobbyist knows his type; the policymaker's prior beliefs about the lobbyist's type are as follows. With probability p_H the lobbyist is of type H (as in "honest"), in which case his per-period payoff function is identical to the policymaker's, $U_H(x_t, \theta_t) \equiv U_{PM}(x_t, \theta_t)$. With probability p_L the lobbyist is of type L. A type-L lobbyist (L stands for "left") represents an interest that wants x_t to be as small as possible, regardless of the value of θ_t; in particular, his per-period payoff is given by $U_L(x_t) = -x_t$. Finally, with probability p_R the lobbyist is of type R (where R is short for "right"). A type-R lobbyist represents an interest that wants x_t to be as large as

[3] The interpretation of this could be that the policymaker does not know for sure which lobbyist he is consulting. An alternative interpretation is that the policymaker knows which group the lobbyist represents, but that he is unsure about that group's position on the policy in question. See Wright (1996, pp. 154–156) for a discussion. See also Austen-Smith (1995) for an analysis of lobbyists' incentives to seek access when their preferences are unknown to the policymaker.

[4] This assumption is *not* important for our main results. It can readily be verified that, in the partially informative equilibrium that we study below, if the policymaker could choose to replace a dishonest lobbyist with one who is randomly drawn in period 2, the expected period 2 policy would be 0.5—just as in the babbling equilibrium that now ensues. Hence, since lobbyists care only about the expected policy, their incentives—and the degree of truthtelling—are the same in the two regimes. (The policymaker would never replace an honest lobbyist, so that lobbyists' incentives are also the same.)

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possible, regardless of the value of θ_t; his per-period payoff is given by $U_R(x_t) = x_t$. The probabilities p_L, p_R and p_H are all strictly positive and satisfy $p_L + p_R + p_H = 1$. The players discount their period 2 payoffs with the (common) discount factor $\delta \in (0, 1]$.

The sequence of events can thus be summarized as follows. (1) The lobbyist learns his own type as well as θ_1 and then chooses m_1. (2) The policymaker observes m_1, updates his beliefs about θ_1, and chooses x_1. (3) The players observe θ_1, which makes it possible for the policymaker to infer whether the lobbyist's report was truthful or not. Using this information, the policymaker updates his beliefs about the lobbyist's type. (4) The lobbyist learns θ_2 and then chooses m_2. (5) The policymaker observes m_2, updates his beliefs about θ_2, and chooses x_2. (6) The players' period 2 payoffs are realized.

In the next section we solve for the perfect Bayesian equilibria of the game described above, where this equilibrium concept is defined in the usual way: both players must make optimal decisions at all information sets given their beliefs, and these beliefs are formed using Bayes' rule whenever that is defined.

III. Analysis

The Second Period

Let us begin the analysis by considering the players' behavior in period 2. As in any cheap-talk game, there exists an equilibrium of the period 2 game in which there is no information transmission at all, a so-called babbling equilibrium. In the following we disregard all babbling equilibria and restrict our attention to equilibria in which the type-H lobbyist in both periods (and at all information sets) tells the truth with probability one: that is, equilibria in which H chooses $m_t = 0$ if $\theta_t = 0$, and $m_t = 1$ if $\theta_t = 1$.[5] Given that H reports truthfully and that the policymaker assigns a positive probability to the event that he is indeed dealing with a type-H lobbyist, the policymaker's decision will (at least to some extent) be made contingent on the lobbyist's message; in particular, a second-period message $m_2 = 0$ will induce a lower x_2 than will a message $m_2 = 1$. As a consequence, since

[5] This is not quite without loss of generality. There may exist informative equilibria in which the honest type "threatens" to babble in period 2 unless the policymaker's first-period decision is relatively moderate. More moderate first-period decisions would lower the biased lobbyists' cost of investing in a reputation, possibly making it optimal for them to be truthful in period 1. However, any such equilibrium would be susceptible to renegotiation between the honest lobbyist and the policymaker. We also disregard any "mirror" equilibrium (of the period 2 game as well as of the full game) where the labels have the opposite meaning, so that, for example, $m_2 = 0$ means $\theta_2 = 1$ and $m_2 = 1$ means $\theta_2 = 0$.

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reputational concerns do not matter in period 2, the type-L lobbyist always chooses $m_2 = 0$ and the type-R lobbyist always chooses $m_2 = 1$, regardless of whether the true state is low or high.

The policymaker realizes that the different types behave in this fashion and updates his beliefs about θ_2 accordingly, using Bayes' rule. Let $\Pi(\theta_2 = 1 \mid m_2)$, where $m_2 \in \{0, 1\}$, denote the probability the policymaker assigns to the event that $\theta_2 = 1$ at the stage where he has just observed m_2. (In the Appendix we derive an explicit expression for these updated beliefs, and others that are stated below, in terms of the parameters of the model.) Given this probability, the policymaker chooses his optimal period 2 policy. Because the policymaker's payoff function is quadratic and the state equals either zero or unity, this policy is identical to $\Pi(\theta_2 = 1 \mid m_2)$.

The First Period

We now turn to period 1 and begin by looking for an equilibrium in which both L and R, also when the state is not in their favor, tell the truth with positive probability. More specifically, we want to find an equilibrium in which the lobbyist's period 1 behavior is such that H always tells the truth, and L and R tell the truth for sure when the state is in their favor and with probability λ_L, respectively λ_R, otherwise (with $\lambda_L, \lambda_R \in (0, 1)$).[6] We call this kind of equilibrium a "partially informative equilibrium".

Let us investigate the incentives to lie, respectively to tell the truth, for a type-R lobbyist who knows that $\theta_1 = 0$. The advantage of lying is that this induces the policymaker to choose a first-period policy that is relatively favorable to R. In particular, that policy will equal $\Pi^{PI}(\theta_1 = 1 \mid m_1 = 1)$, the policymaker's updated beliefs that $\theta_1 = 1$ after message $m_1 = 1$, given the lobbyists' equilibrium behavior. However, if the lobbyist is untruthful he will be recognized as a type-R lobbyist in period 2. If so, no information transmission is possible in that period[7] and, since the policymaker's prior assigns equal probability to the two states, the second-period policy equals 1/2. This is the disadvantage to R of lying: it deprives him of the opportunity to have an influence on the second-period policy. Hence, the overall payoff for a type-R lobbyist who knows that $\theta_1 = 0$ and who plays $m_1 = 1$ equals

$$\Pi^{PI}(\theta_1 = 1 \mid m_1 = 1) + \frac{\delta}{2}. \tag{1}$$

[6] Formally: H chooses $m_1 = 0$ if $\theta_1 = 0$, and $m_1 = 1$ if $\theta_1 = 1$; L chooses $m_1 = 0$ if $\theta_1 = 0$, and $m_1 = 1$ with probability $\lambda_L \in (0, 1)$ if $\theta_1 = 1$; and R chooses $m_1 = 1$ if $\theta_1 = 1$, and $m_1 = 0$ with probability $\lambda_R \in (0, 1)$ if $\theta_1 = 0$.

[7] It is straightforward to verify that if it is common knowledge that the lobbyist is of type R (or if it is common knowledge that he is of type L), then any equilibrium must be babbling.

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If a type-*R* lobbyist who knows that $\theta_1 = 0$ truthfully plays $m_1 = 0$, the first-period policy equals $\Pi^{PI}(\theta_1 = 1 \mid m_1 = 0)$. It also means that the policymaker will attach a smaller probability to the event that the lobbyist is of type *R*, relative to the prior. Since *R* always sends $m_2 = 1$, in period 2 the second-period policy equals $\Pi^{PI}(\theta_2 = 1 \mid m_2 = 1)$. This is the same notation as in the preceding subsection, except that we have added the superscript *PI*, since these are the updated first-period beliefs given that a partially informative equilibrium is played. Hence, the overall payoff for a type-*R* lobbyist who knows that $\theta_1 = 0$ and who plays $m_1 = 0$ equals

$$\Pi^{PI}(\theta_1 = 1 \mid m_1 = 0) + \delta \Pi^{PI}(\theta_2 = 1 \mid m_2 = 1). \tag{2}$$

For $\lambda_R \in (0, 1)$ indeed to be part of an equilibrium, *R* must be indifferent between being truthful and not when $\theta_1 = 0$. By setting (1) and (2) to equality and using the explicit expressions for the policymaker's updated beliefs (stated in the Appendix), we get

$$\frac{1 - p_R(1 - \lambda_R) - p_L(1 - \lambda_L)}{1 - [p_R(1 - \lambda_R) - p_L(1 - \lambda_L)]^2} = \frac{\delta p_H}{2(p_H + 2p_R\lambda_R)}. \tag{3}$$

The LHS of this equation is symmetric with respect to *L* and *R*. Hence, the corresponding incentive constraint for the type-*L* lobbyist (i.e., that $\lambda_L \in (0, 1)$) must lead to an equation with the same LHS as in (3); in particular, (3) and the requirement that $\lambda_L \in (0, 1)$ imply that $p_R\lambda_R = p_L\lambda_L$ (see the denominator of the RHS of (3)). By solving the two equalities (3) and $p_R\lambda_R = p_L\lambda_L$ for λ_L and λ_R, we have

$$\lambda_j^* = \frac{1}{2p_j}\left[\sqrt{\frac{\delta(1 - \Delta)}{2}p_H} - p_H\right], \quad j = L, R, \tag{4}$$

where $\Delta \equiv (p_R - p_L)^2$. It can be verified that, under our assumption that $\delta \le 1$, both λ_L^* and λ_R^* are always below unity; for a proof, see Frisell and Lagerlöf (2006). Moreover, it is readily seen from (4) that in order to have $\lambda_L^* > 0$ (or, equivalently, $\lambda_R^* > 0$),[8] we must have $p_H < \delta(1 - \Delta)/2$.

So far we have checked only one of the *R*-lobbyist's two incentive constraints. The other one requires that *R* prefers to play $m_1 = 1$ with probability one when knowing that $\theta_1 = 1$. It is easy to verify, however, that this is always satisfied. Moreover, the two incentive constraints for *L* are satisfied exactly when those for *R* are. The following proposition sums up the results.

[8] The fact that the requirements $\lambda_L^* > 0$ and $\lambda_R^* > 0$ are satisfied for exactly the same parameter values is due to the assumption that the type-*L* and type-*R* lobbyists have linear payoff functions: both of them care only about the distance between the policy induced by a report $m_t = 0$ and the policy induced by a report $m_t = 1$.

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Proposition 1. *A partially informative equilibrium exists if and only if* $p_H < \delta(1-\Delta)/2$. *In such an equilibrium* $(\lambda_L, \lambda_R) = (\lambda_L^*, \lambda_R^*)$, *where* λ_L^* *and* λ_R^* *are given by (4).*

We will shortly return to a further discussion of this kind of equilibrium. Now we look for an equilibrium in which L and R always report their preferred state in period 1, and only H reports truthfully.[9] Although somewhat of a misnomer, we call this kind of equilibrium a "non-informative equilibrium", since only the type-H lobbyist transmits any information.

In order to see under what circumstances a non-informative equilibrium exists, consider the incentives for a type-R lobbyist who knows that $\theta_1 = 0$ to follow the equilibrium and lie (by playing $m_1 = 1$), respectively to deviate and tell the truth (by playing $m_1 = 0$). R's first-period payoff if he lies is given by $\Pi^{NI}(\theta_1 = 1 \mid m_1 = 1)$, the policymaker's updated beliefs that the first-period state is high on observing a message $m_1 = 1$ (given the behavior of the players in a non-informative equilibrium). If he lies he will be recognized as a type-R lobbyist in period 2, so the second-period policy will be 1/2.

Suppose instead that R deviates and tells the truth in the first period. R's first-period payoff now equals the policymaker's updated belief that the first-period state is high on observing a message $m_1 = 0$, $\Pi^{NI}(\theta_1 = 1 \mid m_1 = 0)$. At the time when the policymaker observes the first-period state, he will believe that he is dealing with a type-R lobbyist with probability zero. Hence, when R sends the message $m_2 = 1$ in the second period, the policymaker will infer that this must come from a type-H lobbyist (since a type-L lobbyist always plays $m_2 = 0$) and accordingly set the second-period policy, which also is R's second-period payoff, to 1.

In summary, R does not have an incentive to deviate from the prescribed first-period behavior if

$$\Pi^{NI}(\theta_1 = 1 \mid m_1 = 1) + \frac{\delta}{2} \geq \Pi^{NI}(\theta_1 = 1 \mid m_1 = 0) + \delta.$$

By using the explicit expressions for the policymaker's updated beliefs that are stated in the Appendix, this inequality can be rewritten as $p_H \geq \delta(1-\Delta)/2$, which is symmetric with respect to p_L and p_R. Because of this symmetry, the corresponding incentive constraint for L is also satisfied exactly when $p_H \geq \delta(1-\Delta)/2$. Moreover, it is quite clear that neither L nor R wants to deviate from a non-informative equilibrium when knowing that the state is in their favor. We thus have the following result.

[9] Formally, we want to find an equilibrium in which H reports $m_1 = 0$ if $\theta_1 = 0$, and $m_1 = 1$ if $\theta_1 = 1$; and L (respectively, R) reports $m_1 = 0$ (respectively, $m_1 = 1$) regardless of the state.

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Proposition 2. *A non-informative equilibrium exists if and only if* $p_H \geq \delta(1-\Delta)/2$.

Can there exist other (non-babbling) equilibria than the non-informative and partially informative equilibria? One possibility would be that, in period 1, only one of L and R is truthful with positive probability when the state is against him, and the other always reports that the state is in his favor (that is, in terms of the notation used earlier, either $\lambda_L > 0$ and $\lambda_R = 0$, or $\lambda_L = 0$ and $\lambda_R > 0$). In the Appendix (Lemma A1), however, we prove that this behavior cannot be part of an equilibrium. The only remaining possibility is that both L and R are truthful with probability one in the first period (i.e., $\lambda_L = \lambda_R = 1$). But this cannot be part of an equilibrium either (see Lemma A2 in the Appendix).[10] Hence, in the remainder of the paper we consider the players' (and, in particular, the lobbyist's) behavior in a non-informative and in a partially informative equilibrium.

IV. Effects of a Change in Equality

The analysis above tells us that we can sustain an equilibrium in which L and R transmit some information in period 1 if (and only if) $p_H < \delta(1-\Delta)/2$, where $\Delta \equiv (p_R - p_L)^2$. By eliminating $p_H = 1 - p_L - p_R$ from the LHS of this inequality and then rewriting, we can express this condition as $p_L > \varphi(p_R,\delta)$, where

$$\varphi(p_R,\delta) \equiv \frac{1}{\delta}\left[1 + \delta p_R - \sqrt{(1-\delta)^2 + 4\delta p_R}\right]. \tag{5}$$

Figure 1 plots the graph of φ in the (p_L, p_R)-space for a given p_H and δ. In the region southwest of the graph of φ a non-informative equilibrium exists,

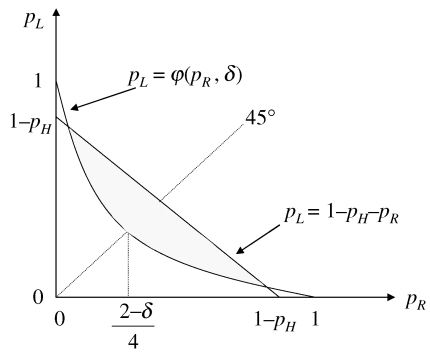

Fig. 1. A partially informative equilibrium exists in the shadowed region

[10] The cases we have mentioned cover all possible equilibria in which H tells the truth with probability one in both periods.

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and in the shadowed region northeast of this graph a partially informative equilibrium exists. In the following we discuss how changes in the relative magnitude of p_L and p_R, for a fixed p_H, affect the degree of information transmission and the policymaker's payoff.

We first consider the effects on the degree of information transmission. From Figure 1 we see that, due to the fact that φ is convex in p_R, the requirement on the parameters for a partially informative equilibrium to exist is weaker, the more *equal* p_L and p_R are. In particular, if $p_L = p_R$, a partially informative equilibrium exists for all $p_H < \delta/2$; but if p_L is sufficiently close to $(1 - p_H)$ and p_R is sufficiently close to zero (or vice versa), a partially informative equilibrium exists only for p_H's very close to zero. That is, more equality in the sense of a lower Δ (recall that $\Delta \equiv (p_R - p_L)^2$) is conducive to the existence of a partially informative equilibrium.

Not only is more equality conducive to information transmission in that it weakens the requirement on the parameters for a partially informative equilibrium to exist, equality is good for information transmission also *within* the region in which such an equilibrium exists. To see this, let us calculate the *ex ante* probability of truthtelling in the first period, given that a partially informative equilibrium is played:

$$p_H + p_L\left(\frac{1}{2} + \frac{\lambda_L^*}{2}\right) + p_R\left(\frac{1}{2} + \frac{\lambda_R^*}{2}\right) = \frac{1}{2}\left[1 + \sqrt{\frac{\delta p_H(1-\Delta)}{2}}\right].$$

This expression is decreasing in Δ: more equality gives rise to more truthtelling.[11]

We sum up the above results in the following proposition.

Proposition 3. *Equality (i.e., a relatively low Δ) is conducive to information transmission in the sense that: (i) a lower Δ weakens the requirement on the parameters needed for a partially informative equilibrium to exist; and (ii) given that such an equilibrium exists, the degree of information transmission in period 1 decreases with Δ.*

To understand the intuition for this result, consider the incentive for, say, a type-R lobbyist to deviate from the non-informative equilibrium by reporting $m_1 = 0$ when $\theta_1 = 0$. The cost of this "investment" is determined by the extent to which the policymaker takes messages $m_1 = 0$ and $m_1 = 1$ into account when choosing the first-period policy. This, in turn, depends on

[11] Calculating the *ex ante* probability of truthtelling in the *second* period yields $p_H + p_L\frac{1}{2} + p_R\frac{1}{2} = (1 + p_H)/2$, which is independent of Δ (or, more accurately, a function only of the sum of p_L and p_R).

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the relative number of type-R lobbyists in the population: an honest message $m_1 = 0$ is less costly to send if there are many type-L lobbyists around—who, in the non-informative equilibrium, always send $m_1 = 0$—since the policymaker then discounts this message more heavily. For the analogous reason, however, with many type-L lobbyists, a message $m_1 = 1$ has a large impact on the decision, which increases the lobbyist's payoff from sending a dishonest message. These counteracting forces are symmetric, which means that the "net" incentive for truthtelling is maximized when the distribution of (biased) lobbyists is symmetric.

In particular, if either p_L or p_R is sufficiently small, a partially informative equilibrium is impossible. Suppose for example that $p_L = 0$. The policymaker then knows that a message $m_1 = 0$ is true and would choose policy 0 on hearing it. Hence, reporting $m_1 = 0$ "costs" at least 0.5 in payoff in period 1 for a type-R lobbyist, but the gain from being perceived as the honest type in period 2 is at most 0.5 (since babbling gives payoff 0.5).

Let us now consider the effects of a change in equality on expected welfare. We define "welfare" as being identical to the policymaker's payoff, so that per-period welfare is given by $W(x_t, \theta_t) = -(x_t - \theta_t)^2$. Even though equality, as we saw above, is conducive to information transmission, this does not necessarily mean that it is welfare-enhancing. In fact, assuming that we are in the subset of the parameter space where a partially informative equilibrium exists (and that it also is played), there are two forces that work in opposite directions. More equality makes the first-period messages of the type-L and type-R lobbyists more informative, which is good for welfare. However, more equality means that there is greater uncertainty about which type of lobbyist the policymaker is facing, and this has a negative impact on (expected) welfare.

In order to see which of these effects is stronger, let us calculate the expected welfare for each of the two periods in a partially informative equilibrium. Doing this for period 1 yields (see Lemma A3 in the Appendix)

$$EW_1^{PI} = -\frac{1}{4} + \frac{\delta p_H}{8}.$$

That is, in the first period, the two effects cancel each other out: the expected first-period welfare is *independent* of p_R and p_L (or, more accurately, it depends only on their sum, $p_R + p_L$). Next, calculating the expected welfare for period 2 yields (see Lemma A4 in the Appendix)

$$EW_2^{PI} = -\frac{1}{4} + \frac{p_H^2}{8(1-\Delta)} + \frac{p_H^2}{8\sqrt{p_H\delta(1-\Delta)/2}}.$$

Hence, the expected second-period welfare is *decreasing* in the degree of equality. Given the discussion above, this should hardly come as a surprise:

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since, in period 2, there is no reputation effect that can be strengthened by an increase in equality, only the second, negative effect (i.e., more equality yields more uncertainty) matters.

Thus, the overall effect on expected welfare of an increase in equality is negative. The following proposition states this result.[12]

Proposition 4. *Suppose that a partially informative equilibrium is played. Then overall expected welfare is decreasing in the degree of equality.*

V. Mandatory Registration and Media Scrutiny

A key assumption of our analysis is that the policymaker faces uncertainty about the true interests of the lobbyist. In reality, the degree to which policymakers know the identity of the employers of any lobbyists that they are confronted with should depend on, among other things, the institutional framework. For example, in the United States, Title III of the Legislative Reorganization Act (known as the Federal Regulation of Lobbying Act) of 1946 requires individuals and groups that accept payment for the purpose of influencing Congress to register with the clerk of the House or the secretary of the Senate; see Wright (1996, pp. 32–36). The media are another institution that could plausibly affect the degree of public knowledge about which interests lobbyists represent.

To the extent that institutions such as these reduce the amount of uncertainty about the lobbyists' true interests, are they also welfare-enhancing? The analysis of Section III suggests one reason why they may in fact be *detrimental* to welfare: it is this uncertainty that disciplines the type-L and type-R lobbyists' first-period behavior and induces them to be truthful with positive probability. There is, on the other hand, also a positive effect associated with making the lobbyist's interests known. On those occasions when the lobbyist is in fact of type H, knowing this will be valuable because the policymaker can then take the lobbyist's message fully into account when choosing policy.

In the following we investigate which of these effects is stronger. We do this by comparing the expected welfare in the partially informative equilibrium of our lobbying game with the expected welfare levels in two benchmarks, both of which are intended to, at least crudely, capture institutions such as those introduced above. Our first benchmark, or institution, we call "mandatory registration". Under this institution, the identity of the lobbyist becomes commonly known at the outset of the game. The expected

[12] In Frisell and Lagerlöf (2006) we show that the same qualitative result holds with the following linear welfare function: $W(x_t, \theta_t) = -|x_t - \theta_t|$.

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single-period welfare in such a situation is $-\frac{1}{4}(p_L + p_R) = -\frac{1}{4}(1 - p_H)$. Hence, expected overall welfare is

$$-\frac{(1 - p_H)(1 + \delta)}{4}.$$

It can be shown that this level of expected welfare is always higher than the expected welfare in a partially informative equilibrium. (The proof of this as well as the other claims made in this section can be found in Frisell and Lagerlöf, 2006.) This result is perhaps not very surprising. After all, knowing the identity of the lobbyist from the very beginning of the game should be quite useful.

Under our second institution, "media scrutiny", the identity of the lobbyist is made known to the policymaker (say, by an investigative journalist) at the end of period 1, and it is common knowledge that this will happen. The expected first-period welfare in such a situation is the same as in the non-informative equilibrium, which is equal to $-\frac{1}{4} + p_H^2/[4(1 - \Delta)]$. The expected second-period welfare is given by $-(p_L + p_R)/4 = -(1 - p_H)/4$. Hence, expected overall welfare is

$$-\frac{1}{4} + \frac{p_H^2}{4(1 - \Delta)} - \frac{\delta(1 - p_H)}{4},$$

which, unsurprisingly, is lower than expected overall welfare under mandatory registration. It can be shown that the institution media scrutiny also dominates the partially informative equilibrium. Apparently, at least in our simple model, the negative effect (i.e., less information transmission in the first period) is dominated by the positive one (i.e., when the lobbyist is of type H, knowing this is valuable).

We summarize the above results in the following observation.

Observation 1. *Mandatory registration yields higher overall expected welfare than media scrutiny. Moreover, mandatory registration and media scrutiny both yield higher overall expected welfare than the partially informative equilibrium.*

VI. Conclusions

In this paper we have developed a model of strategic advice and reputation-building that draws on the work of Sobel (1985). In contrast to Sobel and other previous papers, we allow for more than one type of biased sender, and the number of each type is arbitrary. The receiver does not know the type of the sender with whom he interacts, but his beliefs about this reflect the relative numbers of types in the population. This modeling framework enables us to ask how the composition of interests in the sender

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population affects information transmission and the receiver's expected payoff. The main insight from the analysis (succinctly summarized by Figure 1) is that a more equal composition of biased senders promotes information transmission.

Applied to a lobbying context, the result lends some support to the normative concern expressed by many commentators that certain groups are much better represented than others: a larger inequality in our model means that the policymaker's (first-period) decision will be less informed by the lobbyist's private information. However, we also pointed out a limitation to this argument: a larger inequality means that the policymaker faces less uncertainty about which type of lobbyist he is consulting. As a consequence, the policymaker's expected payoff is actually greater, the more unequal is the representation.

A common concern about lobbying in legislatures and other decision-making bodies is the lack of transparency. This has led the U.S. to introduce a regulation that requires active lobbyists to register, and other countries such as the UK, have considered similar measures; see Liebert (1995, p. 432). To the extent that such regulation reduces the amount of uncertainty on the part of legislators about lobbyists' true interests, the analysis of this paper suggests that transparency comes at a cost: it is this uncertainty that induces biased lobbyists to be (relatively) truthful in order to build a reputation. However—at least in our model—the benefits of transparency always exceed this cost. It may be an interesting topic for future work to investigate how general this conclusion is.

Appendix

In this appendix we first derive the explicit expressions for the policymaker's updated beliefs about θ_1 and θ_2 that were omitted from the analysis in Section III. Thereafter we state and prove Propositions A1–A4, which we invoked at the end of Section III and in Section IV.

Let $\widetilde{p}_j$ (for $j = L, H, R$) denote the policymaker's updated beliefs about the lobbyist's type at the stage where he has inferred θ_1 but not yet observed m_2. Then, by making use of Bayes' rule, we can compute $\Pi(\theta_2 = 1 \mid m_2)$:[13]

$$\Pi(\theta_2 = 1 \mid m_2) = \begin{cases} \dfrac{\widetilde{p}_H + \widetilde{p}_R}{\widetilde{p}_H + 2\widetilde{p}_R} & \text{if } m_2 = 1 \\ \dfrac{\widetilde{p}_L}{\widetilde{p}_H + 2\widetilde{p}_L} & \text{if } m_2 = 0. \end{cases} \tag{A1}$$

[13] Here we implictly assume that $\widetilde{p}_L < 1$ (in the expression for $m_2 = 1$) respectively $\widetilde{p}_R < 1$ (in the expression for $m_2 = 0$). But these inequalities must hold given that H reports truthfully in both periods.

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Next, we can write $\Pi^{PI}(\theta_1 = 1 \mid m_1)$ as

$$\Pi^{PI}(\theta_1 = 1 \mid m_1) = \begin{cases} \dfrac{1 - p_L(1-\lambda_L)}{1 + p_R(1-\lambda_R) - p_L(1-\lambda_L)} & \text{if } m_1 = 1 \\ \dfrac{p_L(1-\lambda_L)}{1 + p_L(1-\lambda_L) - p_R(1-\lambda_R)} & \text{if } m_1 = 0. \end{cases} \tag{A2}$$

Plugging (A2) into (1), we have that the overall payoff for a type-R lobbyist who knows that $\theta_1 = 0$ and who plays $m_1 = 1$ equals

$$\frac{1 - p_L(1-\lambda_L)}{1 + p_R(1-\lambda_R) - p_L(1-\lambda_L)} + \frac{\delta}{2}. \tag{A3}$$

A type-R lobbyist who knows that $\theta_1 = 0$ and who, truthfully, plays $m_1 = 0$ will (at the stage when the policymaker has inferred θ_1 but not yet observed m_2) give rise to the following posterior beliefs about his type:

$$\widetilde{p}_R = \frac{p_R\lambda_R}{p_L + p_H + p_R\lambda_R}, \qquad \widetilde{p}_H = \frac{p_H}{p_L + p_H + p_R\lambda_R}, \tag{A4}$$

and $\widetilde{p}_L = 1 - \widetilde{p}_R - \widetilde{p}_H$. This means that the second-period policy equals

$$\Pi^{PI}(\theta_2 = 1 \mid m_2 = 1) = \frac{\widetilde{p}_H + \widetilde{p}_R}{\widetilde{p}_H + 2\widetilde{p}_R} = \frac{p_H + p_R\lambda_R}{p_H + 2p_R\lambda_R}, \tag{A5}$$

where the first equality follows from (A1) and the second from (A4). The first-period policy equals $\Pi^{PI}(\theta_1 = 1 \mid m_1 = 0)$, as given by (A2). Plugging (A5) and (A2) into (2), we have that the overall payoff for a type-R lobbyist who knows that $\theta_1 = 0$ and who plays $m_1 = 0$ equals

$$\frac{p_L(1-\lambda_L)}{1 + p_L(1-\lambda_L) - p_R(1-\lambda_R)} + \delta\frac{p_H + p_R\lambda_R}{p_H + 2p_R\lambda_R}. \tag{A6}$$

Setting (A3) and (A6) equal to each other and then rewriting, we obtain (3).

We can further write $\Pi^{NI}(\theta_1 = 1 \mid m_1 = 1)$ as

$$\Pi^{NI}(\theta_1 = 1 \mid m_1 = 1) = \frac{p_R + p_H}{2p_R + p_H} = \frac{1 - p_L}{1 + p_R - p_L}.$$

Finally, we can write $\Pi^{NI}(\theta_1 = 1 \mid m_1 = 0)$ as

$$\Pi^{NI}(\theta_1 = 1 \mid m_1 = 0) = \frac{p_L}{2p_L + p_H} = \frac{p_L}{1 - (p_R - p_L)}.$$

Lemma A1. *An equilibrium in which the types behave as follows does not exist: H chooses $m_1 = 0$ if $\theta_1 = 0$, and $m_1 = 1$ if $\theta_1 = 1$; L chooses $m_1 = 0$ regardless of whether $\theta_1 = 0$ or $\theta_1 = 1$; and R chooses $m_1 = 1$ with probability one if $\theta_1 = 1$, and $m_1 = 0$ with probability $\xi \in (0, 1)$ if $\theta_1 = 0$.*

Proof: First note that, given the stated behavior, the first-period policy after a message $m_1 = 0$, respectively $m_1 = 1$, is given by

$$\frac{p_L}{2p_L + p_H + \xi p_R} \quad \text{and} \quad \frac{p_H + p_R}{p_H + (2-\xi)p_R}.$$

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Now consider the period 1 incentives for R when knowing that $\theta_1 = 0$. If R tells the truth in the first period ($m_1 = 0$) and then optimally reports $m_2 = 1$ in the second, his overall payoff equals

$$\frac{p_L}{2p_L + p_H + \xi p_R} + \delta\frac{\widetilde{p}_H + \widetilde{p}_R}{\widetilde{p}_H + 2\widetilde{p}_R} = \frac{p_L}{2p_L + p_H + \xi p_R} + \delta\frac{p_H + \xi p_R}{p_H + 2\xi p_R}. \quad \text{(A7)}$$

Here, the second term before the equality sign uses (A1), and the second term after the equality sign uses the fact that $\widetilde{p}_H = p_H/(p_L + p_H + \xi p_R)$ and $\widetilde{p}_R = \xi p_R/(p_L + p_H + \xi p_R)$. If instead R lies in the first period ($m_1 = 1$), he will be recognized as the R-type ($\widetilde{p}_R = 1$) in the second period . Thus, his overall payoff then equals

$$\frac{p_H + p_R}{p_H + (2-\xi)\, p_R} + \frac{\delta}{2}. \quad \text{(A8)}$$

Setting (A7) equal to (A8), as $\xi \in (0, 1)$ requires, we have

$$\frac{p_L}{2p_L + p_H + \xi p_R} - \frac{p_H + p_R}{p_H + (2-\xi)\, p_R} = \frac{\delta}{2} - \delta\frac{p_H + \xi p_R}{p_H + 2\xi p_R}. \quad \text{(A9)}$$

Next consider the period 1 incentives for L when knowing that $\theta_1 = 1$. If L follows the prescribed behavior and chooses $m_1 = 0$, he will be recognized as the L-type in period 2. Thus, his overall payoff equals

$$-\frac{p_L}{2p_L + p_H + \xi p_R} - \frac{\delta}{2}.$$

If L deviates and plays $m_1 = 1$, he will be regarded as the L-type with zero probability in period 2. Hence, by then sending the message $m_2 = 0$, he can induce the policymaker to set the second-period policy equal to zero. His overall payoff is therefore given by $-(p_H + p_R)/[p_H + (2-\xi)p_R]$. In order for L not to have an incentive to deviate from the prescribed behavior, we must thus have

$$-\frac{p_L}{2p_L + p_H + \xi p_R} - \frac{\delta}{2} \geq -\frac{p_H + p_R}{p_H + (2-\xi)\, p_R} \Leftrightarrow$$

$$\frac{p_L}{2p_L + p_H + \xi p_R} - \frac{p_H + p_R}{p_H + (2-\xi)\, p_R} \leq -\frac{\delta}{2}.$$

Using (A9) to eliminate the LHS of this inequality and then rewriting, we have $1 \leq (p_H + \xi p_R)/(p_H + 2\xi p_R)$, which is impossible. ■

Lemma A2. *An equilibrium in which all three types choose* $m_1 = 0$ *if* $\theta_1 = 0$, *and* $m_1 = 1$ *if* $\theta_1 = 1$, *does not exist.*

Proof: It suffices to show that R has an incentive to deviate from his prescribed behavior $m_1 = 0$ if $\theta_1 = 0$. If R knows that $\theta_1 = 0$ and follows the prescribed behavior, then $x_1 = 0$ (since all types of lobbyists are truthful, the policymaker follows their advice). In period 2, R will report $m_2 = 1$ regardless of which state he has observed. Observing this message, the policymaker chooses x_2 according to (A1), but with $\widetilde{p}_H = p_H$ and $\widetilde{p}_R = p_R$ (since all types are truthful in period 1, the policymaker does not update his prior beliefs about the lobbyist's type). Thus, if knowing that $\theta_1 = 0$ and by following

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his prescribed strategy, R gets the overall payoff $\delta(p_H + p_R)/(p_H + 2p_R)$. If instead R deviates and chooses $m_1 = 1$, then $x_1 = 1$. Since this leads to an out-of-equilibrium event, the policymaker's beliefs will not be determined by Bayes' rule. Let us suppose that his beliefs are the worst ones possible from R's point of view, namely $\widetilde{p}_R = 1$ (if this nevertheless gives R an incentive to deviate, then clearly we have proven the claim in the lemma). This means that there cannot be any information transmission in period 2, so $x_2 = 1/2$. Summing up, R has an incentive to deviate if

$$\delta\frac{p_H + p_R}{p_H + 2p_R} < 1 + \delta\tfrac{1}{2}.$$

One can easily verify that this holds for all $\delta \in (0, 1]$. ■

Lemma A3. *Expected first-period welfare in a partially informative equilibrium is given by* $EW_1^{PI} = -\frac{1}{4} + \delta p_H/8$.

Proof: There are four possible realizations of (θ_1, m_1):

$$(\theta_1, m_1) \in \{(0, 0), (1, 0), (0, 1), (1, 1)\}.$$

The event (1, 1) happens with probability $\frac{1}{2}[p_R + p_H + p_L\lambda_L^*]$, in which case welfare is (here, as well as in the expressions that follow, we make use of (A2))

$$-\left(1-\frac{1 - p_L\left(1-\lambda_L^*\right)}{1 + p_R\left(1-\lambda_R^*\right) - p_L\left(1-\lambda_L^*\right)}\right)^2 = -\left(\frac{p_R\left(1-\lambda_R^*\right)}{1 + p_R\left(1-\lambda_R^*\right) - p_L\left(1-\lambda_L^*\right)}\right)^2.$$

The event (0, 1) happens with probability $\frac{1}{2}p_R\left(1-\lambda_R^*\right)$, in which case welfare is

$$-\left(\frac{1 - p_L\left(1-\lambda_L^*\right)}{1 + p_R\left(1-\lambda_R^*\right) - p_L\left(1-\lambda_L^*\right)}\right)^2.$$

By symmetry, the event (0, 0) happens with probability $\frac{1}{2}[p_R\lambda_R^* + p_H + p_L]$, in which case welfare is

$$-\left(\frac{p_L\left(1-\lambda_L^*\right)}{1 + p_L\left(1-\lambda_L^*\right) - p_R\left(1-\lambda_R^*\right)}\right)^2.$$

Finally, again by symmetry, the event (1, 0) happens with probability $\frac{1}{2}p_L(1-\lambda_L^*)$, in which case welfare is

$$-\left(\frac{1 - p_R\left(1-\lambda_R^*\right)}{1 + p_L\left(1-\lambda_L^*\right) - p_R\left(1-\lambda_R^*\right)}\right)^2.$$

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Hence, expected first-period welfare can be written as

$$
\begin{aligned}
EW_1^{PI} = & -\tfrac{1}{2}\left[p_R + p_H + p_L\lambda_L^*\right]\left(\frac{p_R(1-\lambda_R^*)}{1+p_R(1-\lambda_R^*)-p_L(1-\lambda_L^*)}\right)^2 \\
& -\tfrac{1}{2}p_R(1-\lambda_R^*)\left(\frac{1-p_L(1-\lambda_L^*)}{1+p_R(1-\lambda_R^*)-p_L(1-\lambda_L^*)}\right)^2 \\
& -\tfrac{1}{2}\left[p_R\lambda_R^* + p_H + p_L\right]\left(\frac{p_L(1-\lambda_L^*)}{1+p_L(1-\lambda_L^*)-p_R(1-\lambda_R^*)}\right)^2 \\
& -\tfrac{1}{2}p_L(1-\lambda_L^*)\left(\frac{1-p_R(1-\lambda_R^*)}{1+p_L(1-\lambda_L^*)-p_R(1-\lambda_R^*)}\right)^2.
\end{aligned}
$$

Using $p_R\lambda_R^* = p_L\lambda_L^*$ and $p_H = 1 - p_R - p_L$, this simplifies to

$$
\begin{aligned}
EW_1^{PI} = & -\tfrac{1}{2}\left[1-p_L(1-\lambda_L^*)\right]\left(\frac{p_R - p_L\lambda_L^*}{1+p_R-p_L}\right)^2 \\
& -\tfrac{1}{2}\left[p_R - p_L\lambda_L^*\right]\left(\frac{1-p_L(1-\lambda_L^*)}{1+p_R-p_L}\right)^2 - \tfrac{1}{2}\left[1-p_R+p_L\lambda_L^*\right] \\
& \times\left(\frac{p_L(1-\lambda_L^*)}{1+p_L-p_R}\right)^2 - \tfrac{1}{2}p_L(1-\lambda_L^*)\left(\frac{1-p_R+p_L\lambda_L^*}{1+p_L-p_R}\right)^2 \\
= & -\frac{\left[1-p_L(1-\lambda_L^*)\right]\left[p_R-p_L\lambda_L^*\right]}{2(1+p_R-p_L)} - \frac{\left[1-p_R+p_L\lambda_L^*\right]p_L(1-\lambda_L^*)}{2(1+p_L-p_R)} \\
= & -\frac{(1-p_L)p_R - p_Hp_L\lambda_L^* - (p_L\lambda_L^*)^2}{2(1+p_R-p_L)} \\
& -\frac{(1-p_R)p_L - p_Hp_L\lambda_L^* - (p_L\lambda_L^*)^2}{2(1+p_L-p_R)}.
\end{aligned}
$$

Multiplying the first ratio by $(1+p_L-p_R)$, the second by $(1+p_R-p_L)$, and then simplifying, we have

$$
EW_1^{PI} = -\frac{p_L + p_R - p_R^2 - p_L^2 - 2p_L\lambda_L^*(p_H + p_L\lambda_L^*)}{2\left[1-(p_R-p_L)^2\right]}.
$$

By using the definition of λ_L^* (see (4)) and by performing some straightforward calculations, it can be shown that

$$
2p_L\lambda_L^*\left[p_H + p_L\lambda_L^*\right] = \frac{p_H}{2}\left\{\frac{\delta}{2}\left[1-(p_R-p_L)^2\right] - p_H\right\}.
$$

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Plugging this into the above expression for EW_1^{PI} and then simplifying, we have

$$\begin{aligned} EW_1^{PI} &= -\frac{2\left(p_L + p_R - p_R^2 - p_L^2\right) - p_H\left\{(\delta/2)\left[1-(p_R-p_L)^2\right] - p_H\right\}}{4\left[1-(p_R-p_L)^2\right]} \\ &= -\frac{2\left(p_L + p_R - p_R^2 - p_L^2\right) + (1-p_L-p_R)^2 - (\delta p_H/2)\left[1-(p_R-p_L)^2\right]}{4\left[1-(p_R-p_L)^2\right]} \\ &= -\frac{1-(p_R-p_L)^2 - (\delta p_H/2)\left[1-(p_R-p_L)^2\right]}{4\left[1-(p_R-p_L)^2\right]}, \end{aligned}$$

which in turn simplifies to the expression in the lemma. ■

Lemma A4. *Expected second-period welfare in a partially informative equilibrium is given by*

$$EW_2^{PI} = -\frac{1}{4} + \frac{p_H^2}{8\left[1-(p_R-p_L)^2\right]} + \frac{p_H^2}{8\sqrt{(p_H\delta/2)\left[1-(p_R-p_L)^2\right]}}.$$

Proof: If either the L-type or R-type was drawn in the first period and if the state was against this lobbyist and he chose to lie, then the lobbyist's type will be known in period 2; hence, there can be no information transmission in period 2, so welfare is $-\frac{1}{4}$. This happens with probability $\frac{1}{2}p_L(1-\lambda_L^*) + \frac{1}{2}p_R(1-\lambda_R^*)$.

If the above event does not happen, then there will be some information transmission in period 2. There are eight possible events. Four of them have $m_2 = 1$:

$$(\theta_1, \theta_2, m_2) \in \{(0,1,1), (1,1,1), (0,0,1), (1,0,1)\}$$

(the remaining four are identical to those above but with $m_2 = 0$). The event $(0,1,1)$ happens with probability $\frac{1}{4}p_H + \frac{1}{4}p_R\lambda_R^*$, in which case second-period welfare is (here, as well as in the corresponding expression for the next event, we make use of (A5))

$$-\left(1 - \frac{p_H + p_R\lambda_R^*}{p_H + 2p_R\lambda_R^*}\right)^2 = -\left(\frac{p_R\lambda_R^*}{p_H + 2p_R\lambda_R^*}\right)^2.$$

The event $(0,0,1)$ happens with probability $\frac{1}{4}p_R\lambda_R^*$, in which case second-period welfare is

$$-\left(\frac{p_H + p_R\lambda_R^*}{p_H + 2p_R\lambda_R^*}\right)^2.$$

The event $(1,1,1)$ happens with probability $\frac{1}{4}p_H + \frac{1}{4}p_R$, in which case second-period welfare is (here, as well as in the corresponding expression for the next event, we make use of (A1) and the fact that $\widetilde{p}_i = p_i / \left(p_L\lambda_L^* + p_H + 2p_L\right)$ for $i = H, R$)

$$-\left(1 - \frac{p_H + p_R}{p_H + 2p_R}\right)^2 = -\frac{1}{4}\left(1 - \frac{p_H}{p_H + 2p_R}\right)^2.$$

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The event $(1,0,1)$ happens with probability $\frac{1}{4}p_R$, in which case second-period welfare is

$$-\left(\frac{p_H+p_R}{p_H+2p_R}\right)^2=-\frac{1}{4}\left(1+\frac{p_H}{p_H+2p_R}\right)^2.$$

The four cases where $m_2=0$ are analogous to those above. Hence, the event $(1,0,0)$ happens with probability $\frac{1}{4}p_H+\frac{1}{4}p_L\lambda_L^*$, in which case second-period welfare is

$$-\left(\frac{p_L\lambda_L^*}{p_H+2p_L\lambda_L^*}\right)^2.$$

The event $(1,1,0)$ happens with probability $\frac{1}{4}p_L\lambda_L^*$, in which case second-period welfare is

$$-\left(\frac{p_H+p_L\lambda_L^*}{p_H+2p_L\lambda_L^*}\right)^2.$$

The event $(0,0,0)$ happens with probability $\frac{1}{4}p_H+\frac{1}{4}p_L$, in which case second-period welfare is

$$-\frac{1}{4}\left(1-\frac{p_H}{p_H+2p_L}\right)^2.$$

Finally, the event $(0,1,0)$ happens with probability $\frac{1}{4}p_L$, in which case second-period welfare is

$$-\frac{1}{4}\left(1+\frac{p_H}{p_H+2p_L}\right)^2.$$

Using the above data, we can write expected second-period welfare as

$$\begin{aligned}
EW_2^{PI}=&-\left[\frac{1}{2}p_L\left(1-\lambda_L^*\right)+\frac{1}{2}p_R\left(1-\lambda_R^*\right)\right]\frac{1}{4}-\left[\frac{1}{4}p_H+\frac{1}{4}p_R\lambda_R^*\right]\\
&\times\left(\frac{p_R\lambda_R^*}{p_H+2p_R\lambda_R^*}\right)^2-\frac{1}{4}p_R\lambda_R^*\left(\frac{p_H+p_R\lambda_R^*}{p_H+2p_R\lambda_R^*}\right)^2\\
&-\left[\frac{1}{4}p_H+\frac{1}{4}p_R\right]\frac{1}{4}\left(1-\frac{p_H}{p_H+2p_R}\right)^2-\frac{1}{4}p_R\frac{1}{4}\left(1+\frac{p_H}{p_H+2p_R}\right)^2\\
&-\left[\frac{1}{4}p_H+\frac{1}{4}p_L\lambda_L^*\right]\left(\frac{p_L\lambda_L^*}{p_H+2p_L\lambda_L^*}\right)^2-\frac{1}{4}p_L\lambda_L^*\left(\frac{p_H+p_L\lambda_L^*}{p_H+2p_L\lambda_L^*}\right)^2\\
&-\left[\frac{1}{4}p_H+\frac{1}{4}p_L\right]\frac{1}{4}\left(1-\frac{p_H}{p_H+2p_L}\right)^2-\frac{1}{4}p_L\frac{1}{4}\left(1+\frac{p_H}{p_H+2p_L}\right)^2.
\end{aligned}$$

The terms that do not contain λ_L^* or λ_R^* (i.e., the fourth, fifth, eighth and ninth terms)

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can be rewritten as

$$
\begin{aligned}
& -(p_H+p_R)\frac{1}{16}\left(1-\frac{p_H}{p_H+2p_R}\right)^2-\frac{p_R}{16}\left(1+\frac{p_H}{p_H+2p_R}\right)^2 \\
& -\frac{1}{16}(p_H+p_L)\left(1-\frac{p_H}{p_H+2p_L}\right)^2-\frac{p_L}{16}\left(1+\frac{p_H}{p_H+2p_L}\right)^2 \\
= & -\frac{1}{16}(p_H+2p_R)+\frac{p_H^2}{16(p_H+2p_R)}-\frac{1}{16}(p_H+2p_L)+\frac{p_H^2}{16(p_H+2p_L)} \\
= & -\frac{1}{8}+\frac{p_H^2}{8(p_H+2p_R)(p_H+2p_L)}=-\frac{1}{8}+\frac{p_H^2}{8\left[1-(p_R-p_L)^2\right]} \qquad \text{(A10)}
\end{aligned}
$$

(here the first equality was obtained by multiplying out the squared terms and simplifying, and the last equality made use of $p_H=1-p_L-p_R$). The remaining terms can be rewritten as

$$
-\frac{1}{8}\left[p_L\left(1-\lambda_L^*\right)+p_R\left(1-\lambda_R^*\right)\right]-\frac{1}{4}\frac{\left(p_H+p_R\lambda_R^*\right)p_R\lambda_R^*}{p_H+2p_R\lambda_R^*}-\frac{1}{4}\frac{\left(p_H+p_L\lambda_L^*\right)p_L\lambda_L^*}{p_H+2p_L\lambda_L^*}.
$$

Using $p_R\lambda_R^*=p_L\lambda_L^*$ and $p_R+p_L=1-p_H$ and then simplifying, the above expression can be rewritten as

$$
-\frac{1}{8}+\frac{\left(p_H+2p_L\lambda_L^*\right)}{8}-\frac{\left(p_H+p_L\lambda_L^*\right)p_L\lambda_L^*}{2\left(p_H+2p_L\lambda_L^*\right)}=-\frac{1}{8}+\frac{p_H^2}{8\left(p_H+2p_L\lambda_L^*\right)}. \qquad \text{(A11)}
$$

From the definition of λ_L^* (see (4)) we have that

$$
p_H+2p_L\lambda_L^*=\sqrt{\frac{p_H\delta}{2}\left[1-(p_R-p_L)^2\right]}.
$$

Hence, (A11) along with (A10) give us the expression for EW_2^{PI} stated in the lemma. ■

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