A SIMPLE MODEL OF VOICE

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We think of *voice* as a means of information aggregation within groups operating in a variety of settings. We explore how the characteristics of groups and their leaders influence voice. In relatively homogeneous groups, members farthest away from the leader have the best incentives to provide information, and their voice tends to moderate policy decisions. In large heterogeneous groups where leaders cannot identify individual members, the possibilities for informational exchange are severely limited, and any communication that exists pushes policies farther to the extreme.

I. INTRODUCTION

In the 30 years since Hirschman [1970] wrote about *voice,* the concept has gained more currency than content. It remains a catchall for the many forms of participatory action through which the members of an organization try to influence organizational outcomes. The goal of this paper is to initiate a theoretical investigation of one aspect of voice—namely, voice as a means of information aggregation within the organization.

If we think of voice as the voluntary expression of people's views, its role in decision making is ubiquitous. Shop floor innovations in many successful firms are the result of informal exchanges of technological information between workers and management (see Aoki [1988]). Trade unions influence labor contracts by voicing changes in worker preferences.[1] The ability to get good advice is often seen as an important attribute of successful political leaders, and political decentralization has often relied on the ability of decision makers to make use of local information through appropriately designed institutions of participatory democracy.[2] At a more abstract level, many recent writers on the nature of the public discourse in America have complained about the lack of a moderate voice on many important and politically charged issues—whatever little debate one sees seems to be dominated by ideological extremists.

1. Freeman [1976] made this claim more than twenty years ago in the context of discussion of voice. See also the comments in Hirschman [1976].

2. Dasgupta [1997] emphasizes that a key to the success of participatory local government in the Indian state of West Bengal was the use of local information in the implementation of investment programs. Santos [1997] describes the remarkably successful institutions developed in the Brazilian city of Porto Alegre which involve the common people in the process of deciding on how to spend public money.

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The goal of the paper is to set up a simple model of an organization which permits us to say something about the structure and limits of communication in different settings. We model the organization as a group of heterogeneous individuals, united by the fact that policy decisions regarding the group are binding on all of them. We have in mind both well-defined groups such as firms, research teams, legislatures, and political parties, and more amorphous groups such as academia or the body politic. We show how the characteristics of these groups and decision makers within them, influence both the amount of communication and the kind of information that gets communicated.

Differences in both beliefs and preferences are potential sources of group heterogeneity. Individuals may share common goals but may differ in their beliefs about which policies can most effectively achieve them. Or, they could share the same beliefs but have different preferences. We focus in this paper on differences in beliefs. This is probably the right assumption in many contexts: for example, think of government committees deciding on monetary or trade policies, firms devising marketing strategies, research teams designing experiments, or a minority group debating appropriate affirmative action policies.[3] Many of our results would also hold in a model with differences in preferences. This is discussed in the concluding section of the paper.

We formally model the organization as a set of people with differing priors about the state of the world. Because we limit ourselves to the case where there are only two states of the world, the set of priors forms a one-dimensional continuum from left to right. This allows us to make a natural distinction between moderates and extremists: moderates in our model are those who put relatively equal weight on the two states of the world, while extremists firmly believe in one or the other of the states. The organization has to take a decision on a particular issue, and we imagine the right decision depends on one's beliefs about the likely state of the world. Decisions are made by the leader of the organization who is, in all other respects, indistinguishable from the other members.[4]

3. It is also easy to think of cases where preference heterogeneity is the right assumption. Members of a village council may all agree, in principle, that wells should be constructed where water is most easily accessible but may still prefer to have the well close to their house.

4. In many situations it is quite transparent who the leader should be—he is the manager of the firm, the leader of the party, the minister of the congregation,

We assume that the leader cannot alienate the right to decide. He chooses what is optimal for him, given his assessment of the probabilities of alternative states of the world at the time of the decision. The only way in which members of the organization can influence a leader's decision is, therefore, by providing him with information that will change his assessment of the probabilities. It is this process of communication between the members and the leader, whereby the members seek to influence the leader's choice by providing him with information without being able to dictate his choice, that we will call *voice.* Paraphrasing Hirschman, voice is thus a process that allows members of an organization to be *influential* while remaining *deferential.*

Given this setup, we first ask how, in strategic settings, the structure of voice depends on the extent of asymmetric information between a group's leader and the other members. We compare two polar cases: the first, which we call the *truthful reports case,* is one in which the reporter cannot or will not report a falsehood but may choose to suppress information. This may be reasonable in situations where information, although hard to get, can be easily verified by the leader. In this case, what limits communication is the reporter's reluctance to report information he has, for fear that it would move the leader in what is, from his point of view, the wrong direction. We show that, in this setting, there is a natural tendency for communication to take place between people with extreme and opposed views—in this sense, *voice* has the potential of being a *moderating* influence.

We contrast this case with the *misleading reports case.* Here people can freely report lies, and this severely limits the possibilities for informative communication. We show that in large groups, only leaders with extreme views receive reports in equilibrium. This happens because, for large groups and moderate leaders, the number of people sending false reports is also large. With the leader not being able to distinguish true reports from false ones, effective communication becomes impossible. The only

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the principal of the research team. In other cases it is less obvious whom we should call the leader—when we think about the political arena, one possibility is to think of the voter as the leader. The organization would then consist of all the politicians and other influential people who are trying to help the voter make up his mind. Alternatively, the politicians and opinion-makers in the media (like Rush Limbaugh, or in a different time and place, Jean-Paul Sartre) could be the leaders, and the organization could be made up of the intelligentsia and anybody else to whom these people will listen.

case where this is not true is if the leader is sufficiently extreme: the reason is that there are few who would want to lie to him. However, communication in this case will move the leader's position farther to the extreme, and voice in this case tends to be an *extremizing* influence.

In each of the above cases, we examine the effects of changes in the costs of communication. Since we measure communication costs in units of utility, high communication costs can be thought of as corresponding to less important issues (the more obvious interpretation of high communication costs as representing an institutional structure where it is hard to reach the leader's ear, also remains valid). More costly communication tends to increase the distance between the leader and those who report to him and, in the truthful reports case, always reduces communication. However, when people can mislead, higher costs, somewhat surprisingly, can actually increase communication by lending greater credibility to reports.

Finally, we look at the effects of an increase in the heterogeneity of views in the population. More heterogeneity means that there are more people at the extremes of the population. In the truthful reports case we show that, in an average sense, this discourages voice. In the misleading reports case, the conclusion is less clear: as we noted above, when there is communication in this setting, it tends to be at the extremes. On the other hand, having more extremists makes it more likely that there will be lots of spurious reports, and this makes informative communication harder.

These results, taken together, suggest two conclusions: first, a high level of communication and especially a lot of communication between people from opposite extremes is only possible in relatively homogeneous groups unless the group is intimate enough, or the information easy enough to verify, to justify the assumption of truthful reporting. Second, in situations where the group is very heterogeneous, people do not necessarily always tell the truth, and the issue is important, whatever communication there is will be among like-minded extremists. Moderates will choose to stay silent.

Since politics is a natural example of a situation where our second conclusion would seem to apply, one objective of this paper is to highlight the rather limited possibility of really enlightening debates on political issues. This echoes the concerns expressed by Loury [1995] about the limitations of the public discourse. Related views about the problematic position of moderates and the consequent impoverishment of the political discourse, are to be found in Kuran [1995], Walzer [1988], and Wolfe [1996]. While our theory is too abstract to have a real empirical counterpart, there are some empirical studies of the American political process that are clearly suggestive. Berelson, Lazarsfield, and McPhee [1954], in their study of the 1948 presidential election, find that the politically well-informed voters also tend to be those with the strongest party affiliations (what we have called extremists) and that exposure to political information tends to harden party commitments (it moves people away from the center) [pp. 196, 245, and 249]. Verba, Schlozman, and Brady [1995], using survey-based evidence on voice in the American political arena, find that on some issues there is a clear extremist bias among those who participate in political opinion-building. At a more local level, Hirschman [1970] has suggested that changes in community composition affect the quality of public schooling by influencing the level of voice the school system receives.[5]

In addition to the studies cited above, there is a theoretical literature on strategic information transmission that is directly related to this work. Our basic framework is an example of what Crawford and Sobel [1982] have called a sender-receiver game,[6] and they show that with a single sender and a single receiver who know each other's position, heterogeneity of views between the sender and the receiver limits communication if the signal can be falsified. We go beyond their work in two directions: (i) in examining what happens when the signal can be suppressed but not falsified and (ii) by showing that when there are multiple potential senders and the leader does not know their positions, communication is not just limited but may break down completely.[7]

The next section presents the basic model. In Section III we present results on the determinants of voice under alternative assumptions on the verifiability of information and on what the

5. To the extent that our model suggests that more heterogeneous groups will have less voice and therefore make less efficient decisions, our results are a potential explanation of the finding of Alesina, Baqir, and Easterly [1999], that levels of local public good provision are lower in communities that are ethnically more divided.

6. There are also a number of studies that apply the Crawford-Sobel framework to specific political settings (see, for example, Austen-Smith [1990, 1992], Banks [1990], and Harrington [1988]) and ask whether communication prior to voting has any effect on the outcome of voting.

7. Spector [1997], Ottaviani [1998], and Krishna and Morgan [1998] are recent papers that extend the Crawford-Sobel framework.

leader knows about the characteristics of reporters. Section IV considers the case of costly communication. Section V considers the effects of changes in the heterogeneity of the population. We conclude with a discussion of some possible extensions of the model and of the many issues left unresolved.

II. The Model

There is a policy that affects the lives of a group of people which needs to be chosen. The appropriateness of different policies depends on the state of the world, which, unfortunately, is unknown. We assume two possible states, θ and θ'. In each of these states, the utility each person in the population gets is a function of the policy choice x which is a number between 0 and 1. We assume that everyone in the group has the same Von Neumann utility function $U(x)$ in state θ and $U(1 - x)$ in state θ'. $U(\cdot)$ is increasing and strictly concave.

People differ in their assessments of the likelihoods of the two states of the world. Formally, we assume that the group has M members each of whom has associated with him a number p, the prior probability that he assigns to state θ. p is drawn independently from a population that is distributed uniformly on $[y, 1 - y]$, where $0 < y < 1/2$.[8]

We assume that the ex ante distribution of priors is common knowledge in the population. We realize that our formulation is somewhat heterodox and violates the so-called Harsanyi doctrine.[9] We feel, however, that this allows us to capture the mutually recognized differences of opinion between reasonable people that we constantly encounter in everyday life and allows us to model the difference between, for example, a moderate and an extremist in the most natural way; a moderate as someone who is unsure of what the state of the world is while an extremist believes that he knows. We feel that in many situations it is in fact these differences in beliefs that result in different choices and

8. The assumption of a uniform distribution is made purely for expositional reasons: our results are preserved for any distribution that is symmetric around $p = 1/2$, and moreover, for almost all of our results there is a corresponding result in the model where the distribution is not symmetric. The main advantage of assuming symmetry is that the results can be stated very simply, and it is clear what we mean when we say that someone is a centrist and someone else is an extremist.

9. Piketty [1995] and Piketty and Spector [1996] are recent papers which, like us, assume that people are aware of their differing priors.

the extreme Bayesian position that such differences of opinion are irrational puts too strong a burden on rationality. We discuss in Section VI how many of our results can be captured in a model with common priors and heterogeneous preferences, for appropriately chosen preferences.

Policy choices are made by the leader of the group, who is in all other respects just a generic member of the group. If a leader believes that the state θ will occur with probability p, then his expected utility from a policy x is given by

$$V(p, x) \equiv pU(x) + (1 - p)U(1 - x).$$

Assuming for convenience that an interior optimum exists,[10] the leader's optimal policy choice is defined by the condition,

$$p/(1 - p) = (U'(1 - x))/U'(x).$$

This defines a function $x(p)$ which, as a consequence of our assumption that U is strictly concave, is increasing in p. For convenience we assume that it is actually strictly increasing in p; this is true, for example, in the case of *CRRA* utility functions, where

$$x = \frac{p^{1/\alpha}}{p^{1/\alpha} + (1 - p)^{1/\alpha}}.$$

A still more special case is where $\alpha = 1$, $U(x) = \log x$, and $x = p$. It is also the case that, for any general U, the $x(p)$ function is symmetric in the sense that $x(1 - p) = 1 - x(p)$. It follows that when $p = 1/2$, $x = 1/2$.

Before policy decisions are made, someone in the population may receive a signal about the state of the world. We make the strong but convenient assumption that at most one such signal is received.[11] Everyone in the population except the leader has an equal chance of receiving a signal. The leader does not receive any signals.[12]

There is only one kind of signal, s, that anyone can re-

10. The interior equilibrium ensures that individuals with different priors also have different preferred policies. It is the heterogeneity in preferred policies that underlies our communication problem and, as long as this heterogeneity exists, we have modified statements of our propositions for cases when the optimum need not be in the interior of the policy choice space.

11. Allowing for more signals raises a number of interesting strategic issues about information transmission in addition to the ones emphasized here, and we briefly discuss these in Section VI.

12. This is assumed merely for convenience. All our results still apply when

ceive, and we assume that s is better correlated with the state θ than with θ'. Specifically, we assume that $\Pr(s|\theta) = \beta\mu$ and $\Pr(s|\theta') = \beta\mu'$, with $\mu > \mu'$. If we think of priors being distributed along a horizontal straight line, getting the signal s moves beliefs, and therefore preferred policies, to the right along this line.

By assumption the leader gets no signals of his own before he makes the policy choice. Members may choose to pass their signal on to the leader (they may also report invented signals). We assume that these reports are private in the sense that no one else overhears them. A member when reporting his signal incurs a constant cost $c \geqslant 0$. As we say in the Introduction, a high cost may reflect institutional arrangements that make communication harder, or it may reflect a low level of interest in the underlying issue.

The exchange of the signal is not regulated by any contract. The agent can be neither rewarded nor penalized on the basis of the contract. If he provides a signal at all, it has to be purely voluntary. At the same time, the leader cannot make promises about how he plans to respond to the signal. In other words, once he gets a signal, he updates his prior on the basis of the signal and then chooses his optimal policy given his posterior.

The basic structure of the game is as follows. If someone in the group has a signal, he must decide whether or not to report it to the leader. All other members decide whether or not to report an invented signal. The goal in each case is to influence the leader's choice. The leader in his turn has to decide whether or not to believe and act on signals that are received (of course, the leader's decision feeds back on the incentives of the members to report and misreport). Any equilibrium of this game determines a set of people who report to the leader: this, in the context of our model, is *voice.* Clearly, the structure of this set will depend on assumptions about what the leader can and cannot observe, as well as on the cost of communication, c, and the leader's relative position in the group. Our task is to determine exactly how these factors influence voice.

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the leader gets a signal with some probability—in that case we focus on what happens when the leader has no signal.

III. The Determinants of Voice: The Extent of Asymmetric Information between the Leader and Other Members

We show in this section how voice depends on the nature of informational asymmetries between the leader and other members. The maintained assumption in this section is that communication is costless, so group members report information if they prefer the leader's policy decision after he gets the report to his choice in the absence of a report. The next two sections consider the effects of costly communication and changes in the heterogeneity of views within the organization.

III.1. The Truthful Reports Case

We begin by analyzing the model under the assumption that agents do not falsify information. While they may choose to suppress information they might have received, they do not actively mislead. This may be because information, although difficult to get and noncontractible, could be verified by the leader once he receives it.[13] Truthful reporting could also exist because of long-term relationships between members of a group that sustains a norm of not lying.

This assumption defines a very simple game of communication. Members of the group only have to take a decision when they have a signal and the decision is whether or not to report it. Denote by i_R the (Lebesgue) measure of the set of people who, in a particular equilibrium of the communication game, choose to report their signal to the leader. The leader then chooses x based on whether or not he gets a signal.

If the leader gets a signal s, his posterior belief will be

$$\pi(s, p) = \frac{p}{p + (\mu'/\mu)(1 - p)}.$$

Since s moves beliefs to the right, we denote this expression as $\pi_R(p)$.[14]

13. In a research team, for instance, a successful experiment may be rare, but once done, might be easily replicated and verified.

14. This formula follows from Bayes' rule as long as $i_R > 0$. In the case where $i_R = 0$, but the leader actually gets a signal, we have the problem (usual in games of communication) of assigning beliefs to an information set that is not reached in equilibrium. However, since only true signals get reported, the only belief for the leader at this information set that is consistent in the sense of Kreps and Wilson [1982] is one that puts probability one on the signal being true. If, therefore, we restrict ourselves to sequential equilibria of the communication

Let π_N be the leader's posterior after he has received no signal. The value of π_N depends on what the leader believes about the likely state of the world, given that he has not received any signals. He knows that not receiving a signal could be due to one of two reasons:

(a) someone got a signal and did not report it to him;

(b) no signals were received.

The probability of no signal, given the event θ, therefore is

$$1 - \mu\beta i_R.$$

Similarly, the probability of no signal, given the event θ' is

$$1 - \mu'\beta i_R.$$

Therefore, the probability of θ, if no signal has been received is

$$\pi_N(p,\, i_R) = \frac{p(1 - \mu\beta i_R)}{p(1 - \mu\beta i_R) + (1 - p)(1 - \mu'\beta i_R)}.$$

It is easy to check that $\pi_N(p,i_R) < \pi_R(p)$.

To determine the set of those who report in any given (sequential) equilibrium, observe that giving the leader a signal moves the leader's choice to the right and that this is desirable in state θ but not in state θ'. The person who stands to gain more from reporting a signal must therefore be the one who believes more strongly that the state is θ. This is a person with a prior of $1 - y$. To show this formally, observe that in any equilibrium, the gain to p' from reporting a signal to a leader whose prior is p is

$$\begin{aligned}&\pi_R(p')U(x(\pi_R(p))) + (1 - \pi_R(p'))U(1 - x(\pi_R(p)))\\ &\quad - \pi_R(p')U(x(\pi_N(p),i_R)) - (1 - \pi_R(p'))\\ &\quad \times U(1 - x(\pi_N(p,i_R))).\end{aligned}$$

This expression is increasing in p' because its derivative with respect to p' is

$$\begin{aligned}&\frac{d\pi_R(p')}{dp'}[\{U(x(\pi_R(p))) - U(x(\pi_N(p,i_R)))\}\\ &\qquad + \{U(1 - x(\pi_N(p,i_R))) - U(1 - x(\pi_R(p)))\}].\end{aligned}$$

game (which requires consistent beliefs), the leader will have to update his beliefs in the case where $i_R = 0$ exactly as he would in the case where $i_R > 0$.

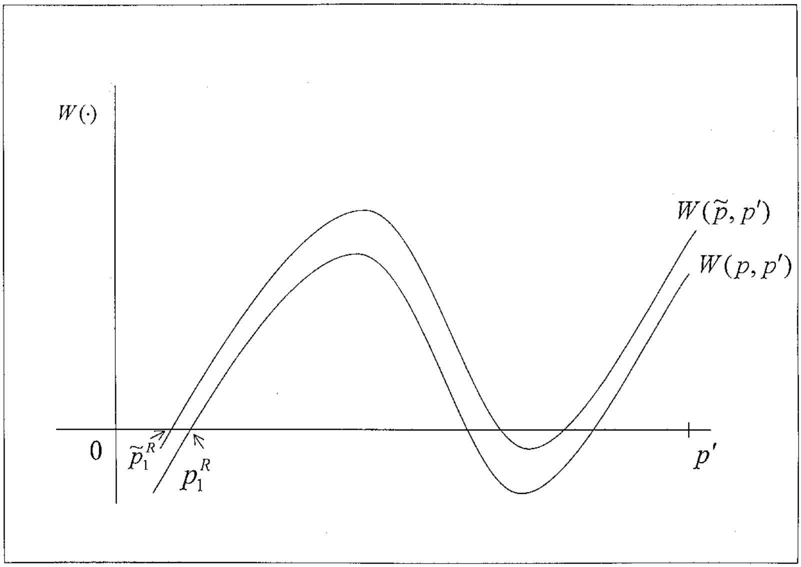

FIGURE I

$\tilde{p}$, p

Both the above terms are positive because $\pi_R(p')$ is increasing in p' and since $\pi_R(p) > \pi_N(p,i_R)$, $x(\pi_R(p)) > x(\pi_N(p,i_R))$. *It follows that the set of people who provide signals must be contained in an interval with people to the right of a certain critical value being the only ones who report.* Call this critical value p^R. Then i_R must be given by $(1 - y - p^R)/(1 - 2y)$, the measure of the interval $[p^R, 1 - y]$, and p^R will be given by the value of p' which solves the equation,

$$W(p, p') = \pi_R(p')U(x(\pi_R(p))) + (1 - \pi_R(p')) \times U(1 - x(\pi_R(p))) - \pi_R(p') \times U\left(x\left(\pi_N\left(p, \frac{1 - y - p'}{1 - 2y}\right)\right) - (1 - \pi_R(p'))\right) \times U\left(1 - x\left(\pi_N\left(p, \frac{1 - y - p'}{1 - 2y}\right)\right)\right) = 0.$$

This expression is graphed in Figure I, as a function of p', the prior of the person reporting. Clearly, $W(p,p')$ is negative when

$p' = 0$ (so that $\pi_R(p') = 0$) and positive when $p' = 1$ (so that $\pi_R(p') = 1$). Therefore, p^R, which is the value of p' that solves the equation $W(p,p') = 0$ for some given p, must lie between 0 and 1. However, there is no guarantee that there is a unique such p': as we have drawn it, the $W(p,p')$ map intersects the horizontal axis three times, and each of these intersections is an equilibrium p^R. These arise because of the endogeneity of $\pi_N(p)$—while the direct effect of an increase in p' on $W(p,p')$ is always positive, $\pi_N(p)$ also goes up when p' goes up, and this tends to lower $W(p,p')$ so that the net effect is ambiguous.[15] The results in this section will therefore be stated without assuming uniqueness of equilibrium. In Appendix 1 we show that if β is small (so that the absence of a report has only a weak effect on $\pi_N(p)$), the equilibrium will indeed be unique.

Coming next to the characterization of $p^R(p)$, notice that for $p' = p$, $W(p,p')$ must be positive since anyone who has exactly the same prior as the leader would want to share information with him. It therefore follows that $p^R(p) \leq p$. *Some people who are to the left of the leader may therefore report a signal to him despite the fact that the signal makes the leader move farther to the right.*

Next note that $W(p,p')$ can be written in the form $V(p',x(\pi_R)) - V(p',x(\pi_N))$, where $V(p',x) = \pi_R(p')U(x) + (1 - \pi_R(p'))U(1 - x)$. Now $V(p',x)$ is concave in x (because U is concave) and is maximized at $x = x(\pi_R(p'))$. Now as long as $\pi_R(p')$ is to the left of both π_N and π_R, $V(x(\pi_R)) < V(x(\pi_N))$ and $W(p,p') < 0$. Therefore, since $W(p,p^R) = 0$, it must be the case that $\pi_R(p^R)$ is to the right of $\pi_N(p)$. In other words, the marginal person who reports must be such that his posterior belief after getting the signal is to the right of what the leader would choose in the absence of a report. This ought to be intuitive: if, even after updating on the basis of his signal, the preferred policy of the person reporting is to the left of what the leader would choose in the absence of a signal, he is clearly better off not reporting since the report would only push the leader farther away from him.

Since $\pi_R(p^R) \geq \pi_N(p)$, it follows that as $p \to 1$, and therefore $\pi_N(p) \to 1$, we also have $\pi_R(p^R) \to 1$. As a result, $p^R \to 1$.

15. Intuitively as p^R goes toward 0, so that the set of people who report when they get a signal becomes larger, the fact of not having observed a signal also becomes more informative, and therefore $\pi_N(p)$ moves to the left. This makes it more costly not to report when one has a signal and as a result, more people would want to report, justifying a lower value of p^R.

Leaders who are at the very extreme right do not get any signals. This again should be intuitive—no one would want to move such a person farther to the right.

This raises the question of whether there is a sense in which more left-wing leaders get more reports? To answer this, we begin by noting that it must be the case that if $W(p,p') \geq 0$, $W(\tilde{p},p') \geq 0$ for all $\tilde{p} < p$. This follows from the fact that Bayesian updating is always order preserving, so that if p and $\tilde{p}$ are two leaders and $p > \tilde{p}$, then p's posterior belief after he does or does not get a signal, must be to the right of the corresponding beliefs for $\tilde{p}$ (note that this is only true because we are making this comparison for a fixed p' so that π_N is only a function of the leader's prior). Therefore, if the gain in moving p to the right is positive, the gain in moving $\tilde{p}$ to the right must also be positive.[16] The implication of this property of the $W(p,p')$ function can be seen from Figure I, where the dotted line represents the effect of lowering the leader's prior: clearly if $W(p,p')$ intersects the horizontal axis at p_1^R when the leader's prior is p, it must intersect the horizontal axis at some $\tilde{p}_1^R \leq p_1^R$, when the leader's prior is $\tilde{p} < p$. In other words, *a more left-wing leader gets more reports in the sense that there is always an equilibrium where the more left-wing leader gets more reports than a less left-wing leader can ever get in any equilibrium.*

The following proposition gives a formal summary of the results discussed above.

PROPOSITION 1. Under truthful reporting, the set of priors of those who provide signals to a leader with prior p in any sequential equilibrium of the communication game, forms an interval $[p^R(p),\ 1 - y]$. $p^R(p)$ has the following properties: (i) $p^R(p) \leq p$. (ii) If $p_1^R(p)$ is the lowest equilibrium value of p^R when the leader's prior is p, then $p_1^R(\tilde{p})$, the lowest equilibrium value of p^R when the leader's prior is $\tilde{p} < p$, must be no greater than $p_1^R(p)$. (iii) As p approaches $1 - y$, and y approaches 0, the size of the interval of people reporting signals to the leader, $[p^R(p),\ 1 - y]$, shrinks to 0.

An interesting implication of the above result is the following. If leaders are equally likely to be anywhere in the interval $[y, 1 - y]$, then the fact that left-wing leaders are more likely to get

16. A simple formal version of this argument was in a previous version of this paper and is available from the authors.

signals makes voice a *moderating influence* in the sense that it is more likely to move left-wing leaders to the right than right-wing leaders farther to the right.

III.2. The Misleading Reports Case

We now allow for the possibility that agents can misrepresent their signals. In other words, they can report a signal even if they have none. It is easy to see that in this case there are many robust equilibria of the communication game. Among these are equilibria where the leader ignores all reports and sending a signal is uncorrelated with having one. Obviously, there is no information exchange in such equilibria.

Our interest in this section, however, is in equilibria that allow for maximal possibilities for information exchange. We endeavor to show that even such equilibria involve very little actual exchange of information if certain conditions hold. In order to ensure that this result does not turn on our choice of a specific equilibrium, we allow for a wide range of possible equilibria in proving this result. We begin the analysis with some preliminaries that will help us impose some structure on the set of possible equilibria.

We describe the strategies used for reporting in any equilibrium by two functions, $q_R(p)$ and $q_N(p)$:[17] $q_R(p)$ is defined to be the probability that a member with a prior p reports a signal if he has one while $q_N(p)$ is the probability he reports a signal if he does not have a signal. Using these we can generate, for a given equilibrium, the probability that a *randomly chosen member* who has a signal, will report it:

$$i_R = \frac{1}{1-2y}\int_y^{1-y} q_R(p)dp.$$

Similarly,

$$i_N = \frac{1}{1-2y}\int_y^{1-y} q_N(p)dp$$

17. Here we are implicitly assuming that the leader treats all the members in the group identically. At the cost of some additional notation, our results can be extended to the case where the leader makes distinctions between different sets of members and plays different equilibria against different sets of members.

is the probability that a randomly chosen member who has no signal will report a signal.

We can now express the probability that in state θ the leader will receive S signals as

$$\Pr\{S|\theta\} = \beta\mu i_R B(M-1, S-1, i_N) + \beta\mu(1-i_R) \times B(M-1, S, i_N) + (1-\beta\mu)B(M,S,i_N) \quad \text{when } M > S \geqslant 1;$$

$$\Pr\{S|\theta\} = \beta\mu(1-i_R)B(M-1, 0, i_N) + (1-\beta\mu)B(M,0,i_N) \quad \text{when } S = 0;$$

$$\Pr\{S|\theta\} = \beta\mu i_R B(M-1, M-1, i_N) + (1-\beta\mu)B(M,M,i_N) \quad \text{when } S = M,$$

where $B(X,Y,z)$ is the probability of getting Y successes in X binomial trials, if the probability of success in any single trial is z. The corresponding probability in state θ', $\Pr\{S|\theta'\}$ is given by an expression that is substantially identical except that μ is replaced by μ'. The three terms in these expressions represent each of the three possible ways in which the leader can get S signals: someone gets a signal and reports it, and the rest report $S-1$ false signals; the person who gets a signal suppresses it, and the rest report S false signals; or finally, no one gets signals, and then S people send false reports.

Armed with these definitions, we can now look at what actually happens in this game. The leader on receiving S signals updates his prior. From Bayes' rule, if his prior is p, his posterior will be

$$\Pr\{\theta|S,p\} = \frac{1}{1 + (1-p\ \Pr\{S|\theta'\})/(p\ \Pr\{S|\theta\})}.$$

We are now in a position to state a key result.

PROPOSITION 2. Assume that $0 \leqslant S \leqslant M-1$. If the leader's prior p is strictly between 0 and 1, in any sequential equilibrium of the communication game where the leader gets both S and $S+1$ signals with positive probability, $\Pr\{\theta|S+1\} > \Pr\{\theta|S\}$ if and only if $i_R > i_N$ and $\Pr\{\theta|S+1\} = \Pr\{\theta|S\}$ if and only if $i_R = i_N$. That is, getting an additional signal from the set of members moves the leader's prior to the right if and only if $i_R > i_N$ and has no effect on the leader's prior if and only if $i_R = i_N$. For the case where the leader has zero probability of getting $S + 1$ signals in equilibrium, $\Pr\{\theta|S + 1\} = \Pr\{\theta|S\}$.

For the case where $i_N > 0$, this result follows from tedious but entirely straightforward manipulations of the definitions in the previous paragraphs. In the case where $i_N = 0$, only those who have signals send reports. *This is the only case where the probability of getting* $S + 1$ *signals* (*given* $0 \leq S \leq M - 1$) *can be zero.* In equilibrium the leader will expect no more than one signal, and this will be a true signal. If he happens to get more than one signal, we face the well-known problem of assigning beliefs at information sets that are not supposed to be reached in equilibrium. This is where the restriction to sequential equilibria plays a role: if, in equilibrium, only those who have signals report, for strategy profiles that are in the neighborhood of the equilibrium strategy profile, the only consistent beliefs (see Kreps [1982]) are those which assign a probability close to one to there being at least one true signal among those reported. Therefore, in any sequential equilibrium where only those who have true signals report, the leader must assign the same belief to the information set where he gets one signal and the ones where he gets more than one.[18]

This proposition simply says that getting a signal should only move the leader's prior to the right if and only if signals are more likely to come from people who have signals. It also implies that if signals were more likely to come from people who have no signals than those who have signals, getting a signal should move the leader to the left. It is important to note that such "perverse" behavior is not inconsistent with equilibrium: here, as in all games of communication, words acquire their meanings in equilibrium. Thus, someone may report no signal, meaning that he has a signal and vice versa. However, for any such equilibrium where $i_R < i_N$ (so that the leader moves left when he gets an additional signal), there is another essentially identical equilibrium where $i_R > i_N$. To construct this equilibrium, require that a member now sends no signal if, in the original equilibrium, he would have sent a signal, and vice versa. Also require that the leader chooses exactly the same x when he gets S signals as he

18. A formal proof is available from the authors.

would have in the original equilibrium if he had got $M - S$ signals. Since this is a pure relabeling of the signals, it remains an equilibrium.

Given this, we feel that little is lost by restricting the set of equilibria to those in which $i_R \geqslant i_N$. Such an equilibrium must always exist because, at the very least, there is always an equilibrium in which $i_R = i_N$.[19] For obvious reasons we call this kind of equilibrium an uninformative equilibrium, in contrast with an informative equilibrium where $i_R > i_N$.

Now consider the decision faced by a member k' who has a prior p' but has no signal. He knows that given that the leader has S signals from the rest of the population, the leader will choose $x(\Pr\{\theta|S,p\})$ if k' does not report and $x(\Pr\{\theta|S+1,p\})$ if he does. Denote by $\Pr\{S|\theta,n\}$ the probability from k''s point of view that in state θ the leader will receive S signals from the rest of the population. Analogously to $P\{S|\theta\}$, $\Pr\{S|\theta, n\}$ can be written in the form,

$$\Pr\{S|\theta,n\} = \frac{1}{1-\beta\mu/M}\frac{(M-1)\beta\mu}{M} i_R B(M-2,\, S-1, i_N) + \frac{1}{1-\beta\mu/M}\frac{(M-1)\beta\mu}{M}(1-i_R) \times B(M-2,S,i_N) + \frac{1}{1-\beta\mu/M}(1-\beta\mu) \times B(M-1,S,i_N), \text{ when } S \geqslant 1.$$

$$\Pr\{S|\theta,n\} = \frac{1}{1-\beta\mu/M}\frac{(M-1)\beta\mu}{M}(1-i_R) \times B(M-2,0,i_N) + \frac{1}{1-\beta\mu/M}(1-\beta\mu) \times B(M-1,0,i_N) \text{ when } S = 0.$$

$$\Pr\{S|\theta,n\} = \frac{1}{1-\beta\mu/M}\frac{(M-1)\beta\mu}{M} i_R$$

19. In this equilibrium the leader ignores all signals, and therefore all members are perfectly happy to report a signal with the same probability irrespective of whether or not they actually have one.

$$\times B(M - 2, M - 2, i_N) + \frac{1}{1 - \beta\mu/M}(1 - \beta\mu)$$

$$\times B(M - 1, M - 1, i_N) \text{ when } S = M - 1.$$

Define $\Pr\{S|\theta', n\}$ correspondingly for state θ'. The net gain to k' from reporting a signal can then be written as

$$\sum_{S=0}^{M} p' \Pr\{S|\theta,n\} U(x(\Pr\{\theta|S + 1,p\})$$

$$+ \sum_{S=0}^{M} (1 - p') \Pr\{S|\theta',n\} U(1 - x(\Pr\{\theta|S + 1,p\})$$

$$- \sum_{S=0}^{M} p' \Pr\{S|\theta,n\} U(x(\Pr\{\theta|S,p\})$$

$$- \sum_{S=0}^{M} (1 - p') \Pr\{S|\theta',n\} U(1 - x(\Pr\{\theta|S,p\}).$$

It follows immediately from the fact that $x(\Pr\{\theta|S + 1,p\}) > x(\Pr\{\theta|S,p\})$ in any informative equilibrium, that this expression is increasing in p'. Not surprisingly, those who are farther to the right benefit more from providing a false signal. It follows therefore that there be some cutoff value of p' (not necessarily in the interval $[y,1 - y]$) such that those who are to the right of p' strictly prefer to send a signal when they do not have one.

A very similar argument establishes that there is some cutoff value of the prior such that those who are to the right of that cutoff value strictly prefer to report a signal when they have a signal. For precision and future reference we report these two results as a proposition.

PROPOSITION 3. The behavior of members in any informative (sequential) equilibrium can be completely described by two numbers: p^R and p_R. Members with priors $p' \geq p^R$ always report a signal when they have one, while those who have priors $p' < p^R$ never report a signal when they have one. Members with priors $p' > p^R$ always report a signal when they do not have one while those who have $p' \leqslant p^R$ never report a signal when they do not have one.[20]

Clearly, the values of p_R and p^R defined in the above proposition depend on the values of M and p as well as on the equilibrium chosen. Wherever necessary, we will therefore refer to $p_R(M,p)$ and $p^R(M,p)$ and refer to a particular equilibrium, but elsewhere we will simply talk about p_R and p^R.

We have already restricted ourselves to equilibria where $i_R \geqslant i_N$, on the grounds that all other equilibria are essentially equivalent to some equilibrium of this type. This, using the above definitions, translates into the property that $p^R \leqslant p_R$, which tells us that all equilibria relevant for us have a rather simple structure. There is an interval $[y,p^R)$ in which people never report, an interval $[p^R,p_R]$ in which people report if and only if they have a signal, and an interval $(p_R,1 - y]$ in which people always report, irrespective of whether they have a signal. However, in any given equilibrium, some of these intervals may be degenerate. It is entirely possible, for example, that $p_R > 1 - y$, in which case there is no interval $(p_R,1 - y]$ where everyone always reports. The fact that an equilibrium is informative, however, does imply that the interval $[p^R,p_R]$ must have nonzero measure, since these are the only people who are responsive to information. Indeed, for a fixed M, the size of the interval $[p^R,p_R]$ relative to the size of the interval $[y, 1 - y]$ provides a measure of the informativeness of the equilibrium.

A potential example of an informative equilibrium in this model is one in which there is in fact truthful reporting; i.e., $i_N = 0$. To see whether such an equilibrium can exist, consider the decision of someone with prior p', assuming that everyone else follows the equilibrium strategies: if he reports a signal, the leader's posterior will be $\pi_R(p) = p/(p + (\mu'/\mu)(1 - p))$, since by Proposition 2, the leader behaves in exactly the same way when he gets one signal or many. If not, it will be $\pi_N(p) = (p(1 - \beta\mu i_R))/(p(1 - \beta\mu i_R) + (1 - p)(1 - \beta\mu' i_R))$.

He is therefore indifferent between reporting and not reporting if

20. Note that those who are exactly at the cutoff values p^R and p_R are going to be indifferent between reporting and not reporting. Because they are of zero measure in the population, their choices cannot affect whether something is an equilibrium or not. As a result, we are free to assign them either choice, and here we have done so in a way that makes the set of those who report, if and only if they have a signal, an interval.

$$p'U(x(\pi_R(p))) + (1 - p')U(1 - x(\pi_R(p))) = p'U(x(\pi_N(p))) + (1 - p')U(1 - x(\pi_N(p))).$$

The value of p' that solves this equation defines $p_R(M,p)$, which, in this case, does not depend on M. Call it $\tilde{p}_R(p)$. If $\tilde{p}_R(p) \geq 1 - y$, no one wants to reports falsely, and there is indeed a sequential equilibrium in which only true signals get reported. The leader's posterior is $\pi_R(p)$ when he gets at least one signal and $\pi_N(p)$ otherwise. By contrast, if $\tilde{p}_R(p) < 1 - y$, there cannot be an equilibrium where people report only true signals because for any $p' \in (\tilde{p}_R(p), 1 - y]$ the gain from reporting a false signal will be strictly positive.

When an equilibrium with truthful reporting exists, the set of people who report in such an equilibrium can also be characterized rather straightforwardly. Knowing that no one else will report, someone who has a signal will be indifferent between reporting and not reporting if

$$\pi_R(p^R)U(x(\pi_R(p))) + (1 - \pi_R(p^R))U(1 - x(\pi_R(p))) = \pi_R(p^R)U(x(\pi_N(p))) + (1 - \pi_R(p^R)))U(1 - x(\pi_N(p))).$$

This defines $p^R(M,p)$, which is the prior of the most left-wing person who would willingly report a signal. Note that this is exactly what in the truthful reporting case we called $p^R(p)$ (this is as it should be, since we are looking at the case where there is only truthful reporting). The interval of people who report in this equilibrium (when it exists) is $[p^R(p), 1 - y]$.

PROPOSITION 4. For any M, there exists a sequential equilibrium of the communication game where only true signals get reported if and only if $\tilde{p}_R(p) \geq 1 - y$. The interval of people who report in this equilibrium is $[p^R(p), 1 - y]$.

This proposition is not yet necessarily very useful because we do not know what to make of the condition $\tilde{p}_R(p) \geq 1 - y$ since $\tilde{p}_R(p)$ is endogenous. The next step is to put a bound on $\tilde{p}_R(p)$. To this end, we first observe that for any S the ratio $\Pr\{S|\theta'\}/\Pr\{S|\theta\}$ is bounded below by the ratio μ'/μ'.[21] Similarly the ratio $\Pr\{S|\theta',$

21. This follows immediately once it is observed that the ratio $\Pr\{S|\theta'\}/\Pr\{S|\theta\}$ can be written in the form $(\beta\mu'A + (1 - \beta\mu')B)/(\beta\mu A + (1 - \beta\mu)B)$ for a particular positive A and B.

$n\}/\Pr\{S|\theta, n\}$ can be shown to be bounded above by the ratio $(1 - \beta\mu')/(1 - \beta\mu)$. Now let $p^*(p)$ (p is the leader's prior) be such that

$$\frac{1-p}{p}\frac{\mu'}{\mu} = \frac{1-p^*}{p^*}\frac{1-\beta\mu'}{1-\beta\mu}.$$

It follows from the discussion above that for any realization of S, the probability that a member who has a prior p' but has no signal assigns to state θ is

$$\begin{aligned}\Pr\{\theta|S,n,p^*(p)\} &= 1/(1 + ((1 - p^*)/p^*) \\ &\quad \times (\Pr\{S|\theta',n\}/\Pr\{S|\theta,n\}) \geqslant 1/(1 + ((1 - p^*)/p^*) \\ &\quad \times (1 - \beta\mu')/1 - \beta\mu) = 1/(1 + ((1 - p)\mu')/p\mu \\ &\geqslant 1/(1 + ((1 - p)/p) \Pr\{S|\theta'\}/\Pr\{S|\theta\}) = \Pr\{\theta|S, p\}.\end{aligned}$$

What this is telling us is that for every realization of the signals that the leader gets, the preferred point of a member with a prior of $p^*(p)$ is (weakly) to the right of the point that the leader would choose *even after he gets an extra (false) signal from the member.* In other words, the member with a prior of $p^*(p)$ can never lose by moving the leader to the right by giving him a false signal and any member to the right of $p^*(p)$ will actually strictly prefer to do so. Therefore, from the definition of $p_R(M,p)$, the next proposition follows.

PROPOSITION 5. The value of $p_R(M,p)$ in any informative sequential equilibrium of the communication game is bounded above by $p^*(p)$ for all M.

By this proposition, a necessary condition for $\tilde{p}_R(p)$ to be greater than $1 - y$, is for $p^*(p)$ to be greater than $1 - y$. Since $p^*(p)$ is increasing in p, this implies that p has to be sufficiently close to $1 - y$. This tells us that an equilibrium with just truthful reporting can only exist when the leader is far enough to the right. Indeed since the distance between $p^*(p)$ and p can be made as small as we like by choosing μ' close enough to μ, the leader may have to be very close indeed to the extreme right of the population before there can be such an equilibrium.

The fact that the leader needs to be an extremist ought to be intuitive: leaders on the extreme right benefit from the fact that no one in the population would want to report a false signal to them and move them even farther to the right.

The fact that the leader's prior p has to be close to the extreme right, also implies that $p^R(p)$ has to be close to the extreme right. In other words, if an equilibrium with truthful reporting has to exist, it is not just that the leader has to be an extremist, the members who report to him, given by the interval $[p^R(p), 1 - y]$, must also be close to the extreme. Moreover, the goal of the communication is to try to move the leader further away from the center. No moderating voices will be heard.[22]

What happens if the condition for an equilibrium with truthful reporting does not hold? Then there will clearly be some false reporting in equilibrium. However, this does not rule out the possibility of some communication. As we saw above, there is always some communication as long as $i_R > i_N$. However, our next result shows that when M, the size of the group, becomes very large, the amount of effective communication, measured by $E_S[|\Pr\{\theta|S, p\} - p|]$, the distance between the leader's prior and his posterior, averaged over all possible realizations of S, shrinks to zero (the proof of the proposition is in Appendix 2).

PROPOSITION 6. If $p_R(M,p) < 1 - y - \epsilon$ for some fixed $\epsilon > 0$, for all $M > M^*$ and all sequential equilibria, then as M becomes large, all sequential equilibria become uninformative in the sense that the average distance between the leader's prior and his posterior shrinks to 0. In other words, for any $\delta > 0$, however small, we can find M^{**} large enough such that all sequential equilibria of the communication game will have $E_S[|\Pr\{\theta|S,p\} - p|] < \delta$ for all $M > M^{**}$.

The basic intuition for this result is that as the number of false reports grows and becomes very large, it becomes harder to detect the true signal. The condition $p_R(M,p) < 1 - y - \epsilon$, for all $M > M^*$, is essentially a way of guaranteeing that the number of those who send false reports does indeed become very large (on average) when M is large. It is worth emphasizing that a large number of false reports do not per se rule out the possibility of

22. We have relied on the fact that it is common knowledge that no one is more extreme than $1 - y$. In the real world it is hard to imagine that any leader will know the exact limits of the distribution. This is not, however, essential for the result. In a model where the population is finite but the exact position of the most extreme person is unknown, right signals will be reported to a leader p as long as the probability of there being a person in this population with a prior greater than $p_R(p)$, is sufficiently small relative to the probability of there being a person in the interval $[p^R(p), p_R(p)]$. This condition clearly gets even further weakened if the leader knows or can detect the real priors of some fraction of the population.

informative communication. To take a specific example, for any size of M, as long as i_R remains larger than i_N, it is always more likely that the leader will get signals from all M members in state θ than in state θ', and consequently, the leader always learns something when he gets all M signals even if M is very large (more precisely $|\Pr\{\theta|S,p\} - p|$ remains bounded away from 0 for all M).[23] This is not inconsistent with the above proposition because, as M becomes large, the probability that the leader will get reports from all M people becomes very small. Indeed, as M becomes large, we will tend to observe only those values of S for which S/M is close to its expectation. Our result holds because *it is precisely at these values of S that observing an extra signal is not informative when M is large.* In fact, when M is large enough and S/M is close to its mean, observing $S + K$ signals rather than S (for some finite K) would also be almost entirely uninformative. One can use this fact to extend this result to the case where K people observe signals rather than one.

However, it is important for the result that the number of signals does not grow as fast as the population. This would be the case, for example, if everyone in the group had an independent chance of getting a signal.[24] We have in mind a situation where there are a smallish number of sources of information. Those who discover one of these sources of information are the ones who have true signals. One reason why it is possible that only a few people get true signals even when the population is large, is that once a source has been discovered, people somehow hear about it and start claiming that they too have discovered it: in other words, it becomes a false signal. Alternatively, the original discoverers may have reason to suppress the signal so that no one else can discover it.

This result tells us that the possibilities for effective communication may become very limited as group size becomes large, unless the leader is sufficiently close to the extreme right. It does not actually tell us what the equilibrium looks like in such cases: in fact the outcome that there is little or no information exchanged is consistent both with an equilibrium where no one reports and the leader ignores all reports, as well as one in which

23. A simple calculation establishes that the likelihood ratio the leader associates with getting M signals, $\Pr\{M|\theta'\}/\Pr\{M|\theta\}$, is given by $(\beta\mu' i_R + (1 - \beta\mu')i_N)/(\beta\mu i_R + (1 - \beta\mu)i_N)$, which stays bounded away from 1 even for large M (indeed it is independent of M).

24. See Spector [1997] for an analysis of this case.

lots of people report but are ignored. In other words, there may be silence in one case and a cacophony of voices in the other, but in both cases nothing useful is achieved.

Even with a group that is not too large, communication tends to fail when the leader's prior becomes very extreme. As $y \to 0$ and $p \to y$, it is easy to see that $p^*(p) \to 0$ which implies that $p_R(M,p) \to 0$. In other words, for any fixed M, the interval of people who never report a signal unless they have one, i.e., the interval $[y,p_R(M,p)]$, disappears as p and y go to 0 and, correspondingly, the interval of people who always report a signal expands to absorb the entire population of the group. Informative communication therefore becomes impossible. Informative communication is also impossible when $y \to 0$ and $p \to 1 - y$. The proof of this result is omitted because it is essentially the same result as part (ii) of Proposition 1 and can be proved in more or less the same way. To summarize:

PROPOSITION 7. In all sequential equilibria of the communication game, as $y \to 0$ and $p \to y$, $p_R(M,p) \to 0$. As a result, for any fixed M, the size of the interval $[p^R(M,p), p_R(M,p)]$ shrinks to zero, and (in the limit) there is no informative communication. The interval $[p^R(M,p), p_R(M,p)]$ also shrinks to zero (and there is no informative communication) when, for a fixed $M,y \to 0$ and $p \to 1 - y$.

This proposition tells us that if the leader is sufficiently extreme (in the sense of having a prior very close to 0 or 1), there is no informative communication. The fact that an extreme right-wing leader does not get information that moves him to the right is perhaps to be expected. It is more surprising that this is also true when the leader is on the extreme left. In this case many people clearly have the incentive to try to move him to the right. The problem is that he is only too aware of this. He knows that it is close to impossible that anyone will actually lose by giving him a fake signal and moving him somewhat to the right. Therefore, quite rationally, he will be paranoid about all the signals he receives, and put very little weight on them.

These results suggest that the possibility of communication may be very limited for issues in the public domain. This is suggestive of the current situation in many public debates in the West: the issues are very important (multiculturalism, affirmative action policies, eliminating welfare), reflecting a c close to zero, but only the extremes participate in the debate. The moderates fear that if they should enter the debate people will question their bona fides (what must this person really believe if he is willing to take this position).

IV. Costly Communication

So far we have not allowed for any costs of communication other than those implicit in the leader's policy choice. Therefore, a signal was reported as long as a member preferred the leader's policy choice after receiving the information to the uninformed choice. If we allow for additional costs of communication (arising, for example, from the time or effort involved in articulation), then group members may not report if the gains from reporting do not outweigh these costs.

The prior p^R of the person indifferent between reporting a signal and suppressing it, will now be given by

$$\pi_R(p^R)U(x(\pi_R(p))) + (1 - \pi_R(p^R))U(1 - x(\pi_R(p))) - \pi_R(p^R)U(x(\pi_N(p))) - (1 - \pi_R(p^R)) \times U(1 - x(\pi_N(p))) = c.$$

To simplify the exposition, let us assume that the p^R which solves this equation is a continuous and differentiable function of c. The conditions under which this is possible—it requires, for example, that the equation have a unique solution—are given in Appendix 1. Under these conditions, since the left-hand side of this equation is increasing in p^R, it is easy to see that an increase in c must increase p^R. This means that the interval of people reporting to the leader, $[p^R, 1 - y]$ becomes smaller and more biased to the extreme right. This is as we would expect: an increase in the cost of communication means that only those who have a very strong incentive to communicate will do so.

Notice that the decision to report is no longer based simply on whether the signal moves the leader in the right direction: the reporter's gain from moving the leader must cover the cost of communication. Which leaders are most likely to get reports now depends on how the *size* of the gain from reporting behaves as a function of the leader's position, and there are essentially two potentially contending effects that determine this gain. On the one hand, giving a signal to an extreme left-wing leader is useful because, given that he is going to choose a very low value of x, the gain from getting him to increase his choice x even a little may be quite large. We call this *a marginal utility effect.* On the other hand, a less left-wing leader may be more responsive to a signal both because he considers it more plausible (the difference between the prior and the posterior shrinks to zero as the prior approaches either of the extremes) and also because his choice may be more responsive to changes in his posterior. This is what we call the *responsiveness effect.*

Consider, for purposes of illustration, the case where the utility function U is linear. Given these preferences, any leader who has a posterior of less than ½ chooses $x = 0$, while any leader with a posterior of more than ½ chooses $x = 1$. As a result, given that communication has a cost, no leader who is already right of center or on the extreme left will receive a signal since the signal cannot push their posterior across the critical value of ½. The only leaders who receive signals are those whose priors are below ½ but whose posteriors, given a signal, are above ½—in other words, those who are just left of center. This result in the linear case follows naturally from the fact that the marginal utility effect is absent. Conversely, one would expect that when the marginal utility effect is large, extreme leaders will attract the most voice for all values of c. In fact, in these cases, for large values of c, only extreme leaders attract any voice at all. This is the essence of the following proposition (formally stated and proved in Appendix 1).

PROPOSITION 8. Under truthful reporting, for $c \geqslant 0$, and for all *CRRA* utility functions where the coefficient of relative risk aversion, $\alpha \geqslant 1$, a more left-wing leader is more likely to get a signal. The leader who has the largest number of people reporting signals to him is the person on the left extreme. When c is large enough, only leaders on the extreme left get signals (if anyone gets a signal).[25]

As mentioned in the introduction, we can interpret high costs of communication as corresponding to issues that are relatively unimportant in the sense that the advantage from changing the leader's position is small when compared with the cost of transmitting information. The above proposition therefore implies that

25. The statement of this proposition is of course only valid under the assumption that the equilibrium is unique, an assumption we made at the beginning of this section.

on issues that are not very important, leaders have to be extremists to induce voice.[26] It is also worth noting that in this case, communication is always between leaders who are one extreme and members who are on the opposite extreme. This is clearly a stronger version of the point made earlier about voice acting as a moderating influence and communication being mainly between people who have very different views.

In the case where false signals may be reported, the introduction of communication costs affects the incentives of both those who report truthfully and those who report falsely. To illustrate the kinds of things that happen in this case, we focus on a specific equilibrium, the equilibrium described above with truthful reporting. Moreover, unless otherwise noted, we assume that there is unique equilibrium of this kind.

In an equilibrium with truthful reporting for a given p, as c goes up $p^R(p)$ clearly moves to the right: intuitively, the person who was strictly indifferent between suppressing and revealing his signal to p, now prefers to suppress it. As a result, the interval of those who report in an equilibrium with truthful reporting, $[p^R(p), 1 - y]$, shrinks. However, for essentially the same reasons, $\tilde{p}_R(p)$, now defined by the equation,

$$(1) \quad p_R U(x(\pi_R(p))) + (1 - p_R)U(1 - x(\pi_R(p))) - p_R U(x(\pi_N(p))) - (1 - p_R)U(1 - x(\pi_N(p))) = c$$

also moves to the right, and this has the implication that the condition $\tilde{p}_R(p) \geqslant 1 - y$, is now more likely to be satisfied. In other words, while the set of people willing to report shrinks, so does the set of people who would want to lie, making it more likely that an equilibrium with truthful communication exists. We summarize this in

PROPOSITION 9. In the misleading reports case, an increase in the cost of communication reduces the set of those who are willing to report in an equilibrium with truthful reporting. However, such an equilibrium may only exist when the cost of communication exceeds a certain level.

26. It is also the case that no matter what the relative sizes of the marginal utility and the responsiveness effects, for any *CRRA* utility function, the leader who gets the most right signals is to the left of center. Intuitively, this follows from the fact that the responsiveness to a right signal starts falling as we approach the center since right signals are less informative for more right-wing leaders.

We have already seen (Proposition 6) that at least for M large, there may be a lot more effective communication when an equilibrium with truthful communication exists than when it does not. That was for the case where communication was costless, but a similar logic applies when it is costly. Combined with the last result this tells us that *it is possible for an increase in the cost of communication to increase (effective) communication.*[27]

One interpretation of this is that there may be more communication on less important issues. This seems eminently plausible: many of the most important social issues in the West today such as race, welfare, and reproductive rights also seem to be exactly the issues where there is little open public discussion.

V. Group Heterogeneity and the Level of Voice

In this section we ask whether an increase in the heterogeneity of beliefs in a group promotes or discourages communication. Not surprisingly, the answer depends on how much leaders know about member characteristics and on whether information, once received, is verifiable or not, since different assumptions along each of these dimensions change the nature of the group providing voice to the leader.

An increase in heterogeneity corresponds in our model to a fall in y. An increase in heterogeneity therefore increases the average distance between the beliefs of a leader and other members of his group. However, in the truthful reporting case it keeps p^R unchanged. The measure of the population providing voice to a leader p in this case is $(1 - y - p^R(p))/(1 - 2y)$. Differentiating this expression with respect to y establishes that this expression is increasing in y if and only if $1 - 2p^R > 0$ which tells us that the effect is of ambiguous sign and depends on the position of the leader. However, if we make the assumption (also made before) that the leader's priors are equally likely to be anywhere between y and $1 - y$, we can look at the average effect of heterogeneity, averaged across possible realizations of the leader's prior. In other words, we compute $d(E_p[(1 - y - p^R(p))/(1 - 2y)])/dy$. This is equal to $E_P[1 - 2p_R(p)] > 0$ which is positive since $E_p[p] = ½$ and $p^R(p) < p$ for every realization of

27. Effective communication is measured as before, by $E|\Pr\{\theta|S, p\} - p|$. The precise result should actually say that there may be more effective communication in a certain equilibrium when c is higher than in any equilibrium with a lower c.

p. In this limited sense, an increase in heterogeneity reduces voice.

In the case where there is a potential for misleading reports, the effect of an increase in heterogeneity is more ambiguous. If there is an equilibrium where there is truthful reporting, which happens when $\tilde{p}_R(p) \geqslant 1 - y$, the measure of the set of people who report will be $(1 - y - p^R(p))/(1 - 2y)$, which is, not surprisingly, what it was in the truthful reporting case. The effect of an increase in y in this case is likely to be negative, because for it to be the case that $\tilde{p}_R(p) \geqslant 1 - y$, the leader's prior p has to be close to $1 - y$, and therefore it is likely that $p^R(p) > 1/2$. In words, an increase in heterogeneity is likely to increase voice in this case. This should be intuitive: in the misleading reports case, all the voice comes from relative extremists and an increase in heterogeneity tends to mean that there are more extremists around. However, there is another effect. An increase in heterogeneity may lead the interval $[\tilde{p}_R(p), 1 - y]$ to become nonempty, which will mean that at least in large populations, there will be no communication at all: in this case an increase in heterogeneity simply brings too many extremists into the population, and these extremists report false signals and block all possibility of communication.

VI. Some Extensions

We have made some fairly stringent modeling assumptions so far, mainly for reasons of tractability. We assumed that there was one leader, that there was at most one signal received by the group and that group members had common preferences and differed only in their beliefs. We argue, in this section, that the model can be generalized in all of these directions.

Turning first to the issue of multiple leaders, we note that the channels through which voice is expressed in some situations may make it impossible for an individual to choose his audience. This is especially true of the public discourse, where opinions are often expressed through public speeches or newspaper articles. Multiple audiences can either reduce or enhance voice relative to the single audience case. Those deciding to report information would consider the effect of their report on each audience, and each leader would also use this fact to evaluate the credibility of reports from different members. Consider, for example, the case where there is truthful reporting and the reporter is located between the two leaders. Now while he would always report a signal to the leader on his left in the single audience case, he may not do so if he fears the leader on his right would move *too much* in response to the report. The dual audience therefore stifles voice in this case. If information is not verifiable on the other hand, multiple audiences may enhance voice by lending credibility to some reports that would otherwise be ignored. Farrell and Gibbons [1989] show this for the dual audience case, and their results can be directly applied here.

If more than one signal is received by the group, then the leader would update, in Bayesian fashion, on the basis of all the signals that he receives and believes to be true. The sender's gain from reporting would now depend on the probability distribution of signals that the leader receives from other members. Characterizing the set who truthfully report is now a much more elaborate exercise, but is in principle no different from the one signal case.

Finally, turning to the assumption of heterogeneous priors and common preferences, notice that what limits the transmission of information in the model is the fact that different individuals have different preferred policies and will report to the leader in order to move group policies in their preferred direction. It really does not matter whether the differences in desired policies arise from heterogeneous beliefs or from heterogeneous preferences. As an example, consider a model where everybody has an identical prior p, but individual preferences given by

$$rV(x) + pU(x) + (1 - p)U(1 - x),$$

where r is uniformly distributed on $[-d,d]$, $U(\cdot)$ is defined as before, and $V(\cdot)$ is increasing and concave. Most of our results characterizing the sets of members providing voice go through for this alternative specification.

VII. Conclusions

We feel that voice is an important and neglected part of the study of the functioning of organizations in general and the political system in particular. We see the work in this paper more as a potential beginning than as a resolution. Using a simple example, we have attempted to isolate some of what we see as the key ingredients that go into determining voice and its effects on group policies.

However, much more remains to be done. Our work neglects important dynamic issues: one would think that, especially in settings where informational asymmetries are important, people will want to invest in reputations by, for example, never expressing certain views. In other words, borrowing terms from Hirschman once again, there may be an important interplay between *loyalty* and voice. We also ignore Hirschman's other concern, the interplay between voice and *exit*—there is only one organization in our world, and exit is not an option. The important role of institutions in encouraging as well as limiting voice is also ignored.

Of perhaps even more immediate concern is the fact that there is no welfare analysis in our paper—our results are purely positive. This is a consequence of our assumption of multiple priors—given that different people have different views of what will happen, the measure of social welfare will depend on whose point of view one takes: more voice on the right extreme is good for those on the right extreme but not necessarily for the rest of the population. At the same time, simply adding up the gains and losses in people's utilities seems hard to justify. Welfare analysis therefore must await the development of sensible welfare criteria for such settings. All of this work, and no doubt more, awaits future papers.

APPENDIX 1: SOME RESULTS FOR THE TRUTHFUL REPORTS CASE

In this appendix we will prove a number of results relating to the truthful reports case. The results are shown for the case where reporting is costly and lead up to Proposition 8 which is about what happens with costly reporting, but they apply mutatis mutandis to the case where reporting is costless.

LEMMA 1. $d\pi_R(p)/dp = \pi_R(p)(1 - \pi_R(p))/(p(1 - p))$.

Proof. By directly differentiating and then substituting the value of $\pi_R(p)$. ■

We will also need the expression for $d\pi_N(p)/dp$, and unfortunately this turns out to be much less straightforward because as was pointed out in Section III, π_N, unlike π_R, depends on p both directly and indirectly through its effect on i_R which in turn depends on p^R. We therefore write π_N as $\pi_N(p, p^R(p))$. We now prove

LEMMA 2. $d\pi_N(p, p^R(p))/dp = (\pi_N(p)(1 - \pi_N(p)))/(p(1 - p)) + \pi_{N2}(p, p^R(p))(dp^R/dp)$, where π_{N2} is the shorthand for the derivative of π_N with respect to its second argument.

Proof. By directly differentiating and then substituting the value of $\pi_N(p)$. ■

Next observe that p^R is defined by the equation,

$$V(\pi_R(p^R), x(\pi_R(p))) - V(\pi_R(p^R), x(\pi_N(p,p^R))) = c.$$

Assume that this equation admits at least one interior solution, i.e., a value of p^R strictly between 0 and 1. This is always the case, for example, if U is of the *CRRA* family with $\alpha \geqslant 1$, the main case that is examined in this section. To save on notation, denote $\pi_R(p^R)$ by π_R, $x(\pi_R(p))$ by x_R, $x(\pi_N(p, p^R(p)))$ by x_N.

Direct implicit differentiation then gives us

$$\frac{dp^R}{dp} = \frac{[\partial V(\pi, x_R)/\partial x]x'(\pi_R(p))(d\pi_R(p)/dp) - [\partial V(\pi, x_N)/\partial x]x'(\pi_N(\cdot))(d\pi_N(\cdot)/dp)}{\pi'_R(p^R)[\partial V(\pi, x_N)/\partial \pi - \partial V(\pi, x_R)/\partial \pi]},$$

which, using the previous two lemmas can be written in the form,

$$\frac{dp^R}{dp} = a + b\,\frac{dp^R}{dp},$$

where

$$a = \frac{[\partial V(\pi, x_R)/\partial x]x'(\pi_R(p))(\pi_R(p)(1 - \pi_R(p)))/p(1 - p)) - [\partial V(\pi, x_N)/\partial x]x'(\pi_N(\cdot))(\pi_N(p)(1 - \pi_N(p))/p(1 - p)}{\pi'_R(p^R)[\partial V(\pi, x_N)/\partial \pi - \partial V(\pi, x_R)/\partial \pi]}$$

and

$$b = -\frac{\pi_{N2}(p, p^R(p))}{\pi'_R(p^R)[\partial V(\pi, x_N)/\partial \pi - \partial V(\pi, x_R)/\partial \pi]} \times [\partial V(\pi, x_N)/\partial x]x'(\pi_N(\cdot)).$$

It follows that

$$\frac{dp^R}{dp} = \frac{a}{1 - b}.$$

A sufficient condition for dp^R/dp to be well defined everywhere is $b < 1$. If, in addition, a is positive, dp^R/dp will be positive.

Now it is easy to check by directly differentiating the expression for π_N, that π_{N2} goes to zero when β goes to zero. It therefore follows that

LEMMA 3. If an interior equilibrium always exists, the equilibrium will be unique, and dp^R/dp will be well defined everywhere if β is close enough to zero.[28]

We therefore assume for the rest of this section that β is small enough to ensure that dp^R/dp is well defined everywhere at interior values of p^R.

PROPOSITION 8. The following properties hold in the truthful reporting case with costly communication:

(i) For *CRRA* preferences as long as $\alpha \geq 1$, dp^R/dp is nonnegative for any value of c.

(ii) For *CRRA* preferences as long as $\alpha \geq 1$, for any $\epsilon > 0$, however small, if leaders outside the interval $[y, y + \epsilon]$ get reports of signals, leaders in the interval $[y, y + \epsilon]$ will as well.

Proof. Part (i): First observe that for *CRRA* preferences,

$$x'(\pi) = \frac{\pi^{(1-\alpha)/\alpha}(1-\pi)^{(1-\alpha)/\alpha}}{\alpha(\pi^{1/\alpha} + (1-\pi)^{1/\alpha})^2} = \frac{x(\pi)(1-x(\pi))}{\alpha\pi(1-\pi)}.$$

Denote $\pi_R(p^R)$ by π:

$$a = \frac{\begin{array}{c}[\partial V(\pi, x_R)/\partial x]x'(\pi_R(p))(\pi_R(p)(1-\pi_R(p))/p(1-p)) \\ -[\partial V(\pi, x_N)/\partial x]x'(\pi_N(\cdot))(\pi_N(p)(1-\pi_N(p))/p(1-p))\end{array}}{\pi_R'(p^R)[\partial V(\pi, x_N)/\partial\pi - \partial V(\pi, x_R)/\partial\pi]}$$

which has the same sign as

$$\begin{aligned}&-(\pi x(\pi_R(p))^{-\alpha} - (1-\pi)(1-x(\pi_R(p)))^{-\alpha}) \\ &\times\left(\frac{x(\pi_R(p))(1-x(\pi_R(p)))}{\alpha p(1-p)}\right) \\ &+(\pi x(\pi_N(p))^{-\alpha} - (1-\pi)(1-x(\pi_N(p)))^{-\alpha})\end{aligned}$$

28. The case where an interior equilibrium sometimes does not exist is similar: specifically, by applying the implicit function theorem it can be shown that the condition $b < 1$ guarantees that the equilibrium is always unique and dp^R/dp is well defined at all interior values of p^R.

$$\times \left(\frac{x(\pi_N(p))(1 - x(\pi_N(p)))}{\alpha p(1-p)} \right).$$

To complete the argument, we now need to show that

$$G(x) = (\pi x^{-\alpha} - (1-\pi)(1-x)^{-\alpha})x(1-x)$$

is a decreasing function of x. By direct differentiation,

$$G'(x) = \pi(1-\alpha)x^{-\alpha}(1-x) - \pi x^{1-\alpha} + (1-\pi)(1-\alpha)(1-x)^{-\alpha}x - (1-\pi)(1-x)^{1-\alpha},$$

which is always negative if $\alpha \geqslant 1$. ■

Proof. Part (ii): For this to be true, all we need to show is that $V(p^R,x(\pi_R(p))) - V(p^R,x(\pi_N(p)))$ is a decreasing function of p. This follows from the fact that its sign is always opposite to that of dp^R/dp. ■

APPENDIX 2: PROOF OF PROPOSITION 6

Proof. We have to show that the expected amount of updating, $E_S[|\Pr\{\theta|S,p\} - p|]$, becomes arbitrarily small as M become large.

By definition,

$$E_S[|\Pr\{\theta|S,p\} - p|] = \sum_{S=0}^{M} |\Pr\{\theta|S,p\} - p| \cdot [p \Pr\{S|\theta\} + (1-p)\Pr\{S|\theta'\}]$$

(the second term on the right-hand side is simply the probability of receiving S signals). Recall that

$$\Pr\{\theta|S,p\} = \frac{1}{1 + ((1-p)/p)} \left(\frac{\Pr\{S|\theta'\}}{\Pr\{S|\theta\}} \right)$$

and

$$\Pr\{S|\theta\} = \beta\mu i_R B(M-1,S-1,i_N) + \beta\mu(1-i_R) \times B(M-1,S,i_N) + (1-\beta\mu)B(M,S,i_N)$$

when $M > S \geqslant 1$;

$$\Pr\{S|\theta\} = \beta\mu(1-i_R)B(M-1,0,i_N)$$

$$+ (1 - \beta\mu) B(M,0,i_N) \text{ when } S = 0;$$

$$\Pr\{S|\theta\} = \beta\mu i_R B(M-1,M-1,i_N) + (1-\beta\mu) B(M,M,i_N) \text{ when } S = M.$$

In the proof we will make use of the properties of $\Pr\{\theta|S, p\}$ and $\Pr\{S|\theta\}$ as M becomes large. To keep track of the direct effect of M as well as the effect of M on i_N and i_R—which in turn influence $\Pr\{\theta|S,p\}$ and $\Pr\{S|\theta\}$—we will write these two expressions as $\Pr\{\theta|S,p,M,i_N, i_R\}$ and $\Pr\{S|\theta,M,i_N, i_R\}$.

We first derive expressions for expectation and the variance of the number of signals. We show that, by making M large enough, the expectation of S/M can be brought arbitrarily close to i_N, and its variance can be made arbitrarily small. This in turn implies that when M is large enough, the fraction of the population reporting to the leader will almost surely fall in an ϵ interval around i_N. In Step 3, we rewrite our expression of interest, $E_S[|\Pr\{\theta|S,p\} - p|]$, as a sum of two terms: the first corresponds to the event that the fraction of the population who report is outside an ϵ neighborhood around i_N, and the second to the event that it is within that neighborhood. The rest of the proof shows that both these terms go to zero for M large enough: the first because as we have already argued, the probability of this event goes to zero; and the second because when the fraction of the population reporting signals is close to i_N, the report of one extra signal conveys little additional information.

In all of these steps we need to be careful about the fact that i_N varies with M, and moreover, since the equilibrium is not necessarily unique, there may be multiple values of i_N corresponding to each value of M. We therefore have to show that each of the bounds we derive hold for all possible values of i_N.

Step 1: It can be shown by direct calculation that

$$E[S|\theta,M,i_N,i_R] = \beta\mu[(M-1)i_N + i_R] + (1-\beta\mu)Mi_N$$

and

$$E[S|\theta',M,i_N,i_R] = \beta\mu'[(M-1)i_N + i_R] + (1-\beta\mu')Mi_N.$$

Somewhat more involved calculations also establish that

$$\text{var}\,[S|\theta,M,i_N,i_R] = \beta\mu[(M-1)i_N(1-i_N) + i_R(1-i_R)]$$

$$+ (1 - \beta\mu)[Mi_N(1 - i_N)]$$
$$+ \beta\mu(1 - \beta\mu)[i_R - i_N]^2.$$

Likewise

$$\begin{aligned}\text{var } [S|\theta',M,i_N,i_R\} = \beta\mu'[(M - 1)i_N(1 - i_N) + i_R(1 - i_R)] \\ + (1 - \beta\mu')[Mi_N(1 - i_N)] \\ + \beta\mu'(1 - \beta\mu')[i_R - i_N]^2.\end{aligned}$$

Step 2: Fix an $\epsilon > 0$. Applying Chebysheff's inequality to S/M, we get that

$$\Pr\left\{\left|C - E\left[\frac{S}{M}\middle|\theta,\ M,\ i_N,\ i_R\right]\right| > \epsilon \middle| \theta\right\} < \frac{\text{var } [S|\theta,M,i_N,i_R\}}{M^2\epsilon^2}.$$

Now it is clear that there exists an M_1 such that for $M > M_1$, $E[S/M|\theta,M,i_N,i_R] = (\beta\mu[(M - 1)i_N + i_R] + (1 - \beta\mu)Mi_N)/M$ will be in δ_1 neighborhood of i_N, for any $\delta_1 > 0$ and *any value* of $i_N \in [0,1]$. Likewise there exists an M_2 such that for $M > M_2$,

$$\begin{aligned}\frac{\text{var } [S|\theta,M,i_N,i_R\}}{M^2\epsilon^2} = \frac{1}{M^2\epsilon^2}\{\beta\mu[(M - 1)i_N(1 - i_N) \\ + i_R(1 - i_R)] + (1 - \beta\mu) \\ \times [Mi_N(1 - i_N)] + \beta\mu(1 - \beta\mu) \\ \times [i_R - i_N]^2\},\end{aligned}$$

will be in an δ_2 neighborhood of 0, for any $\delta_2 > 0$ and *any value* of $i_N \in [0,1]$. In other words, there must be an M_3 such that for $M > M_3$, $\Pr\{|S/M - i_N| > \epsilon|\theta,M,i_N,i_R\}$ will be less than any prespecified δ_3, *for all possible values of* i_N and for any fixed choice of ϵ. By the exact same argument this is also true of $\Pr\{|S/M - i_N| > \epsilon|\theta',M,i_N,i_R\}$.

Step 3: Define $\mathrm{S}(M,i_N,\epsilon)$ to be the set of (integral) values of S such that $|S/M - i_N| \leqslant \epsilon$. Using this definition, we can rewrite the expression for

$$E_S[|\Pr\{\theta|S,p,M,i_N,i_R\} - p|]$$

as

$$\sum_{S\in \mathrm{S}(M,i_N,\epsilon)} |\Pr\{\theta|S,p,M,i_N,i_R\} - p| \cdot [p \Pr\{S|\theta,\ \cdot\}$$

$$+ (1-p)\Pr\{S|\theta',\cdot\}] + \sum_{S\notin \mathrm{S}(M,i_N,\epsilon)} |\Pr\{\theta|S,p,M,i_N,i_R\} - p| \cdot [p\Pr\{S|\theta,\cdot\} + (1-p)\Pr\{S|\theta',\cdot\}].$$

A consequence of what was said above is that for any $\delta_4 > 0$ and $\epsilon > 0$, however small, we can find an M_4 such that

$$\sum_{S\notin \mathrm{S}(M,i_N,\epsilon)} |\Pr\{\theta|S,p,M,i_N,i_R\} - p| \cdot [p\Pr\{S|\theta,\cdot\} + (1-p)\Pr\{S|\theta',\cdot\}] < \delta_4$$

for all $M > M_4$ and for *any value of* $i_N \in [0, 1]$ (because $p\Pr\{S|\theta, M,i_N,i_R\} + (1-p)\Pr\{S|\theta',M,i_N,i_R\}$ goes to zero and $|\Pr\{\theta|S, p, M,i_N,i_R\} - p|$ is bounded above by 1). Therefore, in order to prove our result, we only need to show that

$$\sum_{S\in \mathrm{S}(M,i_N,\epsilon)} |\Pr\{\theta|S,p,M,i_N,i_R\} - p| \cdot [p\Pr\{S|\theta,\cdot\} + (1-p)\Pr\{S|\theta',\cdot\}]$$

goes to zero as M becomes large.

Step 4: For this step consider only equilibria where i_N is bounded above by $1-\eta$ for some $\eta > 0$, for all M. The alternative case, where there is no equilibrium in which i_N remains bounded away from 1 for large enough M, will be dealt with in the next step. Consider the likelihood ratio,

$$\frac{\Pr\{S|\theta',M,i_N,i_R\}}{\Pr\{S|\theta,M,i_N,i_R\}}.$$

Using the above formulae and eliminating terms, it can be written as

$$\frac{\beta\mu' i_R(1-i_N)S + \beta\mu'(1-i_R)i_N(M-S) + (1-\beta\mu')(1-i_N)i_N M}{\beta\mu i_R(1-i_N)S + \beta\mu(1-i_R)i_N(M-S) + (1-\beta\mu)(1-i_N)i_N M}.$$

If $S \in \mathrm{S}(M,i_N,\epsilon)$, $Mi_N - M\epsilon$, S , $Mi_N + M\epsilon$ and $M(1-i_N) - M\epsilon$, $M - S$, $M(1-i_N) + M\epsilon$. Using this for $S \in \mathrm{S}(M,i_N,\epsilon)$, the above likelihood ratio can be bounded above by

$$\frac{i_N(1 - i_N) + \beta\mu'[i_R(1 - i_N) + i_N(1 - i_R)]\epsilon}{i_N(1 - i_N) - \beta\mu[i_R(1 - i_N) + i_N(1 - i_R)]\epsilon},$$

and below by

$$\frac{i_N(1 - i_N) - \beta\mu'[i_R(1 - i_N) + i_N(1 - i_R)]\epsilon}{i_N(1 - i_N) + \beta\mu[i_R(1 - i_N) + i_N(1 - i_R)]\epsilon}.$$

Evidently by choosing ϵ small enough, we can make both these bounds arbitrarily close to 1, and from above, we can make ϵ as small as we want by choosing M large enough. Therefore, for M large enough, for $S \in \mathrm{S}(M,i_N,\epsilon)$, the likelihood ratio $\Pr\{S|\theta',M,i_N,i_R\}/\Pr\{S|\theta,M,i_N,i_R\}$ will be in the neighborhood of 1, and therefore $|\Pr\{\theta|S,p,M,i_N,i_R\} - p|$ will be close to zero. This gives us the claimed result.

Step 5: Consider now the alternative case in which for any $\epsilon > 0$, however small, we can find an M^*, such that i_N is in an ϵ neighborhood of 1 for all $M > M^*$. In this case since $i_R \geqslant i_N$ and $i_R \leqslant 1$, for large enough M, $i_R \simeq i_N \simeq 1$. Therefore, for M large enough, $\Pr\{S = M|\theta\} \simeq 1$ and $\Pr\{S = M|\theta'\} \simeq 1$ and, consequently, $\Pr\{\theta|S,M,p,i_N,i_R\} \simeq p$. It follows that in this case, for large enough M, $E[|\Pr\{\theta|S,p\} - p|] \simeq 0$. ■

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