Policy Advice with Imperfectly Informed Experts

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Abstract

We study policy advice by several experts with noisy private information and biased preferences. We highlight a trade-off between the truthfulness of the information revealed by each expert and the number of signals from different experts that can be aggregated to reduce noise. Contrary to models with perfectly informed experts, because of this trade-off, full revelation of information is never possible. However, almost fully efficient information extraction can be obtained in two cases. First, there is an equilibrium in which the outcome converges to the first best benchmark with no asymmetric information as we increase the precision the experts' signals. Second, the inefficiency in communication also converges to zero as the number of experts increases, even when the residual noise in the experts' private signals is large and all the experts have significant and similar (but not necessarily identical) biases.

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1 Introduction

Policy-makers often make decisions that depend on variables over which they have no direct knowledge. In these situations, a policy maker may find it useful to query experts who have relevant private information: such as economists sought to design a tax plan, generals for war, or even lobbyists who speak on behalf of special interests. As it is often the case, these experts may also have a conflict of interest with the policy maker and incentives to misrepresent their information. A large literature has recently investigated this problem, analyzing the condition under which information can be extracted from these parties. With some relevant exceptions, the literature has focused on the role of the conflict of interest between the policy maker and the experts, simplifying the problem with the assumption that experts have perfect information on the state of the world.

Considering a model with imperfectly informed experts may seem a step toward realism of the analysis, but, perhaps, only a technical extension. On the contrary, in this paper we argue that in order to fully understand the effectiveness of communication and its impact on policy choices, it is important to study experts with noisy information. Indeed, when the experts' signals are noisy, we show that there is a *trade-off* between *information aggregation* and *information extraction* which could not be appreciated in the existing literature: by using signals from many different experts, the policy maker can reduce idiosyncratic noise; but in order to extract this information, the policy maker has to accept less precise messages from each of them in equilibrium. In this paper, we study this conflict and its impact on policy and welfare.

The first consequence of this trade-off is that, independently of the number n of experts, or the dimensionality of the state of the world, or of the policy variable, full extraction of information is impossible in equilibrium. This result, therefore, is in apparent contrast with the case in which experts' signals are not noisy. In this case, as proven in Battaglini [2002], full revelation is achieved with only two experts and for any dimensionality larger or equal than two.

However, we show that, even with noisy signals, previous results on efficient extraction of information in multidimensional environments are robust in two senses. First, when the *residual* noise in experts' private signals is small, the inefficiency is also small; and there is an equilibrium in which the outcome converges to the first best benchmark with no asymmetric information as the residual noise is reduced.

Second, and perhaps more importantly, our model with noisy signals allows us to study cheap talk with more than two experts, a question which could not be analyzed in previous frameworks with perfect signals (if all experts observe exactly the same signal, information extraction with three or more experts is immediate since a unilateral deviation can be easily detected). We prove that the inefficiency in communication converges to zero as the number of experts increases, even if the residual noise in experts' signals is large, all the experts have significant and similar (but not necessarily identical) biases (for example, many generals who all like to make war, or many economists who all like to increase taxes), and the policy maker has only an arbitrarily small ability to commit to a policy rule. If the policy game is repeated, even only for a finite number of periods, then the policy maker needs no commitment power at all to obtain almost full extraction of information in equilibrium, even if the discount factors is arbitrarily small.

Among other implications, these results show a natural environment (multidimensional, with noisy signals) in which, even if experts have an initial informational advantage, the policy maker does not find it optimal to delegate a decision to any expert. Rather, she prefers to keep the right to take it directly after a communication stage. Indeed, after the cheap talk stage, she can take a decision that is as informed as the decision that any expert can take (or better), but without the bias due to the conflict of interest. In the context of legislative committees, this result contributes to the debate on "open rules vs. closed rules", showing new conditions under which the "open rule" system is superior, independently from the informational advantage of the committee. These results are also insightful to understand the optimal organization of jurisdictions in committees or other organizations: in the equilibrium that achieves full information revelation (as the number of experts increases), experts necessarily report on overlapping jurisdictions. This feature is well documented in the empirical literature on legislative organizations.

Besides this, there is another reason why it is important to study noisy communication. When there are many experts and they all observe the same signal, there may be situations in which the posterior beliefs of the policy maker are not defined: for example, in a fully revealing equilibrium, it would be impossible that two experts report two different observations. This leaves some arbitrariness in the construction of the equilibria because some of them can be constructed with *ad hoc* out-of-equilibrium beliefs. Battaglini [1999] and Krehbiel [2001] have recently criticized these constructions on the grounds of the "plausibility" of out-of-equilibrium beliefs. In our model with imperfect signals, out-of-equilibrium beliefs never arise and therefore equilibria are robust to this criticism.

The paper is organized as follows. In Section 2 we present the model. Section 3 proves that it is impossible to achieve full revelation in equilibrium, for any finite number of experts and with any dimensionality of the environment. In Section 4.1 we explore the case in which only two experts can be consulted and we show that as the experts' residual noise is decreased, the inefficiency in communication converges to zero. In Section 4.2, we consider the case with $n > 2$ experts. Section 4.3 discusses when it is optimal to delegate the policy choice and the robustness of the equilibria to beliefs specification. Section 5 concludes. In the remainder of this section we discuss some related literature.

1.1 Related literature

A vast literature has recently built on the seminal paper by Crawford and Sobel [1982] to study how communication by privately informed agents can affect policy making.[1] Gilligan and Krehbiel [1989] study a model in which privately informed committees report in front of the floor before a decision is taken by majority rule and study the effect on information transmission of different institutional arrangements: in particular they compare a "closed rule" in which the floor delegates the decision to a committee to an "open rule" in which the committees can only make a report. This model has started a literature characterized by two assumptions: first, the policy space is unidimensional; secondly the experts are perfectly informed on the state of the world. Krishna and Morgan [2001] have recently completed the analysis of this framework providing a careful characterization of the possible equilibria.[2]

Austen-Smith [1990a] is the first to study the case of imperfectly informed experts. This approach is used in Austen-Smith [1990b, 1993b] to analyze the case of multiple referrals under an open rule decision procedure, comparing the informative properties of the equilibria with either joint or sequential referrals. As in previous literature, these papers continue to assume a unidimensional environment. Different from our work, however, these papers do not focus on the size of the inefficiency and do not present results under which the policy maker can achieve full information extraction.

Wolinsky [2002] considers a related problem in which there are more than two biased experts with noisy signals. He is interested in the optimal organization of communication procedures. In a model with binary information and binary policy space, he shows that allowing partial communication among the experts might induce more information revelation.

An alternative model with imperfectly informed experts is developed by Ottaviani and Sorensen [2003]. Contrary to our approach and from the papers cited above, they study the case in which the state can be verified ex post, and therefore they focus on situations in which experts' compensation does not depend on the policy choice but, because of reputation effects or particular incentive schemes, only on the accuracy of their signals.

All of these papers, therefore, do not consider the trade-off between information aggregation and information extraction that we wish to highlight and study in this work.[3]

The study of multidimensional models of cheap talk is introduced by Austen-Smith [1993a] and Battaglini [2002]. The first paper attempts to combine noisy signals with a multidimensional environment in a model in which experts receive a finite number of imperfect signals. The author extends the model introduced by Austen-Smith [1990a] to the case in which the policy space is two dimensional. In this environment, he provides conditions that guarantee some information transmission and studies the experts' incentives to acquire information.

[1] An excellent account of this literature can be found in Grossman and Helpman [2001].

[2] The work by Gilligan and Krehbiel has stimulated a large empirical literature that we can not fully discuss because of space constraints. See Krehbiel [1991] for an extensive discussion of this literature.

[3] Battaglini and Bénabou [2003] have also studied a model of policy advice (by lobbyists or activists) with noisy signals. In this model, however, communication is costly: although the cost is assumed to be very small, its presence introduces a free-rider problem that is not studied in this paper.

This paper too, however, does not focus on finding conditions under which the inefficiency of communication is small and it does not study the trade-off between information aggregation and information extraction. Battaglini [2002], on the contrary, considers a model with a continuous state variable and shows that when experts are perfectly informed, full revelation is generically possible; experts, however, receive signals with no noise.

As mentioned, our results have implications for organization design, showing conditions under which the policy maker does not find it optimal to delegate the policy choice to the experts despite the fact that they have an informational advantage. Only few papers have studied the relationship between institutional design and information transmission. We have already cited the work by Gilligan and Krehbiel [1989] and Krishna and Morgan [2001] on the choice between an open and a closed rule. In a seminal work, Dessein [2002] constructs a general theory of delegation based on information transmission between an informed expert and a decision maker. Focusing on a one-dimensional model of cheap talk with only one sender, he shows conditions under which delegation is optimal. Our results complement this literature on delegation by considering the case with multiple experts and noisy signals.[4]

Finally, the issue of plausibility of out-of-equilibrium beliefs has been raised by Battaglini [1999] and Krehbiel [2001]. Baron and Meirowitz [2001] have recently studied how the assumption that experts observe perfect signals can be exploited to construct out-of equilibrium beliefs that support particular equilibria. Our paper contributes to a solution of these problems presenting a framework in which equilibria are generally and naturally well-defined.[5]

2 The Model

We consider the case of a policy maker who has to take a decision given the advice of $n > 1$ informed experts. Let $Y \equiv \Re^q$ denote the set of alternatives for the policy maker. Following a standard approach in the literature[6] we distinguish between the policy space and the outcome space. Given a policy y in Y, the outcome is $x = y + \theta$ where θ is a q-dimensional vector in $\Re^q$. Nature chooses θ according to some continuous distribution function $F(\theta)$ with density $f(\theta)$, support $\Re^q$ and zero expected value. The policy maker chooses y without knowledge of θ but she can request advice from the experts. Contrary to the standard approach, experts are not perfectly informed: each expert i observes only an unbiased signal $s_i(\theta)$ which is a random variable with continuous

[4] The relationship between our results an these papers is discussed in greater detail in Section 4.3.

[5] The issue of out-of-equilibrium beliefs in cheap talk games with multiple experts is different from the questions typically studied in the literature on refinements of equilibria in cheap talk games, since this focuses on refinements of equilibrium beliefs (in games with one sender). On this literature, see Farrell [1993], Matthews, Okuno-Fujiwara and Postlewaite [1991] and Olszewski [2004].

[6] This approach was first introduced by Austen-Smith and Riker (1987), followed then by Gilligan and Krehbiel [1989], Battaglini [1999, 2002], Krishna and Morgan [2001].

distribution and full support in $\Re^q$.

Since in this framework no agent observes the state of the world, we need to make assumptions on the information structure in order to have a simple closed-form posterior distribution to work with. We make two main assumptions. First we assume that contingent on a realization of the state $\theta = \{\theta_1, ..., \theta_q\}$, the signal observed by agent i is a random variable

$$\begin{pmatrix} s_{i,1}(\theta) \\ ... \\ s_{i,q}(\theta) \end{pmatrix} = \begin{pmatrix} \theta_1 + \varepsilon_{i,1} \\ ... \\ \theta_q + \varepsilon_{i,q} \end{pmatrix} \tag{1}$$

where $\varepsilon_i = \{\varepsilon_{i,k}\}_{k=1}^q$ is a random vector with multivariate normal distribution with zero mean and covariance matrix Σ_i. It is quite natural that two experts who observe signals from the same phenomenon have an unbiased estimate, however, it is hardly the case that they observe exactly the same signal; the representation of noise as in (1) guarantees that the two experts receive the same signal with zero probability. We assume that the *residual* noisiness of the signals of the two experts are independent: i.e. for any expert i and $j \neq i$ and any dimensions k, l, $E(\varepsilon_{i,l}\varepsilon_{j,k}) = 0$.[7] In many situations, in fact, it is natural to assume that the experts have independent sources of information, and therefore the residual noises associated with the two experts are independent. If we think of the experts as two lobbyists (for example, an environmentalist and a representative of the auto industry), we may imagine that the errors that they may commit depend on their ability to interpret the world, their background, etc., and therefore they are independent. We do not assume, however, that the errors that agent i may commit in the jth dimension are not correlated with the error on the kth dimension; indeed it might be that $E(\varepsilon_{i,j}\varepsilon_{i,k}) \neq 0$. Note, moreover, that although residual noises in the signals of the two experts are uncorrelated, the *signals are correlated* since they both depend on the realization of the state of nature θ. Although it is not necessary for most of the results, it simplifies that analysis to assume that the covariance matrix of the residual noise is constant across experts ($\Sigma_i = \Sigma\ \forall i$), so that they are all equally informed. We say that noise converges to zero if the elements of Σ converge to zero.

Second, we also need an assumption of the prior belief of the policy maker. There are a number of alternative prior distributions for θ that, combined with the signals as in (1), would give 'closed form' posterior beliefs.[8] We choose the agnostic view (Laplacian using the terminology of Morris and Shin [2001]) that the principal has a uniform prior belief.[9] This assumption allows us to focus on the main intuition without technical complications: indeed, it implies

[7] Signals are therefore conditionally independent. This is the standard assumption in the literature on information aggregation (see, for example, Feddersen and Pesendorfer [1997]).

[8] In his model of cheap talk, Austen-Smith [1993a] assumes the signals to be distributed as a Bernoulli with prior distribution on the state that is a Beta. However, in this approach, agents observe only discrete signals (the realizations of the Bernoulli); moreover, Austen-Smith [1991] assumes that noise on each dimension is independently distributed, while we assume a general variance-covariance matrix Σ.

[9] Technically, since the domain is $\Re^d$ we are assuming a so-called improper uniform prior. This is a standard assumption in Bayesian updating theory. An excellent introduction to

that if the policy maker observes n independent and unbiased signals $\{\widehat{s}_i\}_{i=1}^n$ with the same covariance Σ, the posterior is a multivariate normal with mean $\frac{1}{n}\sum_i \widehat{s}_i$ and covariance $\frac{1}{n}\Sigma$.[10] More fundamentally, when the precision of the signals is large compared with the precision of the prior, or when there are many signals, then the posterior distribution under these assumptions will be an arbitrarily close approximation to the posterior density derived from any arbitrary specification of the prior distribution.[11] This assumption, therefore, corresponds to the plausible case in which the information of the expert is much more precise than the information available to the policy maker. Finally, note that the uniform prior assumption is adopted in Gilligan and Krehbiel [1987, 1988] and in almost all papers inspired by this work.[12]

The timing of the game is the following. At time 0 nature chooses θ according to $F(\theta)$ and each expert observes the signal $s_i(\theta)$ introduced above. At time 1, the experts are asked to make a report simultaneously or privately on the information that they have on the state of nature to the policy maker; the policy maker decides y and the outcome that is realized is $x = y + \theta$. We assume that agents care only about the outcome x of the policy. As standard in the literature,[13] we assume that all agents have a well defined ideal point in the outcome space and try to minimize the Euclidean distance between this and the outcome; in particular we assume weighted euclidean utilities defined as

$$u_i(x) = \left\|x - x^i\right\|_{\gamma_i} = -\sum_{k=1}^{q} \gamma_{i,k} \left(x_k - x_{i,k}\right)^2 \tag{2}$$

where $x^i = \{x_{i,j}\}_{j=1}^q$ is the agent's ideal point.[14] This norm captures the fact that, although for each agent 'the nearer to the ideal point, the better', the trade-off between the dimensions is not symmetric and an agent may benefit more in one dimension than in the other: these trade-offs are described by the vector of coefficients γ.

Given (2), each agent is characterized by an ideal point x^i and weights γ_i. In order to distinguish the $n+1$ players of this game (the policy maker and the n experts), we will denote the ideal points respectively x^P, x^i, $i = 1...n$. Without loss of generality we normalize the ideal point of the policy maker so that $x^P = 0$. We also assume that the sender's ideal points are generically chosen; therefore $\{x_i\}_{i=1}^n$ and $\{\nabla u_i(0)\}_{i=1}^n$ are linearly independent collections of vectors.

improper priors is DeGroot [1970], § 10. For an application of this assumption to an economic model see Morris and Shin [2001].

[10] See DeGroot [1970], § 10.3, p.196.

[11] This is what Savage called the "principle of stable estimation" (Edward, Lindman and Savage [1963]). For a result in this sense see Theorem 1 in DeGroot §10.4.

[12] However, Battaglini [2002] assumes a general prior distribution.

[13] For example, these are the preferences used in a one dimensional space by Austen-Smith [1990a], Gilligan and Kehbiel [1987] and [1989], Krishna and Morgan [1999]; and by Austen-Smith [1993a] in a two dimensional space. The result can be extended to the case in which utilities are only quasi-concave and differentiable.

[14] For simplicity and without loss of generality, we drop the square root.

3 Full information extraction: an impossibility result

Crawford and Sobel [1982] were the first to show that full revelation of information is impossible in a cheap talk game with one sender and one receiver. Battaglini [1999, 2002] and Krishna and Morgan [2001] have extended this result to situations in which there is more than one expert, the state of the world is unidimensional and each expert perfectly observes the true state of the world. Battaglini [2002], however, has shown that a fully revealing equilibrium always exists if the state variable is multidimensional. In this section we generalize previous impossibility results to the case in which the experts observe noisy signals, showing that it is impossible to extract all the information from the experts, independently from their number or from the dimensionality of the problem.

Definition 1 *An equilibrium is fully revealing if the policy maker's posterior after the experts' messages have been sent is equal to the posterior under the assumption that the policy maker can directly observe the experts' signals.*

In a fully revealing equilibrium each expert perfectly reveals his signal on each dimension of the problem and therefore there is no trade-off between information aggregation and incentives for truthful revelation.

Proposition 1 *For any finite number of experts, any residual noise and any dimensionality q of the environment, no Fully Revealing Equilibrium can exist.*

To see the intuition of this result, it is useful to compare it with the efficiency result in Battaglini [2002], where it is proven that in any multidimensional space full extraction of information can be achieved by querying only two experts. Consider the two dimensional case. The equilibrium that supports full information transmission is such that each expert's advice is used to find the optimal policy only on one dimension. Efficiency is obtained because when experts perfectly observe the true state, it would be redundant to use the signal of more than one expert for each dimension. When experts observe noisy signals, however, it is important to use as many signals as possible in all dimensions of the problem. However, if the message of a sender affects all the dimensions of the problem, then the sender can always bias the outcome toward his own ideal point. In order to eliminate conflicts of interest with a sender, the policy maker needs to limit the amount of information that the sender can transmit. *This is exactly the trade-off between information aggregation and information extraction mentioned in the introduction.* Proposition 1 shows that this trade-off cannot be solved: *if truthful revelation is required, then we cannot have aggregation of all signals; if aggregation of all signals is achieved, then signals would not be perfectly truthful.*

The result presented above shows that there is always an inefficiency in information extraction, but it does not quantify the inefficiency. In the next section, we show that there are two important cases in which the inefficiency is arbitrarily small.

4 Efficiency results

In this section we study how large is the inefficiency in communication that has been identified in Proposition 1 when, realistically, the environment has more than one relevant dimension ($q > 1$). In Section 4.1, we consider the hardest case in which the policy maker has access to only two experts. We show that the inefficiency of communication converges to zero as the residual noise in the experts' private signals is reduced. This result, therefore, generalizes the equilibrium construction and the efficient extraction results in Battaglini [2002] to cases with perturbed signals. One immediate implication of this result is that, despite the policy maker starting with no information (uniform prior), when the noise of the experts is not too large, there is an equilibrium in which the policy maker would never find optimal to delegate the decision to one expert, even if the conflict of interest is very small.

Second, in Section 4.2 we study how the trade-off between information extraction and information aggregation can be reduced if more than two experts are available. As said in the introduction, this question could not be studied in previous frameworks because extraction of information is trivial in environments in which the experts perfectly observe the state of the world: since all experts observe exactly the same information, even if one of them lies, the outcome would not change because the other two would still perfectly reveal the true state. Clearly this approach has little theoretical or empirical interest, and it is impossible when signals are noisy. The problem is more complicated with noisy signals since reports are different with probability one.

4.1 The two experts case

The characterization of the most informative equilibrium when the environment has more than one dimension and there is noise in the signals is extremely hard because, as proven by Proposition 1, the need to guarantee incentive compatibility for information revelation has to be balanced with the need to aggregate as many signals as possible on all dimensions. This implies randomizations and "partitional" strategies as in Crawford and Sobel [1982], but in a multidimensional world in which a simple monotonicity condition cannot be used to pin them down. For these reasons, we prove our results characterizing a class of equilibria which can be used to find a *lower bound* on the maximal level of efficiency of communication in the cheap talk game.[15] The equilibria in this class have the property that each dimension is truthfully revealed by at least one expert. We say that a dimension of θ is truthfully revealed by an expert, if the exert reveals the best prediction of this dimension given his private signal.

Definition 2 *An equilibrium is truthful if there exists a coordinate system in*

[15] As standard in the literature, we focus on the most informative equilibrium. Indeed in all cheap talk games, and our model is no exception, there are multiple equilibria and there is always a "babbling equilibrium" with no information transmission.

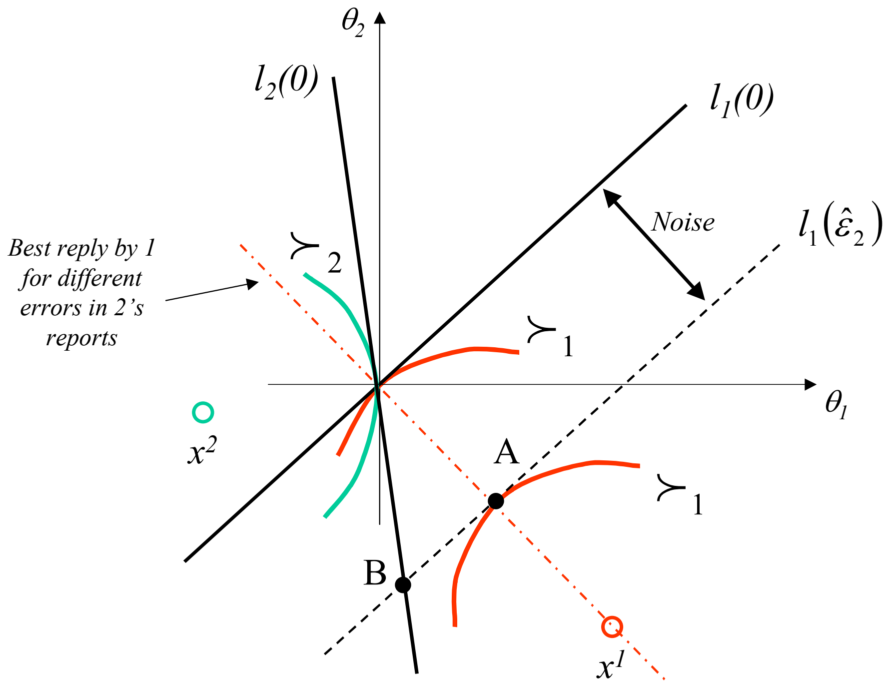

Figure 1: The construction of the equilibrium with noisy signals.

which each dimension of the state θ in this coordinate system is truthfully revealed by at least one expert.

Two characteristics of this class of equilibria should be noticed. First, even if there is more than one informed expert, some dimensions may be reported by only one expert in this class of equilibria. These equilibria, therefore, sacrifice information aggregation in favor of truthful information extraction (and this explains the name). In a truthful equilibrium as defined above, moreover, communication does not necessarily occur in the usual orthogonal coordinate system. In order to guarantee incentive compatibility, the policy maker can require the experts to report the state of the world on some different coordinate system. Since in these equilibria messages are truthful, the policy maker can, after the communication stage, translate them in the original system and obtain an unbiased vector of signals. One implication of the existence of such equilibria is that the policy maker (who has a uniform initial prior, and therefore no initial information whatsoever) after hearing the messages becomes an expert himself, as if she also observed an unbiased private signal. The next result generalizes the equilibrium construction in Battaglini [2002] to the present environment with noisy signals.

Proposition 2 *For any $q > 1$ dimensional environment, for any given level of the conflict of interest between experts and the policy maker, and for any given level of the variance of the experts' noises, there exists a truthful equilibrium.*

To see the intuition of the result, consider Figure 1, which represents a particular example in a two dimensional environment. The thick lines $l_1(0)$ and $l_2(0)$ which are constructed to be tangent at the origin to the indifference curve of, respectively, agents 1 and 2, represent a new coordinate system: agent i will be required to report the coordinate of θ on the $l_i(0)$ axis based on his own private signal. When there is no noise, this coordinate system guarantees that each expert has incentives to truthfully reveal his information on the assigned dimension. If j reports the jth coordinate truthfully, then the policy maker will be able to neutralize the effect of the state θ on the jth dimension of the policy outcome, and agent i will be able to induce only a point on the $l_i(0)$ coordinate. The best point that agent i can induce on this coordinate is, by construction, the origin: this is also the policy makers's ideal point, so agent i finds optimal to achieve it by truthfully reporting the $l_i(0)$ coordinate to the policy maker.[16]

Consider now the case in which there is noise. Even if agent i reveals the truth, the hyperplane on which agent j is influential passes through the ideal point of the policy maker with probability zero since noise has a continuous distribution. In Figure 1 this is represented by the dashed line $l_1(\widehat{\varepsilon}_2)$ which is the line on which agent 1 induces a point for a particular realization in expert 2's noise. For example, assume that the realization of the signal of expert 2 is $s_2 = \theta_2 + \widehat{\varepsilon}_2$ (where $\widehat{\varepsilon}_2$ is the realization of ε_2). In this case, if the policy maker believes the experts choosing $y_i = -s_i$, expert 1 would induce a point on the locus:[17]

$$\begin{pmatrix} \theta_1 + y_1 \\ \theta_2 + y_2 \end{pmatrix} = \begin{pmatrix} \theta_1 - s_1 \\ \theta_2 - s_2 \end{pmatrix} = \begin{pmatrix} \theta_1 - s_1 \\ -\widehat{\varepsilon}_2 \end{pmatrix} = l_1(\widehat{\varepsilon}_2) \neq l_1(0) = \begin{pmatrix} \theta_1 - s_1 \\ 0 \end{pmatrix}$$

Indeed, it is *impossible* to force agent 1 to be influential only on the hyperplane passing through the policy maker's ideal point because no agent in the model knows the true realization of nature. This may create problems for agent 1's incentives to be truthful because his optimal reaction function depends on the realization of the signal. If agent 1 could predict that the residual noise in 1's signal is $\widehat{\varepsilon}_2$ (and therefore that he would induce a point on $l_1(\widehat{\varepsilon}_2)$) he would know that by being truthful he would induce point B; on the contrary, by misrepresenting his signal he could induce point A, which is superior. The new coordinate system, in fact, guarantees incentive compatibility in equilibrium at the origin, not in other points.

Proposition 2, however, proves that to provide incentives to the senders to be truthful, it is not necessary to induce exactly the right hyperplane passing through the policy maker's ideal point. On the one hand, since the receiver

[16] See Battaglini [2002] for a complete discussion of the equilibrium in the case in which experts' signals have no noise.

[17] In the following we denote $\begin{pmatrix} x \\ y \end{pmatrix}$ the x, y coordinate in $l_1(0), l_2(0)$.

can use the truthful signal received by agent 2, agent 1 knows that the outcome would be a hyperplane which, *on average*, passes through the receiver's ideal point ($l_1(0)$). On the other hand, the residual error in agent 2's signal that affects the hyperplane is uncorrelated with the information available to the other expert: so he cannot use his private information to predict on which hyperplane he will be influential. Agent 1, therefore, cannot predict if it is better to deviate declaring a higher state or a lower state and the benefit of such a deviation is exactly compensated by the cost (as formally proven in the proof of Proposition 2). It follows that the agent behaves as if he knows that he will be influential on the expected hyperplane $l_1(0)$ and truthful revelation remains optimal as if there were no noise. Indeed, for truthful revelation, it is only necessary that incentives are provided at the *interim* stage, i.e. when expert 1 does not know the realization of the signal of expert 2.

As we mentioned, the existence of a truthful equilibrium has strong implications for welfare. We started with the assumption that the policy maker had no knowledge of the state of the world since we assumed a uniform prior; we have shown that there is an equilibrium in which all the coordinates of some coordinate system are truthfully revealed by at least one expert. The next result uses this existence result to bind from below the policy maker's utility:

Proposition 3 *When $q > 1$ there is an equilibrium in which:*

i. As the experts' residual noise is reduced, the policy maker's utility converges to the first best in which the policy maker observes the state of the world.

ii. An implication of this result is that for any given level of the conflict of interest, even very small, if the residual noise in the experts' signals is small enough, then the policy maker would find it strictly suboptimal to delegate the decision rule to any of them.

Given Proposition 2, the intuition of this result is simple. Whatever coordinate system is used for information extraction, the impact on utility of the error term in the policy maker's posterior is a linear combination of the variances and covariances of the experts' signals, so as these converge to zero, the error of the policy maker also converges to zero. This immediately implies that when the noise in the experts' private signals is small enough, the inefficiency due to the lack of direct information is smaller than the distortion the experts' preferences would induce if they could choose the policy (which is always strictly positive, independently of noise): so delegation is strictly suboptimal.

4.2 More than two experts

There are many situations in which the policy maker can ask the advice from more than two informed experts. As we mentioned above, when the experts observe only imperfect signals, the policy maker cannot crosscheck the messages, because the private signals will be different with probability one and these differences may be due to the noisy component. It is however intuitive to imagine that if we can construct overlapping jurisdictions that preserve incentives for truthful revelation for the experts, then we might obtain informative signals from many different experts for each dimension of the state: in this case, the larger the number of experts, the better the equilibrium policy would be. To construct a system of jurisdictions with these properties, however, we have to make sure that the overlaps on the jurisdictions do not "disturb" the incentives for truthful revelation.

In this section we formalize this idea. We first consider the case in which the policy maker has some limited ability to commit to a policy rule.[18] Given this, we prove that even if the residual noise in the experts' signals is large, and even if the commitment ability is *arbitrarily* small, the equilibrium policy converges to the policy that would be chosen in the first best benchmark with complete information as the number of experts increases. Then, using this result, we prove that when the policy game is repeated for a *finite* number of periods there is an equilibrium *with no commitment* in which the average payoff approximates the theoretical first best payoff with full information in all periods except at most the last, even if the discount factor is arbitrarily small (when the number of experts is large enough).

Assuming that the policy maker can commit to implement a decision that is very inefficient is clearly not realistic. However, it is certainly realistic to assume that the policy maker has some, perhaps very limited, commitment power: in the sense that she can commit to implement a policy that is not "too much" inefficient. The policy game may be repeated and the policy maker may be concerned about her reputation. On the other hand, however, the probability of reelection may be stochastic and perhaps very low, so the reputational motive may appear ineffective in giving credibility to the policy maker's promise, except when it is cheap to maintain it. We say that a policy maker has ε-commitment if she can commit to take a policy that generates no less than $\varepsilon > 0$ welfare than the ex-post optimal policy. Indeed, the assumption that the policy maker has ε-commitment, is probably the *most* realistic assumption, at least for ε small enough.

The following result shows that any arbitrarily small commitment power is sufficient to extract all the information if the number of experts is large enough. Let us denote $W(n, \varepsilon)$ the policy maker's maximal welfare in equilibrium when n experts are available and commitment is ε; and define W^* as the first best level of welfare with complete information. We have:

Lemma 1 *For any $\varepsilon > 0$ and $\eta > 0$, there is a $\overline{n}$ such that if $n > \overline{n}$, then $W^* - W(n, \varepsilon) < \eta$, for any level of noise of the signals, any dimensionality $q > 1$ of the environment and any level of the conflict of interest.*

[18] The assumption that the receiver can commit to a policy rule is common in the literature. It is indeed standard to assume a so called "closed rule:" the decision maker commits to implement either policy suggested by the senders or a fixed status quo. This is a strong assumption since the ex post inefficiency of this policy may be very high and even potentially unbounded. See Section 4.3 for a more complete discussion.

It is important to observe that while an ε amount of commitment is required from the policy maker, the senders find it *strictly optimal* to report truthfully. Indeed, while it is natural to assume that the policy maker is concerned by her reputation and therefore has some ability to credibly commit, this is certainly not true for any of the many senders that, as assumed in this section, can be anonymous citizens with little interest at stake in the decision (and little information too).[19]

The intuition of this result is the following. Assume here, for the sake of illustration, that there is an even number of experts and group them in couples so that agent i is associated with agent $i+1$. For each couple i (the couple takes the name of the first component) we can associate a base of vectors A_i. This new coordinate system is constructed as in Proposition 1, so that each of its components is orthogonal to the gradient of some expert, as $l_1(0), l_2(0)$ in the example described in the previous section. Assume that, as in Proposition 1, each dimension in A_i is revealed by some expert in the couple: then the policy maker would extract from each couple an unbiased signal on the state θ, say $\widehat{\theta}^i$ (in the coordinate system A_i), which can be transformed in the original orthogonal coordinates as $z_i = A_i\widehat{\theta}^i$.[20] Assume that all the couples except the ith couple are following the equilibrium strategies, and the policy maker simply averages the experts messages implementing the average policy $y^* = -\sum_{j=1}^{\frac{n}{2}} \frac{2}{n} z_j$. So the expected outcome would be:

$$E(\theta + y) = E\left(\theta - \sum_{j=1}^{\frac{n}{2}} \frac{2}{n} z_j\right). \tag{3}$$

Because the signals sent by each couple $j \neq i$ are unbiased ($Ez_j = \theta$) (3) can be written as

$$E\left[\left(I - \frac{n-2}{n} I\right)\theta - \frac{2}{n} z_i\right] = \frac{2}{n} A_i \left[\theta^i - \widehat{\theta}^i\right]$$

where θ^i is the representation of θ in the A_i coordinate space (so $\theta = A_i\theta^i$). As in Proposition 2, the experts in the ith couple would be truthful if they had to report on coordinates in A_i because each of these coordinates is constructed to be orthogonal to the gradient of some expert's utility. But the same would be true for the coordinates described by the matrix obtained pre-multiplying A_i by the scalar $\frac{2}{n}$: each of its coordinates remain orthogonal to the gradients of the assigned experts, and *therefore experts would still report truthfully as if there were no other experts except them.* As the number of pair of experts that can be consulted increases, the number of independent and unbiased signals available to the policy maker increase: and the posterior becomes increasingly precise.

[19] Note that since senders are required to play (strictly) optimal strategies, an equilibrium with ε-commitment (as defined above) is a stronger concept than a standard ε-equilibrium.

[20] So we denote $\widehat{\theta}^i = \begin{pmatrix} m_i \\ m_{i+1} \end{pmatrix}$ where m_i is the coordinate sent by i.

The policy maker's choice of the average policy $y^* = -\sum_{j=1}^{\frac{n}{2}} \frac{2}{n} z_j$ is not optimal given the updated beliefs. Even if, as we assume, all experts receive signals with the same precision, the fact that they report on different coordinates distorts the precision of their messages. Because of this each couple will generate an informative signal $\widehat{\theta}^i$ with a particular variance covariance $\widehat{\Sigma}_i$ and it is not optimal to average them with equal weights. However, the coordinate transformation is a linear operator so, as we said, $E\widehat{\theta}^i = \theta$ for any i, and $Ey^* = -\theta$ is unbiased. Moreover as n converges to infinity it has the variance covariance of the estimator $\sum_{j=1}^{\frac{n}{2}} \frac{2}{n} z_j$, which converges to zero. Therefore, given any $\varepsilon > 0$, for n large enough the policy y^* cannot yield less than ε welfare than the optimal policy.

We can now introduce and prove the main result of this section. So far we have assumed that the policy game is strictly one shot, but it is actually natural to assume that the interaction between the policy maker and the experts can be repeated over time for some perhaps *finite* number of periods T. For example, the length of a legislature is more than one period, but finite; the length of the mandate of the president of the United States (or of a congressman) is also more than one period, but finite. We now consider an extension in which a new state of the world and new informative signals are drawn in each period, and the policy game is repeated; and, as usual, the players evaluate the entire game discounting future payoffs by a factor $\delta \in (0,1)$. For a given equilibrium, let us denote $W_t(n,\delta)$ the equilibrium welfare in period t when the discount factor is δ and $W^A(n,\delta) = (1-\delta)\sum_{t=1}^{T} \delta^{t-1} W_t(n,\delta)$ the average welfare (i.e. the policy makers' utility) generated in this repeated game. We have:

Proposition 4 *For any $\delta \in (0,1)$, $\eta > 0$ and any $T > 1$, there is $\overline{n}$ such that for $n > \overline{n}$ there is an equilibrium of the cheap talk game in which $W^* - W_t(n,\delta) < \eta$ for any period t except, at most, the last. Therefore, for any $\eta > 0$, there is a $\overline{n}$ and a $\overline{T}$, such that for $n > \overline{n}$ and $T > \overline{T}$ there is an equilibrium in which $W^* - W^A(n,\delta) < \eta$.*

This result, therefore, shows that even if the policy maker is very myopic (δ small) and even if the interaction with the experts spans a finite interval of time, the cheap talk game can be very effective and lead to approximately full efficiency.

The idea of this result exploits the natural multiplicity of equilibria that arise in cheap talk games. Assume, for simplicity, that $T = 2$. Assume that in period 1 the senders and the policy maker play an equilibrium as in Lemma 1. In period 2, however, all the experts except two, say i and j, play a completely uninformative strategy. The policy maker and the remaining two experts play at *t=2* an equilibrium that is contingent on the outcome in period one. If in period one the policy maker follows the equilibrium strategy, then at *t=2* they play an informative equilibrium as constructed in Proposition 2; and we choose the identity of agents i and j that would maximize the policy makers' welfare in this class of equilibria.[21] If instead the policy maker deviates in period one, then they play a "bad equilibrium": which can either be a simple babbling equilibrium (which also always exists) in which no information is transmitted at all; or a less harsh informative equilibrium in which the identity of i and j are chosen to minimize the policy maker's welfare (by Proposition 2 we can construct an informative equilibrium for any couple i, j). At $t = 2$, the strategies are clearly optimal for all agents because, whatever is the history at that stage, they are required to play a static Nash equilibrium. Consider now period one. The second period clearly provides incentives for the policy maker to play the equilibrium strategy, but is the incentive enough even if δ is small? Whatever is the level of the incentive, from Lemma 1 we know that there is a $\overline{n}$ such that if $n > \overline{n}$, the benefit of deviating is smaller than any $\varepsilon > 0$. Therefore for n large enough we have an equilibrium even if the expected discounted benefit from period two is very small because δ is small. It is easy to generalize this idea for $T > 2$: the longer is the length of the interaction the higher are the incentives of a threat to revert to a babbling equilibrium. So we can construct an equilibrium in which we have almost full revelation in any period except the last: as T and n increase, therefore, the average payoff will approximate the first best level.

We now present some concluding remarks.

Remark 1. The proof of Proposition 4 fully exploits the properties of the constructions of Proposition 2 and Lemma 1. In particular, note that it is important that at any stage the strategy played by the senders is a (strict) static best reply. Indeed, no player can observe the true signals of other experts, so no agent can verify if they are following the equilibrium strategies. This is a (finitely) repeated game with private monitoring: without this property it would be impossible to punish a deviation by the senders.

Remark 2. A considerable literature has studied different versions of cheap talk models in repeated games. Sobel [1985] and Bénabou and Laroque [1992] consider repeated models with one sender who is concerned about his reputation. More similar to our setting, Aumann and Mashler [1995], Aumann and Hart [2003], and Krishna and Morgan [2002], all consider models of repeated communication in which the equilibrium played at each stage is contingent on the outcome of the previous stages. Differently from our model, however, these works assume only one sender and a simpler "policy space:" Aumann and Hart, for example, restrict the analysis to bimatrix games with finite actions; Krishna and Morgan assume a unidimensional environment.[22] Although both papers show that the repetition of the communication stage increases the space

[21] The more the ideal point of i and j are "collinear", the worst is the transmission of information because one dimension is poorly captured by the coordinates that are orthogonal to the gradients of the experts' utilities at the origin. So we would choose the i and j who have preferences that are "as orthogonal" as possible.

[22] Another difference is that in order to obtain all the equilibrium payoffs, an arbitrarily large number of stages is used in some of these constructions (see in particular Aumann and Hart [2003]); moreover, while in our model an action is taken at the end of each stage, in these models the action is taken only at the end of all the stages.

of equilibrium payoffs and can be beneficial to the policy maker, these papers are not interested in studying when efficiency or near efficiency is achieved.

Remark 3. The results in Lemma 1 and Proposition 4 hold even if the noise in the experts' signals is very large because no restriction is imposed on the variances of the ε_is. Realistically, if the residual noise is small, then a few experts will be sufficient to achieve almost full extraction of information.

Remark 4. An important assumption of the model is that experts receive conditionally independent signals. This assumption is standard in the literature on information aggregation (it is adopted, among others, by Austen-Smith and Banks [1996] and Feddersen and Pesendorfer [1996] and [1997]) and very plausible in many situations (as discussed in Section 2). Whether this assumption can be relaxed, and to what extent it can be relaxed to obtain information aggregation even when residual errors are correlated are open questions that we leave for future research.

Remark 5. To solve the model in closed form we made assumptions on the signal structure: normally distributed signals and uniform prior. The results, however, are robust to changes in these assumptions in the following sense. As we mentioned above[23], for any arbitrary specification of the initial prior, as the precision of a signal increases, the posterior distribution of the state of the world converges, under general assumptions, to the posterior with a uniform prior. Therefore, for large n, ε-commitment is sufficient for full information extraction regardless of the particular assumption on the receiver's prior. This fact also proves the robustness of the results with two experts. Indeed, even without characterizing the equilibrium for any possible prior distribution, we can conclude that truthful strategies are, at least, an equilibrium with ε-commitment (and therefore an ε-equilibrium as well) for any general choice of initial prior when residual noise is not large.

Remark 6. Finally, we are making no assumption on the degree of conflict of interest between the policy maker and the experts, and among the experts as well: therefore, we might have full information extraction with many experts even if they all have very similar preferences and all of them have a very large conflict of interest with the policy maker. The case in which experts have similar biases seems the most realistic since experts often share the same background and self-select when they decide to invest in information accumulation. Proposition 4, however, makes clear that information extraction can be arbitrarily accurate even if this is the case.

4.3 Discussion

We conclude this section discussing some implications of the model on two important institutional questions: the *choice between communication vs. delegation*; and the *role of overlapping jurisdictions* in information transmission.

[23] See Section 2, and DeGroot [1971], §10.4.

Both these questions have not only a theoretical interest, but also practical institutional implications regarding the choice of "open" vs. "closed" decision rules in legislative committees, and the definition of their jurisdictions. Finally we discuss the robustness of the equilibrium to beliefs specification and its plausibility.

Delegation vs. communication. So far we have assumed that the policy maker consults the experts, but always keeps decision rights for herself. An uninformed policy maker, however, can decide to delegate the decision to one of the experts. Recent literature has argued that there are situations in which this is optimal. Gilligan and Krehbiel [1988] have proven that when the conflict of interest between the policy maker and the expert is small, a particular form of delegation (a "closed rule"[24]) is superior to pure communication ("open rule"). Krishna and Morgan [2001] have further investigated this question carefully characterizing all the possible equilibria of these games. Dessein [2002] has constructed a more general model of delegation based on information transmission, and used it as the building block for a novel theory of the organization of the firm. He shows that an uniformed decision maker may find it optimal to delegate decision power to an informed agent when the conflict of interest is small enough. Intuitively, delegation reduces the ability of the policy maker to control the outcome, but guarantees a commitment device that may help provide better incentives to the expert.

All of these models, however, consider only one sender (Gilligan and Krehbiel [1987], Krishna and Morgan [2001] and Dessein [2002]) or two senders with perfect signals (Gilligan and Krehbiel [1988], Krishna and Morgan [2001]); and they all assume a unidimensional environment.

In the present work, we have shown that even in a model in which signals are noisy and the environment is multidimensional, either when the noise in the experts' private signals is not too large, or when there are enough experts available to be consulted, cheap talk is strictly superior to the option of delegating the decision to any expert. In these cases, the inefficiency in communication is strictly smaller than the bias that any expert would impose on the decision due to the conflict of interest, even if the conflict is very small. The larger the number of experts and the more precise their signals, the stronger the result, since cheap talk becomes increasingly more efficient in aggregating information that would otherwise be dispersed.

It is interesting to note, however, that our results are not necessarily against delegation of authority.[25] For example, when there are two experts, in the equilibrium that achieves the efficient outcome, each expert is assigned a particular

[24] We have a "closed rule" when the policy-maker can only choose the expert suggested policy or a fixed status quo policy. This, therefore, corresponds to a form of partial delegation, since the policy maker can always choose between the expert's suggestion and an exogenous outside option.

[25] The fact that delegation and communication may actually reinforce each other in the design of the optimal institution is also pointed out by Aghion and Tirole [1997] in a related but different environment. Aghion and Tirole [1997] study a model in which the principal (the policy maker, in our terminology) can also exert effort in acquiring pay-off relevant information. In this case it may be optimal to delegate authority to the agent and allow the

dimension of a coordinate system. Along this jurisdiction the expert reports truthfully and the policy maker simply rubber stamps this declaration (see below for more discussion on this and its empirical plausibility). This means that if the policy maker delegates the decision to the expert on that particular jurisdiction, the outcome would be the same, as in the case without delegation. The key point is that the *optimal jurisdictions are not exogenous* (as in the previous literature which assumed a unidimensional world) *but endogenous* and can be tailored to the experts' preferences in order to eliminate conflicts of interests. This observation may contribute to better understanding the optimal organization of institution as complex as the congress, in which committees' jurisdictions are indeed endogenous and changing over time (see the section on plausibility of beliefs below for more on this point).

The decision between an institutional setting in which the decision is delegated to the informed agent, or in which there is no-delegation but the principal extracts information with a cheap talk stage may depend on the ability of the policy maker to commit to a policy rule. As we have seen in the previous section, in an environment in which the game is repeated, no commitment is necessary for almost full extraction of information, even if the discount factor or the probability of repetition is very small, and the maximal number of repetitions is finite. When (perhaps less realistically) we have a static one shot game, however, the policy maker obtains the full benefit of communication with ε-commitment. With ε-commitment the government has discretion in the decision, and if it is not possible to perfectly detect her deviations, it might be difficult to enforce a punishment for a policy maker's deviation. In some environments delegation may have the benefit of simplicity: it might be easier to write an ex ante contract which only prescribes delegation of the action to one agent. Even in these cases, however, delegation has two relevant problems. First, it is not clear what delegation means when there are many experts. With two experts and two dimensions, as we discussed above, our model shows that optimal jurisdictions are endogenous and part of the equilibrium. However, when the experts are more than the dimensions, how should the decision be delegated? The policy maker may delegate the jurisdiction to choose the decision on a particular dimension to a group of agents, but then the problem of information aggregation is simply transferred to the group. Or the policy maker can ignore some of the experts: but this may imply a substantial loss in information aggregation. The second problem is that once the decision is delegated, the planner has no control on the policy outcome, and the losses that she may face ex post may be potentially unbounded. Clearly in these cases full delegation would not be credible. We can imagine institutions in which some form of partial delegation is chosen. A part the fact that the efficiency property of such institutions is not clear, these institutions would lose the main appeal of a contract with pure delegation, it simplicity.

The informative role of overlapping jurisdictions. The equilibrium

agent to send a message to the principal: indeed this type of communication may increase the incentives of the principal to acquire valuable information.

that supports efficient information extraction as the number of experts increases cannot only contribute to the understanding of the optimal allocation of jurisdictions, but also to explain the benefits of *overlaps in jurisdictions' allocation*. The construction in Lemma 1 and Proposition 4, in fact, assigns to each couple of experts a particular jurisdiction system over which the experts have to report. These jurisdictions are overlapping: indeed each couple is reporting on the same variable θ, although using a different coordinate system. The intuition for why this *must* occur is simple and robust: overlapping jurisdictions allow the policy maker to use information from many different experts and therefore reduce the noise in their signals. Simple as it is, this idea has never been stated or formalized before.

Congressional scholars who have studied jurisdictions of legislative committees confirm this characteristic, proving that often the jurisdiction of different committees have substantial overlaps (see Baumgartner and Jones [1993] and King [1997]). Interestingly, this feature of the organization of the Congress is often seen as a sign of inefficiency and redundancy. This is certainly partly true: and many reforms have been attempted over time to periodically rationalize the system (see King [1997]). Overlapping jurisdictions, however, also allow the accumulation of many different informative signals on the same phenomenon and therefore reduce the noise associated with the experts' signals. This feature could not be captured in models in which experts are perfectly informed: in these cases it is not necessary to receive messages by more than one agent on a particular dimension of the problem. Our model, therefore, may contribute to explaining, from a theoretical point of view, why overlapping jurisdiction and the dynamic evolution of the overlaps may be a sign of efficiency of the system.

Robustness and plausibility of beliefs. In this paper, truthful equilibria defined in Section 4.1 are used as a lower bound to characterize the properties of the best equilibria. This class of equilibria, however, has an interest in itself because it has a very simple structure and it is consistent with empirical evidence. It has a simple structure because it does not require the experts or the policy maker to follow complicated strategies. On the one hand, the experts just report their best prediction on their assigned jurisdictions; on the other hand, the policy maker simply implements the suggested policies. This behavior is consistent with evidence since, as Shepsle [1978] pointed out:

> "*It is the case that* most of the time *legislative action recommended by a committee is the legislative action taken by the House. And it is especially rare for the House to reverse a committee's negative judgement on a bill or, in any other fashion, to discharge a committee of its authority over a piece of legislation. Committees, that is, are effective veto groups within their legislative jurisdictions.*"[26]

Our model generates an equilibrium behavior that is perfectly consistent with this observation. Interestingly, however, although this empirical pattern might

[26] Shepsle [1978], p. 9.

be interpreted as a sign of monopoly power of the committee and therefore as evidence in favor of 'pork barrel' theories of legislative committees, in our model it reflects a situation in which the committee is 'expropriated' of its informational advantage, and the policy maker can perfectly pursue her policy goals.

Besides these considerations, the equilibrium presented in Proposition 1 has three further important properties. Many models of legislative cheap talk are based on the idea of 'confirmatory signalling'. Since in these models experts are assumed to perfectly observe the state, they require, in equilibrium, both experts to report exactly the same signal. If this does not happen, then the path of play is out-of-equilibrium and beliefs are not univocally defined: this indeterminacy is exploited to construct out-of-equilibrium beliefs that punish the deviation. This approach is not only used to construct equilibria that achieve full revelation, but also to construct partially revealing equilibria in one dimensional models. However, these beliefs are often implausible and robust neither to simple theoretical refinements, nor to empirical evidence. The model and the equilibrium that we have constructed do not have this problem. First, note that experts observe the same signal only with zero probability since we are assuming noise with a continuous distribution: therefore confirmatory equilibria are not feasible. Second, in this equilibrium all messages are sent in equilibrium, no sub-game is out-of-equilibrium and beliefs are always well defined.

5 Conclusion

In this paper we have studied policy advice by imperfectly informed experts. We have shown that there is a trade-off between the precision and truthfulness of the messages that can be extracted by the experts (information extraction), and the number of experts' signals that can be consulted (information aggregation). In order to extract truthful information, an expert must have a well defined jurisdiction and be aware that, with his message, he will be able to influence only that restricted domain. Because of this, however, there is necessarily a loss of useful information.

However, we have proven that the inefficiency may be irrelevant in two important cases: when the precision of the experts' signal is high; and, perhaps even more importantly, when many experts can be consulted. Indeed, in the latter case, information can be almost perfectly extracted regardless from the fact that perhaps all experts share similar (but not necessarily identical) preferences, and a large bias with respect to the policy maker; that the precision of the signals is very low; and that the policy maker has only an arbitrarily small ability to commit.

These theoretical results have some direct implications for institutional design and, in general, for the theory of organizations. First, we have proven that even when the signals are very noisy, the policy maker may be better informed than any expert after the communication stage. In these cases, delegation of decision rights (as for example with a "closed rule") is strictly suboptimal.

Second we have shown that when signals are noisy, it is important to have overlapping jurisdictions in order to extract all the information disseminated among the experts.

6 Appendix

6.1 Proof of Proposition 1

If there exists a fully revealing equilibrium, then there exists an equilibrium in which the agents simply report the observed state in the usual orthogonal coordinate system. Indeed, let us define $\mu(\{m_i\}_{i=1}^n)$ and $y(\{m_i\}_{i=1}^n)$ the posterior belief and the optimal policy after hearing a set of messages $\{m_i\}_{i=1}^n$; and let us define $m_i(s_i(\theta))$ for $i \in \{1,2\}$ the message sent by agent i after observing signal $s_i(\theta)$ (where $s_i(\theta)$ is the signal observed by agent i in the original orthogonal coordinate system). In a fully revealing equilibrium we have that $\mu(\{m_i(s_i(\theta))\}_{i=1}^n) = E\left[\theta \,|\{s_i(\theta)\}_{i=1}^n\right]$. If we define $\widetilde{y}(\{s_i(\theta)\}_{i=1}^n) = y(\{m_i(s_i(\theta))\}_{i=1}^n)$, then $\widetilde{m_i} = s_i(\theta)$ for $i \in \{1,2\}$, $\widetilde{\mu}(s_i(\theta)) = E\left[\theta \,|\{s_i(\theta)\}_{i=1}^n\right]$ and $\widetilde{y}(\{s_i(\theta)\}_{i=1}^n)$ is a truthful fully revealing equilibrium in which senders report in the original orthogonal coordinates. Given this, we only need to prove that there exist no fully revealing equilibrium in which the expert's message space are the coordinates of the state in the usual orthogonal coordinate system. When this is the case, in a fully revealing equilibrium the posterior $\mu(\{s_i(\theta)\}_{i=1}^n)$ is a multivariate normal distribution with mean equal to $E\left[\theta \,|\{s_i(\theta)\}_{i=1}^n\right] = \frac{1}{n}\sum_i^n s_i(\theta)$, which is continuous and differentiable in the signal $s_i(\theta)$ declared by i, $\forall\, i$ (see DeGroot [1970] par. 10.3, p. 196).[27] Since the receiver's optimal reaction is $y = -E\left[\theta \,|\{m_i\}_{i=1}^n\right]$, the expected outcome is also continuous and differentiable in the messages: $E(\theta+y) = E\left(\theta - \frac{1}{n}\sum_i^n m_i\right)$, and equal to zero at $\{m_i\}_{i=1}^n = \{s_i(\theta)\}_{i=1}^n$. Consider now the decision of an expert i. Because the gradient of the expected value of $\theta + y$ with respect to agent i's message has full rank (each component of the message vector affects a different coordinate of the expected value), we know that, by the Implicit Function Theorem, at least for any point z in a neighborhood of the origin, there must exist a declaration $\widehat{s}_i(z)$ such that $E\left[\theta \,\middle|\, \widehat{s}_i(z), \{s_j(\theta)\}_{j\neq i}\right] = z$. Since there is a conflict of interest between the senders and the receivers, we can assume without loss of generality that there exists at least one agent i such that $x^i \neq 0$. Concavity of the utility functions implies that for any $0 < \alpha < 1$ $u_i\left(\alpha x^i\right) > u_i(0)$. We can therefore find an α small enough such that, if all the other experts are reporting truthfully, a report $m_i = \widehat{s}_i(\theta - \alpha x^i)$ induces an expected outcome αx^i. Sender i, therefore, has a strictly profitable deviation. We conclude that a fully revealing equilibrium cannot exist. ■

6.2 Proof of Proposition 2

For each agent $i = 1, 2$ we can consider an equation

$$(\nabla u_i(0))^T \cdot a^i = 0 \qquad \forall i = 1...n \tag{4}$$

[27] Note that this formula for the expected value takes advantage of the fact that the experts' signals have the same precision matrix, and so receive the same weight $\frac{1}{n}$. The result would easily generalize to the case with different precision matrices.

which defines a vector a^i in $\Re^q$ that is orthogonal to the gradient of agent's i utility. The following preliminary result is used in the proof of Proposition 2.

Lemma 2 *If the gradients of the utilities of the senders are linearly independent, the system (4) always admits a set of solutions* $\begin{bmatrix} a_1, & ... & a_j, & ... & , a_q \end{bmatrix} \equiv A$ *which has full rank.*

Proof. First note that the space of solutions a^i the equation $\nabla u_i(0)^T \cdot a^i = 0$ is isomorphic to a $(q-1)$ dimensional space (see for example Shilov [1977]).[28] This implies that we can, without loss of generality, associate for each sender $i = 1, 2$ a collection of linearly independent vectors $\{a_1^i, ...a_{q-1}^i\}$ that solve the equation. Assume, by contradiction, that for any choice of a solution a_l^2 of the equation for $i = 2$ we have that the vectors $\{a_1^1, ...a_{q-1}^1, a_l^2\}$ are linearly dependent. It follows immediately that any vector that is orthogonal to agent 2's gradient is also orthogonal to agent 1's gradient; in fact:

$$\nabla u_1(0)^T \cdot a_l^2 = \sum_{k=1}^{q-1} \kappa_k \left(\nabla u_1(0)^T \cdot a_k^1\right) = 0 \text{ for some set of coefficients } \{\kappa_k\}_{k=1}^{q-1}.$$

Note, now, that we can always find a vector ξ such that $\{a_1^2, ...a_{q-1}^2, \xi\}$ are linearly independent; with this vector, lets define the scalars $\tau = \nabla u_1(0)^T \cdot \xi$ and $\tau' = \nabla u_2(0)^T \cdot \xi$. We can consider the system of equations:

$$\begin{pmatrix} \left(a_1^2\right)^T \\ ... \\ \left(a_{q-1}^2\right)^T \\ (\xi)^T \end{pmatrix} \nabla u_1(0) = \begin{pmatrix} 0 \\ ... \\ 0 \\ \tau \end{pmatrix}. \tag{5}$$

But then, we also have:

$$\begin{pmatrix} \left(a_1^2\right)^T \\ ... \\ \left(a_{q-1}^2\right)^T \\ (\xi)^T \end{pmatrix} \left[\left(\frac{\tau}{\tau'}\right) \cdot \nabla u_2(0)\right] = \begin{pmatrix} 0 \\ ... \\ 0 \\ \tau \end{pmatrix}.$$

But the system (5) has a unique solution so it must be that $\nabla u_1(0) = \left(\frac{\tau}{\tau'}\right) \nabla u_2(0)$ which is in contradiction with the fact that the gradients are linearly independent.

■

We can now show the main result.

Proof of Proposition 2. Consider a collection of column vectors $\{a_1, .., a_j, .., a_q\}$ such that the its generic element a_j is a solution of (4) for some i. We may

[28] For example,we can always find a solution orthogonal to $\nabla u_1(0)$ and $m-1$ linear independent solutions of the system orthogonal to $\nabla u_2(0)$. Indeed, if $m = 3$ we can choose 2 solutions among the linear independent vectors that are in the plane tangent to ∇u_2 and the remaining vector in the plane tangent to ∇u_1.

define a matrix

$$A \equiv \left[\begin{array}{ccccc} a_1, & ... & a_j, & ... & ,a_q \end{array}\right] \equiv \left[\begin{array}{ccc} a_{1,1} & ... & a_{1,q} \\ ... & ... & ... \\ a_{q,1} & ... & a_{q,q} \end{array}\right]$$

where $a_{l,j}$ is the jth element of the lth row. From Lemma 1 it follows that we can always select a set of solutions from the system defined by (4), such that this matrix A has full rank. Given this we can express any vector in θ in $\Re^q$ with the new base as a vector θ^* defined:

$$\left(\begin{array}{c} \theta_1^* \\ ... \\ \theta_q^* \end{array}\right) = A^{-1} \left(\begin{array}{c} \theta_1 \\ ... \\ \theta_q \end{array}\right).$$

For notational convenience, we denote $\alpha_{i,j}$ the jth element of the ith row of A^{-1}. Consider now the following strategies and beliefs. From Lemma 1 we may assume, without loss of generality, that a_1 is orthogonal to $\nabla u_1(0)$ and all the other columns are orthogonal to $\nabla u_2(0)$. Agent 1 reports coordinate 1 in the new coordinate system of the observed signal, i.e. $m_1 = s_{1,1}^*$, where $s_{1,1}^*$ is the first coordinate of $A^{-1}s_1(\theta)$. Agent 2 reports the remaining dimensions $m_2 = \left(\begin{array}{c} s_{2,2}^* \\ ... \\ s_{2,q}^* \end{array}\right)$. In the following we will use the notation $\iota^{-1}(l)$ to identify the agent to whom it is allocated the lth dimension in the coordinate system A . The receiver implements $y^* = -m = -\left(\begin{array}{c} m_1 \\ m_2 \end{array}\right)$ in the new coordinate system or, expressed in the original coordinate system, $y = -Am$.

We first show that these strategies are optimal for the senders and then that they are optimal for the receiver. Consider a unilateral deviation for agent 2, the case of agent 1 is similar. When the other two players are following the equilibrium strategy, the expected utility for sender 2 is[29]

$$\begin{aligned} u_2(\theta + y) &= -E_2 \sum_{l=1}^{q} \gamma_{2,l} \left[\theta_l + y_l - x_{2,l}\right]^2 = \\ &= -E_2 \sum_{l=1}^{q} \gamma_{2,l} \left[\sum_{k=1}^{q} a_{l,k}\left(\theta_k^* + y_k^*\right) - x_{2,l}\right]^2 \\ &= -E_2 \sum_{l=1}^{q} \gamma_{2,l} \left[a_{l,1}\left(\theta_1^* + y_1^*\right) + \sum_{k=2}^{q} a_{l,k}\left(\theta_k^* + y_k^*\right) - x_{2,l}\right]^2 \end{aligned}$$

where $x_{2,l}$ is the lth component of the ideal point of agent 2. But $y_1^* = -m_1$ and $m_1 = s_{1,1}^*$ so

$$y_1^* = -\left[\theta_1^* + \sum_{j=1}^{m} \alpha_{1,j}\varepsilon_{1,j}\right].$$

[29]Let E_2 be the expectation operator conditional on the information available to agent 2.

Therefore we can write

$$\begin{aligned}
u_2(\theta+y) &= -E_2 \sum_{l=1}^{q} \gamma_{2,l} \left[\sum_{k=2}^{q} a_{l,k} \left(\theta_k^* + y_k^*\right) - x_{2,l} - a_{l,1} \sum_{j=1}^{q} \alpha_{1,j}\varepsilon_{1,j} \right]^2 \\
&= -E_2 \sum_{l=1}^{q} \gamma_{2,l} \left\{ \begin{array}{c} \left[(x_{2,l})^2 + a_{l,1}^2 \left(\sum_{j=1}^{q} \alpha_{1,j}\varepsilon_{1,j} \right)^2 \right] \\ + \left[\sum_{k=2}^{q} a_{l,k} \left(\theta_k^* - m_{2,k}\right) \right]^2 \end{array} \right\} \\
&\quad +2 \sum_{k=2}^{q} \left\{ \left[\sum_{l=1}^{q} a_{l,k} \left(\gamma_{2,l} x_{2,l}\right) \right] \left(\left(E_2 \theta_k^* - m_{2,k} \right) \right) \right\}.
\end{aligned}$$

By the definition of the new coordinate system in (4), we have that

$$\sum_{l=1}^{q} a_{l,k} \left(\gamma_{2,l} x_{2,l}\right) = -\frac{1}{2} \left[\nabla u_2(0)^T \cdot a_k \right] = 0$$

for any $k \in \iota(2)$ i.e. $k = 2, ..., m$; so if we call

$$K_1 = -E_2 \sum_{l=1}^{m} \gamma_{2,l} \left[x_{2,l}^2 + a_{l,1}^2 \left(\sum_{j=1}^{m} \alpha_{1,j}\varepsilon_{1,j} \right)^2 \right],$$

we have:

$$u_2(\theta+y) = K_1 - E_2 \sum_{l=1}^{q} \gamma_{2,l} \left[\sum_{k=2}^{q} a_{l,k} \left(\theta_k^* - m_{2,k}\right) \right]^2.$$

Now note that the posterior on θ given s_2 is a normal with mean s_2 and variance-covariance $\Sigma(\varepsilon_2)$, so we can write:

$$\begin{aligned}
u_2(\theta+y) &= \left[K_1 - E_2 \sum_{l=1}^{q} \gamma_{2,l} \left(\sum_{k=2}^{q} a_{l,k} \left(\sum_{j=1}^{q} \alpha_{k,j}\varepsilon_{2,j} \right) \right)^2 \right] \\
&\quad - \sum_{l=1}^{q} \gamma_{2,l} \left[\sum_{k=2}^{q} a_{l,k} \left(s_{2,k}^* - m_{2,k} \right) \right]^2
\end{aligned} \tag{6}$$

which is maximized at $m \in \arg\min \sum_{l=1}^{q} \gamma_{2,l} \left[\sum_{k=2}^{q} a_{l,k} \left(s_{2,k}^* - m_{2,k} \right) \right]^2$: clearly zero is a minimum of this and it can be achieved with $m_{2,k} = s_{2,k}^*$ for each $k = 2$ to q. So truthful revelation is optimal for the expert.

Consider now the receiver. The relationship between the messages and the state of the world in equilibrium is this: $m_l = \theta_l^* + \sum_{k=1}^{q} a_{l,k}\varepsilon_{\iota^{-1}(l),k}$ where m_l is the message sent on the l dimension by the assigned expert $i^{-1}(l)$[30] and θ_l^* is

[30] So expert 1 if $l = 1$, expert 2 otherwise.

the l dimension of θ in the new coordinate system. So in equilibrium we have $m = \theta^* + \omega(\iota, A)$ where the second addend is a random variable defined by

$$\omega(\iota, A) = \underbrace{\left[\begin{array}{ccc} \alpha_1 & 0 & 0 \\ 0 & \alpha_2 & 0 \\ 0 & 0 & ...\ \alpha_q \end{array}\right]}_{q\times q^2} \underbrace{\left(\begin{array}{c} \varepsilon_{\iota^{-1}(1)} \\ ... \\ \varepsilon_{\iota^{-1}(q)} \end{array}\right)}_{q^2\times 1} \tag{7}$$

and $\varepsilon_{\iota^{-1}(p)}$ $\forall p = 1, ..., q$ is the noise vector of the agent $\iota^{-1}(p)$, i.e. the agent who has coordinate p in his jurisdiction; the diagonal matrix is an $q \times q^2$ matrix whose generic fth component α_f is the fth row of the matrix A^{-1}. It follows that, given the senders' strategies, the posterior belief about θ conditional on a message vector $m = (m_1, m_2)$ is distributed according to a normal random variable with mean $E(\theta^* |m) = m$ and variance-covariance of the variable $\omega(\iota, A)$, i.e. $\Sigma(\omega(\iota, A))$ (see DeGroot §10.3). Because the utility of the policy maker is quadratic, we do not need to specify the $\Sigma(\omega(\iota, A))$ matrix in details. Indeed, by a similar argument as the one presented to decompose the experts' utilities, the optimal choice for the policy maker can also be decomposed in a part that depends on the expected value of the state and a constant:

$$\begin{aligned} E\left[u_P(\theta + y)|m\right] &= E\left[u_P A(\theta^* + y^*)|m\right] \\ &= u_P\left[A\left(E(\theta^*|m) + y^*\right)\right] + K \end{aligned}$$

where K is a constant. It follows that the optimal policy is $y^* = -E(\theta^* |m) = -m$. This implies that the proposed strategies are an equilibrium in the jurisdictional system defined by the base $\{a_1, ..., a_q\}$. ■

6.3 Proposition 3

Observe that in the equilibrium of Proposition 1, utility of the policy maker differs from the first best only by a term which is a linear combination of the variances and covariances of the experts signals (see (6)): as these converge to zero, the distortion converges to zero too. Moreover, as noise converges to zero, cheap talk becomes strictly superior to delegation, because in the first case the policy maker achieves approximately the first best (0); but if she delegates, then she achieves a strictly negative utility in correspondence to the policy proposed by the expert to whom the decision is delegated or, in case of a "closed rule," the best between this proposed policy and the status quo.

6.4 Proof Lemma 1

Define $\upsilon = \left\lceil \frac{n}{2} \right\rceil$ the largest integer smaller than $\frac{n}{2}$. We can therefore form υ couples pairing agents i and $i+1$ for $i = 1$ to υ. For any couple of agents define $\widehat{\theta}^i = \{m_i, m_{i+1}\}$ the couple of messages sent by respectively by i and $i+1$ (for simplicity, the vector $\widehat{\theta}^i$ takes the name of the first agent in the couple). We now construct an equilibrium in which the posterior distribution of θ after all the messages are heard is unbiased ($E\left[\theta \middle| \left\{\widehat{\theta}^i\right\}_{i=1}^{\upsilon}\right] = \theta$) and such that $\lim_{n\to\theta} Var\left[\theta \middle| \left\{\widehat{\theta}^i\right\}_{i=1}^{\upsilon}\right] = 0$.

Given Lemma 1, for any couple we can construct a base $A_i = \{a_{i1}, ..., a_{iq}\}$ the elements of which satisfy (4) for some agent i or $i+1$. Moreover we can pair each of the vectors in A_i to the associated agent i or $i+1$, whose gradient is orthogonal with. Similarly to the case in Proposition 1, we define $\iota_i^{-1}(j)$ the agent associated to the jth vector in A_i. We denote the true coordinate of the state θ in A_i with the vector θ^i and the coordinates reported by the couple $i, i+1$ with the vector $\widehat{\theta}^i$; the variable z_i, instead, is the corresponding coordinates of $\widehat{\theta}^i$ in the original orthogonal system, $z_i = A_i\widehat{\theta}^i$.

Consider the following strategies. Each expert $j \leq 2\upsilon$ truthfully reveals the correct coordinates (that he was assigned) of his signal in the coordinate system associated with his couple (A_j if j is odd and A_{j-1} if j is even). The agent $N - 2\upsilon$th (if there is one) uses a babbling equilibrium strategy. The policy maker will choose a policy

$$y^* = -\sum_{i=1}^{\upsilon} \frac{1}{\upsilon} z_i. \tag{8}$$

In step 1 we show that the strategy of the experts is optimal given y^*; in step 2 we show that as $n \to \infty$ policy y^* converges to the first best reaction function.

Step 1. Since the message sent by the $N - 2\upsilon$th expert is ignored in y^*, it follows that the babbling strategy is optimal. Consider now an agent $i \leq 2\upsilon$ and assume, without loss of generality that he has to report on the coordinate system A_i. Given any collection of bases $\{A_l\}_{l=1}^{\upsilon}$, and a couple $j, j+1$ following the equilibrium strategies, the reported $\widehat{\theta}_j$ is equal to $\theta^j + w(\iota_j, A_j)$ where $w(\iota_j, A_j)$ is the error term due to the noisy observations defined, as in Proposition 1, by (7). It follows that if all couples except couple $i, i+1$ are following the equilibrium strategy, we have:

$$\begin{aligned} x &= \theta + y^* = \theta - \sum_{j=1}^{\upsilon} \frac{1}{\upsilon} z_j = \theta - \sum_{j\neq i} \frac{1}{\upsilon} A_j \left[\theta^j + w(\iota_j, A_j)\right] - \frac{1}{\upsilon} A_i \widehat{\theta}^i && (9) \\ &= \left[I - \frac{\upsilon - 1}{\upsilon} I\right] \theta - \frac{1}{\upsilon} A_i \widehat{\theta}^i + \sum_{j\neq i} \frac{1}{\upsilon} w(\iota_j, A_j) \\ &= \frac{1}{\upsilon} A_i \left(\theta^i - \widehat{\theta}^i\right) + \widetilde{\varepsilon}^i && (10) \end{aligned}$$

where $\widetilde{\varepsilon}^i = \sum_{j\neq i} \frac{1}{\upsilon} w(\iota_j, A_j)$ is a noise component with mean zero and independent from the actions of i or $i+1$; and θ^i is the true coordinate of θ on A_i, defined by $\theta = A_i \theta^i$. Following the same passages as in Proposition 1 we have:

$$\begin{aligned} Eu_i(\theta + y^*) &= Eu_i\left(\frac{1}{v} A_i \left(\theta - \widehat{\theta}^i\right) + \widetilde{\varepsilon}^i\right) \\ &= u_i\left(EA_i^*\left(\theta - \widehat{\theta}^i\right)\right) + K \end{aligned}$$

where $A_i^* = \frac{1}{v} A_i$ and K is a constant independent from i's action. Note that if A_i satisfies (4) for the couple i or $i+1$, then A_i^* also satisfies (4) and it is also full rank. Therefore, following the same steps as in Proposition 1, it is easy to show that both agent i and agent $i+1$ find it optimal to report truthfully.

Step 2. The utility of the policy maker can be written as:

$$\begin{aligned} Eu_P(\theta, y^*) &= -E(\theta + y^*)' \Lambda (\theta + y^*) \\ &= -E\left[(\theta + Ey^*)' \Lambda (\theta + Ey^*) + (Ey^* - y^*)' \Lambda (Ey^* - y^*)\right] \end{aligned}$$

where Λ is the matrix with the utility coefficients $\left\{\gamma_{P,i}\right\}_{i=1}^q$ on the main diagonal and zero otherwise. Since the estimator of the state of the world $\sum_{i=1}^v \frac{1}{v} z_i$ is unbiased and has multivariate normal distribution with variance matrix $\Sigma^v = \frac{1}{v}\sum_{i=1}^v \frac{\widehat{\Sigma}_i}{v}$, if we denote $\widehat{\varepsilon}_j^i$ the error on the jth dimension associated with the report of the ith couple, we have that

$$\begin{aligned} Eu_P(\theta, y^*) &= -E(Ey^* - y^*)' \Lambda (Ey^* - y^*) \\ &\geq -\frac{1}{v} E \sum_{j=1}^q \gamma_{P,j} \sum_{i=1}^v \frac{\left(\widehat{\varepsilon}_j^i\right)^2}{v} \end{aligned}$$

which converges to zero as n (and so v) converges to infinity. The result, therefore, follows from the fact that zero utility is the maximal value achievable with full information. ■

6.5 Proof of Proposition 4

Consider the following strategies. At any period $t < T$ each of the players (sender and receive) may play one of two equilibria, depending on the preceding history. If $t = 1$, or if $1 < t < T$ and in all periods $k \in \{1, 2, ..., t-1\}$ the policy maker has chosen the policy as if she and the senders were playing the strategies of the equilibrium of Lemma 1 (i.e. policy (8)), then at t the players play the strategies prescribed by the equilibrium of Lemma 1: i.e. each expert is informative on the assigned jurisdiction, and the policy maker chooses the policy according to (8). Otherwise, if there exists a $k < T$ such that the policy maker has not aggregated the messages according to (8), then all the senders play a babbling equilibrium in which no information is transmitted at t; the policy maker, consequently, ignores their reports in all the periods following and including t.[31] At $t = T$ all the players except players i and j always play

[31] Alternatively the equilibrium can be reverted to the less harsh "bad equilibrium" in which only two experts are informative as in Proposition 2, and the two agents are those who would minimize the policy maker's utility.

a babbling equilibrium for any preceding history. If there exists a period $t < T$ in which the policy maker has not followed the policy prescribed by (8), then senders i and j also follow a babbling strategy, and the policy maker ignores the reports of all the experts.[32] If instead in all periods $t < T$ the policy maker has aggregated the strategies according to (8), then the informative equilibrium described by Proposition 2 is played and i and j are chosen among those that would maximize the policy maker's utility in this equilibrium. We now prove that these strategies are indeed an equilibrium. Clearly at $t = T$ the strategies are an equilibrium: indeed for any possible history the agents are playing a static Nash equilibrium (the equilibrium described in Proposition 2 or a babbling equilibrium). Consider now $t = T-1$. Assume first that the proceeding history is such that the agents should play the strategies as in the equilibrium of Lemma 1. As $n \to \infty$ the cost of choosing policy (8) converges to zero. Therefore, for any given positive δ, there is an $\overline{n}$ such that $n > \overline{n}$ implies that the benefit of having a more informative equilibrium at $t = T$ overwhelms the cost of playing a ε-best response at $t = T - 1$. The senders are playing an optimal strategy, so the strategies of all the players are optimal at $T - 1$. If the proceeding history is such that the players have to play a babbling equilibrium, then they would find it optimal since babbling equilibria are static Nash equilibria in all the periods. We now proceed by induction to show that the strategies are optimal in any $t < T$. Assume that the strategies are an equilibrium for all the periods following and including some $t < T$. Consider $t-1$: at this stage the benefit for the policy maker of following and ε-best response (i.e. (8)) are at least as high as at $t = T-1$ since a deviation would imply the loss of the informative equilibrium in more than one period and, if she does not deviate, the equilibria in all the following periods are at least as informative as the informative equilibrium in the last stage. So $n > \overline{n}$ continues to be sufficient for the strategy to be optimal for all the agents. We conclude that if $n > \overline{n}$, then there is an equilibrium in which the strategies of the equilibrium as in Lemma 1 are played and the equilibrium has the properties described in Proposition 4. ■

[32] See footnote 31.

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