# Information Disclosure with Many Alternatives*

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**Abstract**

We consider two-stage collective decision problems where some agents have private information about alternatives and others don't. In the first stage informed agents (experts) may or may not disclose their private information, thus eventually influencing the preferences of those initially uninformed. In the second stage the resulting preferences of all agents after disclosure are aggregated by a social choice function. We provide general conditions on social choice functions guaranteeing that the collective outcome will be the same that would obtain if all agents shared all the information available in society. Experts should be granted a coalitional veto power: changes in the social outcome that are due to changes in the preferences of other agents after information disclosure should not

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harm all the experts at the same time. We then specialize our general results. When the set of experts is a priori determined, we characterize those strategy-proof rules defined on single-peaked or separable preference domains that ensure that desired level of information disclosure. We also prove that, when the set of experts is unknown, no voting rule can fully achieve this goal, but majority voting provides a unique second best solution when preference profiles are single-peaked.

**Keywords**: information disclosure, implementation, social choice functions, single-peaked preferences, separable preferences.

**JEL Codes**: D70, D71, D82.

# 1 Introduction

A set of agents must choose their collective course of action. Their preferences regarding potential outcomes will typically differ. Moreover, the perception of the same outcome by each agent may depend on what she knows and eventually learns about it. If information that is relevant to the appraisal of an outcome by one agent is in the hands of another, the latter can condition the choice of the first, by inducing a change in her preferences.

In some cases, the set of better informed agents is predictable. Members of a House committee will know more than other representatives about what happened behind closed doors. Faculty in a hiring committee of an academic institution get better chances to learn about candidates than other colleagues. Yet, in other cases, who becomes better informed may depend on varying factors, and it may be impossible to know a priori who will become an expert. In either case, it is important to understand under what circumstances will informed members of society be inclined to share their knowledge with others.

To analyze the problem of strategic disclosure of information, Milgrom and Roberts (1986) introduced the class of persuasion games, in which all better informed agents share the same knowledge, can withhold information but not lie, and players interact only once, so that issues of reputation do not arise. Theirs and subsequent papers (Lipman and Seppi, 1995; Dewatripont and Tirole, 1999; Bhattacharya and Mukherjee, 2013; Gentzkow and Kamenica, 2017) have studied the case where a single decision maker must elicit the private information she receives from competing experts. By contrast, we consider settings where the decision maker is a set of individuals, experts or not, but some of them more informed than others, who must jointly contribute their preferences as the means to arrive at a collective decision.

The question of information disclosure has been addressed by Schulte (2010) and Jackson and Tan (2013) for the special situation where the group has only two choices[1]. We tackle the general case where society faces any number of alternatives.

We consider two-stage collective decision problems where in the first stage informed agents (experts) may disclose their private information and in the second stage a social choice function maps agents' preferences into an outcome. We shall later discuss in detail how to interpret the social choice function that operates in the second stage.

As for the decisions adopted by experts in the first stage, they are modelled and interpreted differently than in the literature about deliberation in committees. There, important papers by Austen-Smith and Feddersen (2005, 2006), building on insights from earlier work by Austen-Smith and Banks (1996) and Feddersen and Pesendorfer (1998) treat the exchange of information by voters as cheap-talk. Our work contrasts with theirs in that we study persuasion games, where agents may decide whether or not to share what they know, but if they do their information is verifiable and refers to hard facts[2].

The analysis of the interplay between information disclosure and preference aggregation in the presence of more than two alternatives is not only theoretically challenging but also of practical importance. The debate in the UK after the Brexit referendum held on June 2016 made clear to British citizens that they had actually decided among more than two alternatives: "remain" in the European Union, and the so called "hard" or "soft Brexit" referring to which type of custom and commercial agreement should be signed with the EU. The long-standing dispute in the US on gun control legislation provides another example of the many available alternatives on firearm regulation.

[1] Another difference with respect to paper of Jackson and Tan (2013) is that in their setting experts do not participate in the decision process.

[2] Mathis (2011) extends Austen-Smith and Feddersen's model incorporating the possibility that individuals may provide verifiable evidence supporting their private information and shows that unanimity is the only voting rule that always promotes fully revealing deliberation.

In order to concentrate on the phenomenon of information transmission we start with rather demanding assumptions. Some of them are relaxed later on, while others are eventually strengthened to obtain additional results. We discuss their role as the paper develops, and elaborate on them in the final comments. Here are those we start with. The only way in which we allow non experts to get additional information is through the experts' public disclosure of their differential knowledge. In most of the paper we assume that all experts are equally informed from the start[3], have nothing additional to learn and thus no reason to change preferences. We assume that the outcome that will result from the interaction between agents is a singleton, common knowledge and fully determined by their preferences after decisions regarding information disclosure have been taken by experts. A social choice function summarizes the connection between preference profiles and social decisions.

Our aim is to provide conditions on social choice functions guaranteeing that the social outcome will always be the same than the one that would obtain if all agents were fully informed when individual preferences are aggregated. We say in this case that there is full outcome-relevant information disclosure. In that setting, a trivial but unsatisfactory situation where full outcome-relevant information disclosure will arise is when one of the experts is a dictator. But it is not the only case where full outcome-relevant information disclosure can be guaranteed: nevertheless, we show that providing incentives to disclose information may come, though not always, at the price of granting experts some special privileges. Specifically, we show that a sufficient condition on social choice functions to guarantee full outcome-relevant information disclosure requires that experts should be collectively granted what we call coalitional veto power, in the following sense: if the social choice function selects two different outcomes at two profiles that only differ in the preferences of non-experts,

[3]This assumption will be relaxed in Section 6.

there must exist two experts who rank these outcomes in opposite directions, according to their unchanged preferences. In other words: if a rule attributes coalitional veto power to experts, changes in the outcome driven by changes in non experts' preferences cannot harm all the experts at a time. In addition to its sufficiency, we also prove that the condition becomes necessary in those cases where the impact of information disclosure on non experts' preferences is ex-ante unpredictable. These results are related to classical models in political economy depicting strategic information transmission as a mutually beneficial exchange, where a legislative committee member (Gilligan and Krehbiel, 1989, 1990; Krishna and Morgan, 2001) or a lobbyist (Austen-Smith and Wright, 1992) offers helpful policy expertise in exchange for some influence over the outcome. They also confirm the intuition that emerges in several previous works that creating competition between experts is beneficial to disclosure.

In summary, we investigate conditions under which experts would be inclined to disclose their private information to other members of society, and that can be used to design mechanisms leading to this main objective.

We take the stand that it is socially desirable that all agents are all informed to the same maximal extent by the time they contribute to the collective decision. Their preferences, of course, can still differ widely even if based on the same factual knowledge. Exceptionally, we may also accept that some information does not flow, but only if the social outcome is guaranteed to be the same than the one which would result in the case of full disclosure.

The search of efficiency, which is the paramount objective in most works on mechanism design, has to be nuanced in our setting. Since the preferences of each agent may depend on how informed they are, and this in turn depends on the disclosure policies of others, ex-ante efficiency becomes an elusive concept. Ex-post efficiency is a more natural objective, though still relative to the information exchanged in the first stage and the way in which it has shaped the final preferences of each agent. Because of that our desideratum is to find mechanisms that level the degree of information available to every citizen in practical terms, rather than direct efficiency considerations. However, we shall be able to show that, under appropriate assumptions, ex-post Pareto efficiency will also be satisfied by the rules that we identify.

We assume that the decision rule to be applied in the second stage once the agents have received whatever information is transmitted in a first stage is fixed, and that it comes in the form of a mechanism. That is, agents are endowed with strategies, and an outcome function selects an alternative for each strategy profile. Let the way in which people will play be reflected by some equilibrium concept. If the outcome resulting from the equilibrium played by agents at each preference profile is unique, a social choice function will be defined, associating an alternative to each profile of preferences. We then say that the function in question is implemented by the mechanism. Our leading interpretation of the scenario we propose and of the results we obtain refers to the case in which the social choice function arises from the strategic interplay of agents under a given mechanism that implements it. In that case, it makes full sense to assume that the mechanism in question can be the object of choice by a planner whose interest is to guarantee that experts will be inclined to disclose their information.

After presenting our general results, we show how they apply under special classes of social choice functions. Specifically we look at social choice functions that are implementable in dominant strategies and we restrict two well-studied domain restrictions that avoid the negative implications of the Gibbard-Satterthwaite theorem. In the domain in which agents have single-peaked preferences, we first study which generalized median voter rules satisfy the additional conditions that guarantee full outcome-relevant information disclosure by experts when the set of experts is known to the designer. After that, we consider the scenario in which the identity of experts cannot enter as part of the description of the social choice function. In this case, our general results imply that no unanimous generalized median voter rule can ensure that all agents will be ex-post fully informed. But then we can prove that majority voting provides, in a precise sense, a maximal amount of disclosure. In the second application we return to the case where experts are known a priori, but preferences and information are separable. We show that in this setting, if society chooses through appropriate voting by quota methods, all the information that is outcome-relevant will arise in equilibrium. Finally, in the same setting, we relax the assumption that experts share the same information and can disclose it in full. Even then, we can provide a sufficient condition on social choice functions guaranteeing that the outcome will always be the same than the one that would obtain if all agents were fully informed.

The paper proceeds as follows. In Section 2 we introduce a motivating example and in Section 3 the model. Section 4 presents general results regarding necessary and sufficient conditions for information disclosure. Sections 5 applies these results to the single-peaked preference domain and to the separable preference domain. Section 6 extends the model to the case in which experts can disclose different private information. Section 7 concludes.

## 2 A Motivating Example

Five agents (1,2,3,4,5) face the choice between five ordered alternatives ($a_1, a_2, a_3, a_4, a_5$). All agents have single-peaked preferences relative to that order. Suppose that (ex-ante) each agent $i$ has peak in $a_i$. Agents 2 and 4 are experts and share one piece of information. Suppose also that agent 2 prefers alternative $a_3$ to alternative $a_1$. If some expert discloses that information, the peak of all non-experts becomes $a_1$. If society decides according to the median rule, the outcome if no expert discloses that piece of information is $a_3$, and changes to $a_1$ in case information is disclosed. Clearly, no expert would want to disclose.

Next, consider the modified rule under which the median is selected as long as it lays between the peak alternatives of experts, and otherwise selects the peak of the expert that is closest to the median. The outcome of the rule in the case we considered before now becomes $a_2$ after disclosure, and expert 2 is happy to disclose this piece of private information. This is achieved due to the power of experts to veto those alternatives that do not lie between their tops.

The modified rule is strategy-proof (every agent has incentive to truthfully report his preferences irrespective of what the other agents report), and unanimous, (if a peak is the preferred one by every agent, then it is the selected alternative). It induces information disclosure thanks to a combination of two ingredients: endowing experts with some veto power against the uninformed, yet creating internal conflict among them. We next extend the ideas suggested by this example to our general framework.

# 3 The Model

A finite set of agents $A = \{1, \ldots, n\}$ faces a set $X$ of two or more alternatives and must choose one of them. Let $\tilde{\mathcal{R}}$ be the set of all complete, reflexive, and transitive binary relations on $X$ and $\mathcal{R}_i \subseteq \tilde{\mathcal{R}}$ be the set of those preferences that are allowed for agent $i$. $R_i \in \mathcal{R}_i$ will denote agent $i's$ preferences and $R \equiv (R_1 \times \ldots \times R_n) \in \mathcal{R}^n$ a preference profile. Let $P_i$ be the strict part of $R_i$.

$\mathcal{I}$ is a finite set of elementary pieces of verifiable hard information and $I \in 2^{\mathcal{I}}$ a generic subset of information. Different information may be available to different agents, and the preferences of each one depend on the information he or she holds. We formalize this dependence through the notion of an agent's type.

Agent $i's$ type $\theta_i : 2^{\mathcal{I}} \to \mathcal{R}_i$ is a function which assigns a preference $\theta_i(I) \in \mathcal{R}_i$ to agent $i$ for each set of information $I$ that she is aware of; $\Theta_i$ denotes the set of types for agent $i$ and $\theta \in \Theta_1 \times \ldots \times \Theta_n \equiv \Theta$ stands for a full profile of types.

The set of agents is partitioned into a set of experts $E$ and a set of non-experts $N$, with $N = A \backslash E$. Without loss of generality let $E = \{1, \ldots, l\}$ and $N = \{l+1, \ldots, n\}$ .

We denote $\theta_E \in \Theta_1 \times \ldots \times \Theta_l$ a profile of types for experts and $\theta_N \in \Theta_{l+1} \times \ldots \times \Theta_n$ a profile for non-experts.

We assume that every expert knows the full set of information $\mathcal{I}$, and this information is not available to the rest of agents.[4]

The collective decision process involves two stages. In the first stage, experts decide what information $I \in 2^{\mathcal{I}}$ they want to disclose and do it publicly. In the second stage, preferences are aggregated and a choice is made.

Non-experts' preferences depend on the overall amount of information disclosed at the first stage, and not on the identity of who has disclosed the information.

Formally, $m_i$ is a message of expert $i \in E$, $M \equiv 2^{\mathcal{I}}$ stands for the set of messages available to every $i \in E$. Profiles of messages are denoted by $m = (m_1, \ldots, m_l) \in M_E = M^l$; disclosure decisions by experts are described by disclosure functions $g : M_E \to 2^{\mathcal{I}}$ and $g(m) = \bigcup_{i \in E} m_i$ is the amount of information disclosed if message profile $m$ is chosen.

Once the first stage is terminated and information $g(m)$ has been publicly disclosed, each non-expert $j \in N$ is endowed with a preference $\theta_j(g(m)) \in \mathcal{R}_j$ and each expert $i \in E$ with preference $\theta_i(\mathcal{I}) \in \mathcal{R}_i$.

We assume that experts play a complete information game in stage one, knowing

[4]To relax the assumption that non-experts do not have private information, we could assume otherwise that non-experts may have some information but lack the technology to disclose it effectively, and adjust the type of that agent to only react when she acquires additional information.

in particular what are the preferences of other experts and which are the consequences of their actions on non-experts. In the second stage, agents aggregate their preferences and an outcome is chosen.

**Definition 1** *A social choice function $f : \mathcal{R}^n \to X$ is a map from each preference profile reported by agents to one alternative.*

We assume the existence of a mechanism to implement the social choice function. A *mechanism* $(S, h)$ is a cross product of strategy spaces $S = S_1 \times ... \times S_n$ and an outcome function $h : S \to X$. Let $s \in S$ denote a strategy profile. Given an equilibrium concept $\mathcal{E} \subset S$ for the game $(S, h, R)$ we define the set of solution outcomes $O_{\mathcal{E}}(S, h, R) = \{x \in X | \exists s \in \mathcal{E}(S, h, R) \text{ s.t. } h(s) = x\}$.

**Definition 2** *A mechanism $(S, h)$ implements the social choice function $f$ on $\mathcal{R}^n$ via equilibrium concept $\mathcal{E}$, if $O_{\mathcal{E}}(S, h, R) = f(R)$ for all $R \in \mathcal{R}^n$. A social choice function is implementable, if there exist a mechanism $(S, h)$ and an equilibrium concept $\mathcal{E}$, such that $O_{\mathcal{E}}(S, h, R) = f(R)$ for all $R \in \mathcal{R}^n$.*

Once the equilibrium strategies in the second stage are determined, we proceed to solve for the overall equilibrium of the game by looking at the Nash equilibria of the resulting one-shot game. Yet, we need not be specific when analyzing what might be the relevant equilibrium concept used to predict the behavior of agents at the second stage. It is worthy noticing that the game in the first stage is played by experts, while the game in the second stage is played by all the agents. Experts know non-experts' type functions and which social choice function $f : \mathcal{R}^n \to X$ will be implemented in the second stage. Therefore they can predict which is the outcome that is associated with any type profile generated by information revelation at stage one. Non-experts in the second stage may have incomplete information about other agents' preferences and which equilibrium concept is more suitable for implementing the social choice function it depends on the specific applications.

Given a type-profile $\theta$, to each message profile $m$ is associated a preference profile $(\theta_E(\mathcal{I}), \theta_N(g(m)))$. Since a mechanism in the second stage implements the social choice function, it follows that to each $m$ is associated a unique alternative $x = f(\theta_E(\mathcal{I}), \theta_N(g(m)))$.

Given a type-profile $\theta \in \Theta$, a $\theta$-game is the corresponding simultaneous move game $(E, \theta_E(\mathcal{I}), M_E, f(\theta_E(g(\mathcal{I}), \theta_N(g(\cdot)))$. A Nash equilibrium of a $\theta$-game is a profile of messages $m^*$ such that

$$u_i(f(\theta_E(\mathcal{I}), \theta_N(g(m^*)))) \geq u_i(f(\theta_E(\mathcal{I}), \theta_N(g(m_i, m^*_{-i})))),$$

for all $i \in E$, $m_i \in M_i$.

We model the choice of social choice functions as if a designer had to select one of them, among the set of social choice functions that are implementable and was interested in methods that would achieve the social decision corresponding to societies where all agents were fully informed. We assume that, at the time of the decision, the designer knows the set of admissible preferences $\mathcal{R}_i$ for each agent $i$, but she does not necessarily observe the sets $\mathcal{I}$ and $\Theta_i$, or which message profile $m$ will be played by the experts.

The following definition describes the first best objective the designer may try to attain.

**Definition 3** *A social choice function $f$ ensures **outcome-relevant information disclosure** if for every $\theta \in \Theta$ and for every Nash equilibrium $m^*$ of the corresponding $\theta$-game, $f(\theta_E(\mathcal{I}), \theta_N(g(m^*)) = f(\theta(\mathcal{I}))$.*

Full outcome-relevant information disclosure requires that every equilibrium outcome coincides with the outcome of the social choice function when all agents have fully informed preferences. It may be the case that in equilibrium not all information is transmitted because the missing pieces are irrelevant for the outcome. However in all profiles where some relevant information is not revealed, there must exist some expert ready to disclose additional pieces of information. Notice that our condition is weaker than the one in Proposition 4 in Milgrom and Roberts (1986), because we do not require experts to prefer the outcome of the social choice function when all agents have fully informed preferences to any other, but only to be interested in contributing some additional information, not necessarily all of it.

Even if full outcome-relevant disclosure could not be guaranteed, one might be able to evaluate what social choice functions would perform better in promoting disclosure. As we shall see, the need for a second best approach arises when the designer does not know who the experts are at the time of selecting a rule.

We model the designer's lack of information about what agents will be experts by assuming that nature draws their set $E$ out of a family $\mathcal{W}$ (with cardinality larger than one) of non-empty coalitions of $A$ . The designer knows $\mathcal{W}$, but she must choose the social choice function $f$ before nature's choice. In that context, we propose the following terms of comparison:

**Definition 4** *A social choice function $f$ ensures **better outcome-relevant information disclosure** than the social choice function $f'$ , if (i) for every $L \in \mathcal{W}$ such that $f'$ ensures full outcome-relevant information disclosure when $L$ is the set of experts, then $f$ also ensures it and (ii) there is some $T \in \mathcal{W}$ such that $f$ ensures full outcome-relevant information disclosure when $T$ is the set of experts, while $f'$ does not.*

This definition provides a partial ordering over social choice functions with respect to the incentives they provide to disclose information, and may be used to compare the performance of social choice functions in settings where it is impossible to achieve the goal of full outcome-relevant information disclosure. We shall use it in Section 5.

# 4 Main Results

In this section we present a sufficient condition for the existence of social choice functions ensuring full outcome-relevant disclosure and prove that under an additional requirement it also becomes necessary. This condition is based on the power attributed to experts by the social choice function and because of that we start with the following definition:

**Definition 5** *A social choice function $f : \mathcal{R}^n \to X$ attributes coalitional veto power to a set $V \subseteq N$ , if for all pairs $R, R' \in \mathcal{R}$ with $R_i = R'_i$ for all $i \in V$, either $f(R) = f(R')$ or there is a pair $i, j \in V$ such that $f(R')P_i f(R)$ and $f(R)P_j f(R')$.*

When a set $V$ is endowed with coalitional veto power, changes in the social outcome that are driven by changes in the preferences of agents outside $V$ cannot harm all agents in $V$ at the same time. Hence, agents in $V$ collectively have the power "to veto" changes in the social outcome that they all dislike. We can now state the following.

**Theorem 1** *If a social choice function $f : \mathcal{R}_1 \times \ldots \times \mathcal{R}_n \to X$ attributes coalitional veto power to the set of experts $E$, then it ensures full outcome-relevant information disclosure.*

Here is the intuition for the result. Suppose that only some information, or none, is disclosed by the experts, and that disclosing some further information would modify the preferences of non-experts in a way that changed the social outcome. Then, coalitional veto power guarantees that there is an expert who has incentives to disclose this additional information.

Attributing coalitional veto power to the experts only requires a conflict of interest among experts when their preferences are unchanged, and yet the social outcome varies due to shifts in the preferences revealed by non-experts. Theorem **??** shows that endowing experts with such power is sufficient to guarantee full outcome-relevant information disclosure, but it is not necessary, unless further conditions are imposed on the set of types.

**Definition 6** *The set* $\Theta_i$ *is rich in the domain* $\mathcal{R}_i$ *if every function* $\theta_i : 2^{\mathcal{I}} \to \mathcal{R}_i$ *belongs to* $\Theta_i$ *.*

Informally we can say that if an agent has a rich set of possible types, the way in which she may react to additional information is unpredictable for the designer. Under this additional assumption, we obtain a full characterization result.

**Theorem 2** *Suppose the type set* $\Theta_i$ *is rich for all* $i \in A$*. A choice function* $f : \mathcal{R}_1 \times \ldots \times \mathcal{R}_n \to X$ *ensures full outcome-relevant information disclosure only if it attributes coalitional veto power to the set of experts* $E$*.*

Notice that any constant social choice function ensures full outcome-relevant information disclosure in the universal preference domain. To avoid conclusions that refer to such uninteresting functions, we shall consider from now on social choice functions that satisfy the additional, mild and compelling property of unanimity. Unanimity requires that if all agents agree at some profile that an alternative $x \in X$ is their preferred one, then it has to be chosen by the social choice function. We have already mentioned that two distinct cases arise, depending on whether the planner knows or does not know who will be the future experts at the time of deciding what rule to adopt. In the first case, social choice functions can be defined by endowing the set of experts with coalitional veto power, thus ensuring full outcome-relevant information disclosure. In the latter case, however, it is not possible to achieve full outcome-relevant information disclosure at large, as expressed by the following corollary of Theorem **??**.

**Corollary 1** *Suppose $\Theta_i$ is rich for every agent $i \in A$, and that the designer does not know who the experts are. No unanimous social choice function $f : \mathcal{R}^n \to X$ ensures full outcome-relevant information disclosure.*

The intuition of this result is clear. Consider for simplicity that there are only two alternatives $a, b \in X$. By unanimity if $x$ is the preferred alternative at $P_i$ for all $i \in A$, then $f(P) = x$ for both $x \in \{a, b\}$. So both $a$ and $b$ are in the range of $f$ . Now consider a (strict) preference $P_i$ for agent $i$ such that $a$ is the preferred alternative and a preference $P_i'$ such that $b$ is the preferred alternative. Let $\bar{\theta}_i \in \Theta_i$ be such that $\bar{\theta}_i(I) = P_i'$ for all $I \subset \mathcal{I}$ and $\bar{\theta}_i(\mathcal{I}) = P_i$; let $\hat{\theta}_i \in \Theta_i$ be such that $\hat{\theta}_i(I) = P_i$ for all $I \subset \mathcal{I}$ and $\hat{\theta}_i(\mathcal{I}) = P_i'$. Consider any arbitrary $V \subset A$. Consider the type profile $(\bar{\theta}_V, \hat{\theta}_{-V})$. Suppose first that $V$ is the set of experts. By unanimity $f(\bar{\theta}_V(\mathcal{I}), \hat{\theta}_{-V}(I)) = a$ for all $I \subset \mathcal{I}$, and therefore the social choice function $f$ ensures full outcome-relevant information disclosure only if $f(\bar{\theta}_V(\mathcal{I}), \hat{\theta}_{-V}(\mathcal{I})) = a$. Similarly, suppose that $A \backslash V$ is the set of experts. By unanimity $f(\bar{\theta}_V(I), \hat{\theta}_{-V}(\mathcal{I})) = b$ for all $I \subset \mathcal{I}$, and therefore the social choice function $f$ ensures full outcome-relevant information disclosure only if $f(\bar{\theta}_V(\mathcal{I}), \hat{\theta}_{-V}(\mathcal{I})) = b$ which is a contradiction.

# 5 Applications: Strategy-proof Social Choice Functions in Restricted Domains

In this section we consider how the additional requirement of full outcome-relevant information disclosure restricts some well known class of social choice functions. Natural candidates are social choice functions that are implemented via direct mechanisms in dominant strategies.

### 5.1 Single-peaked Preferences

We first focus on generalized median voter rules defined on single-peaked preference domains. Consider a set $X$ of ordered alternatives, which may be identified with an interval in the real line, or with a finite integer interval $[a, b]$ . For each $i \in A$, $R_i$ is single-peaked over $X$ if there exists a unique $B(R_i) \in X$ (agent $i'$ s peak), and $xP_iy$ for all $x, y \in X$ such that $y < x \leq B(R_i)$ or $B(R_i) \geq x > y$. Let $\hat{\mathcal{R}}_i$ denote the set of all single-peaked preferences for agent i and $|A|$ be odd. Generalized median voter social choice functions can be described through the use of left coalition systems (Barberà, Gul and Stacchetti 1993).

Before providing formal definitions, let us describe informally how they work. Let us first consider the case when we must choose among two alternatives only, identified by 0 and 1. Ask agents what is their best alternative. Then, a given rule would be to choose 1 unless there is "enough"support for 0, in which case this lower value will be selected. What do we mean by "enough"support? We could establish the list of coalitions that will get 0 if all their members prefer it to 1; and it is natural to require that, if a coalition can enforce 0, then its supersets are also able to. Such a family of "winning"coalitions will fully describe the rule. We can now extend this same idea to cases where we must select an alternative among a set $X$ of ordered alternatives. Let each voter declare her best value. Now, we can start by asking whether value $x$ should be chosen. If "enough"people have voted for values at least as high as $x$ , but not "enough"of them have voted for values below $x$ , then $x$ is chosen. To determine what we mean by "enough", we associate a list of coalitions $W \in 2^A$ to each possible alternative $x$ , and consider that support by any of these coalitions is "enough". In order to guarantee that the rules so described do satisfy strategy-proofness and unanimity, we require from them that 1) if a coalition is "strong enough"to support an outcome, its supersets are too; 2) if a coalition is "strong enough"to support the choice of a given value, it is also “strong enough”to support any higher value; and 3) any coalition is “strong enough”to guarantee that the choice will not exceed the maximum value in $X$, if that exists.

In particular we can generate anonymous generalized median voter social choice functions by requiring that if a coalition is strong enough for a given alternative, all other coalitions of the same size are also strong enough.

**Definition 7** *A left coalition system on $X = [a, b]$ is a correspondence $W$ assigning to every $x \in X$ a non-empty collection of non-empty coalitions $W(x)$ , satisfying the following requirements:*

*1. if $c \in W(x)$ and $c \subset c'$, then $c' \in W(x)$;*

*2. if $x' > x$ and $c \in W(x)$, then $c \in W(x')$ ; and*

*3. $W(b) = 2^A$ .*

**Definition 8** *Given a left coalition system $W$ on $X$, its associated generalized median voter social choice function $f : \hat{\mathcal{R}}^n \to X$ is defined so that, for all profiles $R$,*

$$f(R) = x \text{ iff } \{i|B(R_i) \leq x\} \in W(x)$$

*and*

$$\{i|B(R_i) \leq y\} \notin W(y) \quad \text{for all } y < x.$$

Generalized median voter rules characterize strategy-proof social choice functions in the single-peaked preference domain (Moulin 1980).

**Definition 9** *Given a social choice function $f : \mathcal{R}^n \to X$, we say that agent $i \in N$ can manipulate at profile $R$ via $R'_i$ , if $f(R_{-i}, R'_i)P_i f(R_{-i}, R_i)$. A social choice function $f : \mathcal{R}^n \to X$ is strategy-proof if no agent can manipulate $f$ at any profile $R$.*

Strategy-proofness only requires that truthful revelation by each agent is a dominant strategy equilibrium of the associated direct revelation mechanism, so it is usually a weaker requirement than implementation in dominant strategies. However, generalized median voter social choice functions in the domain of single-peaked preferences are implementable in dominant strategies. This is a corollary of a result by Mizukami and Wakayama (2007). It justifies our interest in mechanisms within that class because of their good incentive properties, and also ensures that they fall within the range of applications of Theorem 1.[5]

We now return to the main purpose of our paper, and analyze under what conditions generalized median voter social choice functions induce information disclosure.

We first consider the case where the designer knows in advance who are the set of experts and can use this information to endow experts of coalitional veto power. The following proposition follows from our main result.

**Proposition 1** *Let the type set $\Theta_i$ be rich in $\hat{\mathcal{R}}_i$ for each $i \in A$ . Then a generalized median voter social choice function $f : \hat{\mathcal{R}}^n \to X$ ensures full outcome-relevant information disclosure if and only if the associated left coalition system is such that for each alternative $x \in X$, $(i)$ there exists $c \in W(x)$ such that $c \subseteq E$; and $(ii)$ for all $c \in W(x)$, $c \cap E \neq \varnothing$.*

Since the type set $\Theta_i$ is rich in $\hat{\mathcal{D}}$ for agent $i$ the planner cannot predict how agent $i$'s preferences will change when additional information becomes available to her, except that eventually modified preferences will still be single-peaked with respect the given order of alternatives.

Full outcome-relevant information disclosure restricts the set of left coalition systems in two ways: first for every alternative $x$, it must contain a coalition $c(x)$ formed by the experts alone. Second, no coalition can contain only non-

[5]Mizukami and Wakayama (2007) prove that if a social choice function satisfies both strategy-proofness and quasi-strong-non-bossiness, then it is dominant strategy implementable by the associated direct revelation. A social choice function $f$ satisfies quasi-strong-non-bossiness if, for all $R, R'$, all $i \in A$, and all $R''_{-i}$, $f(R_i, R''_{-i}) I_i f(R'_i, R''_{-i})$ then $f(R_i, R''_{-i}) = f(R'_i, R''_{-i})$. It is easy to check that generalized median voter rules satisfy this property.

experts. Unanimity, in turn, requires that the empty coalition cannot belong to the left coalition system associated with any alternative.

Theorem **??** tells us that coalition veto power has to be granted to experts. In our case, coalitional veto power narrows the set of generalized median agent social choice functions guaranteeing information disclosure in a very intuitive way, as expressed in the following corollary.

**Corollary 2** *A generalized median voter social choice function that attributes coalitional veto power to the set of experts $E$ always selects alternatives that lie in between the minimum and the maximum peak of experts.*

The formal proof of this corollary is left to the reader. To see how this simple condition works in favor of information disclosure, consider any pair of profiles for which the rule selects two different alternatives. Since both of them fall between the maximum and the minimum peak of the experts, at least two of them will have opposite views on the two outcomes. Whenever the change from one of the two profiles to the other can be prompted by information disclosure, some expert will be inclined to reveal additional information. This was, indeed, the main intuition behind our initial motivational example.

When the number of experts is large enough, attributing them veto power becomes compatible with anonymity[6], thus avoiding the bias in favour of experts that, in general, is needed to induce information disclosure. The median voter social choice function plays a central role among the anonymous generalized median voter social choice functions: its associated left coalition system is such that for all $x \in X$, $c \in W(x)$ if and only if $|c| \geq \frac{n+1}{2}$. In other words, it selects the median among the agents' peaks.[7]

[6] A social choice function $f : \mathcal{R}^n \to X$, is anonymous if for all $R, R'$, $f(R) = f(R')$ whenever $R$ is a permutation of $R'$ .

[7] This result contrasts with Jackson and Tan (2012)'s conclusion that unanimity is the superior method in their context. This is due to the fact that experts are not voters in their context, while they have a relevant say on the outcome in our case.

**Corollary 3** *If* $|E| \geq \frac{n+1}{2}$*, then the median voter social choice function ensures full outcome-relevant information disclosure.*

We are finally ready to consider the case in which the designer does not know the identity of the experts. In this case it seems natural to focus on anonymous social choice functions.

**Proposition 2** *Suppose agents have single-peaked preferences and the type set* $\Theta_i$ *is rich for every agent* $i \in A$*. The median voter social choice function ensures better information disclosure than any other anonymous, unanimous, strategy-proof social choice functions.*

Corollary **??** gives the intuition for this result. The median voter rule minimizes the cardinality of the set of experts that is needed to ensure full outcome-relevant information disclosure. If the cardinality is exactly (n+1)/2, the median voter rule is the only anonymous, unanimous, strategy-proof social choice function that ensures full outcome-relevant information disclosure.

## 5.2 Separable Preferences

In this section we sketch the analysis of an interesting class of collective decision problems, whose structure admits further understanding of situations where social choice functions inducing information sharing exist, and even to characterize such rules. The situations we refer to are those where the alternatives can be described by the collection of characteristics they hold, out of a given list. For example, if the present members of a club are allowed to vote for new entrants, and there is no limit to their number, each possible list of elected ones is an alternative and each candidate is a characteristic. Another example is given by the problem faced by an assembly that must legislate on a general topic, say on housing, or health. They must decide what issues within their scope to regulate, and on which ones to keep silent. Lists of issues will then be the alternatives they face. In such cases, agents will have preferences on lists of characteristics. In that context, separability of preferences regarding characteristics may become a natural assumption, if the contribution of each characteristic to the value that agents attribute to each alternative is independent of the contribution of others. In our case, where preferences of uninformed agents may change because of new information, it is also natural to consider another form of separability, this time regarding the case where each piece of information may only affect the valuation of a single characteristic by the agents who receive it.

Before we formalize these ideas and present our main result in that section, let us announce where we are headed to. We shall identify a class of social choice functions that guarantee information disclosure in the doubly separable context we propose, and yet do not satisfy coalitional veto power. This is not in contradiction with our previous Theorem **??**, since the type space we shall consider is not rich. Let us also mention that in the case we are about to formalize, full outcome-relevant information disclosure may obtain as the result of partial disclosure decisions by different experts, even in the case that none of them might be interested in disclosing all the outcome-relevant information. This contrasts with the case considered in the preceding section.

Let $\mathcal{P}_i$ denote the set of all strict preferences (asymmetric orderings) on $2^X$ for agent $i$ and $P_i$ stands for agent $i$'s preferences. $X$ is the set of characteristics and an alternative a subset of $X$; a social choice function $f : \mathcal{P}_1 \times \ldots \times \mathcal{P}_n \to 2^X$, assigns a set of characteristics (an alternative) to each preference profile. We focus on problems in which agents' preferences satisfy a restriction named separability. Let $G(P_i) = \{x \in X | \{x\} P_i \varnothing\}$ denote the set of good characteristics for agent $i$, and $G^c(P_i)$ its complement. Separability means that once agents partition the set of characteristics in the two sets of desirable (good) characteristics and undesirable ones, their preference relations satisfy the following condition.

**Definition 10** *A preference relation $P_i$ is separable if for all $T \in X$ and all $x \notin T$, $T \cup \{x\} P_i T$ if and only if $x \in G(P_i)$. The family of all separable preferences for agent $i$ is denoted by $\tilde{\mathcal{P}}_i$.*

The following definition will help us describe a family of social choice functions in terms of the power they attribute to coalitions.

**Definition 11** *A committee (or a monotonic simple game) is a pair $\mathcal{C} = (A, \mathcal{W})$, where $A = \{1, ..., n\}$ is the set of agents, $\mathcal{W}$ is a non-empty set of non-empty coalitions of $A$, such that $L \in \mathcal{W}$ and $L' \supseteq L$ implies $L' \in \mathcal{W}$.*

**Definition 12** *A social choice function $f : \mathcal{P}_1 \times \ldots \times \mathcal{P}_n \rightarrow 2^X$ is based on voting by committees, if for each $x \in X$, there exists a committee $\mathcal{C}_x = (A, \mathcal{W}_x)$ such that: for all preference profiles $P \in \mathcal{P}^n$, $x \in f(P)$ if and only if $\{i | x \in G(P_i)\} \in \mathcal{W}_x$.*

One nice feature of methods based on voting by committees is that they only depend on the subset of $X$ that is ranked higher by each agent. Barberà, Sonnenschein and Zhou (1991) show that a unanimous social choice function is strategy-proof on the domain of separable preferences if and only if it is based on voting by committees.

Strategy-proofness on this domain is a weaker concept than implementation in dominant strategy, because other equilibria could exist different than truth-telling. We therefore assume that agents operating under these rules are partially honest and this is common knowledge (see for instance Dutta and Sen, 2011; Kartik, Tercieux, and Holdeny, 2014): if truthfully reporting their preferences is a weakly dominant strategy, then agents declare their true preferences. In this way we rule out untruthful dominant strategy equilibria in the direct mechanism.

We formalize now the notion of separability on the set $\Theta_i$. Informally, a type set $\Theta_i$ is separable if every piece of information in $\mathcal{I}$ affect at most how one single characteristic is ranked. The set $\mathcal{I}$ can be partioned into sets $I_x \in 2^S$ for every $x \in X$ (possibly $I_x$ can be empty) each of them containing all the information about characteristic $x$ and no information about any other characteristic $y \neq x$.

**Definition 13** *A type set $\Theta_i$ is separable in $\tilde{\mathcal{P}}_i$ for agent $i$ if for every $\theta_i \in \Theta_i$,and for every $x \in X$, $\exists I_x \in 2^{\mathcal{I}}$ such that for all $I \in 2^{\mathcal{I}}$ : a) $x \in G(\theta_i(I \cup I_x)) \Leftrightarrow x \in G(\theta_i(\mathcal{I}))$; and b) for all $\hat{I} \subseteq I_x$, either $G(\theta_i(I \cup \hat{I})) \backslash G(\theta_i(I)) = x$ or $G(\theta_i(I \cup \hat{I})) \backslash G(\theta_i(I)) = \varnothing$.*

The next proposition proves that when the set of types is also separable, we are able to identify which social choice functions based on voting by committes ensures full outcome-relevant information disclosure.

**Proposition 3** *Assume that for all $i \in A$, the type set $\Theta_i$ is separable. A social choice function $f : \mathcal{P}_1 \times \ldots \times \mathcal{P}_n \to 2^X$ based on voting by committees ensures full outcome-relevant information disclosure if and only if for each $x \in X$,*
*$(a)$ there exists $T_x \subseteq E$ and $T_x \in \mathcal{W}_x$; and*
*$(b)$ for each $L \in \mathcal{W}_x$, $L \cap E \neq \varnothing$.*

**Proof.** See the Appendix. ■

The existence of the nice rules considered in Proposition **??** is compatible with our previous statements. Theorem **??** does not apply, because experts do not have veto power, but this poses no problem, since veto power is sufficient but not necessary to induce disclosure. Theorem **??** is not contradicted either by our present proposition, because a separable type set $\Theta_i$ is not rich. The following example shows that coalition veto power may be violated by a social choice function based on voting by committees satisfying the conditions stated in Proposition **??**.

**Example 1** *Let* $A = \{1, 2, 3\}$, $E = \{1, 2\}$ *and* $X = \{y, w, z\}$. *Let* $f$ *be based on voting by quota two: a characteristic is selected if and only if at least two agents report that it is good. Notice that this social choice function satisfies the conditions of Proposition* **??**. *Suppose that agent 1's preferences* $P_1 \in \tilde{\mathcal{P}}_i$ *are such that* $G(P_1) = \{w, z\}$, *agent 2's preferences* $P_2 \in \tilde{\mathcal{P}}_2$ *are such that* $G(P_2) = \{y, z\}$ *and for both* $i \in \{1, 2\}$ $\{z\} \, P_i \, \{y, w, z\}$. *Let* $P_3 \in \tilde{\mathcal{P}}_3$ *be such that* $G(P_3) = \{z\}$ *and* $P'_3 \in \tilde{\mathcal{P}}$ *such that* $G(P'_3) = \{y, w, z\}$. *Notice that* $f(P_{-3}, P_3) = \{z\}$ *and* $f(P_{-3}, P'_3) = \{y, w, z\}$ *and therefore* $f$ *does not attribute coalition veto power to the set of experts, because all experts prefer* $f(P_{-3}, P_3)$ *to* $f(P_{-3}, P'_3)$.

The previous example illustrates another interesting feature of this case. Full outcome-relevant information disclosure may occur in equilibrium because some experts have incentives to disclose some partial information, even if no expert has incentives to disclose all of it: nonetheless all information is disclosed in the aggregate. Since the type functions of each non-expert are separable, any expert may disclose information about a single characteristic without affecting how other characteristics are evaluated.

Assume that the set of characteristics chosen at a preference profile $(\theta_E(\mathcal{I}), \theta_N(I))$ is different than the one chosen at profile $\theta(\mathcal{I})$, where all agents are fully informed. The conditions stated in Proposition **??** guarantee that at every profile the chosen characteristics will be all those that are good for every expert and no other. It follows that if the alternatives chosen at two different profiles do not coincide, there must exist some characteristic about which experts have conflicting preferences.

To see this, let $x$ be a characteristic that is good for some but not for all experts. If $x$ was chosen at profile $(\theta_E(\mathcal{I}), \theta_N(I))$ but not at profile $\theta(\mathcal{I})$; $I$ would not be the full amount of information disclosed in equilibrium. This is because any expert who considers $x$ a bad characteristic could profitably deviate by disclosing $I \cup I_x$ and prevent $x$ from being chosen. The same argument applies if there existed a characteristic $y$ who was chosen at profile $\theta(\mathcal{I})$ but not at a profile $(\theta_E(\mathcal{I}), \theta_N(\hat{I}))$ for some $\hat{I} \subset \mathcal{I}$. Notice, however, that if the type set was not separable for some non-experts, then the class of social choice functions described in Proposition **??** would not guarantee full outcome-relevant information disclosure, as shown be the following example that continues the previous one.

**Example 2** ***(cont')*** *Keep the same social choice function $f$, set of agents and of characteristics, but now consider a (non-separable) type $\theta_3 \in \Theta_3$ such that $\theta_3(\varnothing) = P_3$ and $\theta_3(I) = P_3'$ for all $I \in 2^S \backslash \varnothing$. If agent 3 remains uninformed she only likes characteristic $z$; otherwise, if some information is disclosed to her, then she likes all three characteristics. The type set $\Theta_3$ is not separable. It is easy to check that $f(\theta_{-3}, \theta_3(\varnothing))) = \{z\}$ and $f(\theta_{-3}, \theta_3(I)) = \{y, w, z\}$ for all $I \in 2^{\mathcal{I}} \backslash \varnothing$. Therefore no expert has incentives to disclose any information and there is a Nash equilibrium $m^*$such that $m_i = \varnothing$ for all $i \in E$.*

# 6 Experts with distinct information

In this last section we discuss a relaxation of our assumption that every expert owns the same private information. The set of agents is still partitioned into a set of experts $E$ and a set of non-experts $N$, with $N = A \backslash E$. Experts' preferences are fixed and do not depend on any message $m$ that is played in the first stage of the game: for every $i \in E$ and for every $m, m'$, $\theta_i(g(m)) = \theta_i(g(m'))$. However here we allow experts to have distinct information that they can credibly disclose to non-experts. There are two possible interpretations consistent with these assumptions. According to the first interpretation, experts are "ideological" or "partisan" agents such that whichever information other experts disclose their preferences do not not change, and they have distinct private information that they can disclose to non-experts. In alternative, we can still assume that experts do all have the same private information but the information that each expert can *credibly* disclose to non-experts may differ. The assumption that experts' preferences are not affected by information implies that they do not have to form beliefs about their own *fully informed* preferences when they decide which information to disclose.

We define a partition $\mathcal{Q}$ of the set of experts and we denote by $E_k \subset E$ with $k \leq l$, a generic element of this partition, such that for any pair $i, j \in E$, and for any $E_k$, $i, j \in E_k \Leftrightarrow M_i = M_j$. This partition groups the experts with the same message space. Let $I_k \subseteq \mathcal{I}$ denote the information that experts in subset $E_k$ have, we assume that for all $i \in E_k$ $M_i \equiv 2^{I_k}$: every expert can disclose any subset of the information she is aware of. We say that if $i \in E_k$ and $j \in E_{k'}$, then experts $i$ and $j$ have different private information. A natural extension of Theorem 1 can be proved in this framework.

**Theorem 3** *Let $\mathcal{Q}$ be a partition of the set of experts in two or more subsets of experts with different information such that for each $E_k \in \mathcal{Q}$, $|E_k| \geq 2$. If a social choice function $f : \mathcal{R}_1 \times \ldots \times \mathcal{R}_n \rightarrow X$ attributes coalitional veto power to every distinct set of experts $E_k \in \mathcal{Q}$, then it ensures full outcome-relevant information disclosure.*

It is important to notice that we do not require that if $i \in E_k$ and $j \in E_{k'}$, then $M_i \cap M_j = \emptyset$, so experts with distinct private information may have some overlapping amount of information. In fact, Theorem **??** only provides a sufficient condition to ensure full outcome-relevant information disclosure. In the setting of Section 5.2 in which agents have separable preferences and information, seems quite natural to assume that experts may have different private information.

**Example 3** *Consider the setting illustrated in Section* 5.2 *where agents have* *strict separable preferences on $2^X$. For each $x \in X$, there is a set of experts, denoted by $E_x$, who have private information over $x$. Let $\mathcal{I}_x$ be the set of pieces of verifiable hard information they have over $x$. Every expert $i \in E_x$ has the same message space $M_i = 2^{\mathcal{I}_x}$. The social choice function $f : \mathcal{P}^n \to 2^X$ based on voting by committees such that for each $x \in X$,*

*$(a)$ if $E_x \neq \emptyset$, there exists $T_x \subseteq E_x$ and $T_x \in \mathcal{W}_x$; and*

*$(b)$ for each $L \in \mathcal{W}_x$, $L \cap E_x \neq \varnothing$,*

*ensures full outcome-relevant information disclosure.*

Notice that an expert may have private information over several characteristics. A real life example are committees that evaluate candidate for a position in which members of the committee have different expertises and have access to different records based on their expertise, or hiring committees with different panels, in which each panel interviews a different set of candidates.

## 7 Conclusions

We have identified conditions under which, by appropriately choosing a mechanism that implements a social choice function, a designer could induce information disclosure from experts, in collective decision problems where society faces two or more alternatives.

Some rules may formally satisfy this property by awarding all power to a single agent or to an oligarchy. But in other cases of interest one can find ways to induce information disclosure while giving a say to all agents, whether they are informed at the outset or not.

We show that, in very broad terms, experts must be given some more decision power than other agents, but this difference may vanish as the relative size of the set of experts increases. This suggests that an increase in the number of initially well informed individuals will ease the need for unequal treatment of agents as a means to stimulate information transmission.

Our results have been obtained within a simplified model that focuses on our main concern: the search of social choice functions which induce a set of informed agents to share what they know with the rest of society.

We do not directly base this search on efficiency considerations, because efficiency is relative to agents' preferences and agents, in our context, may change opinions as a function of what they know and what they learn. Rather, we base our interest in information disclosure on the belief that a well informed agents are the best guarantee that democratic decisions work in the favour of society. In times of fake news, our interest in information disclosure must be qualified, either by restricting attention to the transmission of reliable information, or else by assuming that rational and informed agents will be able to discriminate against false information. These are certainly restricting assumptions, but relaxing them would require a separate paper. Yet ex-post Pareto efficiency will be guaranteed by rules that induce information disclosure in the case where all informed agents share the information.

Also notice that we have avoided, in the present paper, some important questions that arise when considering information acquisition, like the amount of effort and resources that rational agents would devote to become better informed by using their own means. The assumption allows us to focus on transmission from voters who possess information to others that lack it. Trade-offs between these two forms of learning about the issues, and a study of the costs involved in learning by oneself versus those of communicating with others would be very worth studying. These and other extensions of our present study open clear directions for future research.

# 8 Appendix

**Proof of Theorem ??.** Suppose $f$ attributes coalitional veto power to the set $E$. If $E = \{i\}$, then for all pairs $R, R' \in \mathcal{R}$ with $R_i = R'_i$ $f(R) = f(R')$ and $f$ trivially satisfies full outcome-relevant information disclosure. If $|E| \geq 2$, then fix any $\theta \in \Theta$. Let $\bar{m}$ be a strategy profile such that $\bar{m}_i = \mathcal{I}$ for all $i \in E$. It is immediate to check that $\bar{m}$ is a Nash equilibrium of the game and $f(\theta_E(\mathcal{I}), \theta_N(g(\bar{m})) = f(\theta(\mathcal{I}))$ . To prove that there are no other Nash equilibrium outcomes, suppose $m$ be a Nash equilibrium involving partial or no disclosure and $f(\theta_E(\mathcal{I}), \theta_N(g(m))) \neq f(\theta(\mathcal{I}))$. By assumption there is an expert $i \in E$ such that $f(\theta(\mathcal{I}))P_i f(\theta_E(\mathcal{I}), \theta_N(g(m)))$. Expert $i$ can profitably deviate by announcing $m'_i = \mathcal{I}$ : in fact $g(m'_i, m_{-i}) = \mathcal{I}$ and therefore $f(\theta_E(\mathcal{I}), \theta_N(g(m'_i, m_{-i})))P_i f(\theta_E(\mathcal{I}), \theta_N(g(m)))$.

**Proof of Theorem ??.** If $f$ does not attribute coalitional veto power to the set $E$, then there exists a pair of preference profiles $(R_E, R_N)$, $(R_E, R'_N)$ such that $f(R_E, R_N) \neq f(R_E, R'_N)$ and $f(R_E, R_N)R_i f(R_E, R'_N)$ for all $i \in E$. Consider a type $\theta_j \in \Theta_j$ such that $\theta_j(I) = R_j$ for all $I \subset \mathcal{I}$ and $\theta_j(\mathcal{I}) = R'_j$. This type exists because $\Theta_j$ is rich for every $j \in A$. Consider a strategy profile $m^*$ such that for all $i \in E$ , $m^*_i = \hat{I}$ for some $\hat{I} \subset \mathcal{I}$. The strategy profile $m^*$ is a Nash equilibrium of the $\theta$-game. In fact any deviation $m'_i \neq \mathcal{I}$ is irrelevant because it does not modify non-experts' preferences and, consequently, the final outcome, while the deviation $m'_i = \mathcal{I}$ is not profitable for any expert $i$, because $\theta_j(\mathcal{I}) = R'_j$ for all $j \in N$, and $f(R_E, R_N)R_i f(R_E, R'_N)$ for all $i \in E$.

**Proof of Proposition ??**. Sufficiency. Consider any generalized median voter social choice function with a left coalition system $W$ such that for all $x \in X$, $i)$ there exists $c_x \subseteq E$ and $ii)$ $c \in W(x)$ only if there exists $i \in E \cap c$. Fix an arbitrary single-peaked preference profile $R_1, \ldots, R_n \in \hat{\mathcal{R}}^n$, where $\hat{\mathcal{R}}^n$ denote the set of all single-peaked preference profiles. Let $l \in E$ be such that for all $j \in E$, $B(R_l) \leq B(R_j)$ and let $r \in E$ be such that for all $j \in E$, $B(R_r) \geq B(R_j)$. By $(ii)$ $f(R) \geq B(R_l)$ and by $(i)$ $f(R) \leq B(R_r)$. Consider now any $R' \in \hat{\mathcal{R}}^n$ such that for all $j \in E$, $R_j = R'_j$. For the same arguments as above $B(R_l) \leq f(R') \leq B(R_r)$. Suppose $f(R') \neq f(R)$, and without loss of generality, suppose that $f(R') < f(R)$. It follows that $f(R')P_l f(R)$ and $f(R)P_r f(R')$ and coalitional veto power is satisfied.

Necessity. Consider any generalized median voter social choice function $f$. Since the type set $\Theta_i$ is rich in $\hat{\mathcal{R}}_i$ for each $i \in A$, then by Theorem **??** the generalized median voter rule should satisfy coalitional veto power relative to $E$. Let $W$ be its associated left coalition system and $X = [a, b]$. Suppose first that there exists $x < b$ such that for each coalition $c \in W(x)$, a member of $c$ is a non-expert. Consider $R \in \hat{\mathcal{R}}^n$ such that for all $i \in E$, $B(R_i) = x$ and for all $j \in N$, $B(R_j) = b$; it follows that $f(R) > x$. Let $R'_j \in \hat{\mathcal{R}}_j$ be a preference such that $B(R'_j) = x$. By unanimity $f(R_E, R'_N) = x$. Consider a profile $\theta$ such that for all $i \in A$, $\theta_i(I) = R'_i$ for all $I \subset \mathcal{I}$ and $\theta_i(\mathcal{I}) = R_i$. It follows that there exists a Nash equilibrium of the $\theta$-game such that for all $i \in E$, $m^*_i = \hat{I}$ for some $\hat{I} \subset \mathcal{I}$ and $f(\theta_E(\mathcal{I}), \theta_N(g(m^*))) \neq f(\theta(\mathcal{I}))$. Therefore, the social choice function does not ensure full outcome-relevant information disclosure. Suppose now that there exists $x < b$ and $c \in W(x)$ such that $E \cap c = \varnothing$. Let $R'_i, \bar{R}_i \in \hat{\mathcal{R}}_i$ be a pair of preference such that $B(R'_i) = x$ and $B(\bar{R}_i) = b$. At preference profile $(\bar{R}_E, R'_N)$ we have $f(\bar{R}_E, R'_N) \leq x$. By unanimity $f(\bar{R}_E, \bar{R}_N) = b$. Consider a type profile $\theta$ such that for all $j \in N$, $\theta_j(I) = \bar{R}_j$ for all $I \subset \mathcal{I}$ and $\theta_j(\mathcal{I}) = R'_j$, and for all $i \in E$, $\theta_i(\mathcal{I}) = \bar{R}_i$. It follows that there exists a Nash equilibrium of the $\theta$-game such that for all $i \in E$, $m^*_i = \hat{I}$ for some $\hat{I} \subset \mathcal{I}$ and $f(\theta_E(\mathcal{I}), \theta_N(g(m^*))) = f(\bar{R}) \neq f(\bar{R}_E, R'_N) = f(\theta(\mathcal{I}))$, and the social choice function does not ensure full outcome-relevant information disclosure.

**Proof of Proposition ??**. By Moulin (1980), we know that a social choice function is anonymous, unanimous and strategy-proof if the left coalition system satisfies this additional condition: for any $x \in X$ if $c \in W_x$ then $c' \in W_x$, for all $c' \in 2^A$ with $|c'| \geq |c|$. By Theorem **??** and Corollary **??**, when $|E| < \frac{n+1}{2}$, it follows immediately that no anonymous, unanimous and strategy-proof social choice function may ensure full outcome-relevant information disclosure. By Corollary **??** we know that the median rule ensures information disclosure when $|E| \geq \frac{n+1}{2}$ . To conclude the proof, we show that every anonymous, unanimous and strategy-proof social choice function different than the median rule does not ensure full outcome-relevant information disclosure when $|E| = \frac{n+1}{2}$. Let $M$ be an arbitrary set of agents with $|M| = \frac{n+1}{2}$. Consider any anonymous, unanimous and strategy-proof voting rule $f$ such that for some $z < b$ $c \in C(z)$ if and only if $|c| \geq k$ with $k \neq \frac{n+1}{2}$. Suppose first $k < \frac{n+1}{2}$. Consider a pair of preference profiles $R^0, R^1 \in \hat{\mathcal{R}}^n$ with $R^1_M = R^0_M = R_M$, $B(R_i) = b$ for all $i \in M$, and $B(R^0_j) = b$, $B(R^1_j) = z$ for all $j \notin M$. Let $\theta$ be a type profile such that for all $i \in M, \theta_i(\mathcal{I}) = R^0_i$ and for all $j \notin M$ $\theta_j(I) = R^0_j$ for all $I \subset \mathcal{I}$ and $\theta_j(\mathcal{I}) = R^1_j$. Consider a $\theta$-game such that $M = E$. It is immediate to check that there exists a Nash equilibrium $m^*$ such that $m^*_i = I$ for some $I \subset \mathcal{I}$ and for all $i \in E$ and $f(\theta_E, \theta_N(g(m^*))) = z \neq f(\theta(\mathcal{I})) = b$. The proof for the case $k > \frac{n+1}{2}$ is analogous: consider a pair of preference profiles $\bar{R}^0, \bar{R}^1 \in \hat{\mathcal{R}}^n$ with $\bar{R}^1_M = \bar{R}^0_M = \bar{R}_M$, $B(\bar{R}_i) = z$ for all $i \in M$, $B(\bar{R}^0_j) = z$, $B(\bar{R}^1_j) = b$ for all $j \notin M$ and a type-profile $\theta$ such that for all $j \notin M$, $\theta_j(I) = \bar{R}^0_j$ for all $I \subset \mathcal{I}$ and $\theta_j(\mathcal{I}) = \bar{R}^1_j$.

**Proof of Proposition ??**. Sufficiency. We prove that a social choice function based on voting by committees that satisfies requirements (a) and (b) ensures full outcome-relevant information disclosure. Suppose by contradiction that there exists a type profile $\theta$ and a Nash equilibrium $m^*$ of the $\theta$-game such that $m^* = I \subset \mathcal{I}$ and $f\left(\theta_E(\mathcal{I}), \theta_N(g(m^*))\right) = f(P) \neq f\left(\theta(\mathcal{I})\right)$. Since every winning coalition contains an expert (requirement (b)) and for every alternative there exists a winning coalition, formed only by experts (requirement (a)), then $x \in \bigcup G(P_i)$ implies that $x$ is selected both at $f(P)$ and at $f(\theta(\mathcal{I}))$ and $x \notin G(P_i)$ for every $i \in E$ implies that $x$ is selected neither at $f(P)$ nor at $f(\theta(\mathcal{I}))$. Therefore (i) for every $x \notin f(P)$ but $x \in f(\theta(\mathcal{I}))$ there exists an expert $i$ such that $x \in G(P_i)$ and (ii) for every $x \in f(P)$ but $x \notin f(\theta(\mathcal{I}))$, there exists an expert $i$ such that $x \notin G(P_i)$.

Consider first case (i). Since $x \in f(\theta(\mathcal{I}))$ then by separability of the type set $f(\theta_E(\mathcal{I}), \theta_N(g(m^* \cup I_x))) = f(P) \cup x$ and therefore the strategy $m_i = m^* \cup I_x$ is a profitable deviation for expert $i$. Case (ii) can be proved in an analogous way: since $x \notin f(\theta(\mathcal{I}))$ then by separability of the type set $f(\theta_E(\mathcal{I}), \theta_N(g(m^* \cup I_x))) = f(P) \backslash x$ and therefore the strategy $m_i = m^* \cup I_x$ is a profitable deviation for expert $i$.

Necessity. Without loss of generality let $X = \{x, y\}$ . Suppose first that there exists an alternative $x$ such that it has an associated winning coalition formed only by non experts. Consider a pair of preference $P, P'$ such that $G(P) = \{x, y\}$ and $G(P') = \{x\}$. Consider a separable type profile $\theta$ such that

(i) for all $i \in N$, $\theta_i(I_x) = P^{'}$ and $\theta_i(I) = P$, for all $I \supset I_x$;

(ii) for all $j \in E$, $\theta_j(\mathcal{I}) = P^{'}$.

It follows that there exists a Nash equilibrium of the $\theta-$game such that in equilibrium every expert $j \in E$ discloses information $m_j^* = I_x$ and therefore full outcome-relevant information it is not disclosed.

Suppose now that there exists an alternative $x$ such that no willing coalition is formed only by experts, that is for every $M \in \mathcal{W}_x$, $M \cap N \neq \emptyset$. Consider a separable type profile $\theta^{'}$ such that

(i) for all $i \in N$, $\theta_i^{'}(I_x) = P$ and $\theta_i^{'}(I) = P^{'}$, for all $I \supset I_x$;

(ii) for all $j \in E$, $\theta_j^{'}(\mathcal{I}) = P$.

It follows that there exists a Nash equilibrium of the $\theta^{'}-$game such that in equilibrium every expert $j \in E$ discloses information $m_j^* = I_x$ and therefore full outcome-relevant information it is not disclosed.

**Proof of Theorem ??.** To simplify notation we do not distinguish anymore the preferences of the experts and non-experts when writing a preference profile at stage 2 after information $g(m)$ has been disclosed and we simply write $\theta(g(m))$, recalling that experts' preference are fixed and do not change with information disclosure. Suppose $f$ attributes coalitional veto power to every set $E_k \in \mathcal{Q}$. Fix any $\theta \in \Theta$. Let $\bar{m}$ be a strategy profile such that $\bar{m}_i = I_i$ for all $i \in E$. It is immediate to check that $\bar{m}$ is a Nash equilibrium of the game since for every $E_k \in \mathcal{Q}$, $|E_k| \geq 2$ and $f(\theta(g(\bar{m})) = f(\theta(\mathcal{I}))$. To prove that there are no other Nash equilibrium outcomes, suppose $m$ be a Nash equilibrium and $f(\theta(g(m)) \neq f(\theta(\mathcal{I}))$. Since $g(m) \neq \mathcal{I}$, there is at least one expert who did not fully disclose her outcome-relevant private information. Let $i \in E_k$ be an expert who did not fully disclose her private information. Consider the strategy $m_i' = I_k$: either $f(\theta(g(m_{-i}, m_{i'})) \neq f(\theta(g(m)))$, meaning that the disclosure of some additional information by agent $i$ affects the outcome chosen by the social choice function, or $f(\theta(g(m_{-i}, m_{i'})) = f(\theta(g(m)))$. Consider the former case. By assumption the social choice function grants veto power to the subset $E_k$, and therefore there is an expert $j \in E_k$ such that $f(\theta(g(m_{i'}, m_{-i}))P_j f(\theta((g(m)))$. It follows that expert $j$ can profitably deviate at $m$ by announcing $m_j' = I_k$. Consider the latter case. It follows that there is some other expert $j \in E_{k'}$ who did not fully disclose her information: $m_j \subset I_{k'}$. Consider then strategy profile $(m_i' = I_k, m_j' = I_{k'}, m_{-i,j})$. Again two cases may occur. Either $f(g(m_i', m_j', m_{-i,j})) \neq f(g(m_i', m_{-i}))$ or $f(g(m_i', m_j', m_{-i,j})) = f(g(m_i', m_{-i}))$. In the former case the same argument as before applies. Since the social choice function grants veto power to the set of agents in $E_{k'}$ there is at least one agent in this group who has a profitable deviation. In the latter case, it must exist some other expert in another set $E_{k''}$ who did not fully disclose the information. Since $f(\theta(g(m))) \neq f(\theta(\mathcal{I}))$, there must exist an agent who by fully disclosing her information affects the final outcome. It follows that there exist an expert $l \in E_{k''}$ and a strategy profile $\hat{m}$ with $\hat{m}_l \neq I''_k$ such that $f(\theta(g(\hat{m}_l, \hat{m}_{-l}))) \neq f(\theta(g(m_l = I_{k''}.\hat{m}_{-l}))$. By assumption the social choice function satisfies coalitional veto power and therefore there exists an expert $h \in E_{k''}$ who can profitably deviate at $\hat{m}$ announcing $m_h = I_{k''}$.

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