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INFORMED PLANNER, DECENTRALIZED DECISIONS AND INCENTIVE COMPATIBILITY

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By

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Abstract. The results on the design of incentive compatible mechanisms for implementing public decisions establish that there is no general solution to the incentive problem if the mechanisms are required to be informationally decentralized. However, even when the planner possesses the knowledge of the agents' characteristics, he may need to reach these decisions through a decentralized decision mechanism, in which the agents act in accordance with their incentives to select the public decision. Thus, even within a complete information model with an informed planner, one may need to find mechanisms that implement public decisions via decentralized decisions of the agents. We show that there exists a mechanism which resolves this problem.

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1. Introduction

Since Leonid Hurwicz (1972 a,b) called attention to the requirement of informational decentralization and incentive compatibility in the design of economic mechanisms, a rich literature has succeeded his seminal work. Both in the models specifically addressed to economic environments, as well as in the context of abstract, general models of collective decisions, there are now conclusive answers as to which class of these models can generate outcomes which are optimal, and/or consistent with the true characteristics of the agents. Surveys of this literature can be found in Green and Laffont (1979), Laffont and Maskin (1982), and Groves and Ledyard (1987). [1]

One of the central results that has emerged from this literature on the theory of incentives is that the requirements of informational decentralization together with incentive compatibility essentially restrict us to a very narrow class of economic mechanisms. The only class of mechanisms that preserve both informational decentralization and the appropriate incentive properties are those in which, for each agent, acting according to his true characteristics is a dominant strategy. In this class of models, either preferences are special (as in Clarke (1971), Groves (1973), Groves and Loeb (1975), and Green and Laffont (1977)), or the economy is large enough to eliminate any impact on the overall allocation of any single agent's deviation from truth (as in Roberts and Postlewaite (1976) and Hammond (1979)). [2] Extending incentive compatibility to a more general class of economic environments requires one to sacrifice the truth-dominance property, and this has led to models in which the incentive properties of the mechanisms under study are analysed in terms of the Nash equilibria of the relevant game (as, for example, in Groves and Ledyard (1977), Hurwicz and Schmeidler (1978) and Hurwicz (1979)). However, these models call for a compromise on the requirement of informational decentralization, for the application of the Nash concept requires essentially that the agents be aware of each other's characteristics. On the other hand, modelling strategic behavior of the agents via the Nash concept is the only approach that preserves incentive compatibility in a general class of economic environments, for, as the characterization result of Laffont and Maskin (1979a) shows, modelling incentive schemes via the Bayesian equilibrium approach that takes account of the imperfect information of the agents – along the line of research pioneered by Arrow (1979) and d'Aspremont and Gerard-Varet (1979a) – does not permit a significant extension of the class of incentive compatible mechanisms of the Clarke–Groves variety. Indeed, as they show elsewhere (Laffont and Maskin (1979b)), even with the special class of quasi-linear preferences assumed for the agents, a number of impossibility results are precipitated under the Bayesian equilibrium framework. [3,4] Thus the research in the past two decades on the theory of incentives leads to the conclusion that, in a general class of economic systems, the requirements of informational decentralization and incentive compatibility are apparently irrecoincilable objectives.

The theory of incentives evolves around the notion of a central planner, whose task it is to devise a mechanism whose outcomes are, in some well-defined sense, desirable, and are robust to individual incentives. If, in designing such a mechanism, one moves away from the notion of dominant strategy equilibrium to concepts such as Nash equilibrium in the modelling of the strategic behavior of the agents, then, as Laffont and Maskin (1982) have noted, there appears to be little rationale in excluding the planner from the knowledge of the agent's characteristics, – the knowledge that the agents themselves must have in order to compute their equilibrium strategies. Clearly, the logic of our analysis requires that, if the only incentive-compatible mechanisms in a general class of economic environments are those in which the agents' behavior is Nash, the central planner himself is vested with the knowledge of the agents' characteristics.

In a complete information model, vesting the planner with the knowledge of the agents' characteristics will make the problem of designing incentive-compatible mechanisms trivial, if we assume that the planner can implement an appropriate public decision through some kind of centralized action. However, while the latter assumption may be true in some instances of public decision-making, it ignores an essential aspect of the problem of implementing public decisions. There are instances where the planner may need to implement public decisions through some form of decentralized actions on the part of the agents, even if the agents' characteristics are known: Policy environment in practice often dictates that these decisions can only be reached through decentralized actions of the agents. [5] Essentially, this requires the planner to design a mechanism in which, given their strategic behavior, the equilibrium actions of the agents pick up the decisions the planner wishes to implement. Various public decisions that can be reached through some form of voting are particularly relevant examples in this context. We may call this the *decentralization of decisions* aspect of the problem of incentives, to distinguish it from the *decentralization of information* aspect of the problem. These are, clearly, distinct aspects of the implementation problem.

The purpose of this paper is to show that, if we assume that the planner possesses the information on the agents' characteristics, then the problem of reaching optimal decisions through decentralized decision-making by the agents can be completely resolved. We consider a class of mechanisms, which we call *planner's mechanisms*, having the following feature: In each such mechanism, the planner proposes an outcome that corresponds to an welfare optimum given by a social choice rule. The mechanism specifies a set of rules, and the corresponding sets of strategies for the agents, by which they can change the outcome proposed by the planner to any other feasible outcome. We assume that the agents, behaving non-cooperatively or otherwise, will use these rules to change the outcome the planner proposes by adopting an appropriate set of strategies only if these strategies and the associated outcome specified by the mechanism constitute an equilibrium (under some given notion of equilibrium): if no other outcome constitutes such an equilibrium, then the planner's proposal prevails. Consistent with the assumption of equilibrium behavior of the agents, we require that the outcome proposed by the planner itself constitutes an equilibrium: in effect, then, we require the outcome proposed by the planner to be the *only* equilibrium outcome of the planner's mechanism. We assume that the planner has all the necessary bargaining power, first, to suggest to the agents a mechanism to select an outcome, and second, to enforce the outcome selected through the given mechanism (or, alternatively, that the agents lack the power to threaten the outcome selected by the planner's mechanism, so that they passively accept any equilibrium outcome under the mechanism).[6] We show that, given the information on the agents' characteristics, it is possible to devise a mechanism that implements any efficient social decision procedure that may be employed to select the optimal public decisions. Specifically, for every possible configuration of the characteristics of the agents, (which we may identify with their preferences on the public alternatives at hand), the mechanism has the following property: Given any social choice rule that selects efficient outcomes, the Nash or strong Nash outcomes of the mechanism coincide with the outcomes of the social choice rule under consideration for the given characteristics of the agents. We note two features of this mechanism which are of interest: First, the mechanism works for any social choice rule, a valuable feature of the mechanism in so far as in real life situations, the social choice rule that is employed to arrive at the optimal public decisions is a datum to the planner. Second, the mechanism can implement optimal public decisions for both Nash and strong Nash behavior of the agents, so that the planner does not need to have information on the agents' strategic behavior as well. This is an important consideration, for the mechanisms that work for strong Nash behavior may not, in general, work for Nash behavior of the agents. [7,8]

The Nash or strong Nash behavior requires that all of the relevant information is common knowledge. However, if we assume only that the planner is informed of the agents' characteristics (and that the planner has this information is common knowledge) but the agents are uninformed, then the notions of dominant strategy or iterated dominant strategy equilibrium are the natural ones to consider. Interestingly, in specifying the strategic behavior of the agents, if we assume that the agents will not adopt a dominated strategy, then the mechanism we specify has the property that reporting one's most preferred alternative in the feasible set of alternatives is a dominant strategy in the set of undominated strategies for every agent. [9,10] Thus the task that we envisage for an informed planner, to implement the optimal public decisions through decentralized actions of the agents, could be achieved even when the agents themselves do not have the relevant information permitting a Nash or a strong Nash equilibrium.

2. Implementation in a complete information model

We assume that the planner has complete information on the agents' characteristics, which we may identify with their preferences, since no restriction is imposed on the set of permissible preferences. These preferences, on a finite set of *feasible alternatives* A, are assumed to be given by anti-symmetric weak orders on A. Let Θ denote the set of all possible anti-symmetric weak orders on A. The set $\Theta_i = \Theta$ is the set of all possible preference orders on A of $i \in N$, where $N = \{1,...,n\}$ is a finite set whose members index the agents. For $\theta_i \in \Theta_i$, we let $\bar{\theta}_i$ denote the asymmetric factor corresponding to θ_i, i.e., for all $i \in N$ and $x,y \in A$, $x \bar{\theta}_i y$ if $x \neq y$ and $x \theta_i y$. Then, according to our assumption, the n-tuple $\theta = (\theta_1,...,\theta_n)$, $\theta_i \in \Theta_i$, that gives the preferences of the agents, is known to the planner. We assume that, for each θ, the planner has a well-defined preference order $\theta_0 \in \Theta$; here and elsewhere, the subscipt 0 is the index for the planner.

Let C, C', and so forth, denote non-empty subsets of N. Let $-C, -C'$, and so forth, stand for the complements in N respectively of C, C', and so forth. Where for each $i \in C$ T_i is a set specified for i, T_C is the set of all functions t on C such that $t(i) \in T_i$ for all $i \in C$. Then, $(t_C, t_{-C}) \equiv t \in T_N$. The restriction of $t \in T_N$ to $N \setminus \{i\}$ is written t_{-i}, and T_{-i} stands for the set of all t_{-i}. For $i \in C$ and $t \in T_C$, $t(i)$ is written as t_i.

Definition 2.1. A *social choice function* (SCF) is a function $F: \Theta_N \to A$.

Definition 2.2. A *social welfare function* (SWF) is a function $W: \Theta_N \to \Theta$.

A social choice function is thus any economic, political or social decision process that specifies a chosen alternative for each profile of the agents' preferences. Given F and given $\theta \in \Theta_N$, we call $F(\theta)$ the *outcome for* θ *under* F. In the economic context, for each $\theta \in \Theta_N$, the outcome $F(\theta)$ under F can be seen as the maximal element of the order $W(\theta)$ on A specified by a social welfare function. We shall interpret $F(\theta)$, $\theta \in \Theta_N$, as the *welfare optimum*. It is assumed that, given the social welfare function W, for each $\theta \in \Theta_N$, $\theta_0 = W(\theta)$, that is, given the profile of preferences of the agents, the planner's preferences on A coincides with the welfare ranking of the alternatives in A given by the social wefare function.

Throughout, we shall be concerned with the notion of implementation of a social choice function, which we now specify. [11] The concept, due to Maskin (1977,1979), is a general formulation of the notion of incentive compatibility in Hurwicz (1972a). The reader is referred to Dasgupta, Hammond and Maskin (1979) for a comprehensive discussion of this notion.

We first define what we call a *social decision mechanism*, or, simply, a *mechanism*.

Definition 2.3. A *social decision mechanism* is the $2n+3$-tuple

$$\mu = \left(A\,;\Theta_N;S_0;S_1,\dots,S_n;f\right),$$

where

(1) S_0 is a finite set of *pure strategies* available to the planner;

(2) $S_1,\dots,S_n$ are finite sets of *pure strategies* available to the agents $1,\dots,n$;

and (3) $f:\left(S_0\times S_N\right)\to A$ is an *outcome function*.

A social decision mechanism μ is thus a game in strategic form under complete information. In designing the mechanism, the planner specifies the sets S_i for each $i\in N$, which consist of the *messages* or *signals* that an agent may send to the planner indicating the information that the planner deems relevant for his task of implementing the social choice function. The set S_0 is the strategy domain of the planner, which he uses to coordinate the strategy choices by the agents so as to reach the outcome that the social choice rule gives as the optimal outcome corresponding to the preferences of the agents. The set of strategies included in S_0 could be quite general, with the exception that there is no strategy in the set which enables the planner to enforce the choice of any strategy $s_i\in S_i$ on any agent $i\in N$. Given the mechanism devised by the planner, the agents choose their messages from their respective strategy sets

S_i, which, together with the strategy chosen by the planner, are used to reach a collective decision under the mechanism. Once the agents report their strategies, the planner computes the outcome corresponding to his chosen startegy together with those chosen by the agents. We assume that the agents send only those messages to the planner which, together with the planner's strategy, constitute an equilibrium point (according to some given notion of equilibrium) of the relevant game. The planner's task in implementing a social choice functions is to design a social decision mechanism having the property that, for each profile of the agents' preferences, the mechanism selects as its equilibrium outcome (under the given notion of equilibrium) only the welfare optimum for the profile, as given by the social choice function.

We shall specialize the class of social decision mechanisms to a more specific class, which will be called *planner's mechanisms*. In a planner's mechanism, the planner announces his strategy at the outset of the operation of the mechanism he devises, that is, at the beginning of the relevant game, which then remains fixed throughout. We assume that there is an one–to–one correspondence between the strategy announced by the planner, and the outcome under the social choice function he wishes to implement. Moreover, such a mechanism specifies a set of rules for the choice of messages (strategies) by the agents from their respective set of strategies S_i. The outcome function for a planner's mechanism operates in the following way. If all the agents happen to choose a message that is consistent with such a rule, then they can compel the planner to adopt the outcome that corresponds to the selection of these messages (together with the fixed strategy for the planner); however, if messages outside those specified by the rules are adopted by one or more agent, then the planner's strategy dictates the outcome. Assuming that the agents choose messages that constitute an equilibrium corresponding to some given notion of equilibrium for the relevant game, the planner must devise the mechanism and choose his strategy in such a way that the choice of the appropriate outcome emerges from the equilibrium behavior of the agents, and this is the only outcome to so constitute an equilibrium.

To formalize this idea, let a *strategy function for the planner* be a function:

$$\alpha : \Theta_N \rightarrow S_0.$$

A strategy function $\alpha(.)$ is used to specify a strategy that the planner uses to implement an outcome under the social choice function F: the strategy he announces at the outset of the relevant game. The strategy function will, in general, depend on the outcome under F the planner wishes to implement via a social decision mechanism, and, given our assumption that the agents report only those messages that are in equilibrium (according to some given notion of equilibrium), on the assumption the planner makes about the strategic behavior of the agents. On the other hand, it is desirable to find a strategy function which is independent of the outcome to be implemented (so that it works for any outcome under F). Moreover, since the planner cannot observe the strategy choices of the agents beforehand, it also has to be independent of the strategy choices of the agents. These considerations motivate the definition of a strategy function given above.

Given $\theta \in \Theta_N$, let

$$\sigma : S_0 \rightarrow \{F(\theta)\}_{\theta \in \Theta_N}$$

specify the outcome for θ under F associated with a strategy $s_0 \in S_0$, which the planner wishes to implement. Given $\theta \in \Theta_N$, the pair of functions $(\alpha(.), \sigma(.))$ will be called an *implementation function* for the planner.

For each $i \in N$, let a *strategy rule*, or, simply, a *rule, for agent i* be given by the map:

$$r_i : \Theta_i \to S_i.$$

The vector $r = (r_1,...,r_n)$, one rule for each $i \in N$, will be called a *societal strategy rule*, or simply, a *societal rule*. Let $\mathfrak{R}$ denote the set of all societal rules.

We are now ready to specify a planner's mechanism.

Definition 2.4. A social decision mechanism μ is a *planner's mechanism* if there exist an implementation function $(\alpha(.),\sigma(.))$, and a class of societal rules $\mathfrak{R}$ such that, for all $\theta \in \Theta_N$ and $s \in S_N$, and for each $x \in A$, there is a societal rule $r \in \mathfrak{R}$ such that

(1) if $s = r$, then $f(\alpha(\theta),s) = x$; and

(2) $f(\alpha(\theta),s) = \sigma \circ \alpha(\theta)$ otherwise.

Note that the definition of a societal rule under a planner's mechanism is very general: it permits a variety of rules, including majority/minority preference rules, to be included in the construction of such a mechanism, through which the agents can choose any social alternative irrespective of the planner's goals. The problem of implementation in the present framework of an informed planner is precisely to devise these rules in a manner that preserves decentralized decisions and the incentives to the agents to reach the optimal outcome specified by the social choice function under consideration. Note also that the specification of a societal rule under a planner's mechanism requires that it is "non-imposed", in the sense that it does not permit the planner to force an outcome on the agents independently of their strategic behavior: given the agents' preferences, for each possible strategy for the planner, the agents have available strategies that can guarantee any of the alternatives in the feasible set under the mechanism.

We now define the notion of implementation of a social choice function by a planner's mechanism. Given a planner's mechanism $\mu = \left(A; \Theta_N; S_0; S_1, \ldots, S_n; f\right)$, define, for $\theta \in \Theta_N$:

$$\mathscr{E}(\mu, \theta, \alpha, \sigma) = \{(\alpha(\theta), s) \mid s \in S_N, \textit{ for all } C \subset N, \textit{ for all } s_C' \in S_C: \\ \exists\, i \in C: f(\alpha(\theta), s)\ \theta_i\ f(\alpha(\theta), (s_C', s_{-C}))\}$$

and

$$\mathscr{E}*(\mu, \theta, \alpha, \sigma) = \{(\alpha(\theta), s) \mid s \in S_N, \textit{ for all } i \in N, \textit{ for all } s_i' \in S_i: \\ f(\alpha(\theta), s)\ \theta_i\ f(\alpha(\theta), (s_i', s_{-i}))\}$$

For each strategy n+1–tuple in the sets $\mathscr{E}(\mu, \theta, \alpha, \sigma)$ and $\mathscr{E}*(\mu, \theta, \alpha, \sigma)$, one of the coordinates – the first – is fixed: this is the strategy announced by the planner. The members of the sets $\mathscr{E}(\mu, \theta, \alpha, \sigma)$ and $\mathscr{E}*(\mu, \theta, \alpha, \sigma)$ then correspond, respectively, to the strong Nash and the Nash equilibrium points of f for the agents, given the planner's strategy. Clearly, $\mathscr{E}(\mu, \theta, \alpha, \sigma) \subset \mathscr{E}*(\mu, \theta, \alpha, \sigma)$ for all $\theta \in \Theta_N$.

Definition 2.5. A social choice function $F: \Theta_N \to A$ is *implementable in coalitional strategies* if there exists a planner's mechanism μ such that for each $\theta \in \Theta_N$:

(1) $\mathscr{E}(\mu, \theta, \alpha, \sigma) \neq \varnothing$; and

(2) $\left(s \in S_N,\ (\alpha(\theta), s) \in \mathscr{E}(\mu, \theta, \alpha, \sigma)\right) \rightarrow (f(\alpha(\theta), s) = F(\theta))$.

Replacing the set $\mathscr{E}(\mu, \theta, \alpha, \sigma)$ by the set $\mathscr{E}*(\mu, \theta, \alpha, \sigma)$ in the foregoing definition, we get the definition of *implementation in Nash strategies* of a social choice function. A social choice function F is said to be *doubly implementable* if it is implementable in both coalitional and Nash strategies.

The idea underlying Definition 2.5 is the following. In order to implement a social choice function, the planner is required to devise a mechanism in which he announces a particular strategy for himself, which depends on the agents' preferences, but which is invariant with respect to their strategy choices. The social choice function is implemented in coalitional strategies (resp. Nash strategies) if, given the agents' preferences $\theta = (\theta_1,...,\theta_n)$, the mechanism has the following properties: (1) there exists a strategy n+1−tuple$(\alpha(\theta),s)$ such that, with the strategy of the planner remaining fixed, no group of agents (resp. no agent acting on his own) can benefit from unilateral deviations from $(\alpha(\theta),s)$; and (2) for each such strategy n+1−tuple, the mechanism yields an outcome that gives the appropriate welfare optimum specified by the social choice function for the given preferences for the agents. Implementability of a social choice rule thus guarantees that, so long as the agents choose equilibrium strategies, no inoptimal outcome can emerge as the group choice. Double implementability of a social choice function requires that the SCF is implementable regardless of whether the agents follow coopeartive or non−cooperative Nash behavior. As mentioned earlier, this property of a SCF, though demanding, is particularly useful in the context of the implementation of a SCF, since (i) if a SCF is dubly implementable, the planner is not required to have information on the strategic behavior of the agents, and (ii) where group action is necessary for the selction of the appropriate outcome via the equilibrium behavior of the agents, it can be achieved by the mechanism designed by the planner, as much as those outcomes for which non−cooperative Nash behavior would suffice. [12]

We now show that a planner's mechanism exists that implements *every* social choice rule that selects only among the *optimal* alternatives as the welfare optimum. We first note the notion of optimality or efficiency.

Definition 2.6. Let $F: \Theta_N \to A$ be a SCF. F is *efficient* if for all $\theta \in \Theta_N$ and all $a \in A$: $(b \in A,\ b \neq a, \textit{for all } i \in N,\ b\,\bar{\theta}_i\,a) \Rightarrow a \notin F(\theta)$.

We are now ready to prove our theorem.

Theorem 2.1. *Every efficient social choice function* $F: \Theta_N \to A$ *is doubly implementable in coalitional and Nash strategies.*

Proof. Let $F: \Theta_N \to A$ be an efficient SCF. We shall construct a planner's mechanism that implements F in coalitional strategies and also in Nash strategies.

Let $\theta \in \Theta_N$ be given. Let the planner's mechanism $\bar{\mu} = (A; \Theta_N; S_0; S_1, \ldots, S_n; f)$ be defined as follows:

Let

(i) $m_0: \Theta_N \to A$ be such that for all $\theta \in \Theta_N$, $m_0(\theta) = F(\theta)$,

and for each agent $i \in N$, let

(ii) $m_i: \Theta_i \to A$.

Let $M_0 = \{m_0(\theta)\}_{\theta \in \Theta_N}$ and for each $i \in N$, $M_i = \{m_i(.)\}$ be the class of all functions $m_i(.)$ on Θ_i. Let

(iii) $M_0 = S_0$, and for all $i \in N$, $S_i = M_i$. (Note that this construction of the strategy sets S_i implies that $S_1 = \ldots = S_n$.)

Let, for all $\theta \in \Theta_N$,

(iv) $(\sigma \circ \alpha)(\theta) = m_0(\theta)$,

where $\sigma(.)$ is an identity map. Finally, let $r = (r_1, \ldots, r_n) \in \Re$ be such that, for all $x \in A$,

(v) $(r_1 = \ldots = r_n = x) \Rightarrow f(\alpha(\theta), r) = x$.

The planner's mechanism $\bar{\mu}$ is defined by (i)–(v).

We now show that the mechanism $\bar{\mu}$ implements F in coalitional and Nash strategies. Note that, from the specification of $\bar{\mu}$, we may define the outcome function f as follows:

For $s_0 \in S_0$, $s_i \in S_i$, $f:(S_0 \times S_N) \to A$ is given by:

$$f(s_0, s_1, \dots, s_n) = \begin{cases} \bar{s} \textit{ if } s_1 = s_2 = \dots = s_n = \bar{s}; \\ s_0 \textit{ otherwise}. \end{cases}$$

Now let $\theta \in \Theta_N$ be fixed. We show that:

(1) $\mathscr{E}(\bar{\mu}, \theta, \alpha, \sigma) \neq \emptyset$; and

(2) $[\bar{s} \in (S_0 \times S_N), \bar{s}_0 = m_0(\theta)] \Rightarrow (\bar{s} \in \mathscr{E}^*(\bar{\mu}, \theta, \alpha, \sigma) \Rightarrow f(\bar{s}) = m_0(\theta) = F(\theta))$.

Since $\mathscr{E}(\bar{\mu}, \theta, \alpha, \sigma) \subset \mathscr{E}^*(\bar{\mu}, \theta, \alpha, \sigma)$, this will show that F is doubly implementable.

To prove (1), let $s* = (s_0, s_1, \dots, s_n) = (m_0(\theta), m_1(\hat{\theta}_1), \dots, m_n(\hat{\theta}_n))$, such that $\hat{\theta}_i \in \Theta_i$ and $m_1(\hat{\theta}_1) = \dots = m_n(\hat{\theta}_n) = m_0(\theta) = F(\theta)$. We show that $s* \in \mathscr{E}(\bar{\mu}, \theta, \alpha, \sigma)$. Suppose not. Then, there exists a non-empty subset C of N and $s_C' \in S_C$ such that $s_C' \neq s_C$, and, denoting $(m_0(\theta), s_C', s_{-C}) = \bar{s}$, we have $f(\bar{s}) \neq f(s*)$ and for all $i \in C$, $f(\bar{s})\, \bar{\theta}_i\, f(s*)$. Since F is efficient, there exists $j \in N$ such that $f(s*) = F(\theta)\, \bar{\theta}_j\, f(\bar{s})$. Then, $j \notin C$. But now from the definition of f, $f(\bar{s}) = m_0(\theta) = f(s*) = F(\theta)$, which is a contradiction.

We now prove (2). Suppose there exists $\bar{s} = (s_0, s_1, \dots, s_n) = (m_0(\theta), m_1(\hat{\theta}_1), \dots, m_n(\hat{\theta}_n))$, $\hat{\theta}_i \in \Theta_i$, such that $\bar{s} \in \mathscr{E}^*(\bar{\mu}, \theta, \alpha, \sigma)$ and $f(\bar{s}) \neq m_0(\theta) = F(\theta)$. Then, from the definition of f, we have $m_1(\hat{\theta}_1) = \dots = m_n(\hat{\theta}_n) = f(\bar{s})$. Since F is efficient, there exists $j \in N$ such that $m_0(\theta) = F(\theta)\, \bar{\theta}_j\, f(\bar{s})$. Let $\hat{s} = (m_0(\theta), s_j', \bar{s}_{-j})$ such that $s_j' = m_j(\theta_j') = m_0(\theta)$. Then, $f(\hat{s}) = m_0(\theta) = F(\theta)\, \bar{\theta}_j\, f(\bar{s})$, and $f(\bar{s}) \notin \mathscr{E}^*(\bar{\mu}, \theta, \alpha, \sigma)$, which is the desired contradition. This completes the proof of the Theorem. □

The mechanism described in the Theorem has a simple interpretation. Given the agents' preferences, the planner proposes an optimal outcome. The planner then asks the agents for their proposals for selecting an alternative from the feasible set. The agents can deviate from the outcome proposed by the planner by unanimously proposing a different outcome, but in the case of a lack of unanimous choice, the planner's proposal prevails. Thus the mechanism is based on an "unanimity rule".

Theorem 2.1 assumes Nash or strong Nash behavior on the part of the agents, and this requires that the characteristics of the agents are common knowledge. What if the planner possesses the information about the agents' characteristics, but the agents themselves do not? In reality, this would be a more appropriate assumption, especially if the agents act non–cooperatively. In the absence of the information on the other agents' characteristics, the most reasonable assumption regarding strategy choices made by an individual is that he would not use a dominated strategy. If we make this assumption, then, it turns out that, under the planner's mechanism we have specified, reporting the best alternative in one's preferences is a dominant strategy for the agents.

To prove this result, we first note some definitions.

Let $\theta \in \Theta_N$ be given and let $\mu = (A\,;\Theta_N\,;S_0\,;S_1,\dots,S_n\,;f)$ be a planner's mechanism. For $i \in N$, a strategy $s_i' \in S_i$ *dominates* a strategy $s_i \in S_i$ for i if:

(1) *for all* $s_{-i} \in S_{-i}$, $f(\alpha(\theta),(s_i',s_{-i}))\ \theta_i\ f(\alpha(\theta),(s_i,s_{-i}))$

(2) *for some* $s_{-i} \in S_{-i}$, $f(\alpha(\theta),(s_i',s_{-i}))\ \bar{\theta}_i\ f(\alpha(\theta),(s_i,s_{-i}))$

Let $i \in N$. We say that a strategy $s_i \in S_i$ is a *dominated* strategy for i if there exists a strategy $s_i' \in S_i$ for i which dominates it. A strategy $s_i \in S_i$ is an *undominated* strategy for i if there is no strategy $s_i' \in S_i$ for i which dominates s_i. A strategy $s_i' \in S_i$ *weakly dominates* a strategy $s_i \in S_i$ for i if (1) in the definition above holds with respect to these strategies. A strategy $s_i' \in S_i$ is a *dominant strategy* for i if it weakly dominates every strategy $s_i \in S_i$.

Given $\theta \in \Theta_N$ and a planner's mechanism $\mu = (A\,;\Theta_N\,;S_0\,;S_1,\dots,S_n\,;f)$, let, for all $i \in N$, $\bar{S}_i^\theta$ stand for the set of undominated strategies for i.

For $i \in N$, we say that a strategy $s_i' \in \bar{S}_i^{\theta}$ is *dominant with respect to* $\bar{S}_N^{\theta}$ for i if for all $s_i \in \bar{S}_i^{\theta}$, and for all $s_{-i} \in \bar{S}_{-i}^{\theta}$, $f(\alpha(\theta),(s_i',s_{-i}))\ \theta_i\ f(\alpha(\theta),(s_i,s_{-i}))$.

Definition 2.7. A social choice function $F: \Theta_N \to A$ is *implementable in dominance-solution strategies* if there exists a planner's mechanism $\mu = (A\,;\Theta_N;S_0\,;S_1,\dots,S_n\,;f)$ such that for all $\theta \in \Theta_N$:

(1) for $i \in N$, each $s_i \in \bar{S}_i^{\theta}$ is dominant with respect to $\bar{S}_N^{\theta}$ for i; and

(2) $\left(s \in \bar{S}_N^{\theta}\right) \Rightarrow f(\alpha(\theta),s) = F(\theta)$.

We now prove the following theorem:

Theorem 2.2. *Every efficient social choice function* $F: \Theta_N \to A$ *is implementable in dominance-solution strategies.*

Proof. Let $\theta \in \Theta_N$ be given and let $\bar{\mu} = (A\,;\Theta_N;S_0\,;S_1,\dots,S_n\,;f)$ be the planner's mechanism as specified in the proof of Theorem 2.1. We shall first show that, for all $i \in N$ and for all $x,y \in A$, if $[\sigma \circ \alpha(\theta) = m_0(\theta) = x$ and $x\bar{\theta}_i y]$, then $\hat{\theta}_i \in \Theta_i$, $s_i \in S_i$ such that $s_i = m_i(\hat{\theta}_i) = y$ is a dominated strategy for i.

Let $i \in N$. In what follows, we let strategy $s_i^* \in S_i$ be fixed, where $s_i* = m_i(\theta_i) = \mathbf{max}-\theta_i$. Let $x \in A$ such that $m_0(\theta) = x$, and let $s_i \in S_i$ and $\hat{\theta}_i \in \Theta_i$ be such that $s_i = m_i(\hat{\theta}_i) = y$, where $y \in A$ such that $x\bar{\theta}_i y$. Consider $s_{-i} = (s_1,\dots,s_{i-1},s_{i+1},\dots,s_n) \in S_{-i}$. There are two possibilities:

(1) For all $j,k \in N$, $j \neq k \neq i$, for $\hat{\theta}_j \in \Theta_j$, $s_j = m_j(\hat{\theta}_j)$, *for* $\hat{\theta}_k \in \Theta_k$, $s_k = m_k(\hat{\theta}_k)$ and $m_j(\hat{\theta}_j) = m_k(\hat{\theta}_k) = m_i(\hat{\theta}_i)$;

(2) For some $j \in N$, $j \neq i$, for $\hat{\theta}_j \in \Theta_j$, $s_j = m_j(\hat{\theta}_j) \neq s_i = m_i(\hat{\theta}_i)$.

If (1) holds, then clearly, $f(\alpha(\theta),(s_i^*,s_{-i})) = x\ \bar{\theta}_i\ y = f(\alpha(\theta),(s_i,s_{-i}))$. If (2) holds, then $f(\alpha(\theta),(s_i^*,s_{-i})) = f(\alpha(\theta),(s_i,s_{-i})) = x$ and $f(\alpha(\theta),(s_i^*,s_{-i}))\ \theta_i\ f(\alpha(\theta),(s_i,s_{-i}))$. Thus

s_i^* dominates s_i and the assertion above follows.

We now show that for all $i \in N$ and for all $x \in A$, if $\sigma \circ \alpha(\theta) = m_0(\theta) = x$ and $s_i \in \bar{S}_i^\theta$, then s_i is a dominant strategy with respect to $\bar{S}_N^\theta$ for i. Indeed, $s_i \in \bar{S}_i^\theta$ can fail to be a dominant strategy with respect to $\bar{S}_N^\theta$ for i if there exists $s' \in \bar{S}_N^\theta$ such that $s_i' \neq s_i$ and $f(\alpha(\theta), s'))\ \bar{\theta}_i\ f(\alpha(\theta),(s_i, s_{-i}'))$. Since for each $j \in N$, $s_j \in \bar{S}_j^\theta$, we have, for $\tilde{\theta}_j \in \Theta_j$, $s_j = m_j(\tilde{\theta}_j)\ \bar{\theta}_j\ x$ for all $s_j \in \bar{S}_j^\theta$. Let $f(\alpha(\theta), s')) = y$, $y \in A$. Then, for all $j, k \in N$, for $\tilde{\theta}_j \in \Theta_j$, $\tilde{\theta}_k \in \Theta_k$, $s_j' = m_j(\tilde{\theta}_j) = s_k' = m_k(\tilde{\theta}_k) = y$. However, since F is efficient, for some $k \in N$, $x\ \bar{\theta}_k\ y$, and for this $k \in N$, it is not the case that $s_k' \in \bar{S}_k^\theta$, and this is a contradiction. This shows that for $i \in N$, each $s_i \in \bar{S}_i^\theta$ is a dominant strategy with respect to $\bar{S}_N^\theta$ for i. Furthermore, given that F is efficient, from the specification of $\bar{S}_i^\theta$ for $i \in N$, it is clear that for all $s \in \bar{S}_N^\theta$, $f(\alpha(\theta), s) = F(\theta)$. This completes the proof. □

3. Concluding Remarks

In this paper, we have considered a model of an informed planner and the problem of implementation of a social choice function through decentralized actions of the agents. As we noted earlier, our model corresponds to a generalized principal–agent model with complete information when one individual, the planner, has all the authority to select an incentive–compatible mechanism to implement the welfare optima corresponding to a social choice function. The central point was to distinguish between the two aspects of mechanism design, namely, the decentralization of information vis–a–vis the decentralization of actions by the agents. Our results here show conclusively that, in the circumstances where the planner has information on the agents' characteristics, implementation problem for social choice functions could be completely resolved.

How relevant is this exercise on decentralization of decision-making with centralized information? Clearly, the important consideration in answering this question must be whether the informed planner model is a feasible real-life model or not. In any application of a model involving public decisions, whether the planner can obtain the information on the characteristics of the agents or not, is an empirical question. If the 'society' is small (as in the context of voting in committees), the assumption may not be overly restrictive. In large societies, if the public decisions involve a relatively small number of large homogeneous groups of agents, each group having essentially similar within-group characteristics – the information on which can be gleaned from such observable indicators as personal income, social status and so on, then the full information assumption may clearly not be too limiting.

Our results have some relevance also in the context of some of the traditional first- and second-best analyses in the theory of optimal taxation and externality. Here, the analyses are carried out with the assumption that the preferences of the individuals are given to the planner, often with the further assumption that the optimal tax/subsidy can be simply imposed on the agents. [13,14] This raises the theoretical, and, in many instances, practical question if the planner could in fact achieve the optimal decisions through decentralized actions of the agents. Our results here answers this question in the affirmative, resolving at least the theoretical issue involved. [15] How far more general mechanisms than the one used to prove the results in this paper can be found for the purpose at hand remains an interesting open question.

Our model has also some bearing on some recent issues in social choice theory concerning liberty and rights, where the devolution of rights is considered in terms of a game form constructed by a planner, with the permissible strategies for the agents capturing the aspects of rights endowments that the planner wishes to confer to the agents. [16] In this framework, our model can be looked upon as resolving the problem of achieving the right structure the planner wishes to secure through voluntary right-exercising by the agents, given the assumption of complete information and the equilibrium behavior of the agents.

We close by noting a possible extension of our informed planner model in the context of incomplete information models. In an incomplete information framework, models where the principal has private information have been studied by Myerson (1983) and Maskin and Tirole (1990, 1992). In these studies, the information available to the principal is modelled by assuming that he could be one of a number of 'types' in the sense of Harsanyi (1967–68). Myerson (1983) emphasizes the problem of designing incentive-compatible mechanisms which do not reveal the private information available to the planner, that is, do not reveal his 'type' to the agents, and studies the cooperative equilibria for these mechanisms. Maskin and Tirole (1990,1992), on the other hand, focus on the nature of the non-cooperative equilibria that could emerge in this framework. Neither Myerson (1983) nor Maskin and Tirole (1990, 1992) address the implementation problem. It it would be clearly of interest to apply the framework they specify to model the problem of implementaion with an informed planner with incomplete information.

NOTES

1. For a survey of the related literature in the context of planning, see Heal (1973), Tulkens (1978) and Roberts (1987). The literature on incentive compatibility and social choice theory has been integrated in Dasgupta, Hammond and Maskin (1979) via the notion of implementation of social choice rules due to Maskin (1977, 1979), the approach to the problem to be taken in this paper. For comprehensive surveys of the implemenation literature, see Maskin (1985), Moore (1992), and Palfrey (1992).

2. Some extension of the class of preferences for the agents that admits Clarke–Groves mechanisms is possible. On this, see Bergstorm and Cornes (1983) and Conn (1983).

3. Even the solution to the incentive problem via the Nash concept has the difficulty that the class of efficient and incentive–compatible mechanisms may not be individually feasible (i.e. the net reduction in the endowment of an agent in an allocation specified by the mechanism may be larger than his given endowment) at disequilibrium messages. This creates the problem that, with small errors on the part of the agents in communicating their equilibrium messages, we may need to use disequilibrium messages to compute the allocation, which then may not be individually feasible. See Groves and Ledyard (1987) for a discussion of this point. Hurwicz, Maskin and Postlewaite (1984) have shown that, an efficient and individually feasible Nash mechanism must permit the message space of the agents to be dependent on the their endowments.

4. This pertains to the models where the probability measure on Θ_N, the set of possible characteristics for the agents is assumed to be given, and common knowledge to the

mechanism designer and the agents, as in d'Aspremont and Gerard–Varet (1979). If the mechanism depends only on the messages sent by the agents, then a stronger result, due to Ledyard (1978, 1979) applies: there are no efficient and Bayes–equilibrium incentive–compatible mechanisms.

5. This is similar to the second–best issues in the context of public policy analyses. The government could, by some form of coercive action, implement the first–best solution to a public policy problem, but this completely undermines the paradigm of competitive markets that most public policy analysis adheres to.

6. In this, the informed planner model we consider corresponds to a class of *generalized principal–agent* models à la Myerson (1982, 1985).

7. The well known example is that of the Prisoners' Dilemma game, where coooperative (strong Nash) behavior works for selecting the efficient outcome, but non–cooperative (Nash) behavior does not.

8. A strategy is *dominated* for an agent if there exists another strategy for the agent which, given his preferences over the outcomes, achieves at least as good an outcome for him in every possible specification of the strategies of the remaining agents, and a better outcome in some; for every possible specification of the strategies of the remaining agents, a *dominant* strategy achieves at least as good an outcome for the agent as any other strategy available to him.

9. This corresponds to the notion of 'secondary domination' in Farquharson (1969). The

notion of secondary domination was used in Sengupta (1978) for the analysis of the choice of strategies by the agents when the assumptions underlying the use of Nash equilibrium concept as a solution of a game are not made. It is related to the notion of *rationalizability* (Bernheim (1984), Pearce (1984)) of a solution for a game, which, in turn, relates to the notion of *iterated dominance solution* or *dominance solvability* of a game. For a discussion of these concepts, see Fudenberg and Tirole (1991) or Myerson (1991).

10. This corresponds to Maskin's (1985) notion of double implementation of a social choice rule.

11. The notion of implementation of a social welfare function is subsumed by the notion of implementaion of a social choice function, with the interpretation that, for $\theta \in \Theta_N$, $F(\theta)$ is the maximal element in $W(\theta)$.

12. See Maskin (1979, 1985), Dasgupta, Hammond and Maskin (1979), and Sengupta (1983) for further discussions of these notions.

13. As mentioned earlier, this is the customary assumption also in the incentives literature. For example, Maskin (1985, p. 175) writes: "It is necessary as well that the planner has poor information; otherwise, he could simply impose a welfare optimal social alternative by fiat". Similarly, Postlewaite (1985, p. 207) notes: "If the planner *did* have all the relevant information, his problem would be a relatively simple maximization problem: Decide which of the alternatives is the best and "impose" it".

14. Following Mirrlees (1974,1975,1976), there is now a rich literature on second-best

analysis with asymmetric information, especially in the context of regulation mechanisms. See, for example, Baron and Myerson (1982) and Laffont and Tirole (1986, 1993).

15. This question, without the incentive compatibility constraint, is implicit in some of the work in public economic theory, classic examples of which are the Coasian and Lindahl markets in the theory of externality and public goods.

16. See Gaertner, Pattanaik and Suzumura (1992) and Pattanaik and Suzumura (1996) for an extremely persuasive exposition of this approach.

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