Some specifics of modeling multi-level agent systems with uncertainty using Groves mechanisms

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Abstract. Uncertainty is often named among the most significant factors impeding decision making in systems with partially independent agents, both technical and social. Among such systems, multilevel systems can be distinguished as a hard case, as uncertainty problem there is combined with the problem of agent opportunism. A special class of mechanisms — the Groves mechanisms that satisfy the requirements of truthfulness in dominant strategies and efficiency — has been well studied in the literature. The article shows how, under conditions of multilevel multi-agent systems with uncertainty, the implementation of Groves mechanisms can solve the problem of systematic distortion of the agents' behaviour.

1. Introduction
The problems of developing effective mechanisms of interaction between independent or semi-independent entities of the system are among the most significant factors that affect overall decision making in technical and social complex multi-agent systems. In multi-level multi-agent systems, like, for example, venture funds, distributed hierarchical management systems, social network structures with agents of various levels, this problem is combined with the problem of agent opportunism [1-3]. In the models of such systems, the heterogeneity of individual agents is usually taken into account by means of various utility functions, and the differences in levels are taken into account by means of principal-agent models when modeling interagency relations [2, 4]. Moreover, an effective mechanism for managing the multi-level multi-agent systems (and more broadly - systems with heterogeneous agents in an uncertain environment, both social and artificial) should take into account the existence of persistent deviations from risk neutrality in the behavior of agents. In this regard, the study of effectiveness of particular decision-making mechanisms for a multi-agent system with uncertainty is very interesting.

At the present stage, one of the significant features of the socio-economic systems of the Russian regions is the existence of so-called interest groups, each of which seeks to realize its goals by influencing potential investors, both public and private. The problems of studying the mechanism for coordinating group interests and the influence of such groups on the effectiveness of the regional investment process began to be studied relatively recently, and the problems of the influence of groups on the processes of managing investment projects in the regions were not considered in detail [5, 6].

One of the most important factors underlying the phenomenon of the influence of regional interest groups on investor decisions is that decision-making mechanisms at all levels of the regional socio-economic system are in constant motion, they constantly collide, compete and conflict with each other.
At the same time, investment project managers are notable for their adaptability, opinions, positions, likes, dislikes, etc., therefore they are accessible to the influence of various interest groups [7].

If managers of investment projects can be considered to a greater extent as direct executors of managerial decisions, then strategic management is carried out by representatives of the groups financing the project (both private and state) - which will be called "investors" later in the paper. They offer shareholders certain strategies, promising a certain sequence of their future property management activities. It is important for investors that shareholders believe that they will carry out certain managerial influences and, most importantly, that they can carry out these influences (that is, that shareholders believe that they have certain resources).

In this case, another problem arises - an interest in managerial decisions being made, because the interests of shareholders on the one hand and individual managers or interest groups on the other do not always coincide [8, 9]. The success of interest groups in lobbying is largely determined by their access to useful information, as well as the low costs of collective action in such groups. The situation when the investment project manager makes managerial decisions guided by group interests can be demonstrated on the basis of formalized models.

Consider a situation in which a group of interests with the aim of resolving issues in relation to a certain investment object affects the target function of the investor making decisions on managing this object. The described situation is best represented in the form of an exchange model. We apply the approach proposed by Denzau and Munger [10] to the model and assume that interest groups may be interested in receiving from the investor something other than his support, because the investor spends his limited time and efforts to solve a number of specific problems.

At first glance, the official interests of the investor managing the investment project should coincide with the target settings of his company, so the target function of the manager should be determined by his nominal role as the representative of the interests of the investment company, and should not take into account his own target needs. However, we should note that behind a formal legal entity (an investment company, in this case) are real people with their inherent utility functions, and the influence of interest groups that affect investing managers is determined by the level of accessibility of information.

2. Model of agent behaviour in multi-level system with hidden information

Consider the activities of the investor, who was elected CEO of a large investment company, whose interests in the field of managing its property, he must represent. His goal is to be re-elected to this post again, so he will do everything to maximize the number of shareholders who will vote for his decisions on managing the company's property in the next election. However, the investor's activity is limited by his capabilities (worktime, natural capabilities, influence). It has some limited resource $E$, which is given exogenously and which it cannot influence in any way. Then he distributes $E$ into three types of activity in such a way as to maximize his function:

1. to actions directly useful to the shareholders of the company;
2. to actions relation to the ownership of the company, which are primarily useful to interest groups that are not shareholders, but that can positively or negatively affect the shareholders of the company;
3. to actions that advertise his activities.

He spends some resources on activities that benefit interest groups, because in exchange for implementing such a policy he receives resources for his PR campaign. His promotion, as a good manager, by a group of interests can be measured in monetary terms. Such an objective function of the investor's welfare level $W$ has the form:

$$ W[P_u(E_u), P_i(E_i), R_i] \rightarrow \max_{E_u, E_i, R_i} $$

The investor spends his resource $E$ on activities that increase the likelihood of his re-election. Spending a share of its $E_u$ resource, the investor brings $P_u$ utility to the company. Other share of the investor’s resource $E_i$ is spent in favor of the $i$-th group of interests. The resource $E_i$ spent on a certain policy brings the investor $P_i$ efficiency level (he invests $E_i$ and receives $P_i$). His utility function also
depends on \( R_i \), which he receives in exchange for \( P_i \), because he invested some efforts of \( E_i (E_1, E_2, ... , E_n) \) in promoting various interest groups and received the resource \( R_i \).

Thus, the investor maximizes his utility function. Consider the border cases:

- a situation where shareholders have complete information about decisions made by the investor;
- a situation where shareholders are uninformed.

In a situation where shareholders have complete information, the real activities of the investor are known to all, and advertising is unproductive. Then the objective function takes the form:

\[
W = W(P_i, P), P = (P_1, P_2, ..., P_n) \tag{2}
\]

The welfare of the investor will depend only on the results of the company. And if the \( P_i \) decision, beneficial to a certain group of interests, will negatively affect the company's results, the investor simply will not accept it. This means that in a situation of complete information, the investor will only pursue a policy that positively affects the shareholders of his company.

In a situation where shareholders are uninformed, they are not able to assess the benefits of investor actions, because they receive all relevant information only from external sources. Then the function will look like this:

\[
W = W[R(P_i(E_i))] \tag{3}
\]

Thus, the activities of the investor for the benefit of the company are not directly taken into account by the shareholders, since they are unobservable for them. In this case, the investor depends entirely on interest groups – only they can “advertise” it by informing shareholders. Obviously, real situations are something in between, but these extreme cases are very obvious.

\[
\begin{align*}
W[P_i(E_i), P_i(E_i), R_i] & \rightarrow \max_{E_i, R_i} \{E_i, R_i\} \\
W[R(P_i(E_i))], E_i & > 0 \tag{4}
\end{align*}
\]

In this model, the interests of the investor are corrected from the outside, influencing its objective function. Assume the opposite situation – the interests of the influence group and the investor coincide, i.e. the investor acts in the direction of resolving issues within the scope of interests of the group, therefore it is possible to consider the case when the impact is on the budgetary constraints of the investor.

Consider a strategy aimed not at changing the position and preferences of the investor (since his preferences already coincided with the group of interests), but at changing his resources, i.e. in this case, there is an impact on the budget line of the investor, and not on its utility function.

A model appropriate to this situation will be based on three assumptions:

1. An investor, in order to be able to make decisions, must actively participate in management, i.e. spend certain resources on the implementation of the decision-making process and monitoring their implementation during the implementation of the investment project.

2. In any period, the investor simultaneously solves several problems related to the management of investment projects, and he spends more of his resources on some issues than on others. Choosing a project for implementation, he will coordinate his preferences about positive results in various areas with other people who have an influence on the company's policy (other directors and managers).

3. Investor’s resources (time, staff, and information) are limited. Therefore, he cannot simultaneously carry out all types of activities that should ensure success in resolving the issues that he supports. Therefore, he sets priorities.

Practically this model reflects the relationship of a group of interests and an investor who are simultaneously interested in solving the same issue (implementation or refusal to implement an investment project). To solve the problem in the context of the model means that the investor brings the current policy in relation to the project closer to the policy preferred by the group of interests, or at least as a result of joint actions, the likelihood of making an appropriate decision increases. As an illustration, we use the case of a decision to sell a share of shares \( D \) of a certain enterprise \( A \). The effectiveness of solution to this issue is indicated on the horizontal axis (Fig. 1) as \( D_a \).

The vertical axis \( D_a \) reflects the changes made by the investor in the framework of other issues to be resolved (selling and buying other property, making decisions on the distribution of profits or...
additional investments in specific projects, etc.). But since the investor has a limited amount of resources, which is represented by budget line $B$ in Fig. 1, his efforts to implement all the issues of interest to him are limited.

In the model, a group of interests subsidizes the information and labor costs for the investor and helps him to take independent actions to change the policy regarding this investment project or protect an existing solution. In fact, the interest group acts as the "additional staff" of the investor.

**Figure 1.** The influence of interest groups on investment decisions.

Investor preferences $i$ in this model are reflected by their willingness to bear the costs (in time and effort) of selling a share in project $A$. The indifference curve $U_i$ is a function of the interests and opinions of shareholders. Suppose that they are informed about the decisions made by the investor - then he will be interested in making decisions that best meet the interests of shareholders. The point of contact of the budget line ($d_a$, $d_o$) and $U_i$ is the optimal distribution of investor time. He will not be able to do anything more while maintaining the available resources.

A group of interests differs from the investor in its interest in solving one problem of interest to it and has a significant resource for solving it. Since a group of interests cannot directly participate in decision-making in the field of managing the property of an investment company, the group’s resource (for example, in the form of a “grant”, change in income) must be realized through those who have the opportunity to participate in making these decisions. To this end, the group of interests provides the investor associated with the management of its resource, and thereby shifts its budget line to the right. The investor's optimum thereby increases ($U_2 > U_1$).

Figure 1 reflects the impact of the resource provided by the investor to make the necessary decisions. An additional resource shifts the investor's budget line in parallel from $B$ to $B'$. As a result, part of the time and effort is redistributed to additional support for the decision to sell a share in the investment project ($d_o' - d_o$), and most of the attracted resources ($d_a' - d_a$) are used to achieve other investor tasks. Obviously, the use by the investor of the resources provided to solve other problems is completely ineffective for the group of interests.

Therefore, the interest group needs to limit the investor's ability to use the provided resources. When establishing control over the intended use of the provided resource, its value to the investor
becomes different depending on how it is used. The investor can fully use the resource to solve the problem. But with the cost of the resource for other purposes, its value for the investor increases, since the provided resource is used not only to achieve other goals, but also to hide the very fact of such activities.

If the restriction works properly (i.e., the interest group can be sure that all the information and work carried out by the investor will be additional to what has already been spent), the new budget line will leave the point on the ordinate axis (curve B), but with a kink at point b, where it shifts horizontally to the right to point b'' (Fig. 2). However, in reality it is difficult to avoid the substitution effect: if the investor organizes the process of making the necessary decisions on project A and further intervention is not necessary, then he will reduce the cost of his resource on this problem and will pay more attention to other investment projects.

![Figure 2. Investor’s agent behavior](image)

A way to minimize the effect of substitution is to limit and balance the use of the resource. An investor may try to convince him that he has sufficient resources, but, unfortunately for a group of interests the effectiveness of maintaining a balance when using a resource can also be affected by the substitution effect. Suppose that an investor allocated a large share of his resources to the solution of the da problem, compared with the one he planned to spend on the solution of the problem on his own. As a result, the distribution of costs of investor resources shifts from point b to b'', and as a result, greater results have been achieved in resolving the issue of the size of the project’s share \(d_{a''} - d_a > 0\), but less effort is spent on achieving alternative goals \(d_{a''} - d_a < 0\).

Ultimately, with the interaction of income and substitution effects, the distribution can be any point on the line \([b; b''']\). Point b'' will be the new distribution point if resource constraints work, but a balance of resources does not.

Three decision-making options are similar in one characteristic – they ensure the sale of a larger share of the investment project as a result of the impact of a group of interests on the budgetary constraint of the investor.
3. Conclusion and Discussion

Based on the situations considered affecting the investor, from manipulating information to direct bribery, the following conclusions can be drawn:

1. Regional interest groups provide the investor with the opportunity to carry out their investment project management functions, achieving a greater level of their own usefulness, increasing the resources that the investor can use, including for the benefit of the company (in particular, in situations where the information advantage is on the side investor). In this regard, regional interest groups are beneficial to the investor, as increase the effectiveness of its activities.

2. The resource provided by the group of interests is used by the investor not only for the implementation of those investment goals for which it was provided, but also for other tasks.

Summing up, we can conclude that in the considered system, the possibility of establishing adequate compensations is associated with the problem of identifying the true demand of the economic agents. One of the ways to identify demand and establish an effective volume of public goods production is set by the Groves-Clark mechanism.

Such a mechanism consists from 3 mandatory rules:
- Each agent makes a “bid” for the particular action, \( b_i \). It can be either truthful or deceitful.
- The action is performed if \( \sum b_j \geq 0 \).
- Each agent \( i \) has a payout equal to the sum of other agents’ bids, \( \sum_{j \neq i} b_j \) if the action is performed (payouts may be negative).

Let’s show that the truthfulness is optimal for each agent in our system. Consider \( n \) agents, each with true \( v_i \) value and declared \( b_i \) value. Truthfulness means that for each agent it is optimal to declare \( b_i = v_i \) regardless of what the other agents behavior. Consider payout for agent \( i \):

\[
Payout_i = \begin{cases} 
  v_i + \sum_{j \neq i} b_j 
  & \text{if } v_i + \sum_{j \neq i} b_j \geq 0 \\
  0 
  & \text{otherwise} 
\end{cases} 
\]

Assume that \( v_i + \sum_{j \neq i} b_j > 0 \). Then agent \( i \) can guarantee that the action will be performed by declaring \( b_i = v_i \). Now, let’s consider the case when \( v_i + \sum_{j \neq i} b_j < 0 \). Then agent \( i \) can guarantee that the action will not be performed by declaring \( b_i = v_i \). In any case, it’s beneficial for the agent to tell the truth. There is no incentive to reveal distorted preferences regardless of the behavior of other agents. As a result, the mechanism for comparing information is modified in such a way that each agent is faced with the problem of a social solution rather than an individual one, and thus everyone has an incentive to identify their preferences correctly.

The described preference identification scheme has a significant and well known drawback – total payments can potentially be very large and the mechanism can be extremely expensive. Unfortunately, in the general case, it’s impossible to make a zero-budget Groves mechanism, but it is possible to establish a mechanism by which payments are always negative.

In such mechanism agents may be required to pay “tax”, but they never will receive payments. Due to these “lost” tax payments, overall solution will not be Pareto-efficient, but the decision of performing a particular action by the multi-level system will be made if and only if it would be efficient in terms of aggregate utility. Let’s describe how this can be done. The essence of the idea is as follows: we can require each agent \( i \) to make an additional payment, which depends only on what other agents do and does not affect incentives \( i \).

Let \( b_{-i} \) be the vector of all bids without the bid of agent \( i \), and let \( h_i(b_{-i}) \) be the additional payment required from agent \( i \).

Then the payout of agent \( i \) is equal to:

\[
Payout_i = \begin{cases} 
  v_i + \sum_{j \neq i} b_j - h_i(b_{-i}) 
  & \text{if } v_i + \sum_{j \neq i} b_j \geq 0 \\
  -h_i(b_{-i}) 
  & \text{otherwise} 
\end{cases} 
\]

If the \( h_i \) functions are reasonably selected, the amount of payments to the agent can be significantly reduced. One of the possible options for choosing a function is as follows:

\[
h_i(b_{-i}) = \begin{cases} 
  \sum_{j \neq i} b_j 
  & \text{if } \sum_{j \neq i} b_j \geq 0 \\
  0 
  & \text{otherwise} 
\end{cases} 
\]
Payout of agent $i$ then will be as following:

$$\text{Payout}_i = \begin{cases} 
  v_i, & \text{if } \sum_i b_i \geq 0 \text{ and } \sum_{j \neq i} b_j \geq 0 \\
  v_i + \sum_{j \neq i} b_j, & \text{if } \sum_i b_i \geq 0 \text{ and } \sum_{j \neq i} b_j < 0 \\
  -\sum_{j \neq i} b_j, & \text{if } \sum_i b_i < 0 \text{ and } \sum_{j \neq i} b_j < 0 \\
  0, & \text{otherwise} 
\end{cases} \quad (8)$$

Note that agent $i$ will never receive positive payout; he may be taxed but will never receive subsidies. Supplementary payments have an effect on the utility of agent $i$ only if he changes the whole system action. Note that for the agent this mechanism is also preferable, since he is never taxed to a greater extent than the system action is valuable to him.

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