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A Mechanism for Quota Distribution in the Local System of Common Resources Use Under Information Asymmetry

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Abstract: This paper proposes an economic mechanism designed to address the problem of overuse in common resource management in local economic systems, in particular – in ecologically fragile mountainous touristic regions. The proposed mechanism draws on recent advancements in behavioural economics, game theory, and environmental economics to develop a framework that can be tailored to the specific characteristics of some local economic systems that depend on using a common resource pool. An allocating agent sequentially proposes possible allocations of a limited number of quotas to entrepreneurs in the form of threshold separating questions. The entrepreneurs' binary choices signal their internal assessments of the minimum number of quotas required for profitable operations. Under complete information, regardless of the principle used to determine the proposed budget allocations, an efficient allocation always exists in such a mechanism, representing a subgame-perfect Nash equilibrium. Under uncertainty, the method for proposing allocation options matters—the optimal solution is found by organizing it in a form of an English auction. An advantage of the proposed mechanism is its robustness: for its effective application, determining precise minimum quotas for each participant is not necessary.

1 INTRODUCTION

The management of common resources, such as fisheries, forests, water systems, and pastures, has long been a focal point of economic inquiry due to the inherent challenges posed by their shared nature. In the absence of clear ownership or regulation, these resources are prone to overuse, a phenomenon commonly referred to as “the tragedy of the commons” (Frischmann et al., 2019, Ferguson & Milgrom, 2024). This occurs when individuals, acting in their own self-interest, exploit the resource to the point of depletion or degradation, ultimately harming the collective well-being.

Traditional approaches to mitigating overuse have relied on mechanisms such as quotas, taxes, or regulation. While these solutions have proven effective in some contexts, they often fail to account for the complex behavioral and economic dynamics that characterize common resource systems. The problem is further compounded by the difficulty of monitoring usage, enforcing rules, and ensuring compliance across multiple actors, especially in large-scale or globally shared resources.

The number of works devoted to the design of economic mechanisms in conditions of high communication complexity has grown significantly in the last two decades. Static single-commodity auction mechanisms with a limited set of messages

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are considered in (Kos, 2012; Pavlov, 2025). In (Blumrosen & Feldman, 2013), the problems of theoretical feasibility of an optimal allocation rule taking into account information characteristics in several variants of mechanisms are considered, in (Mookherjee & Tsumagari, 2014), necessary and sufficient conditions for Bayesian compatibility with respect to incentives are proposed, and the design of an iterative detection mechanism for a single-commodity auction with limited communication is considered in (Zhang & Zhou, 2016).

This paper considers a system in which agents (entrepreneurs) have quasi-linear utility functions and belong to one of the disjoint types. Each agent has dichotomous preferences, i.e., the results of the mechanism's operation fall into one of two classes: "good" or "bad". Thus, the agent type can be represented by a single value – the assessment of a "good" result, taking the assessment of a "bad" result as zero. A similar approach to the normalization of assessments is widely used in the literature (Sano, 2016; Chi et al., 2019). It allows, with minor assumptions, to consider both mechanisms for organizing the distribution of financing from a single source and from several competing sources simultaneously (Dütting et al, 2018; Milgrom & Segal, 2020). When several competing offers exist simultaneously, identifying the preferences of market participants is difficult, since the utility function becomes more complex for both innovators and investors. In such cases, VCG mechanisms that are ex post compatible in preferences are effective (Ausubel, 2006; Nisan & Segal, 2006), although the number of interactions required to achieve optimal distribution grows exponentially with the increase in the number of proposals (Nisan & Segal, 2006).

Let’s consider the problem of distributing a common pool of resources, for example, the optimal number of tourists in a particular area from an environmental perspective, between several entrepreneurial projects (hotels, tourist routes, resorts, etc.) utilizing this pool of resources. The local administration, when issuing quotas, cannot directly estimate the minimum number of tourists required for each project to be profitable due to information asymmetry. However, the administration assumes that the number of quotas initially requested by each entrepreneur is excessive and can be reduced without jeopardizing the survival of that entrepreneur's business (Gurtuev et al., 2020). One method for solving this problem is a series of bilateral negotiations with each entrepreneur. During the negotiations, additional external project assessment is conducted, if necessary. The disadvantage of this approach is that, despite significant additional costs, its effectiveness depends almost entirely on the quality of the external assessment (Gurtuev et al., 2020). Another approach is to use a discovery mechanism, whereby the administration offers a menu of possible solutions, and entrepreneurs interested in participating, by choosing specific solutions, signal their internal assessments of the minimum number of tourists attracted for the project to be profitable.

Our aim in this paper is to develop a mechanism for solving the problem of allocating quotas for the use of a common resource among several independent entrepreneurial projects. We propose a class of iterative, eliciting distribution mechanisms for dynamic resource allocation, consisting of so-called threshold discrimination questions and a simple pay-as-bid fund transfer rule. In each round of this mechanism, the allocation center proposes a certain allocation of quotas to entrepreneurs. Entrepreneurs may accept or reject, but not submit counter-proposals (i.e., the possible answer is either "yes" or "no"), and a "yes" answer commits the entrepreneur to accept the quota of the given amount. By iteratively conducting this survey, it is possible to approximately determine the maximum quotas for each project and formulate the final allocation of quotas for the use of the common resource within predetermined constraints.

Under perfect information in such a mechanism, regardless of the principle for determining the proposed quota allocations, there always exists an efficient allocation, which is a subgame-perfect Nash equilibrium.

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2 MATERIALS AND METHODS

We consider a hypothetical eco-tourism destination characterized by high environmental sensitivity (e.g., a protected mountain valley, alpine lake basin, or glacial cirque) where tourist access and use generate ecological impacts (trail erosion, wildlife disturbance, vegetation damage, water resource stress). From environmental assessments for the area we impose a maximum sustainable daily visitor capacity (D = 1000) tourists, meaning no more than 1,000 visitors may enter in a given day without risking irreversible ecological degradation (e.g., soil compaction, loss of alpine flora, disturbance of endemic fauna).

The core assumptions of the model remain: heterogeneous visitors with varying willingness-to-pay (WTP), limited enforcement and monitoring capacity, no single private owner controlling access (i.e., a commons or quasi commons regime), and the potential for introducing an economic mechanism (market‐based permit or variable pricing) to regulate access.

Below we describe three plausible real-life scenario variants situated in mountainous areas of the North Caucasus region, each with different contextual features and thus different operational implications for our mechanism. In each scenario we hold (D=1000) as the ecological cap (for modelling purposes) although in reality actual caps may differ.

Scenario A: Alpine Lake Basin with Moderate Infrastructure

Location: A glacial‐fed alpine lake high in the North Caucasus foothills (e.g., similar in character to Kezenoy Am Lake).

Nature of tourism: Relatively accessible by road/foot from a valley settlement; day hiking, overnight stays in guest houses, some guide services.

Ecological features: Alpine meadow and forest transition zone; fragile vegetation; unique endemic species; moderate existing visitor numbers.

Institutional setting: Local guest house network, rural mountain settlement, limited formal regulation of visitor numbers.

Scenario B: Mountain Valley with Ethno Cultural and Agritourism Blend

Location: Rural mountain valley in the North Caucasus where local communities host agritourism (guest houses), ethnocultural tourism (traditional crafts, local festivals), trekking routes, and spring mineral water spas.

Nature of tourism: Longer stays (2-4 nights), combination of nature and culture; moderate infrastructure but more dispersed (guest houses in villages, trails connecting hamlets).

Ecological features: Mixed forest, sub alpine meadows, sensitive riparian zones; visitor use includes guided walks, horseback rides, cultural visits.

Institutional setting: Local cooperatives of guest house operators, regional tourism authority, linkages to rural employment and community development.

Scenario C: High Altitude Wilderness Zone with Minimal Infrastructure

Location: A rugged high-altitude region of the North Caucasus (e.g., near glacier endpoints or high mountain ridges, akin to parts of Kabardino-Balkaria Nature Reserve)

Nature of tourism: Primarily trekking and mountaineering, small group size, overnight camping, minimal facilities, high ecological sensitivity.

Ecological features: Alpine tundra, glacier‐fed water systems, rare alpine flora/fauna, fragile soils, slow recovery rates for disturbance.

Institutional setting: Entry via permit only, limited access roads, possible conflict with wild‐life protection and local pastoral uses.

While our scenarios remain stylised, we draw guidance from documented eco-tourism developments in the North Caucasus: for example, the documented increase of eco trail construction in the region. The richness of mountain ecotourism types (agritourism, speleotourism, etc.) in North Caucasus mountain regions provides background parameter ranges for attractiveness and demand coefficients (Zaburaeva et al, 2023).

2.1 Model

Let *N* be the set of all entrepreneurs receiving quotas for the use of a common resource. The quota-distributing agent (hereinafter referred to as the Administration) selects some allocation x from a finite set of such allocations X. Each entrepreneur is characterized by a quasi-linear utility function $u_i: X \to Z$ and has dichotomous preferences. Thus, the entrepreneur's evaluation function takes the following form:

$$u_i(x) = \begin{cases} v_i, & x \in X_i \\ 0, & x \notin X_i \end{cases} \quad (1)$$

Let's assume that v_i belongs to a certain set of possible valuations V, bounded above and below, known to all participants in the system. For each individual entrepreneur, v coincides with their minimum quota Q_{min}. The goal of the administration in such a system is to find an efficient budget allocation.

$$x^*(v) \in argmax_{x \in X} \sum_{i \in N} u_i(x) \quad (2)$$

where $v = (v_i, \ldots, v_i)$ is the vector of entrepreneurs' quota evaluations.

For simplicity, we assume that the domain of the utility functions is the set of real numbers and that for any state of the system there is a unique optimal solution to the allocation problem.

The total social utility function $W(u)$ in the system state v is determined by the maximum utility of the system participants with optimal allocation:

$$W(v) = \max_{X} \sum_{N} u_i(x) \tag{3}$$

In the same way, we can define the total social utility function for a system without a specific participant i:

$$W_{-i}(v_{-i}) = W(\underline{v}_i, v_{-i}) \tag{4}$$

3 RESULTS AND DISCUSSION

In a system of distributing quotas for the use of a common resource, when the administration and entrepreneurs interact, the parties naturally find themselves in a situation of information asymmetry: entrepreneurs know the maximum possible use of the common resource, while the administration cannot divide the minimum acceptable quota Q_{min} and the premium quota Q_{extra} for each project. To achieve rational distribution, the administration in such a system gradually collects information about entrepreneurs through a sequential series of binary questions. This procedure is structured as follows: the administration simultaneously proposes a certain budget to all entrepreneurs. In doing so, the administration discloses the size of the total budget to be distributed. When the administration proposes a budget pi, and entrepreneur i accepts it, this means that vi ≤ pi, that is, the entrepreneur's minimum required quota is no greater than the administration's proposal. Step by step, by proposing various budget distributions, the administration determines the boundaries within which vi lies for all entrepreneurs. For example, the fact that the first entrepreneur refuses the distribution (40, ...) but accepts the distribution (70, ...) means that his minimum quota Q_{min} lies within the boundaries [40, 70].

Let's define an iterative quota distribution mechanism (IQDM) as a multi-period non-cooperative game as follows:

$$G = (\{J^t, p^t\}_t, g, p), \tag{5}$$

where t is a round of the game, J_t is the set of entrepreneurs to whom the administration offers quota distribution, g is the entrepreneur's choice function ("yes" or "no", depending on the entrepreneur's u_i(x)), p is the rule for determining the offered quota (the rule for redistributing the general quota budget by the administration). Let $h^t \epsilon H^t$ be the history of the game at the end of round t. The quota offered to entrepreneur i is defined as p_i^t: H^{t-1}. Without loss of generality, we can assume that for each round t, each history $h^{t-1} \epsilon H^{t-1}$, and each rational entrepreneur $i \epsilon J^t(h^{t-1})$, $p_i^t \in V_i(h^{t-1}) \setminus \{\underline{v}_i(h^{t-1})\}$, where $V_i(h^{t-1})$ is the set of possible assessments of entrepreneurs given the game history. At time t, each entrepreneur makes a decision on whether to participate in the quota distribution {"yes", "no"}. The game stops at time T when $J^{T+1}(h^T) = 0$. An example of a general game tree for a simple case with two entrepreneurs and a budget sufficient to finance all projects (the sum of the distributed quotas is greater than the sum of Q_{min} of all entrepreneurs) is shown in Figure 1.

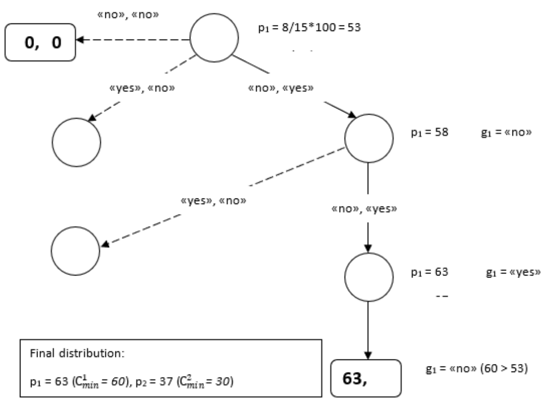

Figure 1. Fragment of the general tree of the game with two entrepreneurs (distributed budget = 100, $Q_{min}^1 = 60$, $Q_{extra}^1 = 80$, $Q_{min}^2 = 30$, $Q_{extra}^2 = 70$, initial step = 5).

If the distributed budget is less than the sum of Q_{min} of all entrepreneurs (for example, if in our example $Q_{min}^1 = 70$, $Q_{min}^2 = 50$), then one entrepreneur is randomly excluded from the list of potential quota recipients, and the game is played anew. Thus, for an entrepreneur, the process $\{J^t, p^t\}_t$ describes a game tree in which each node gives rise to two subsequent nodes (Fig. 2), and g and p are functions mapping each terminal node of this tree to some quota distribution.

All participants in the mechanism, both the administration and the entrepreneurs, know all the information about previous rounds. The equilibrium in such a mechanism is a subgame-perfect Nash equilibrium. If communication between participants in the mechanism occurs in the cheap talk mode, i.e., without transaction costs, and there are no restrictions on the number of rounds of the game or its duration, then the administration proposes many successive quota allocations until an efficient allocation is found. An iterative quota distribution mechanism leads to an efficient quota allocation for some history h if there exists an allocation $x_h \in X$ and $x^*(\tilde{v}) = x_h$ for every $\tilde{v} \in V(h)$. Let's call an allocation mechanism "efficient" if it always leads to an efficient allocation if all participants act in accordance with their true preferences.

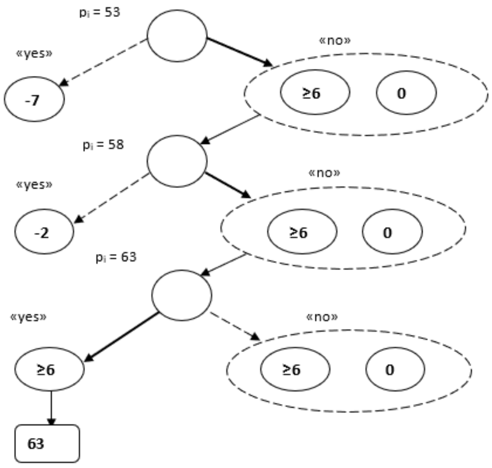

Figure 2. Fragment of the game tree for entrepreneur *i* (only payoffs for player *i* are shown).

In an efficient iterative quota distribution mechanism for shared-resource resource management systems with constraints, the administration must propose a new quota allocation each round until an efficient allocation is achieved. However, the proposed mechanism does not necessarily require the determination of precise minimum quotas Q_{min} for each entrepreneur. Another advantage of the proposed mechanism is the ability to use various round-organization processes – such as English- or Dutch-style auction mechanisms, tenders, mechanisms with the exclusion or inclusion of entrepreneurs, etc.

Of course, in many economic systems with dichotomous agent preferences and cost signals (Muramoto & Sano, 2016), the overall utility function for a coalition of agents may not be submodular, since this implies the fulfillment of the substitution condition, while dichotomous preferences, on the contrary, most often exhibit complementarity properties. For example, this is typical for the problem of public goods financing, where, under the condition of cost signals, it is impossible to create a mechanism in the form of an English auction with a Vickrey-Clarke-Groves outcome.

The assumption of cheap talk significantly simplifies the design of our mechanism, but there are still systems for which achieving efficient ex post equilibrium is impossible (Augenblick & Bodoh-Creed, 2018). This occurs because efficient ex post equilibrium presupposes a Vickrey-Clarke-Groves equivalent mechanism, and an iterative quota distribution mechanism may not collect sufficient information to calculate Vickrey-Clarke-Groves results. However, it is known that every efficient allocation rule is implemented as a Bayes-Nash equilibrium (Augenblick & Bodoh-Creed, 2018).

Considering these specifics and limitations, for systems managing shared resource use with constraints, an iterative quota distribution mechanism can be created, and it allows for various implementation forms depending on the specific system.

4 CONCLUSIONS

For a number of local economic systems, particularly for systems managing the use of common-pool resources with constraints, an iterative quota distribution mechanism is an efficient resource allocation instrument under asymmetric information and hidden agent preferences. The iterative quota distribution mechanism described in this article belongs to the class of dynamic indirect revealing mechanisms. In this mechanism, the administration, allocating a limited number of quotas for the use of a common-pool resource, iteratively proposes distribution options and determines the efficient quota allocation after a series of such proposals. With complete information and dichotomous revealed preferences, the efficient quota distribution is a subgame-perfect Nash equilibrium, regardless of the method of proposing allocation options. Under uncertainty, the method of proposing allocation options matters—the optimal solution is found by organizing it through some form of English auction. However, an iterative quota distribution mechanism does not necessarily exist for every specific system with independent agents whose preferences are inconsistent.

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