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Optimal sorting in group contests with complementarities

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ABSTRACT

Contests between groups of workers are often used to create incentives in organizations. Managers can sort workers into groups in various ways in order to maximize total output. We explore how the optimal sorting of workers by ability in such environments depends on the degree of effort complementarity within groups. For moderately steep costs of effort, we find that the optimal sorting is balanced (i.e., minimizing the variance in ability between groups) when complementarity is weak, and unbalanced (i.e., maximizing the variance in ability) when complementarity is strong. However, when the cost of effort is sufficiently steep, the optimal sorting can be unbalanced for all levels of complementarity or even alternate between unbalanced and balanced as the level of complementarity increases.

1. Introduction

In countless business settings, a worker or group of workers receives a reward based on their performance relative to their peers. An economic contest, or tournament, is a model of such a situation, where participants choose to expend resources, such as time or effort, in order to increase their probability of being rewarded (Lazear and Rosen, 1981; Lazear, 1995; Connelly et al., 2014). Contests are important tools that organizations use to incentivize high productivity from workers when there is an indivisible reward (e.g., promotion); to reduce monitoring and measurement costs, or to filter out the risk of common uncertainties (O'Keeffe et al., 1984).

Often, the performance of a firm depends on the combined input of a group of individuals. In this case, the firm's management may wish to design a group contest where employees work together in teams, but compete against other similar groups, with a prize awarded to the members of the winning group (Chen and Lim, 2013; Lim and Chen, 2014). For example, consider a sales contest among branches of a chain store. To incentivize employee effort and managerial oversight in each branch, the restaurant chain Dunkin' Donuts offered a reward to the best-run store within a region (O'Keeffe et al., 1984). Similarly, a Korean grocery store chain E-Mart Everyday used a sales competition to increase its sales of U.S. beef.[1]

In this paper, we are interested in the following question: When an organization uses an incentive scheme involving a group contest, how should it *sort* workers of heterogeneous abilities into groups in order to maximize the total output of all

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[1] http://www.agweb.com/article/sales_competition_boosts_u.s._beef_at_korean_grocery_chain_NAA_News_Release/

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the participating groups? Consider, for example, an architectural firm employing multiple designers, business developers, and construction administrators, all with varying abilities. If the firm has several ongoing projects, each of which requires one of each type of employee, the firm will form teams and may use a contest to incentivize high effort. In order to maximize total output (measured, for example, as a combination of quality, cost effectiveness, timeliness of project completion and client satisfaction), should the firm put the best designer, developer, and administrator together in the same team, or create a balance of highly skilled and less skilled employees in each team?[2] Another example would be the sorting of researchers into parallel R&D teams competing to produce an innovation (Nelson, 1961), as, e.g., in the Manhattan Project.

The principal result of this paper is in showing that the answer to this question depends, sometimes in nontrivial and counter-intuitive ways, on the level of complementarity between the efforts of the team members in the production process, as well as on the shape of the workers' effort cost function. For illustration, suppose there are four workers enumerated 1 through 4 in the descending order of ability, and assume that the production process involves groups of two workers. In a group contest with *balanced* sorting, group (1,4) would compete with group (2,3); whereas, in the case of *unbalanced* sorting group (1,2) would compete with group (3,4).[3] Consider first the case when within-group efforts are strong substitutes. Because of free-riding, competition between the groups will be determined primarily by the effort of the best worker in each group. Thus, the balanced contest will be similar to an individual contest between workers 1 and 2, whereas the unbalanced contest will be similar to a contest between workers 1 and 3. Given that the average ability is higher in the former contest, it appears that the balanced sorting should be preferred by the management in this case. In the opposite case of strong complementarity of efforts within groups, the equilibrium will be determined primarily by a contest between the lowest ability workers in each group, i.e., between workers 3 and 4 in the case of balanced sorting and workers between workers 2 and 4 in the case of unbalanced sorting. Here, the average ability is higher in the latter contest; therefore, it appears that the unbalanced sorting should be preferred by the management.

Group production processes are characterized by different levels of complementarity between workers. For example, an airport security checkpoint operates in a manner close to perfect complementarity, while waiters in a restaurant or facilitators at a children's summer camp are close to perfect substitutes. Given the different effects of sorting on aggregate contest output in the two extreme cases discussed in the previous paragraph, there must be a cut-off level of complementarity at which the optimal sorting of workers in a group contest switches from balanced to unbalanced.

We model a group contest with complementarities using a lottery (Tullock, 1980) group contest success function (CSF) with a constant elasticity of substitution (CES) aggregation of within-group efforts and workers with heterogeneous convex costs of effort. We consider the combined output of all groups in equilibrium as a function of the level of within-group effort complementarity. Surprisingly, we find that the way in which complementarity interacts with optimal sorting is more complex than the simple intuition above suggests, and depends on the shape of the workers' cost function of effort. For example, for certain parameters, there are intermediate levels of complementarity, such as a Cobb–Douglas aggregation function, where balanced sorting is optimal, even though unbalanced sorting is optimal at either extreme. In order to explore the effect of sorting on output, similar to Ryvkin (2011), we use the quadratic approximation to the true equilibrium efforts and develop an expansion of output in the moments of the distribution of abilities. Within the quadratic approximation, we describe all possible cases for how optimal sorting depends on within-group effort complementarity, and provide an example of each case.

The problem of optimal sorting of heterogeneous players in a group contest with perfect substitutes has been explored by Ryvkin (2011), who showed that the optimal sorting is balanced as long as the players' effort function is not too steep. Being an important benchmark case, the perfect substitutes technology is not the most realistic in applications. Indeed, within-group complementarities, or synergies, are one of the key reasons group production exists in the first place (Alchian and Demsetz, 1972). In this paper we extend the analysis of Ryvkin (2011) to arbitrary levels of within-group complementarity.

The theoretical literature on group contests goes back to Katz et al. (1990) and Nitzan (1991) who first considered symmetric group contests with a lottery CSF, perfectly substitutable within-group effort, and linear effort costs. In a similar setting, Baik (2008) considers the case of heterogeneous prize valuations and shows that only the highest-valuation player in each group exerts positive effort in equilibrium. Other within-group aggregation functions have also been analyzed. Lee (2012) considers the weak-link (perfect complements) technology, while Chowdhury et al. (2013) study the "best-shot" technology in which a group's output is determined by the maximal effort. The same aggregation functions have also been analyzed in an alternative perfectly discriminating contest (all-pay auction) setting in which the group producing the highest output wins with certainty (e.g., Baik et al., 2001; Topolyan, 2014; Chowdhury et al., 2013; Barbieri et al., 2013). A group contest involving groups with different aggregation technologies (one weak-link and the other – best-shot) is analyzed by Chowdhury and Topolyan (2013). Finally, Kolmar and Rommeswinkel (2013) use the CES aggregation function and allow for different complementarity levels in different groups and within-group player heterogeneity with linear effort costs.[4]

[2] Presumably, the firm does not want any of the projects to fail; therefore, the minimal necessary skill level is still assumed even for the lowest-skill employees, otherwise they would not be employed by the firm in the first place.

[3] The third possible sorting, (1,3) versus (2,4), has the intermediate level of inter-group balance. In this example, we compare the two polar sortings.

[4] For a similar setup, see also Epstein and Mealem (2009).